Watershed

April 2021

# Rainy River – Rainy Lake Watershed Stressor Identification Report

A study of local stressors limiting the biotic communities in the Rainy River – Rainy Lake Watershed.

MINNESOTA POLLUTION CONTROL AGENCY

CLEAN WATER LAND & LEGACY AMENDMENT

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# Key terms and abbreviations

| | |
|---|---|
| AMSL | Above mean sea level |
| AUIDs | Assessment Unit Ids |
| BANCS | Bank Assessment for Non-point source Consequences of Sediment |
| BMPs | Best Management Practices |
| DOC | Dissolved organic carbon |
| DNR | Minnesota Department of Natural Resources |
| DO | Dissolved oxygen |
| F-IBI | Fish index of biological integrity |
| GMWL | global meteoric water line |
| HSPF | Hydrological Simulation Program – FORTRAN |
| HUC | hydrological unit code |
| IWM | Intensive watershed monitoring |
| MFRC | Minnesota Forest Resources Council |
| M-IBI | Macroinvertebrate index of biological integrity |
| MPCA | Minnesota Pollution Control Agency |
| MSHA | MPCA Stream Habitat Assessment |
| PGG | Potential Groundwater Grid |
| RLSC | Rainy Lake Sport fishing Club |
| RRRLW | Rainy River - Rainy Lake Watershed |
| SID | Stressor identification |
| SOD | Sediment oxygen demand |
| SWCD | Soil and Water Conservation District |
| TIV | Tolerance Indicator Values |
| TP | Total phosphorus |
| TSS | Total suspended solids |
| TSVS | Total suspended volatile solids |
| UT | Township Road |
| WID | Waterbody ID |
| WQ | Water quality |
| WRAPS | Watershed Restoration and Protection Strategy |

# Executive summary

Over the past 10 years, the Minnesota Pollution Control Agency (MPCA) has substantially increased the use of biological monitoring and assessment as a means to determine and report the condition of the state's rivers and streams. This basic approach is to examine fish and aquatic macroinvertebrate communities and related habitat designated impaired due to the fish or macroinvertebrate conditions, stressors to the aquatic community must be identified. Stressor Identification (SID) is a key component of the major watershed restoration and protection projects being carried out under Minnesota's Clean Water Legacy Act.

This report summarizes SID work in the Rainy River – Rainy Lake Watershed (RRRLW). During water monitoring in 2017-2018, MPCA scientists found that generally the streams in this watershed are in good condition, though there is some room for improvement and these waters must be preserved and protected to prevent future impairments. No reaches within the watershed are designated as impaired for aquatic life use; however, fish index of biological integrity (F-IBI) and macroinvertebrate index of biological integrity (M-IBI) scores are below their expected thresholds in a middle section of the Rat Root River, the largest river in the watershed. Aquatic life indicators, including total suspended solids (TSS) and dissolved oxygen (DO), frequently exceed state water quality (WQ) standards in parts of the watershed. Both TSS and DO at times do not meet respective standards in the downstream to mid-river reaches of the Rat Root River. TSS is frequently elevated in the downstream to mid-river reaches of the East Rat Root River. Despite elevated TSS in the East Rat Root River, biological index scores are good with F-IBI and M-IBI scores meeting their expected thresholds at the sampled locations.

The landscape of the heavily-forested and wetland-dominated watershed is generally flat and consists of fine glacial till and lacustrine soils. Emerging from headwater wetlands, the Rat Root River and East Rat Root River flow north and merge at Rat Root Lake, and continue to flow north to Black Bay of Rainy Lake. Combined, the two streams form a major tributary to Rainy Lake on the Minnesota side of the border.

This report begins with a summary of the monitoring and assessment findings and previous watershed protection and restoration efforts. SID is focused on hydrology, TSS, DO, and physical habitat to evaluate reaches with poorer IBI scores and WQ that does not meet state standards. After examining many candidate causes for poorer than expected IBI scores in the Rat Root River, the following were identified as probable causes of stress to aquatic life: low DO, sedimentation, slow flow velocity, lack of physical habitat, and to a lesser degree TSS. Natural conditions such as low gradient stream channels and glacially-derived clay soils are factors influencing WQ and habitat conditions. Although development is low compared to watersheds statewide, human impacts over the past century have contributed to some of the stressors identified in the report. Report conclusions are summarized in Figure 20 and recommended actions are included in Table 7 and Table 8.

# 1. Introduction

## 1.1. Monitoring and assessment process

The MPCA, in response to the Clean Water Legacy Act, has developed a strategy for improving WQ of the state's streams, rivers, wetlands, and lakes in Minnesota's 80 Major Watersheds, known as Major Watershed Restoration and Protection Strategy (WRAPS). The MPCA receives assistance from Minnesota Department of Natural Resources (DNR) and local governmental units to complete a WRAPS project, which is comprised of several steps. The initial phase of WRAPS is called the Intensive Watershed Monitoring (IWM), through which the MPCA and partners, including DNR, characterize the overall health of streams and lakes, and designate waters as impaired for not meeting established 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 2017 through 2019 in the RRRLW, and resulted in the completion of a Monitoring and Assessment Report in June, 2020. An electronic copy can be found on the MPCA RRRLW webpage: https://www.pca.state.mn.us/water/watersheds/rainy-river-rainy-lake. The Monitoring and Assessment Report should be read together with this SID Report for a more complete understanding of the process leading up to SID.

## 1.2. Stressor identification process

The SID process builds on the results of the IWM with a greater emphasis placed on evaluating physical and chemical factors that either harm or protect aquatic life in a given stream. Whereas IWM is geared to be a nonbiased assessment of ecological health, the SID process often targets specific locations in a given watershed to highlight potential restoration or protection priorities. More details on the SID process, common stressors, and causes of stressors can be found in documents (MPCA 2017a) and on the MPCA's webpage: Is your water stressed: https://www.pca.state.mn.us/water/your-water-stressed. This document is the summary of SID results for the RRRLW which focused primarily on Rat Root River (locally known as *West Branch Rat Root River*) and East Branch Rat Root River (referred to as *East Rat Root River* throughout the remaining report).

## 1.3. Report format

This SID Report follows a format to first summarize the RRRLW and detail the monitoring and watershed restoration projects that were considered leading into the SID process, found in Section 2. Section 3 focuses on SID investigations and begins with a summary of the biological communities and community indicators of stress and/or influence from WQ and habitat parameters. The section then discusses available data and analysis for each of the four most likely stressors (hydrology, TSS, DO, and physical habitat) in the RRRLW. While the main focus is on the Rat Root River, stressor-level data from the East Rat Root River is reported throughout the report for comparison to the Rat Root as well as a more complete evaluation of the overall watershed. Section 4 outlines the final report conclusions and recommendations for future watershed work.

# 2. Rainy River – Rainy Lake Watershed overview

## 2.1. Background

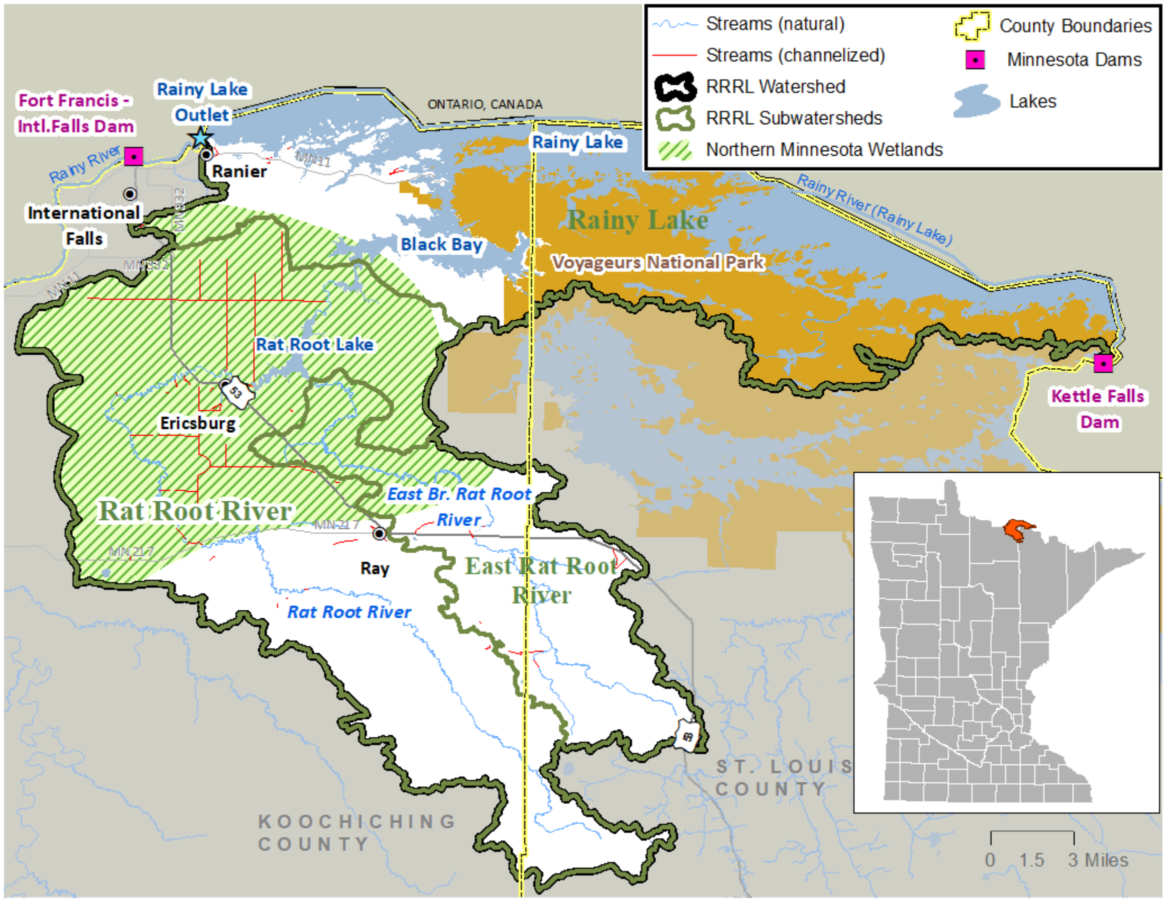
The RRRLW is located within the mixed deciduous and boreal forests along the United States-Canadian border, covering 7400 square miles. The Minnesota portion of the watershed drains 463 square miles of Koochiching and St. Louis counties combined. The unincorporated community of Ray is the only city located within the watershed; however, both International Falls (population 6,424, U.S. Census Bureau 2019) and Ranier (population 145, U.S. Census Bureau 2019) are located along the watershed border.

RRRLW consists of three aggregated hydrological unit code (HUC)-12 subwatersheds; Rat Root River, East Rat Root River, and Rainy Lake (Figure 1). Rat Root River and East Rat Root River emerge at their respective headwaters in forested wetlands and flow north to join at Rat Root Lake, which outlets into Black Bay of Rainy Lake, a eutrophic region of the Lake (USGS 2003). Together, they form a major tributary to Rainy Lake on the Minnesota side of the border. The Rainy Lake Subwatershed consists mostly of Rainy Lake itself as well as smaller tributary streams that outlet directly to the lake.

Land in the RRRLW is mostly undeveloped forest and wetlands with less than 5% of the watershed in development, rangeland, row-crop, and mining (MPCA 2020a). Wilderness recreation and tourism are major economic drivers in the RRRLW. Rainy Lake is a popular tourist destination and walleye are the major sought after gamefish on Rainy Lake. Voyageurs National Park, a network of wilderness and waterways, is located in the Rainy Lake Subwatershed (Figure 1). Besides recreation, logging is the other major economic driver in the watershed. The Packaging Corporation of America paper mill in nearby International Falls is among the largest employers in Koochiching County. Much of the forested area within the RRRLW was clear-cut in the early 1900s and subsequent harvest of the regenerated forests, under a more conservation-based approach, (MFRC 2012), has occurred since.

The landscape, geology, and ecoregions within the watershed are largely defined by the former extent of Glacial Lake Agassiz and glacial lobe advances. The downstream drainages of Rat Root and East Rat Root Rivers lie within the former extent of the glacial lake, which is closely defined by the Northern Minnesota Wetlands ecoregion (Figure 1). The flattened landscape of the downstream drainages contains an abundance of bogs and wetlands and soils that are primarily a mix of peat deposits and silty clays. The upper watershed is more heavily forested and contains more topographic features such as rolling hills. Soils in the upper watershed are slightly coarser and shallower; and bedrock is closer to the ground surface. Stream types vary throughout the watershed with narrower, steeper stream reaches near the headwaters and wider, flatter reaches downstream.

**Figure 1. Rainy River-Rainy Lake Watershed, subwatersheds, and water bodies.**




## 2.2 Monitoring and assessment findings

Four stream segments, referred to Assessment Unit IDs (AUIDs) or Waterbody IDs (WIDs), in the RRRLW were assessed for aquatic life use, aquatic recreational use, or both. Four WIDs were assessed, including two for each the Rat Root River and East Rat Root River Subwatersheds (Figure 2). A summary of findings and data gaps for each WID is reported in Table 1 ; and more details on the assessment can be found in the RRRLW Monitoring and Assessment Report. Fish were sampled in all four WIDs, while macroinvertebrate sampling was attainable in only two. All four of the assessed streams supported aquatic life use and/or recreational use based on the information available at the time of the watershed assessment. Although several lakes were impaired for aquatic consumption (mercury in fish), all lakes clearly met recreational use goals (MPCA 2020a).

The IWM process concluded that stream WQ conditions in the RRRLW are generally good; however, aquatic life indicators, including TSS and DO, frequently exceed state WQ standards in parts of the watershed. Rat Root River WID-635, which extends from Rat Root Lake to almost the middle of the watershed, has the most exceedances of the DO and TSS standards. Elevated TSS concentrations are also observed in isolated areas of Rat Root River WID-634 (middle watershed to headwaters) and in the East Rat Root River downstream WID-633. Although not designated impaired for biology, the F-IBI and M-IBI scores are slightly below their respective thresholds in a middle section of the Rat Root River that extends across the upstream end of Rat Root River WID-635 and the downstream end of Rat Root River

WID-634. (Table 2 and Figure 2). Biology near the headwaters and near the stream outlet indicate good WQ.

A decision was made not to propose a new aquatic life use impairment in the Rat Root River based on the following: 1) the lowest F-IBI and M-IBI scores, recorded at biology site 05RN086, were based on data collected outside of the assessment timeframe (10 years) and 2) there were insufficient assessment level data such as macroinvertebrate community data in two of the four WIDs with which to further characterize biological community health. The process identified a need for further investigation of natural verses anthropogenic conditions leading to elevated TSS, low DO, and marginal biology in the middle reaches of the Rat Root River.

**Table 1: Summary of Monitoring and Assessment process finding in the RRRLW.**
Those highlighted in "red" indicate potential stressors to aquatic life and are discussed further in Section 3. TSS= Total suspended solids, DO= dissolved oxygen, TP= Total phosphorus

| | | | Assessment | |
|---|---|---|---|---|
| **Stream Name/ WID** | **Monitoring Sites** | **Reach Description** | **Biological** | **Water Quality** |
| **Rat Root R.** (upstream) 09030003-634 | 17RN003, 17RN004, RR3, RR4, RR5, RR6 | Flows north from headwaters (T67 R21W Sec33) to 2 miles upstream of MN highway 217 (T68 R23W Sec4) | Fish and Macroinvertebrates – **Full Support** | Insufficient information (small data sets) |
| **Rat Root R.** (downstream) 09030003-635 | 17RN001, 05RN186, RR1, RR2 | Flows north from 2 miles upstream of MN highway 217 to Rat Root Lake | Fish – **Full support** Macroinvertebrates -**Not assessed** | Elevated TSS Elevated TP Low DO |
| **East Rat Root R.** (upstream) 09030003-632 | 17RN007, ERR3, ERR4 | Flows north from headwaters (T67 R21W Sec1) to 2 miles downstream of US highway 53 (T69 R22W Sec26) | Fish – **Full support.** Macroinvertebrates -**Not assessed** (stream did not meet assessment criteria) | Insufficient information (small data sets) |
| **East Rat Root R.** (downstream) 09030003-633 | 17RN006, ERR1, ERR2 | Flows north from 2 miles downstream of US highway 53 to Rat Root Lake | Fish and Macroinvertebrates – **Full Support** | Elevated TSS Elevated TP |

**Table 2: Fish and macroinvertebrate IBI scores by biological station within respective WID.**
Key to color coding in

Table **3**. GU=General Use, CI =Confidence Interval for threshold. Findings from (MPCA, 2020).

| Watershed ID | Biology Site (Year) | Fish Class | Fish IBI | Fish GU Threshold | Fish CI | Invert IBI | Invert GU Threshold | Invert CI |
|---|---|---|---|---|---|---|---|---|
| Rat Root WID-635 | 17RN001 (2017) | Northern Streams | 69.61 | 47 | 9 | NS | ND | ND |
| | 05RN186* (2006) | Northern Streams | 36.09 | 47 | 9 | 30.3 | 51 | 13.6 |
| Rat Root WID-634 | 17RN003 (2017) | Northern Streams | 40.79 | 47 | 9 | 50.2 | 51 | 13.6 |
| | 17RN004 (2017) | Low Gradient | 76.92 | 42 | 10 | NS | 51 | 13.6 |
| East Rat Root WID-633 | 17RN006 (2017) | Northern Streams | 57.52 | 47 | 9 | 54.6 | 53 | 12.6 |
| East Rat Root WID-632 | 17RN007 (2017) | Low Gradient | 79.77 | 42 | 10 | NS | 51 | 13.6 |

**Table 3. Color-coding for Table 2 based on General Use thresholds and Confidence Intervals for biology.**

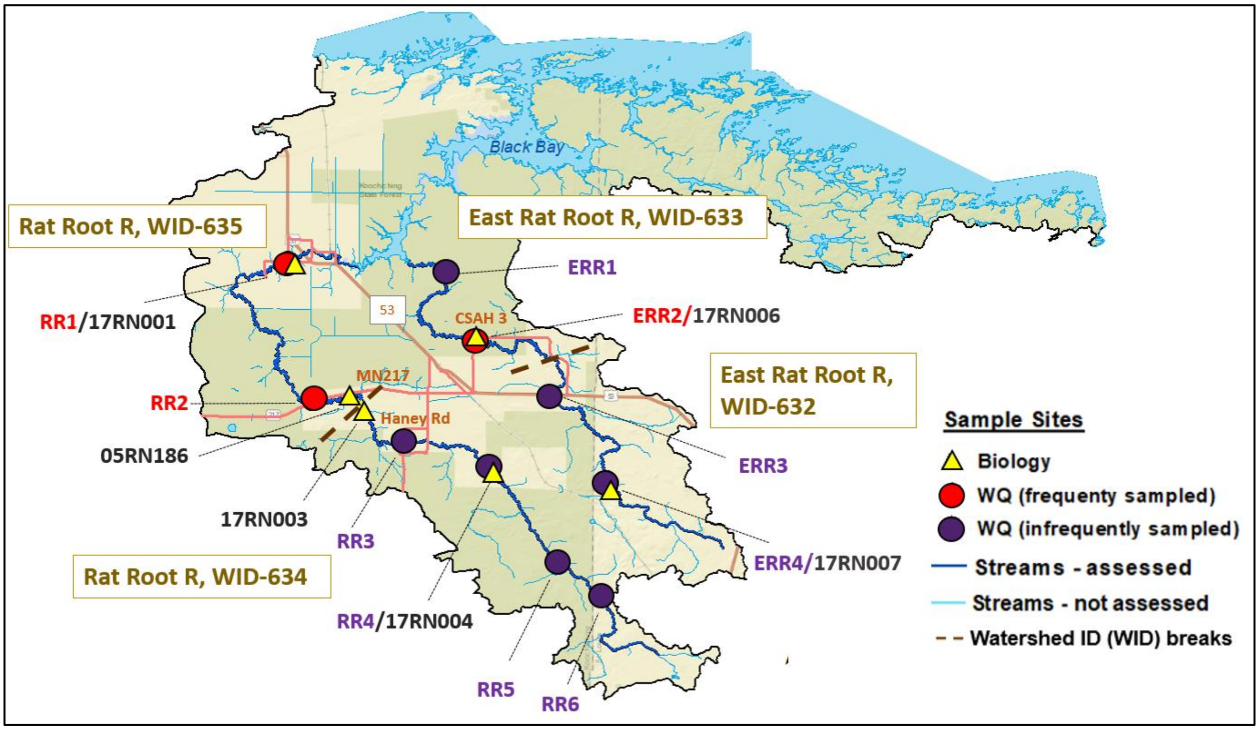
| Description |
|---|
| Below lower CI |
| Below threshold but within lower CI |
| Above threshold but within upper CI |
| Above upper CI |
| Exceptional score |

## 2.3 Water quality and hydrology monitoring sites

WQ and biology monitoring stations contributing to the IWM and SID processes are shown in Figure 2. WQ data was collected from the headwaters to the downstream reaches along both Rat Root River and East Rat Root River. While some sites were limited to a few samples, others such as sites RR1 and RR2 on Rat Root River and site ERR2 on East Rat Root River were sampled often over a three to six year timeframe. The most sampled site in the RRRLW is RR1, located near the outlet of WID-635. The data records for that site include samples collection prior to the start of IWM.

Stream gage data were collected during the SID phase (years 2018 to 2019) of WRAPS at two locations on the Rat Root River: DNR flow gage 74033001 at Koochiching County Road 145 crossing (WQ site RR1) and MPCA gage 74033003 at MN State Highway 217 crossing (WQ site RR2). Although streamflow data at the DNR gage was not available for the IWM or SID phases of the WRAPS, water level and stream velocity data were provided under a provisional status and are expected to be published in the future upon refinement of the level-discharge relationship. Flow and water level data for MPCA gage 74033003 were published during the SID phase of this WRAPS. Additionally, Rainy Lake water level data was obtained from the Government of Canada's Rainy Lake near Fort Frances gage (05PB007).

**Figure 2: Watershed ID (stream reaches) and monitoring sites in the RRRLW.**




## 2.4. Hydrological Simulation Program – FORTRAN Model

A Hydrological Simulation Program – FORTRAN (HSPF) model was developed for the RRRLW to simulate the hydrology conditions throughout the watershed on an hourly basis from 1996 to 2009. These simulated flows are used to supplement WQ data in evaluating stream health and dynamics outlined in this report; and are particularly useful at WQ site RR1, where published flow data from gage 74033001 are not yet available. For additional information regarding HSPF modeling, see modeling documentation (RESPEC 2014, RESPEC 2015a, RESPEC 2015b, and RESPEC 2016).

Comparison of HSPF simulated flows and measured flows at site RR2 indicate that HSPF simulation for the river is reasonable with the exception of minor differences. When comparing hourly time series (Figure 21, Appendix A), HSPF appears to simulate spring runoff slightly early and high with a peak recession that recedes too sharply. Post-snowmelt flows, both low and event flow, are also sometimes slightly overestimated by the model. These were considered in utilizing modeled values.

## 2.5. MPCA Stream Habitat Assessment

The MPCA Stream Habitat Assessment (MSHA) was developed to rapidly assess physical habitat conditions and riparian condition of streams and rivers. Good, fair, or poor thresholds for the qualitative habitat assessment were developed by examining MSHA scores at three levels of disturbance (MPCA 2014a). Disturbance levels were quantified using a watershed disturbance index known as the Human Disturbance Score developed by the MPCA. Over 1,700 sites across the state were used to set the criteria. MSHA values above the median of least disturbed sites (MSHA > 66) were considered “good”, MSHA values below the median for most disturbed sites (MSHA < 45) were considered “poor”, and values falling in between these thresholds were considered “fair”.

During the monitoring and assessment process, habitat scores were calculated using MSHA protocol (MPCA 2017b) for all biological stations in the RRRLW, including at least one in each assessed WID. Additional MSHA data were collected during the SID process to more precisely define habitat conditions within reaches. These data are presented in Section 3.5: *Physical habitat findings*.

## 2.6. Local watershed priorities and projects in the RRRLW

Over the past two decades, locally-driven monitoring and implementation projects have increased on the Rat Root River in efforts to improve walleye spawning and reduce sediment loading to Rat Root Lake. Rainy Lake is a popular walleye fishing lake in Minnesota and historically the Rat Root River had a sizable walleye spawning run. Although adequate spawning is currently occurring in Rainy Lake and its other tributaries, there appears to be a large decline in the Rat Root River. The DNR operated a walleye spawn take operation on the lower end of the Rat Root from 1933 through 1943 and again from 1971 through 1978. This operation used a large net across the river to catch the walleyes moving upstream during the spawn. These efforts showed a large decrease in female walleyes using the river during the intervening period with an average of 3,887 females per year recorded for years 1933 through 1943 and an average of 243 from 1971 through 1978 (DNR 1933 through 1978). In 1991, the DNR resumed efforts to monitor walleye spawning using electrofishing-based methods and continued to see lower numbers of walleyes using the river.

With an interest to improve the spawning run, the Rainy Lake Sport fishing Club (RLSC), funded a study (Ellen River Partners 2008) to assess the Rat Root River and East Rat Root River and identify factors contributing to the walleye decline. Key findings of the study are outlined in a DNR fisheries report (DNR 2015a) and include the following: 1) walleye movement is limited by sedimentation in Rat Root Lake and/or inadequate outflow from the lake to encourage walleye movement upstream, 2) clean and oxygenated spawning substrates are lacking in the river due to sedimentation and inefficient streamflow, 3) several large channel-spanning log jams in Rat Root River and East Rat Root River were at the time affecting sediment transport, and 4) channel incision of up to 1.5-feet is estimated in the lower East Rat Root River. Sedimentation in the downstream reaches of the Rat Root River was attributed to the compounded effects of early-century logging and several large floods of the 1950s. Log jams were attributed to a more recent increase in fallen trees associated with an aging riparian monoculture (aspen) and disease (Dutch elm).

A coordinated effort to improve walleye spawning in the Rat Root River through implementation of Best Management Practices (BMPs) began in 2010 and continues today. Participating partners in various implementation efforts and funding include RLSC, Koochiching Soil and Water Conservation District (SWCD), DNR, Nature Valley Preserve the Parks Program, National Park Conservation Association, and Minnesota Conservation Corps. Efforts began with a RLSC-funded bottom survey of Rat Root Lake and a DNR log jam removal project (DNR 2015a). Additional stream projects to clear channel-spanning wood from the Rat Root River continued through May 2018, coordinated through Koochiching SWCD and RLSC. Several sediment load reduction projects and walleye spawning habitat projects were completed through cooperative local efforts between 2013 and 2019. These included tree plantings, stream bank stabilization projects, and stream riffle habitat installations. Many of these projects were focused in the downstream half of WID-635 between Rat Root Lake and the Arrowhead State Trail crossing (two miles upstream of Galvin Road/Township Road (UT) 198). Wood removal efforts extended further upstream and ended just a few miles downstream of the MN State Highway 217 crossing.

# 3. Stressor Identification

Typically, the primary focus of MCPA's "SID" monitoring efforts is to identify the cause(s) of impaired stream biological communities (fish/macroinvertebrates). In the RRRLW, as well as many of the less disturbed areas of Northeast Minnesota, the emphasis of this effort has shifted from identifying stressors of biologically impaired waters to providing data that will help guide watershed planning, protection, and restoration efforts on locally important streams that range from high to poor quality. Priorities identified in SID planning phases for the RRRLW included 1) characterize environmental factors influencing biological communities, 2) identify natural and anthropogenic sources of pollutants that contribute to poorer WQ and 3) provide data and information that can be used in watershed planning for locally-significant streams.

The Rat Root River was the main focus of SID investigations based on the monitoring and assessment findings outlined in Section 2.2 and local watershed priorities described in Section 2.6. Of the typical stressors commonly evaluated, the focus of investigations were narrowed to hydrology, TSS, DO, and physical habitat based on assessment level results outlined in Table 9 of Appendix A. East Rat River data were evaluated for WQ parameters that did not meet state WQ standards, but also as a reference for the Rat Root River that included analysis of data that did meet state standards.

## 3.1 Stressor signals from biology

The Rat Root River is divided into two assessment units (WIDs 634 and 635), with the former being the upstream section and the latter being the downstream section. Each of these WIDs had two biological monitoring locations. Also for each of these WIDs, one site did well, and one site did not meet the health (IBI) threshold. The two poorer sites were the middle two of the four (Table 2). When taking into account all samples and other factors, both WIDs were assessed as meeting the aquatic life use standard. Though neither WID is designated impaired, some analysis of the fish and macroinvertebrate communities has been conducted to provide insight into what environmental or WQ factors are influencing the biological community composition in the Rat Root River, and what might explain the poorer communities found in the middle part of the river.

### The fish community

There are two sites on downstream WID-635 that have been sampled for fish, 17RN001 (the farther downstream site), and 05RN186, which is very near the upstream end of WID-635. The latter site was last sampled in 2006, and was outside the window of 10 years utilized in the 2019 assessment of WID-635, and thus not used in the assessment decision for the reach. The fish community at 17RN001 scored above the threshold of a passing score, while 05RN186 did not. The upstream segment of the Rat Root River is WID-634. There are two biological monitoring locations on this segment, 17RN003 and 17RN004, with the latter being farther upstream and also categorized under a different fish class (Low Gradient Streams) than the more downstream sites (Northern Streams fish class). The fish community at 17RN003 scored below the F-IBI threshold of a passing score, but upstream site 17RN004 scored extremely well. In summary, the lowest scores were recorded at the middle sites 05RN186 and 17RN003, which bracket a WID break. Low numbers of late-maturing and intolerant individuals negatively impacted the middle stations F-IBI.

*WID-635 (downstream)*

In general, the fish community at mid-river site 05RN186 (year 2006) was more skewed toward tolerant species than downstream site 17RN001 (year 2017).The sample at 17RN001 contained 12 fish species. There were 4 species that were relatively more abundant than the other species; golden shiner, common shiner, yellow perch, and black crappie. There were three species present that are considered to be sensitive to habitat disturbance; spottail shiner, logperch, and Iowa darter. The sample at 05RN186 contained 10 fish species. The fish community was quite different than farther downstream, as none of the 4 most-abundant species at 17RN001 were present at site 05RN186. This may partly be due to site 17RN001 being in fairly close proximity to Rat Root Lake. Black crappie and yellow perch are lake-oriented species. Site 05RN186 contained 1 sensitive species, Iowa darter. There were also 6 species that are considered tolerant; brassy minnow, brook stickleback, central stoneroller, fathead minnow, bigmouth shiner, and black bullhead (the latter three species are considered “very tolerant”).

*WID-634 (upstream)*

The sample at 17RN003 (year 2017) contained 13 fish species. The 2 dominant species present were creek chub and common shiner. Two other quite abundant species were white sucker and central mudminnow. All 4 of these species are extremely prevalent throughout Minnesota’s streams. There were 2 sensitive species present at 17RN003, logperch and pearl dace, each represented by a single individual. At upstream site 17RN004, the fish sample collected 15 species, the most among the four Rat Root River sites, suggesting the overall habitat was best here. The 3 most-dominant species were common shiner, creek chub, and white sucker. Three more species were in a second tier of relative dominance, these being pearl dace, brassy minnow, and northern redbelly dace. This community had 3 sensitive species; pearl dace, Iowa darter, and blacknose shiner. The F-IBI score at 17RN004 was far better than the threshold defining a healthy community for a Low Gradient class stream.

## The macroinvertebrate community

There is less macroinvertebrate data available for WID-635 and WID-634 than for the fish community. Only one site in each WID was able to be sampled, and WID-635 only has data from 2006. Site 17RN001 was too deep to sample using protocols, and site 17RN004 was impounded by a beaver dam, which was not present earlier in the summer when the fish sample was collected. This means only site 17RN003 has data from 2017. The macroinvertebrate class for both sampled sites is Northern Forest Streams.

The macroinvertebrate community at site 05RN186 (year 2006) in WID-635 was dominated by two taxa, the mayflies *Stenacron* and Leptophlebiidae. High numbers of mayflies in a sample is generally considered very positive, though in this case, these taxa are not among the more sensitive mayflies. There were several taxa that are generally found in sluggish waters or wetlands, including the hemipteran *Sigara*, the beetles *Dubiraphia* and *Hydraena*, and the snails *Amnicola* and Lymnaeidae. Only one intolerant taxa was present (the mayfly *Eurylophella*), and only represented by a single individual. There were few filter feeding taxa or individuals, suggesting flow is normally very slow in this portion of the river. Field notes stated that there was no stream flow observed at the time of sampling.

The macroinvertebrate community at site 17RN003 (year 2017) in WID-634 slightly missed the passing M-IBI threshold, though was within the range of uncertainty. Because the M-IBI score was so close to the passing threshold, and some sensitive taxa were present, a decision to assess the reach as achieving its macroinvertebrate health threshold was made. The sample contained one dominant taxon, the midge *Thienemannimyia*. The two very abundant mayflies from 05RN186 were also relatively abundant again at 17RN003. There were three individuals from the stonefly genus *Acroneuria*; stoneflies are a sign of good WQ.

## Tolerance Value Indicators

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

TIV scores and individual TIV metrics (general comparison of tolerant verses intolerant taxa/species and individuals) were evaluated for fish at all four sites and for macroinvertebrates at the two mid-river sites. TIV scores were considered for four parameters: DO, TSS, Fines (fine particle substrate), and Flow Velocity. TSS and DO were chosen based on observed exceedences of the respective standards. Fines was chosen because reaches with high TSS loads often have excess fine particle deposition on the stream bed, which can smother important microhabitats. Flow Velocity was chosen because it is a prominent factor in determining suitability for many riverine fish species and because of observed backwater conditions in WID-635. For DO and Flow Velocity, a higher index score is better, while for TSS and Percent Fines, a lower index score is better. The percent probability of a site to meet its respective regional WQ standard is a calculated value based off of WQ and community data for that region.

The Community TIV Index scores and individual TIV metrics for fish and macroinvertebrates are found in Table 10, Table 11, Table 13, and Table 14 of Appendix B, where detailed analyses and discussion of tolerance metrics at the four fish sample sites and two macroinvertebrate sample sites is reported. Brief summaries of TIV findings are found below:

## Composite conclusion from biology

Only fish have widely-spread sample sites along a large stretch of the Rat Root River; therefore, it is mainly the fish community that can be used to show how the character of the river and suitability for biological communities differs on a broad scale. The two macroinvertebrate sample locations are fairly close together, located in the middle portion of the river where fish and macroinvertebrate IBI scores are lowest. They provide additional insight on WQ and habitat influence on biology in that section of the river.

In summary, low DO is influencing the biological community at all four sites, most prominently at the two sample sites on WID-635. TSS does not appear to be influencing the fish community, but is somewhat influencing the macroinvertebrate community. Fines are affecting both the fish and macroinvertebrate community with tolerance increasing longitudinally from upstream to downstream. Flow velocity is affecting the downstream and mid-river fish communities (three sample sites) and the two mid-river macroinvertebrate sites. A short description of findings for each parameter is reported below. See Appendix B: *Detailed TIV analyses* for a complete summary, TIV scores, individual tolerance metrics, and a more detailed discussion on tolerance in the biological communities of the Rat Root River.

### DO tolerance

TIV analysis of the fish community show some tolerance to low DO at all four sites, but it is most apparent at the two downstream sites (17RN001 and 05RN186), which are in WID-635. Both fish and macroinvertebrate communities show agreement that the area around 05RN186 (near WQ site RR2) is the most problematic regarding DO levels for aquatic organisms. Low DO tolerance is a primary reason the fish community at 05RN186 did not meet the F-IBI threshold. The macroinvertebrate community was also skewed toward low-DO Tolerant taxa at 05RN186, whereas it did not show significant influence from low-DO a few miles upstream at 17RN003.

### TSS tolerance

The Rat Root River often has turbid water due to suspended mineral particles. Such conditions can be a negative influence on aquatic organisms. TIV analysis suggests that the TSS levels are not significantly influencing the Rat Root River fish community, although are somewhat influencing the macroinvertebrate community. All four sites have a high probability that the sampled fish community would come from a stream with standard-meeting TSS levels. Among the four sites, only a single individual that is TSS Tolerant was collected; one walleye from the farthest downstream site (17RN001). Macroinvertebrates do appear to be somewhat influenced by TSS levels at both mid-river sites (05RN186 and 17RN003), with communities showing low probabilities of coming from a TSS standard-meeting stream and noticeably more TSS Tolerant taxa than TSS Intolerant ones.

### Fines tolerance

Often associated with elevated TSS is excessive deposition of fine particulate material on the streambed, which smothers important microhabitats. Some tolerance to fines was observed in both the fish and macroinvertebrate communities. For fish, there was a continuous progression of poorer Fines scores moving from upstream to downstream. Macroinvertebrates TIV score did not differ much between the two mid-river sites where data was collected, but there was a noticeable difference in individual TIV metrics. Macroinvertebrate taxa and percent individual metrics suggest there is a significant increase in deposition of fine material between 17RN003 and 05RN186. This may be due to a slope change that occurs between these two sites. Although the change in gradient is slight (< 0.2%), the presence of riffle features at 17RN003 and absence of riffle features at 05RN186 supports this concept. Other possible causes such as changes in geology and tributary influence are discussed more in Section 3.5: *Physical habitat findings*. Differences in flow velocity between years 2006 (site 05RN186) and 2017 (17RN003) may also influence percent fines, which is discussed more below.

### Flow Velocity tolerance

TIV and individual tolerance metrics suggests the fish community is being influenced negatively by very slow flow velocities, especially at the middle two sites (05RN186 and 17RN003), and to a lesser degree at the farthest downstream site (17RN001). There is also evidence that very slow moving water is a factor that shapes the macroinvertebrate community composition at the two mid-river sites. Comparing the two macroinvertebrate sites suggests that there is higher general flow velocity at the more upstream site (17RN003) compared to site 05RN186 or that flow velocities were slower in year 2006 compared to 2017.

### Spatial and temporal influence on biology in the mid-river reach

Individual macroinvertebrate metrics suggest there is more flow velocity at the more upstream location (17RN003) of the two mid-river sites (includes 05RN186); or that flow conditions differed between respective years 2017 and 2006 when biological data were collected. Supporting data suggests that both spatial and temporal factors may explain the differences between the two sampled macroinvertebrate communities. The spatial explanation is supported by physical habitat conditions observed in 2019 and reported in Section 3.5: *Physical habitat findings*. Riffle features and diverse velocities (slow to fast) were identified at 17RN003; whereas, no riffles and uniform slow flow were observed in the flatter reach that includes 05RN186. The temporal explanation is supported by rainfall totals (DNR 2020a) reported for Ericsburg, Minnesota, during the warm season months (May through September), which were normal (reporting 17.8 inches) in 2017 and below normal (reporting 12.4 inches) in 2006.

These spatial and temporal differences can also explain the differences in community response to DO and Fines that is also observed between the two locations, again with tolerance to poorer conditions at the downstream site. Both differences in stream geomorphology (flattened slope and fewer riffles at 05RN186) and lower rainfall totals (observed in 2006) can result in slower and less turbulent velocities, which in turn diminishes scouring of fines from the stream bed and oxygen aeration in streamflow.

## 3.2 Hydrology

The movement of water in the hydrologic cycle drives the watershed system and affects all aspects of watershed health (DNR 2021a). Water movement in a watershed occurs in longitudinal (headwaters to outlet), lateral (floodplain-streambed interaction), vertical (groundwater-streambed interaction), and temporal (change over time) dimensions. Precipitation is the main source of flow for most Minnesota watersheds, and it makes its way into rivers through direct runoff or infiltration into the soil profile or into wetlands and lakes. The path or sources of flow as well as the rate and timing influence the chemical and biological components of the river system; and these sources vary longitudinally between the headwaters and the river outlet. Flow alteration, human influenced modifications to natural flow conditions, can disrupt the system and lead to biological or chemistry impairments.

### Flow sources and pathways

In the Rat Root River Watershed, the most likely flow sources or pathways to the main rivers are surface runoff, wetland-release, and shallow groundwater discharge, as there are no lakes upstream of Rat Root Lake. Wetlands are distributed throughout the watershed, but are largest and most abundant in the downstream half of the drainage. Bogs are the dominant wetland type in the RRRLW, but coniferous/hardwood wetlands are also present and most abundant near the headwaters. Tools used to further investigate flow sources to the river systems include the Potential Groundwater Statewide Grid (Smith and Westenbroe 2015) and stable isotope (oxygen and hydrogen) samples.

Estimating infiltration rates provides a measure of average groundwater as well as the relative contribution of precipitation that does not infiltrate, but instead is carried by surface run-off into surface waters. It is not a direct estimation of the surface water contribution, but can be used to judge relative differences between locations in a watershed. The Rat Root River was divided into 12 circular sections (radius = 5-km), in which the average recharge based off of the Potential Groundwater Grid (PGG) data was calculated for each circle.

A casual review of PPG data indicates that infiltration/groundwater recharge values are highest near the Rat Root River headwaters and generally decrease as the river approaches Rat Root Lake. There is a steady decline in infiltration longitudinally downstream from the far headwaters (8.5 inches/year) to WQ site RR4 (7 inches/year). There is an anomalously high value (8 inches/year) at WQ site RR3, which is oriented at an elevation just below the Glacial Lake Agassiz shoreline, and then infiltration stabilizes at around 6 inches throughout the entire length of WID-635. Lower infiltration rates in the downstream WID suggest that more precipitation enters the downstream reach via surface pathways (direct runoff or wetland-release) compared to upstream WID-634 where infiltration is greater. Comparatively, the East Rat Root River has slightly lower infiltration rates overall, but a similar longitudinal trend with more infiltration potential in the upstream WID.

Isotopes of oxygen and hydrogen are another tool commonly used to understand flow pathways in hydrologic systems including streams. The global meteoric water line (GMWL) defines a linear relationship between oxygen and hydrogen observed in precipitation worldwide (Craig 1961; Rozanski et al. 1993). Most precipitation and groundwater plot along the line, with the exact positioning dependent on various environmental factors including temperature and condensation. Alternatively, waters that have undergone evaporation, having spent extended time at the ground surface, tend to plot below the GMWL along a line with a flatter slope. Evaporation is typically observed in water that has been exposed to evaporative conditions as it is stored above the ground surface such as in wetlands, lakes, oxbows, and ponds. Stream waters that show no sign of evaporation are primarily runoff-driven or are inferred to have higher volumes of groundwater upwelling near the collection site as long as groundwater recharge occurred via direct soil infiltration rather than coming from a lake or wetland where evaporative loss may dominate the signature (Brooks et al. 2013). Groundwater upwelling sites tend to have isotope values that are relatively constant in value over time, whereas runoff or shallow aquifer isotopes change seasonally and in response to individual precipitation events.

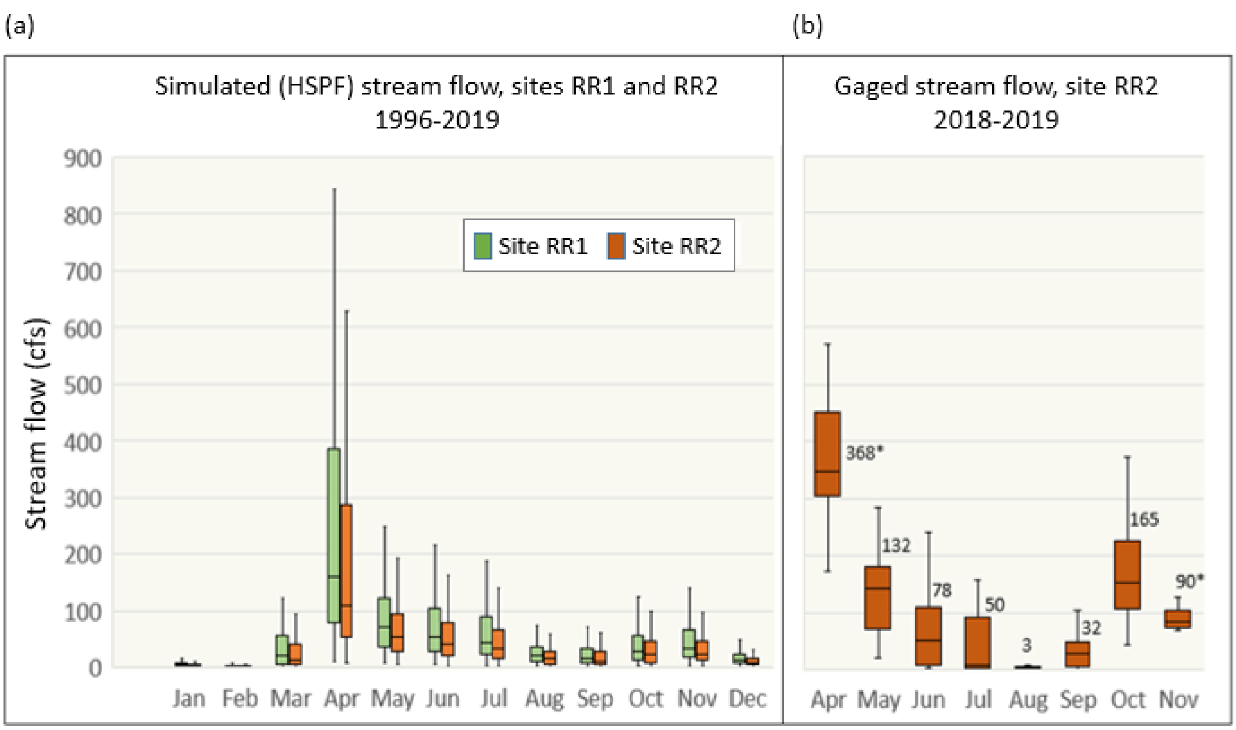
Isotope data collected in the RRRL Watershed suggest that the primary sources of flow to the Rat Root and East Rat Root Rivers are 1) direct runoff/interflow following snowmelt and rain events and 2) wetland-release. Isotope data were collected at two locations each on the Rat Root River (RR1 and RR2, WID-635) and East Rat Root River (ERR3 of WID-632 and ERR2 of WID-633). The two Rat Root River site datasets include 15 samples collected April through September in year 2018, while the East Rat Root river is limited to 5 samples July through September of 2018. Isotope signatures of oxygen and hydrogen from water samples collected April through June plot along the GMWL (Figure 22 in Appendix A) and infer a linear relationship with seasonal changes in temperature which is commonly observed in streamflow recharged by direct run-off and soil interflow following snowmelt and rainfall. July through September samples plot below the line, indicating the presence of evaporative waters in streamflow. Wetland-release is a likely source of evaporative isotope signatures in the RRRLW; although, it is possible that evaporation occurs within stagnant reaches of the river itself. Evaporative signals are present at all sites during the July to September season, which indicates that this is generally true across the extent of the sample area, mid-watershed to Rat Root Lake.

Isotope data do not support strong groundwater upwelling; at least not from reservoirs that are isolated from wetland influences. Isotope samples were not collected in the upper watershed near the headwaters, but other WQ parameters such as temperature and specific conductance measured in the headwaters also do not indicate the presence of deep groundwater inputs to the river system.

## Seasonality of streamflow

Streamflow, both simulated and measured, for the Rat Root River are shown in Figure 3a-b. Measured flows (Figure 3b) were only available at the upstream gage (site RR2, located mid-river), while simulated flows (Figure 3a) were available for both gages (sites RR1 and RR2). Typical of most Minnesota streams, flow in the Rat Root River is highest during spring runoff (April to May) and lowest during the summer and winter months. During the 2018-2019 monitoring years, several months had higher than average precipitation which resulted in higher than normal streamflow. The annual rainfall total was 5 inches above normal in 2019 with September and October being exceptionally wet. (DNR 2020a). Higher streamflow during those months is observed at RR2 by comparing 2018-2019 monthly streamflow (Figure 3b) to those simulated over an extended period (Figure 3a). The lowest measured flows (median = 3 cfs, minimum = 0 cfs) were recorded in August (2018-2019). Additionally, flows less than 1 cfs were recorded in July, August, and September and rates as low as 2.5 cfs were recorded in June as well. Low flows were not related to drought conditions as monthly precipitation totals were normal to high through much of the 2018 to 2019 seasons.

**Figure 3: Monthly variation of daily average streamflow for Rat Root River sites RR1 and RR2, using (a) HSPF simulated flows 1996-2019 and (b) 2018-2019 gaged flows.**
Labels on graph (b) report monthly average flows for the 2018-2019 gage record at site RR2



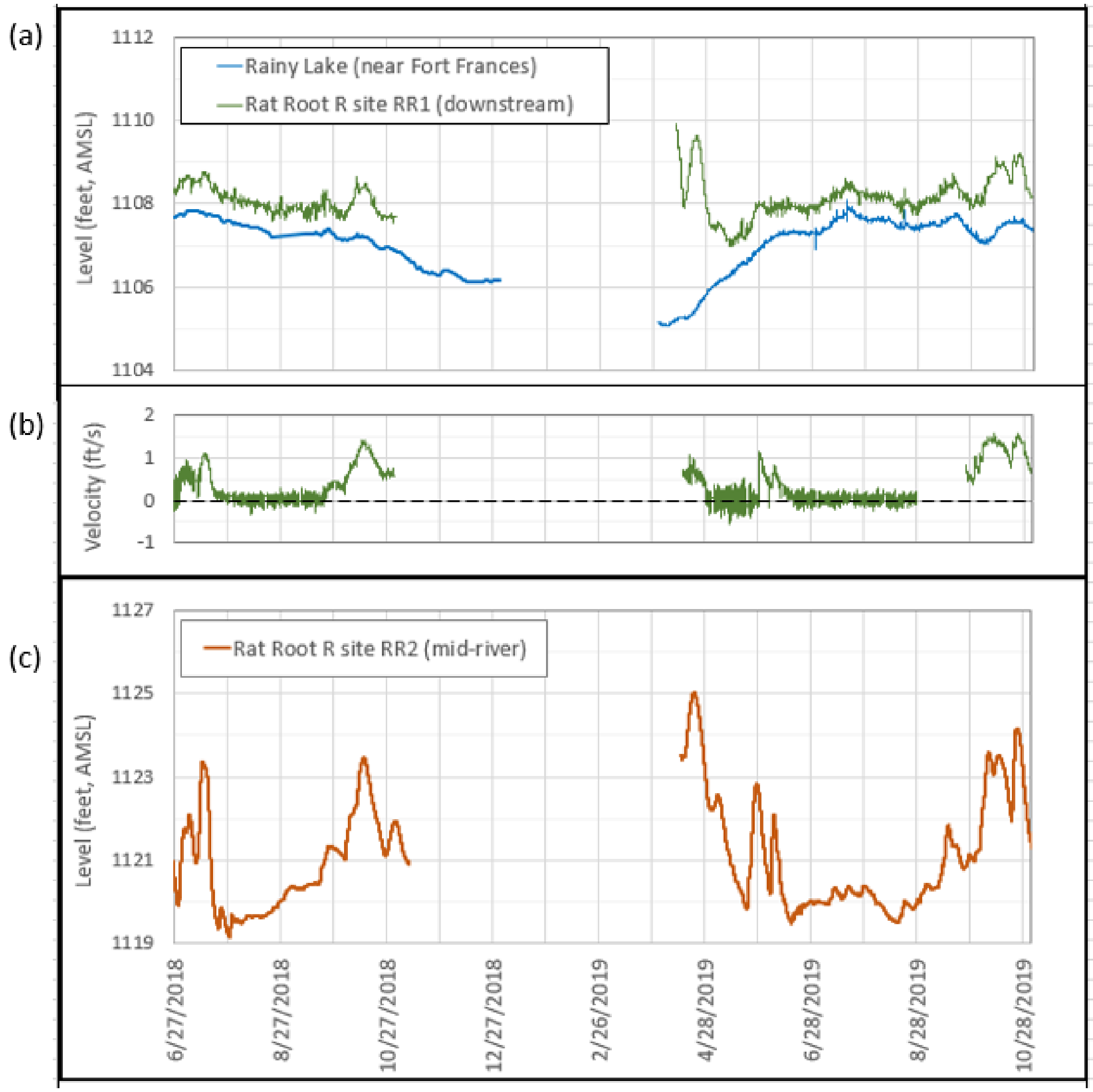

## Dam influence on water level and stream velocity

The hydrology of the RRRLW has been altered by both dams and stream channelization. Two dams constructed in the early 1900s control the inflow and outflow to the RRRLW (Figure 1). The Fort Frances-International Falls hydropower dam, located at the outlet of Rainy Lake, controls water levels on Rainy Lake and inadvertently affects outflow of the Rat Root River. In this low gradient landscape, backwater effects of the dam have been observed on the Rat Root River more than 10 miles upstream of Black Bay at the downstream-most stream gage (site RR1 at the County Road 145 crossing) and are further supported by data presented below. The second dam at Kettle Falls controls inflow to the RRRLW from the east. Lake level management for both dams has recently been modified to better balance the shared ecological, flood control, and hydropower uses of the waters (IRNLRCSB 2017). Thirty-seven percent of total stream miles in the RRRLW are considered impounded (compared to pre-settlement) due to dam backwater effects from the dam.

Water level data (2018 to 2019) at the two Rat Root River stream gages, located near the outlet and at the upstream end of WID-635, were compared to water levels recorded on Rainy Lake. Hydrology data for Rainy Lake and the downstream Rat Root River gage (site RR1) indicates the that lake level management is affecting stream water levels (Figure 4) and velocities (Figure 4b) in the downstream reaches of the Rat Root River during the late-spring to late-summer season. The stream gage is located 10 miles upstream of Rainy Lake and 6 miles upstream of Rat Root Lake. Early spring data, available for the 2019 season, show that when lake levels are low (post-winter), stream water levels and velocities are primarily driven by spring runoff (snowmelt and rainfall). As lake levels rise and spring runoff subsides (early May 2019), stream velocities at site RR1 recede to rates near zero and stream water levels become synchronous with Rainy Lake levels. From early May through mid-September, stream and lake water levels follow a similar trace and are within 0.5 to 1 feet elevation of each other. As lake levels begin to decline in September, the traces are no longer in lock-step with one another, which indicates the lake is less of a control on streamflow at that time.

The gage record at RR1 shows velocities, both positive and negative, near zero for much of the 2019 and 2018 (partial record) summer seasons. DNR measured a flow of -5.7 cfs on July 29, 2020, which further confirms the occurrence of negative flows at the downstream gage. Exceptions to near-zero velocities during the May to September record are observed following rain events when velocities peak above zero for brief (2 to 3 week) periods before returning to stagnant conditions.

**Figure 4: Water level at site RR1 compared to Rainy Lake (a), velocity at RR1 (b), and level at RR2 (c).**




The upstream gage (site RR2) and Rainy Lake are separated by 27 stream miles and 14 feet of elevation. Water levels at the upstream gage (Figure 4c) are not synchronous with lake levels (Figure 4a) and are considered independent of Rainy Lake influence. Although the upstream gage shows much flashier flows than the downstream gage, the summer response to rainfall is low at both locations compared to the rainfall response recorded in the spring and fall seasons. Although independent of dam management, summer flows at site RR2 can reach near-stagnant conditions. Nineteen flow measurements were taken during the 2018 to 2019 season and velocities ranged from 0 ft/s to 1.1 ft/s. All nine velocities measured during the July through August period were less than 0.5 ft/s, including 5 values less than 0.02 ft/s. While further investigations are needed to identify the exact cause of slow velocities at RR2, it is suspected that slow velocities are influenced by naturally flat stream slopes and also may be affected by seasonal backwater effects at a former railroad/trail crossing located one mile downstream of the gage, where logs have piled up against old pilings left behind from a remnant bridge.

## Other altered hydrology and connectivity investigations

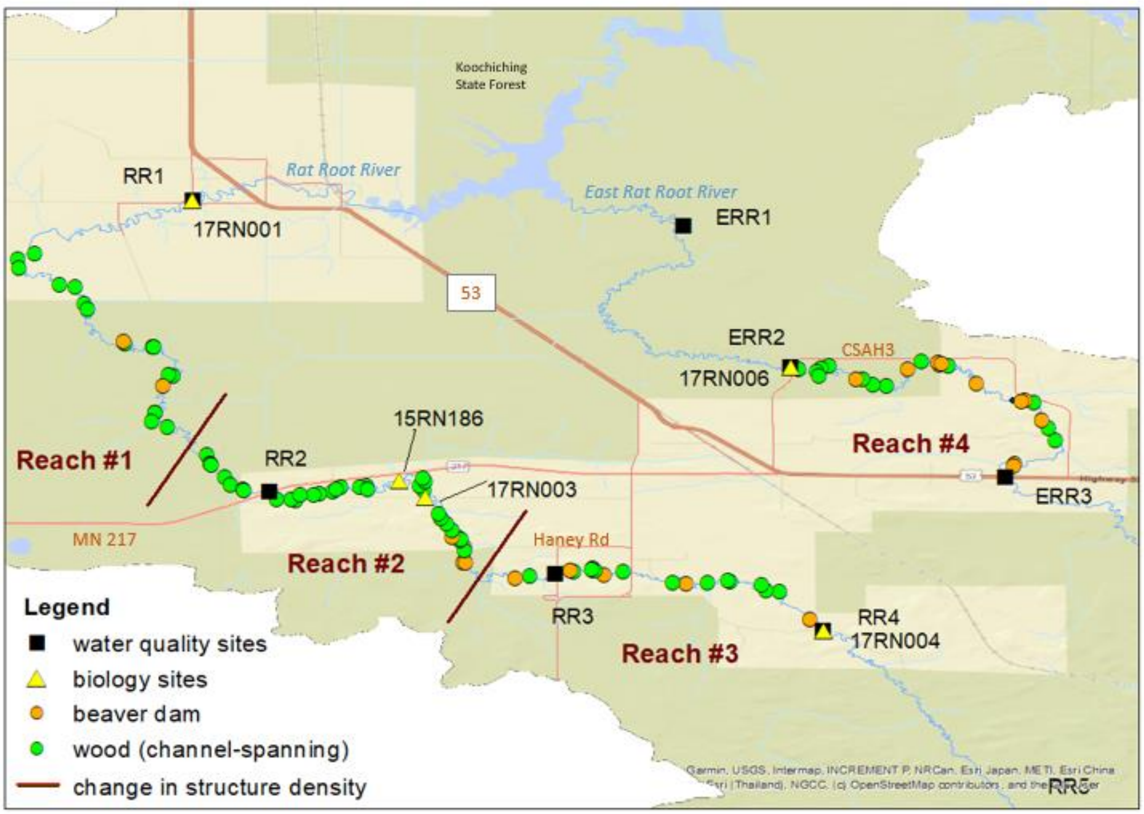
Stream channelization, stream barriers, and increased runoff due to landscape alterations are other common examples of flow alteration. Structural barriers that alter flow such as dams, log jams, beaver dams, and misaligned road crossings also can be barriers to fish passage, disrupt sediment transport, and lead to erosion and stream instability issues. Desktop reconnaissance and field observations provided little to no evidence that these were causing stress to the assessed WIDs, at least not at a detectable level. A brief summary of findings are below.

- **Channelization** in the RRRLW is low (12%of total stream miles) compared to many watersheds statewide (MPCA 2020). More than half of the channelized miles are found in remote wetlands near Rat Root Lake. Monitoring sites with poorer biology scores and WQ (05RN186 and 17RN003) are located upstream of most channelization. The downstream-most monitoring site (RR1) is most influenced by ditching, yet has good fish scores. The site is however impacted by elevated TSS, low DO, and elevated total phosphorus (TP); which may be wetland-influenced. These parameters are discussed more in following sections.
- **Land alterations** in the RRRLW is very low compared to watersheds across Minnesota. There are no urbanized areas and other development including agriculture covers less than 2% of the drainage area. The RRRLW has undergone historic clear-cutting and more recent conservation-approached harvesting. Understanding and quantifying the effects of forest harvest, as well as threshold levels for stress to occur to streams, is less well known compared to agriculture. There is little to no evidence in geomorphology data (Section 3.3: *Assessments of stream stability and bank erosion*) or field observations to suggest flashier flows associated with increased runoff nor excessive erosion or instability linked to logging.
- **Road crossings** are few within the RRRLW, with 12 crossings on 58 miles of the Rat Root River and 5 crossings on 43 miles of the East Rat Root River. Only 4 of those are culverts, which are most often associated with channel erosion, instability, and connectivity issues. These are located near the headwaters of the Rat Root River and near the WID-break of the East Rat Root River, where the closest biology sites have F-IBI scores that are good to exceptional. Although none of the road crossings were officially surveyed using DNR culvert survey methods

  (DNR 2015b), there were no observations of blockages, backflow, or channel instability directly associated with any of them during SID monitoring. A culvert that previously appeared undersized at WQ site RR5 was being replaced during the 2019 field season. There is one crossing, the previously mentioned former rail/trail crossing, that warrants further review, located one mile downstream from the MN State Highway 217 crossing (site RR2) that may be causing intermittent backwater issues due to wood stacking up against remnant bridge pilings.
- **Wood jams and beaver dams** on the Rat Root River were mapped in the Ellen River Partners 2008 study. The study concludes that while beaver dam occurrence rates were high on tributaries, the main stem contained mostly wood jams. Occurrence rates of log jams on the Rat Root River were high in 2008, noted on nearly every stream bend (every 250 to 450 feet) on several reaches of WID-635. Several large dams were identified as potential problems for impounding water, slowing flows, and causing sediment deposition. Large channel-spanning jams and other wood were removed through watershed projects (years 2010 through 2018).

DNR, MPCA, and Koochiching SWCD floated sections of the river (Figure 5) through various efforts in years 2017 and 2019 and similarly observed that beaver dam occurrence rates on the mainstem were generally low to normal (1 to 3 dams per mile), decreasing longitudinally downstream from the headwaters. Wood jam occurrences ranged from several (moderate) to 10 jams (high) per mile and were highest in a stream segment (reach #2, Figure 5) that starts a few miles downstream of WQ site RR3 and extends 2 miles downstream of WQ site RR2. Wood jam occurrence decreased downstream of site RR2 (reach #1, Figure 5) where wood was removed during past removal efforts. The high-wood reach (reach #2) is naturally flatter and slower than upstream reaches, resulting in less efficient transport of wood and sediment. In addition to natural causes of high occurrence, the Ellen River Partners 2008 study described how the succession of aspen and birch increases wood in the channel; a consequence of early to mid-century clear cutting.

**Figure 5: Wood and beaver dam structures mapped in year and 2019 via MPCA and DNR float surveys.** Reaches 1 through 3 were determined during analysis of survey points and are based off of longitudinal changes in structure “density” or occurrence (brown lines = reach breaks) on the Rat Root River. Reach 4 is on the East Rat Root River.




When wood jams become too large in size and too dense, the potential for them to slow flow and cause deposition of sediment increases; as was the case in 2008 when Ellen River Partners conducted their study. However, some amount of wood is very beneficial to river ecology and it is recognized that wood removal from rivers can have negative ecological consequences (Dolloff et al. 2003, Gregory et al. 2003, and PSU 2021b). Much of the wood surveyed in 2017 and 2019 efforts appeared to provide good fish habitat and encourage downstream scouring of fines from gravels. Many of the structures were observed directing flow through narrow openings, providing localized areas of faster flow. The full impact of wood in the channel is inconclusive as data were not collected to examine the impact of wood in detail, but there is no strong evidence that wood jams are systemically slowing flow in the Rat Root River or East Rat Root River; rather, slow flows are preventing wood from being transported once fallen.

## Hydrology discussion and summary

The primary flow inputs to the Rat Root River are runoff from rain events and wetland-release; although, higher infiltration rates in the upstream WID infer that groundwater plays a role in supplying flow to the upstream drainage as well. Natural slope changes in the river result in flatter, wider, and slower reaches in the downstream half of the watershed, within the glacial/till and wetland dominated landscape where surficial flow inputs are most-dominant.

Streamflow and velocity in the Rat Root River decreases quickly following snowmelt and can reach near zero levels in July, August, and September. Stream water level response to rain in mid-to-late summer is much lower than observed in spring and fall seasons. Biological data indicate that the fish community is influenced by slow velocities in the middle to downstream reaches. This is most-prevalent near mid-river chemistry site RR2 (biology sites 05RN186 and 17RN003). There is evidence that very slow moving water also shapes the macroinvertebrate community composition there.

In addition to the naturally low-gradient condition of the watershed and downstream sedimentation from historic-flooding (Ellen River Partners 2008), water level management on Rainy Lake further causes backwater effects in the lower reaches of the Rat Root River. Effects on stream water levels and velocities are observed at monitoring site RR1, located 10 miles upstream of the lake. The effects of the dam on streamflow are most noticeable May through mid-September. The dataset contributing to findings of backwater effects is limited to a 2-year record; and it is recognized that a longer-term record of contiguous lake-stream water level data would further define this relationship.

Slow velocities and backwater conditions are very likely exacerbating sedimentation in the downstream reaches of WID-635 due to inadequate downstream transport of particulates. The building of fines over time can further diminish effective flow and can have destabilizing effects on the channel. Excess sedimentation can result in adverse walleye spawning conditions by changing substrate characteristics. Lack of flow velocity at the outlet may be another factor limiting the spring spawning run.

Slow to stagnant stream velocities were also measured further upstream at mid-watershed monitoring site RR2 (MN State Highway 217 crossing). Too distant to be affected by the dam (verified through water level analyses), the lack of flow velocity is likely due to the low-gradient nature of the channel and possibly exacerbated by backflow conditions initiated downstream one mile at a former trail crossing, where bridge pilings and other remnants of the former bridge at times trap large quantities of wood. Velocities visually appeared faster in steeper upstream sections of the watershed including reaches near Haney Road (WQ site RR3) and in the headwaters (WQ site RR5).

Besides effects of the dam, various human-influenced or altered flow conditions were assessed including ditching, road crossings, beaver dams, and wood jams. There are no evidence that the latter three are causing systemic impacts to streamflow in the Rat Root River; however, there may be isolated areas exacerbating naturally low velocity reaches such as at the trail crossing mentioned above. Data on ditched streams is limited due to the remoteness and limited access to the wetlands, which are most concentrated in the vicinity of Rat Root Lake.

## 3.3 Total suspended solids

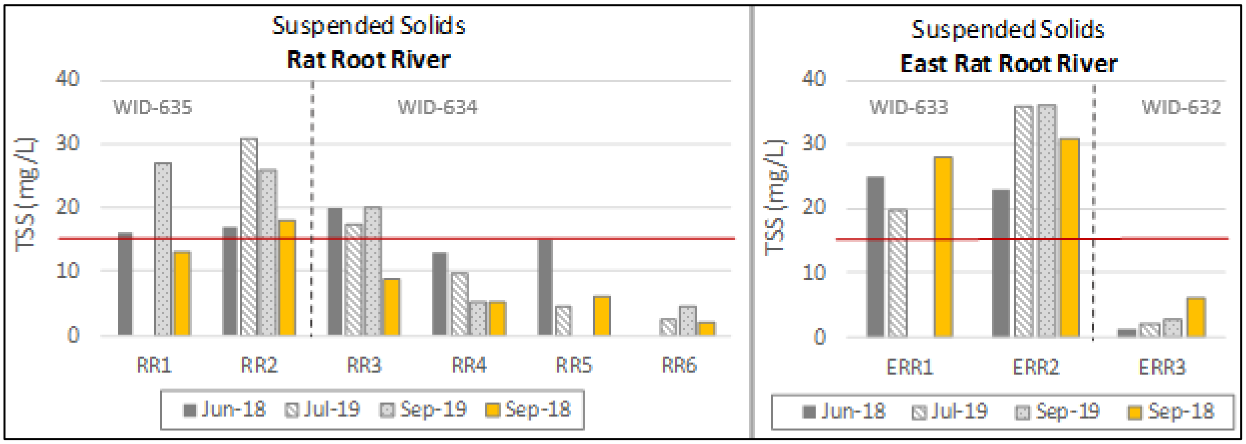
Monitoring efforts associated with IWM and SID identified elevated TSS concentrations in the Rat Root and East Rat Root Rivers. TSS was measured at eleven monitoring sites (10 WQ sites in Figure 2 and one farther downstream at U.S. Highway 53) across the watershed for a total of 229 measurements during years 2014 through 2019. Most samples (163) were collected in Rat Root River WID-635, where 40% of observations exceeded the northern rivers TSS standard (15 mg/L) with an average concentration of 15.3 mg/L and a maximum concentration of 68 mg/L. Twenty-nine samples collected on East Rat Root River WID-633 showed that this reach also exceeded (89% of samples) the TSS standard with an average concentration of 28.6 mg/L and maximum concentration of 70 mg/L. Fewer samples (3 to 13 per site) were collected in the upstream WIDs of the Rat Root River and East Rat Root River. Among the six upstream stations, only site RR3 had exceedances of the TSS standard. Specific flow events were targeted for sampling the headwater stations, which is described in more detail below (See *Longitudinal TSS*).

### Longitudinal TSS

TSS results from samples collected longitudinally upstream to downstream during four different flow conditions (years 2018 to 2019) provide more detail on how TSS varies along the Rat Root and East Rat Root Rivers (Figure 6). Samples were collected at six sites on the Rat Root River and three sites on the East Rat Root River under three different flow conditions: snowmelt, mid-to-late summer rain events, and baseflow.

Generally, TSS concentrations gradually increase longitudinally downstream in the Rat Root River (Figure 6), exceeding the standard between stations RR1 and RR3 under various flow conditions. In contrast to the other Rat Root River monitoring sites, TSS concentrations exceed the standard during low flow conditions at site RR2 in addition to runoff events. This is also observed at East Rat Root River sites ERR1 and ERR2, in which TSS measured in the low flow sample is approximately two times the WQ standard, while also above the standard during runoff events. The most abrupt longitudinal increase in TSS between any sites and under all flow conditions is observed between East Rat Root River sites ERR3 and ERR2, indicating that there is a major source of suspended solids between the two monitoring sites.

**Figure 6: Longitudinal TSS in Rat Root River and East Rat Root River.**
Longitudinal TSS plotted from downstream (left) to upstream (right) for each river. TSS during snowmelt (dark gray bar), post-rain (pattern gray bars), and baseflow (yellow bar) conditions. Dashed vertical lines divide WIDs. Red line = Northern Region TSS standard.



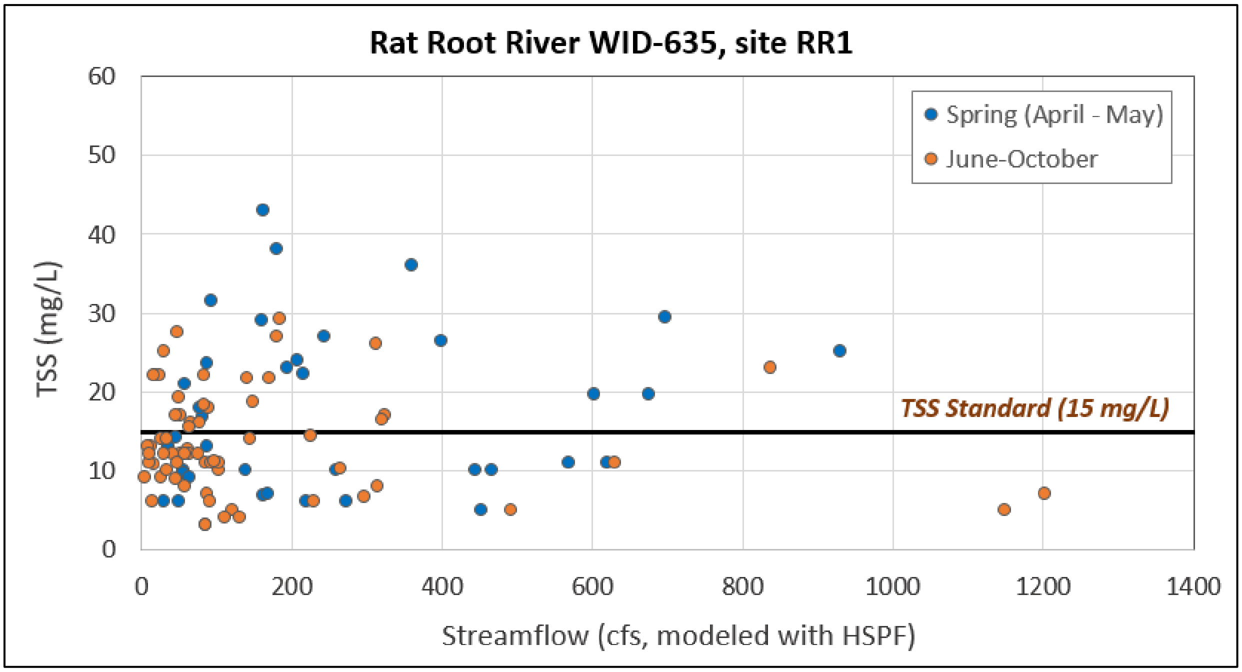

## TSS -streamflow response

To further investigate how TSS varies with streamflow in WID-635, TSS is plotted with respect to flow at sites RR1 (modeled flow, Figure 7) and RR2 (gaged flow, Figure 9). The TSS-flow relationship differs between the downstream and upstream sites. While TSS exceeds the standard over a wide range of flows (low to very high) at downstream site RR1, exceedances at upstream site RR2 are mostly associated with low to comparatively more moderate flow conditions. To verify that HSPF-modeled flows used in the TSS-flow analysis at site RR1 are not biasing the relationship, TSS collected at site RR1 is also paired with gaged flows (2018 to 2019 record) from the upstream gage (site RR2) and plotted in Figure 23 of Appendix A. These findings infer the same conclusion that TSS is exceeded over a wider range of flows at downstream site RR1 compared to mid-river site RR2.

Data were reviewed for two different seasons. April and May data represent the spring season when most trees have not yet leafed out and grasses have not completely greened up. In the earlier part of the spring period, the ground is often still frozen and ice may be present in the channel. June through October data represent the growing season into the fall season when more vegetation and organic litter cover the landscape. In October, vegetation is returning to dormancy and trees and shrubs are in various stages of dropping their leaves. Transpiration is quite less in October compared to mid-summer months of July and August.

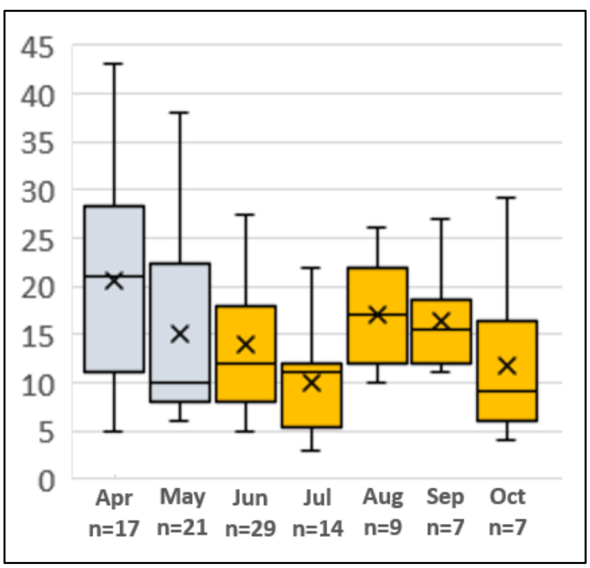
TSS concentrations above the WQ standard at site RR1 plot within a similar range of flows (10 cfs to > 400 cfs) for the two seasons (Figure 7); although spring TSS concentrations tend to be higher. The four highest concentrations (> 30 mg/L) occur during the spring season. Furthermore, while spring samples account for only 36% of the total samples, they account for 54% of the upper quartile (75% of the data lies below this point) of TSS concentrations. More runoff, less interception and transpiration of early season vegetation, build-up of solids in snow banks, and ice-scouring of the channel are potential causes of higher TSS levels in spring.

**Figure 7: TSS plotted with HSPF-modeled streamflow at Rat Root River WQ site RR1 (years 2014-2019).**




What is less clear, is that there is a fairly wide range of TSS concentrations for a given flow within a season (Figure 1). For example, TSS ranges from 6 mg/L to 27 mg/L at a flow rate of ~230 cfs in mid-May samples of different years. The wide range of TSS concentrations may be due to whether samples were collected on the rising or falling limb of a rain event and/or the amount of rainfall leading up to the sampled event. Figure 8 suggests that a greater range of TSS is observed in leaf-off months (April, May, and October) and lower during leaf-on months. This supports that vegetation plays an important role in buffering in-stream TSS concentrations through bank stabilization and interception and transpiration processes.

**Figure 8: Monthly TSS concentration distributions at Rat Root River site RR1 (years 2014-2019).**
Colors follow the code identified in Figure 7 with blue indicating spring season months and orange the remaining months. The “x” on each box plot represents the monthly average TSS concentration.



In contrast to downstream WQ site RR1, TSS is generally highest during low flow conditions at upstream WQ site RR2 (Figure 9). TSS always exceeds the standard at flows less than 40 cfs and sometimes exceeds it at flows between 40 and 72 cfs. The two highest TSS measurements (> 60 mg/L) are paired with flows less than 10 cfs. Similarly, East Rat Root River site ERR2 also most frequently exceeds the TSS standard during lower flows (Figure 23 of Appendix A). To add context to the TSS data at site RR2, daily average turbidity (observed June through early November 2019) are plotted with respect to flow in Figure 9. Turbidity, a measure of the transparency of water due to the presence of suspended particulates, only sometimes has a strong relationship with TSS in streams. The power trend lines plotted in Figure 9 show that TSS and turbidity have a similar relationship with flow at site RR2.

Continuous flow and turbidity data (Figure 10) collected at site RR2 show that rainfall can have varying effects on the streamflow-turbidity response; however, the cause for variable response in somewhat unclear. Relatively small rises in streamflow in response to greater than 1-inch rain events recorded in June and July 2019, resulted in abrupt increases in turbidity followed by equally abrupt decreases (dilution) in TSS and finally a gradual rebound of TSS that occurred over a period of days to weeks. A rainfall event of similar magnitude in August resulted in an increase in turbidity, despite little observed change in streamflow. Subsequent smaller rain events presumably kept turbidity at an elevated level for the next two weeks as streamflow gradually and slightly increased. In contrast, prolonged rain in September and October resulted in a relatively significant streamflow increase and longer-term (>1-month) dilution of turbidity.

**Figure 9: Turbidity and TSS plotted with streamflow (gage 74033003), at WQ site RR2 (years 2018-2019).** Yellow box shows range of flows in which the TSS standard was always exceeded. Blue box shows the range of flows that TSS was sometimes exceeded. The purple box shows the extended range of flow in which TSS might be exceeded, based on turbidity (FNU). TSS (mg/L) are lab analyzed samples. Turbidity (FNU) is the daily average value, collected at the stream gage between 6/01/2019 to 11/04/2019.

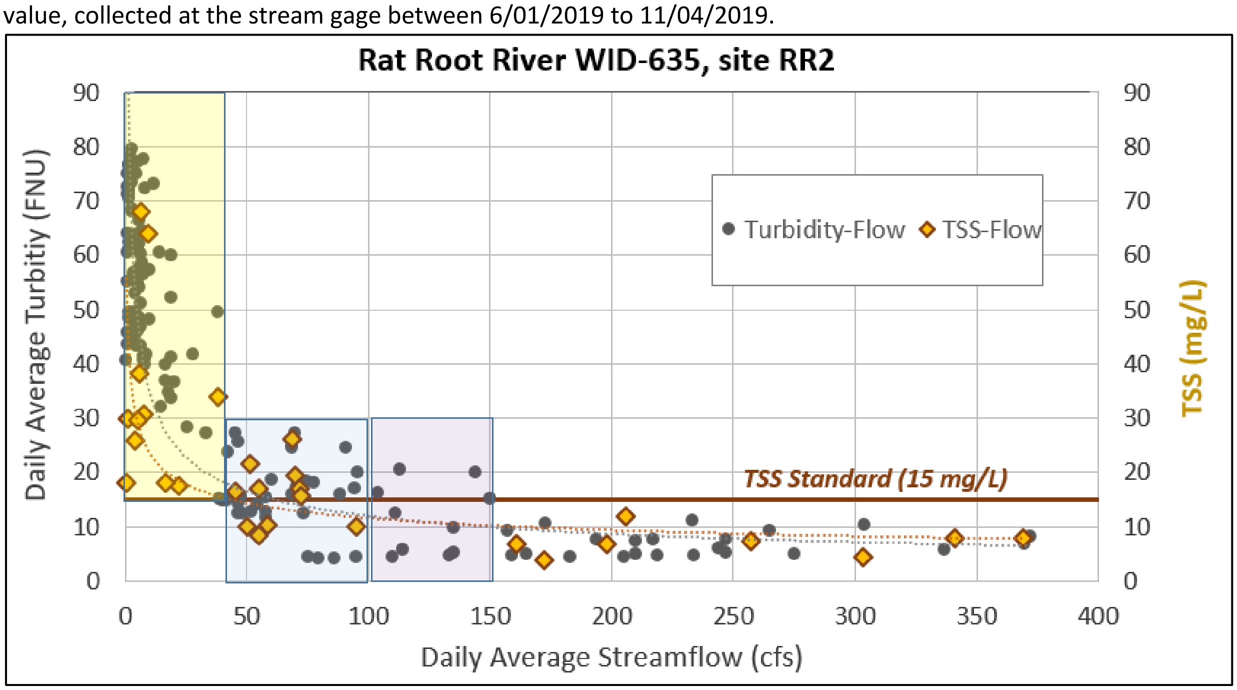
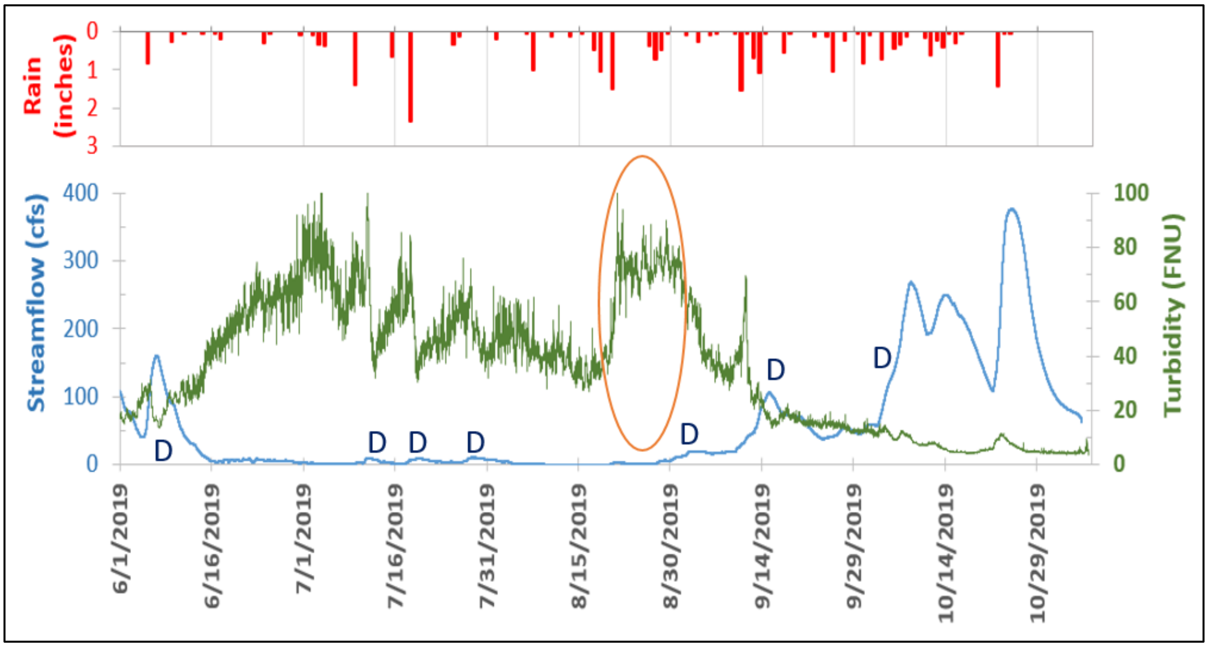


**Figure 10. Streamflow, continuous turbidity, and rainfall at Rat Root River WQ site RR2, year 2019**

"D" = Dilution of turbidity in response to rising streamflow. Orange circle = Increase in turbidity in response to rainfall that resulted in little to no rise in flow.




## Sources of TSS

In low to moderate developed areas, sources of excess TSS can include runoff from roadways, agricultural sites, construction areas, and forest clear cuts. Elevated TSS can also be a by-product of bank erosion or excess bed movement in incised or otherwise unstable stream channels. Many of these sources are runoff-driven which results in TSS loading following precipitation events. Desktop analysis of geology and soils data, as well as survey observations of soil erosion, bank height, and upland erosion were used to evaluate sources of TSS in reaches of the Rat Root River and East Rat Root River where longitudinal increases in TSS are observed. Survey observations were made between sites RR4 and RR2 on Rat Root River and between sites ERR3 and ERR2 on East Rat Root River.

## Geology and soils

Fine silty clay soils in the lower half of the Rat Root River and East Rat Root River Subwatersheds are remnants of glacial activity, both lacustrine and till. Data suggests that these deposits are a primary driver of elevated TSS in the Rat Root River and that the former glacial Lake Agassiz shoreline is a critical geologic boundary within the watershed, where stream TSS concentrations change. The former shoreline of glacial Lake Agassiz (elevation ~1160 feet above mean sea level [AMSL]) marks a natural geologic transition within the watershed; in which soils are coarser and shallower to bedrock in the drainage upstream and finer and deeper downstream. Monitoring sites positioned at lower elevations have elevated TSS concentrations; whereas, sites at equal or higher elevations do not. All sites with TSS exceedances (RR1, RR2, RR3, ERR1, and ERR2) are associated with areas of heavy clay soils (Figure 11) and are located downstream of the former glacial Lake Agassiz shoreline (Figure 12). The fine particulates associated with glacial clays are easily suspended upon disturbance and once suspended, are slow to settle out of the water column, resulting in elevated TSS concentrations.

**Figure 11: TSS water monitoring sites in relation to geologic/geomorphologic features and soil clay content.** Clay soils are prevalent downstream of site RR4 on the Rat Root River and downstream of site ERR3 on the East Rat Root River.

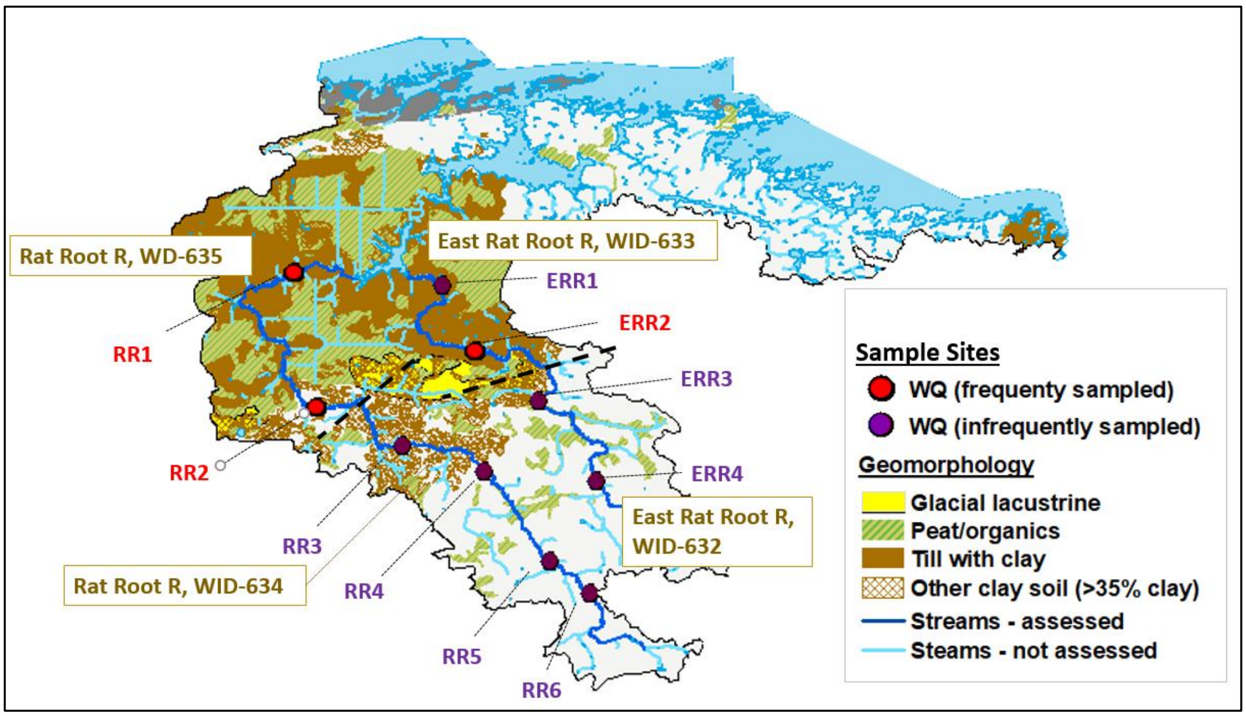
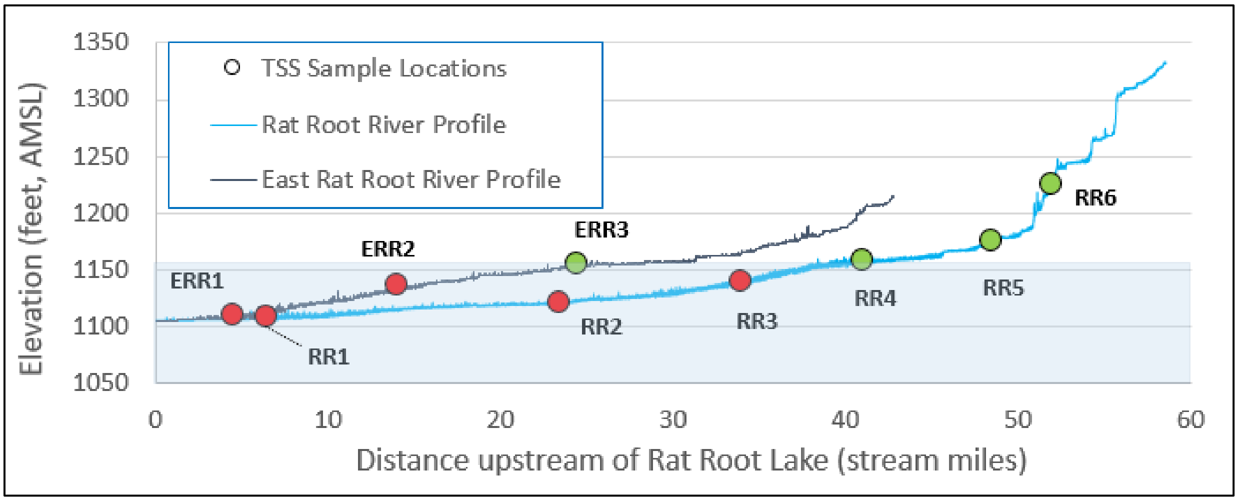


**Figure 12: TSS sample sites plotted on the Rat Root River and East Rat Root River stream profiles**
TSS sites (circles) are colored green if samples meet the 15 mg/L standard and red if they sometimes exceed the standard. The shaded area represents the elevation extent of former glacial Lake Agassiz.




## Types of suspended particulates

Both organic and mineral particles can contribute to elevated TSS concentrations. Testing for Total Suspended Volatile Solids (TSVS) or organic particulates of plant or animal origin allows for the determination of the particle type, and provides information on the source of the problem. High percentages of TSVS in relation to TSS concentrations can be indicative of excess nutrients (algal growth) or can be bits of decayed vegetation, whereas very low concentrations of TSVS in relation to elevated TSS can indicate soil erosion and runoff. In low-gradient and heavily wetland influenced reaches of Northern Minnesota streams such as the Rat Root River, it is important to understand the influence of organic particulates on TSS concentrations.

Generally, there are more mineral soil particulates than organic particulates in TSS concentrations observed near the downstream end of Rat Root River WID-635, particularly for observations where TSS exceeds the 15 mg/L standard. Forty-eight paired TSS and TVS data points collected at site RR1 (years 2014 to 2015) show that TSVS concentrations are low, ranging from below the reporting limit (1 mg/L) to 4 mg/L. TSVS concentrations below the reporting limit account for 40% of total observations. While TSVS is consistently low, TSS concentrations range from 3 mg/L to 38 mg/L.

To better understand TSS exceedances elsewhere in the watershed, TSVS was collected longitudinally along both the Rat Root and East Rat Root Rivers during the low flow event described previously in this *Section 3.3: Longitudinal TSS*. Longitudinal sampling of TSVS was not done for a high flow event. As would be expected the percentage of organic particulates (TSVS) were highest (80% to 100% of total TSS) at the headwaters sites (RR6 and ERR4) where TSS concentrations clearly met the standard. Generally, the percentage of organics contributing to TSS decreased and mineral soil contributions increased longitudinally downstream in both rivers with respect to the low flow event. TSS exceeded the standard at sites RR2, ERR1, and ERR2 for the low flow event but the mineral-organic soil contributions differed. Mineral soil concentrations (21 and 28 mg/L) in the East Rat Root River were at levels greater than the TSS standard independent of organics, which contributed an additional 7 and 8 mg/L to TSS. In contrast, the mineral soil concentration (13 mg/L) at Rat Root River site RR2 was below the TSS standard, but combined with TSVS (5 mg/L) resulted in an exceedance. This infers that there may be additional mineral soil sources of TSS in the East Rat Root, compared to the Rat Root River.

## Assessments of stream stability and bank erosion

Channel conditions, including erosion and bank height, were assessed in increasing TSS reaches in the fall season of 2019. This was a DNR led effort with assistance from the MPCA and Koochiching County SWCD. Data was collected using the Bank Assessment for Nonpoint source Consequences of Sediment (BANCS) model (Rosgen 2001). Surveyed reaches were located between TSS monitoring sites RR4 and RR2 on Rat Root River and between stations ERR3 and ERR2 on East Rat Root River. Additionally, stream geomorphology surveys using Rosgen Level 2 methods (Rosgen 1996) were completed at sites RR1 and RR2 of the Rat Root River to further assess channel stability. The complete BANCS summary (DNR 2020b) and channel stability findings (DNR 2020c) were finalized and made available in fall of year 2020.

The stream geomorphology survey report (DNR 2020c) concluded that stream segments containing monitoring sites RR1 and RR2 are stable low-gradient reaches that have adequate access to the river floodplain. It is noted that the channel bottom at each location has little depth variation (5.2 feet to 6.8 feet at bankfull flow) whereas streams with distinct riffle/pool sequences often have pools with more than twice the depth of riffles at bankfull flows. Nor does the stream have areas of different flow rates normally associated with riffles and pools. Geomorphic surveys were not conducted on the East Rat Root River; however, the 2008 Ellen River Partners study estimated that the East Rat Root River is incised by 1.5 feet downstream of Ericsburg, Minnesota.

The BANCS summary report states that average erosion rates on the Rat Root River and East Rat Root River are generally low due to low-gradient stream slope, well vegetated banks, and adequate floodplain accessibility. Both rivers have isolated banks and a few extended reaches with elevated erosion rates that could be contributing to increases in TSS; however, compared to the nearby Ash River and Blackduck River, eroding reaches on the Rat Root River are much shorter and overall erosion is lower (DNR 2020b). No large sources of upland sediment were identified, although field investigations were limited to observations that could be made from the stream channel. Beaver dams and, to a greater degree, channel-spanning log jams are prevalent in the mainstem of both rivers; although, they do not appear to be causing elevated bank erosion rates (DNR 2020b). It is likely they are a symptom of inadequate stream power to transport large materials.

Banks with higher erosion rates were mostly scattered throughout the surveyed section, as opposed to being concentrated in one area, which indicates that most erosion is a symptom of local conditions rather than a systemic issue. There are three exceptions or reaches where erosion and/or bank stability issues were identified. Listed in order from least to more obvious erosion, areas of erosion are described here:

- **A one-mile reach (1 stream mile length downstream of latitude: 48.402038°/longitude: -93.301813°) in the area of the Old Highway 217 (Town Rd 174)**, high bank heights were recorded. This reach overall does not have high erosion rates, but visual signs of incision there suggest there could be future erosion. Further investigation is needed to confirm the reason for higher banks and the presence of incision.
- **Between monitoring sites RR4 and RR3 on Rat Root River WID-634**, respectively higher bank heights and erosion rates suggest that the river is either incised or abutting a valley wall or terrace. A few small gullies were noted, particularly just upstream of Koochiching County Highway 29. Gully contribution of sediment to the overall system is unknown. Based on gully

drainages, sediment contributions would most likely affect TSS levels at a reach-scale as opposed to at a watershed scale. More information is needed to estimate erosion and TSS-impacts of gullies in this reach.

- **A 3,500-feet reach immediately upstream of East Rat Root River site ERR3 (Koochiching County Highway 3 crossing)**, higher bank heights and erosion rates suggest the channel is incised or abutting a valley wall or terrace. This is the longest reach of stream with contiguous eroding banks. Recovering bank slumps, estimated to be 5 years old based on new vegetative regrowth, were noted in the reach, indicating that natural recovery of eroding banks is occurring under hydrological conditions that allow it. Increased erosion was not associated with beaver dams or debris jams in this reach. TSS is elevated in this reach and the findings in Section 3.3: *Longitudinal TSS* suggest that mineral soil is a larger source of TSS than wetland or other organic inputs. The BANCS survey was not completed downstream of this location; although visual observations from the road crossing show a continuation of erosion and possible incision downstream of the highway crossing.

In both reaches with elevated erosion rates, field notes indicate that the banks have a higher proportion of gravel. Higher gravel content can be more easily eroded and can lead to increased bank erosion. The Ellen River Partners study (2008) suggested the same cause for erosion in the East Rat Root River. A more detailed geomorphic assessment of those specific reaches could help verify if incision is occurring and to what degree, as well as provide more insight on the causes of erosion. Bank erosion surveys were not extended further downstream of site RR2 on Rat Root River WID-635 or downstream of site ERR2 of East Rat Root river WID-633 where TSS is at times elevated beyond the standard.

## Total suspended solids summary

TSS is at times elevated beyond the standard in both streams, particularly in the clay-dominated geology that is within the extent of the former Glacial Lake Agassiz shoreline. This includes all of WID-635 and part of WID-634 of the Rat Root River and WID-633 of the East Rat Root River which have been described throughout this report as downstream and mid-river reaches. The TSS standard is not exceeded upstream of the former glacial lake extent where soils are slightly coarser. Channel geomorphology survey results from two locations suggest that the downstream to mid-river reach of the Rat Root River is generally stable (DNR 2020c). BANCS survey results (DNR2020b) identify erosion in localized areas of both streams where banks are higher and/or have a higher gravel content. The longest longitudinal extent of erosion is found within East Rat Root River WID-633, just upstream of WQ site ERR2. Both recent erosion and older slumps that are now revegetated were observed there. Future geomorphology surveys of the higher erosion reaches identified in the BANCS report would be needed to verify or disprove incision in those areas.

TSS exceeds the standard at a variety of the flow regimes in the downstream reach of the Rat Root River where data from WQ site RR1 indicates multiple TSS sources contribute to elevated concentrations. Evidence such as high flow TSS exceedances and a high mineral soil content (opposed to organics) of TSS suggest that erosion and surface runoff are sources of elevated TSS. Low flow TSS exceedances are also sometimes observed in the downstream reach and are likely the result of prolonged suspension of fine soil particles following stream bank and the stream bed disturbance with a smaller low flow TSS contribution coming from organic particulates.

Upstream at mid-river site RR2, an inverse relationship between TSS and streamflow suggests prolonged suspension of particles upon disturbance during low to moderate flow conditions is a primary cause of elevated TSS in the mid-river reach of the Rat Root River. TSS concentrations are highest during low flow periods. Possible, but unconfirmed, forms of disturbance include low to moderate rainfall, fish activity, wildlife (especially beaver), and other physical processes. A single observation made under low flow conditions indicates that organics and mineral soil particles combined result in low flow exceedances in this reach, as opposed to either individually causing an exceedance. This is in contrast to low flow observations for the same event at East Rat Root mid-river site ERR2 where mineral soil concentrations alone were high enough to cause an exceedance of the TSS standard.

Although bank erosion was observed in several locations upstream of mid-river WQ site RR2, TSS concentrations above the standard were not associated with high to very high flow events. Furthermore, continuous turbidity and streamflow data show that significant and/or extended increases in streamflow can result in prolonged periods of TSS dilution. This is likely due to an inadequate amount of sheer stress or upstream sediment supply to cause erosion proportional to increasing flow, which has been documented in sediment studies on other low-gradient, low-topography streams in Minnesota (Vaughan et al. 2016; Ellison et al. 2013).

## 3.4 Dissolved oxygen

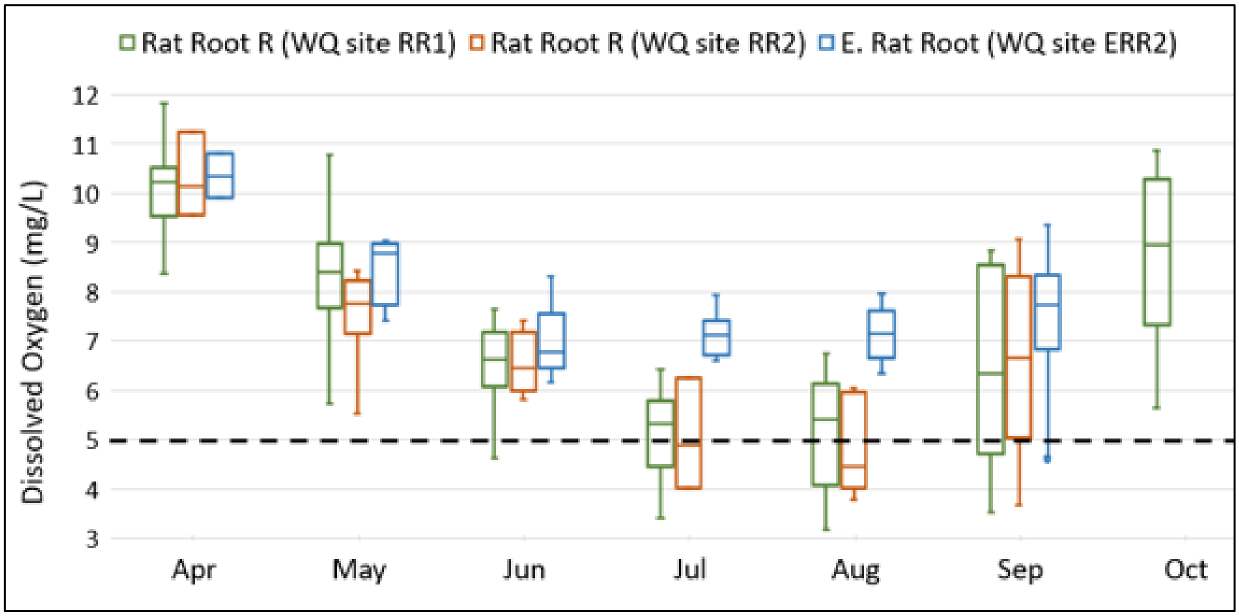
DO, needed by aquatic fish and invertebrates, enters streams from the atmosphere. In some streams DO also enters by groundwater discharge; however, in most instances, groundwater is quite low in DO. DO concentrations are affected by water temperature, stream velocity, and biological processes such as photosynthesis, respiration, and decomposition. Cold water can hold more DO than warm water; therefore, fluctuations in DO often coincide with seasonal and diurnal temperature cycles. Regarding stream velocity, fast moving water tends to be higher in DO due to turbulence-induced aeration at the water surface and stagnant water tends to be lower in DO. Photosynthesis, which can be a primary influencer of DO in streams is dependent on variables such as nutrient availability, water clarity, and sunlight. DO is used by two main processes: respiration and decomposition. Respiration is when plants (at night) and animals take in oxygen and decomposition is when organisms break down dead organic material. Sediment oxygen demand (SOD) is respiration and decomposition that occurs in stream sediments as opposed to in the water column. It is most common in streams with high contents of organic materials (peat, plant matter, and wood) buried within the sediments.

### Dissolved oxygen findings

DO was measured at nine locations across the watershed for a total of 225 measurements during years 2014 through 2019. Most observations (143) were measured in Rat Root River WID-635 at WQ sites RR1 and RR2. DO concentrations measured across the extent of WID-635 did not meet the warmwater DO standard (5 mg/l) for 15% of May through September observations and were lowest at upstream site RR2 where 20% failed to meet the standard. Few measurements were taken before 9 a.m., and so daily minimums were not reflected in the dataset. Improved DO conditions were observed in reaches with comparatively steeper gradients including upstream Rat Root River WID-634 and East Branch Rat Root River WID-633 where less than 7% of the DO observations did not meet the standard.

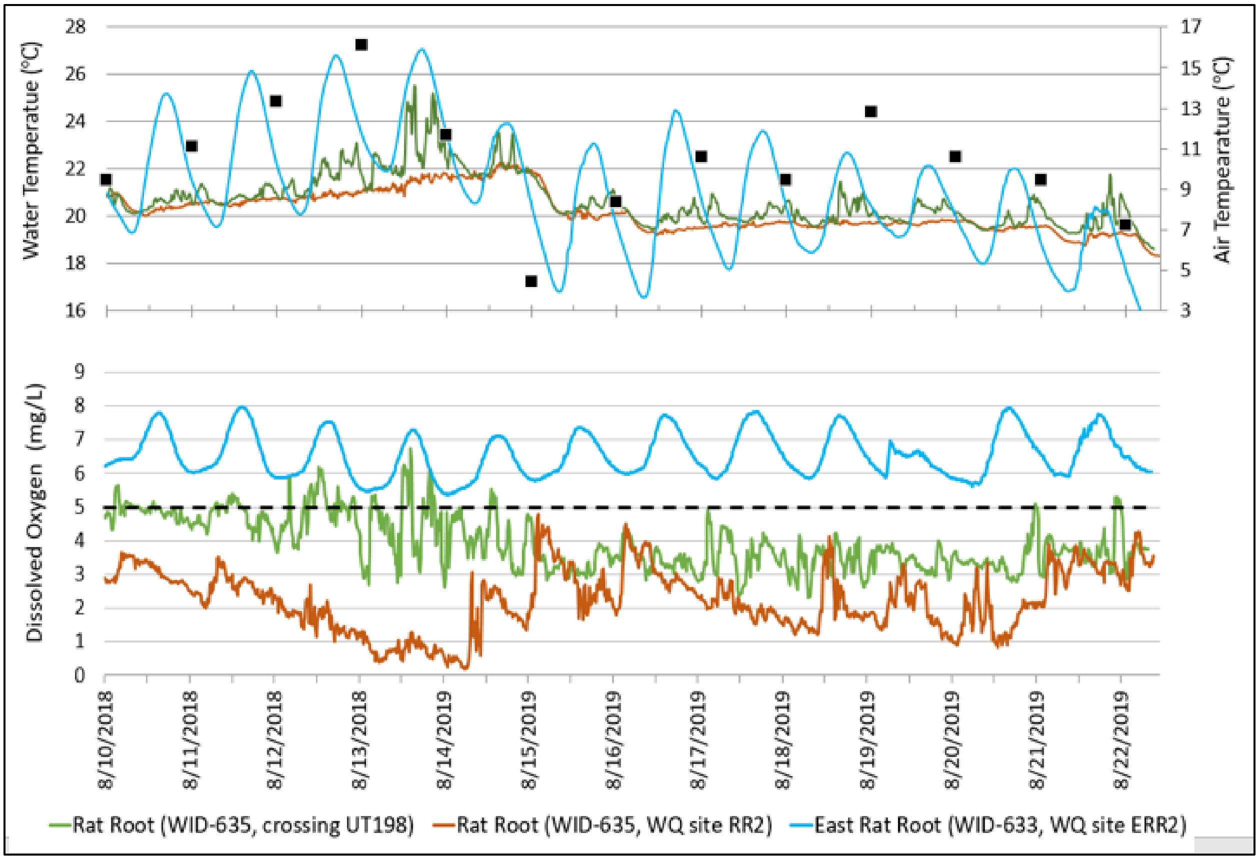
Seasonal variations of DO were evaluated at sites RR1, RR2, and ERR3 (Figure 13). DO at all three sites is highest during the early spring season and declines following the spring season peak, reaching lowest concentrations in summer. Most exceedances of the warmwater DO standard occurr at sites RR1 and RR2 during the months July through September with the most critical levels measured in July and August. DO concentrations begin to rebound in late summer, increasing to pre-summer levels by the end of October. DO concentrations on the East Rat Root River are better, and meet the standard for most observations. Based on these data, mid-to-late summer is the critically low DO period on the Rat Root River. Flow records available for WQ site RR2, show that periods of low DO in WID-635 correlated with periods of low streamflow. All DO observations below 5 mg/L at WQ site RR2 occurred at flow rates less than 8 cfs. Field notes indicate near stagnant conditions during these low flow periods at both the upstream and downstream gages.

**Figure 13: Seasonal DO variations for Rat Root River and East Rat Root River (2014-2019 dataset).**




Continuous measurements of DO provide a better understanding of how DO fluctuates daily; and when compared to other WQ parameters, can provide a clearer understanding of DO influences. DO and water temperature were measured continuously over a two-week period under low flow conditions in August, 2018, at two locations on Rat Root River WID-635 (Figure 14). DO sensors were installed near the upstream and downstream ends of WID-635, respectively at site RR2 and at Township Highway 198 crossing (Galvin Line Road). The downstream site was co-located with a stream riffle project site, completed in 2014. Data was also collected at East Rat Root River site ERR3 for comparison.

**Figure 14: Continuous DO and temperature for Rat Root and East Br. Rat Root Rivers.**
Black dashed line represents the DO standard of 5 mg/L for warmwater streams. Continuous water temperature and discrete points of air temperature data (black squares) is provided to explain changes in dissolved oxygen (e.g. abrupt change in dissolved oxygen on 8/14/2018).




DO concentrations were below the 5 mg/L standard for extended periods at both WQ sites on WID-635. DO levels ranged from 0.18 mg/L to 4.78 mg/L with 100% of the readings falling below the 5 mg/L standard at mid-river site RR2 and 40% below sub-optimal levels (2mg/L). Sub-optimal levels are avoided by most desirable fish species, but others such as the fathead minnow can easily thrive. Fathead minnows were sampled in large numbers (142) at biological site 05RN186 (near site RR2) in 2006. DO was only slightly improved downstream at Galvin Line Road with concentrations ranging from 2.32 to 6.74 mg/L and 89% of the readings falling below the standard. During the same period, all readings at East Rat Root site ERR3 were above 5 mg/L.

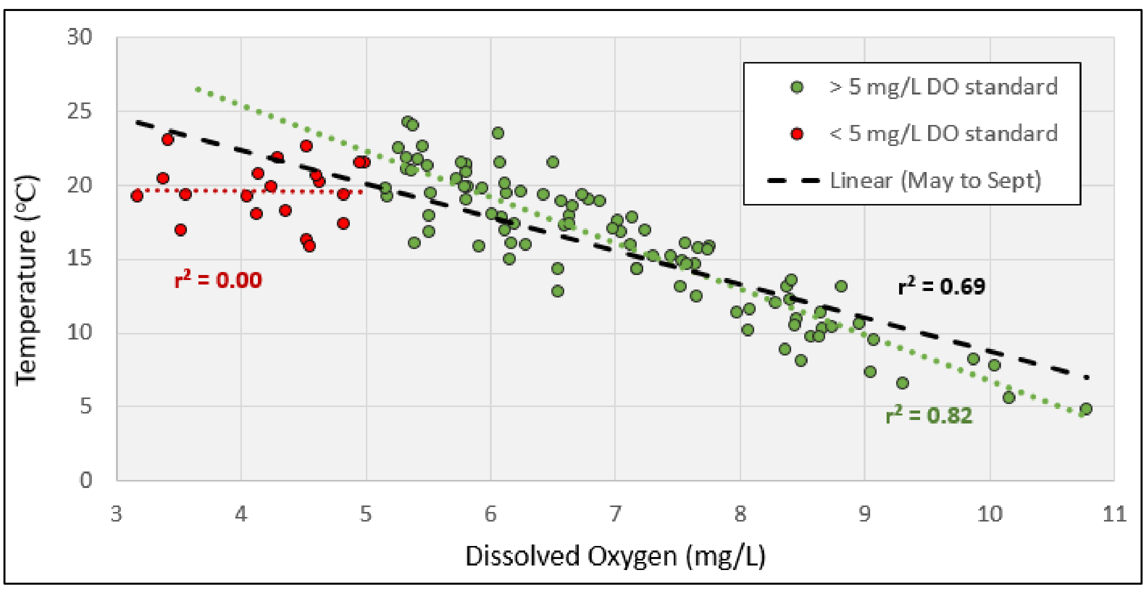
DO flux (daily fluctuations of DO) meet regional eutrophication criteria (average DO flux < 3.0 mg/L) at all three stations (Table 4). Distinct daily oscillations in both temperature and DO at East Rat Root River WQ site ERR3 reflect a typical stream response to daily fluctuations in ambient air temperature, where stream temperatures rise and fall in sequence with ambient conditions; and DO responds with an inverse or lagged signal. Comparatively, no distinct diurnal pattern in DO or temperature is observed at the two Rat Root River sites. One explanation for this is the greater depth in combination with elevated TSS in the Rat Root River, as the range of temperature variation in streams often decreases with increased volume and turbidity. DO fluctuations can be further buffered in turbid waters due to lack of light penetration needed for primary production (algal and diatom growth); and low-DO inputs such as discharge from anoxic wetlands can further buffer daily oscillations.

Even though daily oscillations in WID-635 show no distinct pattern, paired DO-temperature data show a linear relationship between DO and water temperature at site RR1 ($r^2$ =0.69, n=113, Figure 15), and a lesser relationship at site RR2 ($r^2$ =0.45, n=30) for observations made May through September, the period used in WQ assessments for DO. At a finer temporal scale, continuous data confirm that abrupt changes in ambient air temperature can result in equally abrupt changes in DO, as is observed on August 15, 2019, (Figure 14) when a decline in minimum daily air temperature resulted in an abrupt decrease in water temperature and increase in DO. DO increased from sub-optimal levels to greater than 4 mg/L. No precipitation is recorded for the area on that day to further explain the response. This suggests that even in deeper, more turbid waters of the Rat Root River, large daily swings in ambient air temperature can initiate a response in DO.

## Dissolved oxygen sources

Linear relationships between DO and temperature, when observed in more detail, indicate that factors other than stream temperature (or the capacity for the water to hold oxygen) influence DO levels in the Rat Root River (Figure 15). The linear relationships defined above for Rat Root River sites RR1 and RR2 improve to 0.82 (n=93) and 0.69 (n=23) respectively when considering only the samples where DO meets the standard. The DO-temperature relationship does not hold true during periods of low DO, suggesting that other processes are causing the low levels. Ninety percent of the low DO samples in Figure 15 (red dots that show no relationship with temperature) were collected during the July to September period.

**Figure 15: DO – Water temperature relationship at Rat Root River site RR1, 2014-2019 dataset.**
The black trendline shows a linear relationship between DO and temperature for all samples collected May through September. The green trendline shows a stronger linear relationship observed at DO concentrations > 5 mg/L and the red trendline shows no relationship at concentrations < 5 mg/L.




### Eutrophication

Although phosphorus concentrations in Rat Root River WID-635 often (64% of 153 samples collected in years 2014 through 2019) exceed the Northern River Nutrient standard (0.05 mg/L) with an average concentration of 0.06 mg/L, other evidence indicates that primary production or eutrophication is not a primary driver of low DO (Table 4). Response variables such as TP, DO flux, and chlorophyll-*a* data are used when looking closer at the potential for eutrophication and related DO issues. Elevated nitrate levels can also be indicative of eutrophication. The response variables do not strongly support eutrophication.

The strongest evidence against eutrophication is DO flux, which are within the expected range (<3.0 mg/L) and do not display mid-day high and early morning low levels of DO that are typical of eutrophic conditions. Nitrate concentrations are extremely low (<0.5 mg/L). Chlorophyll-a data are limited to 17 samples and are inconclusive due to a wide range in concentrations (<1 to 39.2 mg/L). Six observations (35%) exceed the regional standard (7 μg/L), whereas five (29%) are below the lab detection limit (1 μg/L). Although chlorophyll-*a* sometimes is high, there were no visual evidence of algal blooms during site visits. Downstream of this WID, there is no eutrophication level data for Rat Root Lake; however, Black Bay is a known eutrophic area of Rainy Lake. TP loading in the Rat Root River could lead to increased TP levels in receiving waters.

Based on available data, there are no distinct differences in DO response variables between the mid-river (RR2) and downstream (RR1 and U.S. Highway 53) monitoring stations on Rat Root River WID-635; however, all response variables for the reach were elevated compared to East Rat Root River site ERR3 (Table 4). The available data do not indicate that eutrophication is a primary process in either stream. Continued monitoring of chlorophyll-*a* could provide more understanding of the wide range of levels previously observed and algal presence in the Rat Root River.

**Table 4: Eutrophication response variables for Rat Root River and East Rat Root River.**
Bold values indicate some exceedances of water quality standards.

| | WQ SITE (WID) | TP AVERAGE | CHLOROPHYLL-A (AVERAGE/MAX) | DO FLUX AVERAGE |
|---|---|---|---|---|
| **DOWNSTREAM** | U.S. Highway 53 (-635) | 0.061a | <6.20/**10.7** | -- |
| ↓ | RR1 (-635) | 0.060 | **<8.67**/39.2**[a]** | 2.16[b] |
| **UPSTREAM** | RR2 (-635) | **0.075[a]** | **9.13[a,c]** | 2.07 |
| **COMPARISON STREAM** | ERR2 (-633) | **0.053** | 1.99[a,c] | 1.04 |
| | *WQ Standards - Northern River Nutrient Region* | *0.050 mg/L* | *7 μg/L* | *3.0 mg/L* |

[a] Insufficient number of samples to compare against water quality standards. [b] Continuous data collected 1 mile upstream of discrete sampling water quality monitoring site. [c] Reported average is based on a single sample.

## In-stream and wetland decomposition

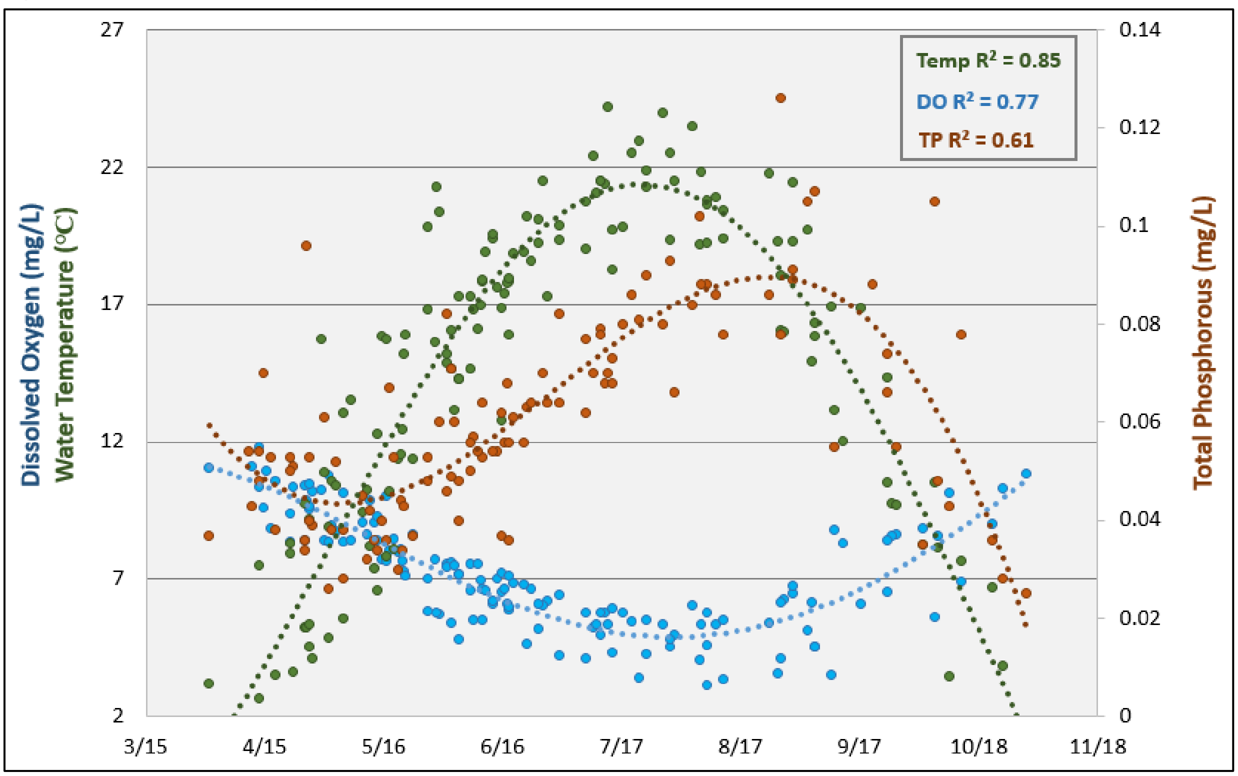
There is an abundance of wetlands in the Rat Root River Subwatershed and water that moves through the organic wetland soils is part of what contributes to the river's flow. Wetland flow can be quite anoxic in summer, due to the use of DO by microorganisms decaying the organic material. Under anoxic conditions, phosphorus is converted to a soluble state that can then move from the peat to the stream water. Decaying of organic material can also occur in the stream channel itself and within stream sediments if a lot of organics are buried within.

Data collected in the RRRLW support wetland release of TP during low-DO periods when wetlands are most likely to be anoxic. The TP pattern in the Rat Root River (Figure 16) is very similar to other wetland-influenced streams documented in natural landscapes elsewhere in northern Minnesota (MPCA 2014; MPCA 2016; MPCA 2017c; MPCA 2019a; MPCA 2019b; MPCA 2020b), with a bell-shaped curve that peaks in late July or early August. The seasonal DO curve plots inversely to TP, reaching a seasonal low just prior to the maximum peak in TP.

Sampling of a low flow event in September 2018 (described below in Section 3.4, Subsection: *Stream Gradient*) verifies that DO in RRRLW wetlands can reach critically low to anoxic conditions as one wetland outlet stream reported DO readings of 0.67 mg/L. Isotope data supports wetland contributions to streamflow in both rivers during the late summer months (See Section 3.2, Subsection: *Flow sources and pathways*). Decomposition is further supported by regionally moderate to high dissolved organic carbon (DOC) concentrations (18-57 mg/L) in the Rat Root River, with the highest DOC concentration observed at site RR1, indicating that decomposition of organic matter can be high.

Although there are no data to evaluate SOD in the RRRLW, it is likely that in-channel consumption of oxygen through SOD may also be a cause of low DO levels. In lakes and slow moving rivers, or rivers with high levels of organic matter in the bed sediment, SOD can be a major cause of low DO concentrations in the water column. SOD was not directly measured in the Rat Root River; however some evidence including stagnant flow conditions, sedimentation, and elevated levels of DOC in the water column infer that SOD may be a source of low DO in the system. Future monitoring of SOD could help evaluate this candidate cause further.

**Figure 16: Seasonal DO, temperature, and TP for Rat Root River site RR1, 2014-2019 dataset.**

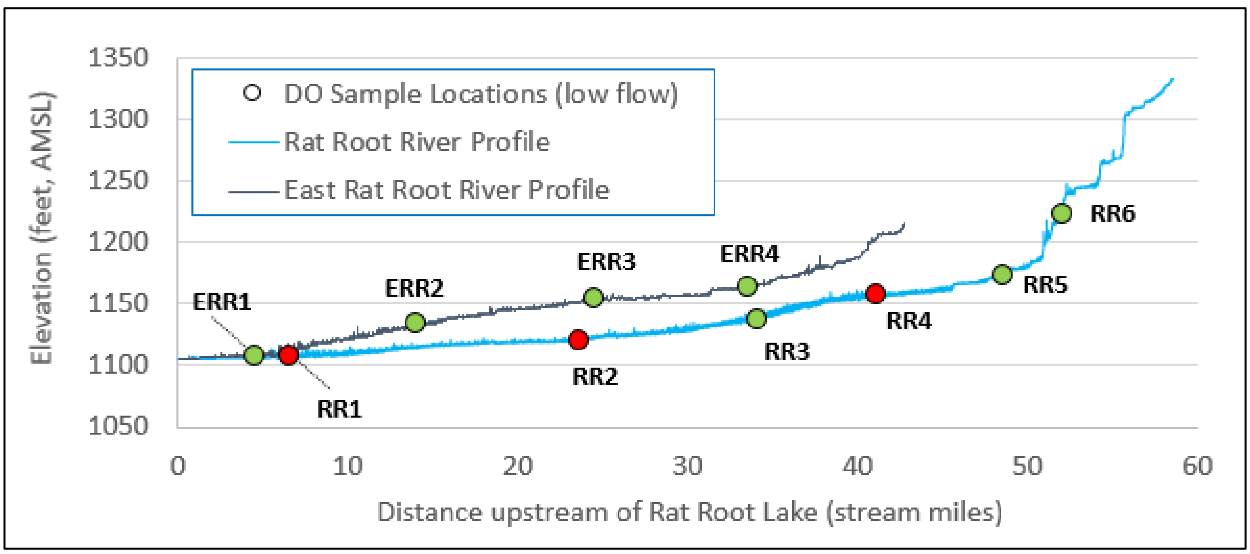


**Stream Gradient**

Flattened stream slopes, slow stream velocities, and lack of riffle habitat also contributes to (or exacerbates) low DO conditions in the Rat Root River. Aeration through turbulence, which is lacking in most of WID-635, is a primary source of DO to streams. Flattened reaches of the Rat Root River correspond with low DO readings, which is observed in the greater dataset, but also during a longitudinal sampling effort on the Rat Root River and East Rat Root River during low flow conditions. On September 6, 2018, DO was measured at sites on the Rat Root and East Rat Root River during WQ sampling. While DO met the 5 mg/L standard at all four East Rat Root WQ sites that day, it was below the standard at three of the six Rat Root River sites (Figure 17). The three sites (RR1, RR2, and RR4) with low DO concentrations (3.1 to 4.5 mg/L) are located in comparatively lower gradient reaches (Figure 17) of the Rat Root River where stream velocities are slow and riffle habitat is lacking or absent, resulting in diminished aeration through lack of physical mixing. Adequate levels of DO were observed at WQ sites RR3, RR5, and RR6, which are located on steeper reaches that have observed riffle features.

Gradient and low DO do not correlate as well on the East Rat Root River. For example, site ERR3 on the East Rat Root is located at the end of a flat reach and DO was above the standard for seven of eight measurements there, including the September 6, 2018 reading.

**Figure 17: DO sample sites plotted on Rat Root River and East Rat Root Rivers stream profiles.**
DO sites (circles) are colored green if samples met the 5 mg/L standard and red if they exceeded the standard during a low flow (critical) period in September 2018.




## Dissolved oxygen summary

DO is often below the warmwater standard in Rat Root River WID-635 during the summer months. Low levels also occur at site RR4, a low gradient reach of upstream WID-634. DO levels are more adequate in steeper gradient reaches of WID-634 and generally throughout the monitored length of the East Rat Root River that spans WID-633 and -632. DO tolerance is observed in the fish communities at all Rat Root River biological sites. Fish and macroinvertebrate assemblages indicate the greatest stress from DO at biology site 05RN186, which is located just upstream of WQ site RR2, where DO is often low (<5 mg/L) and sometimes at sub-optimal levels (<2 mg/L).

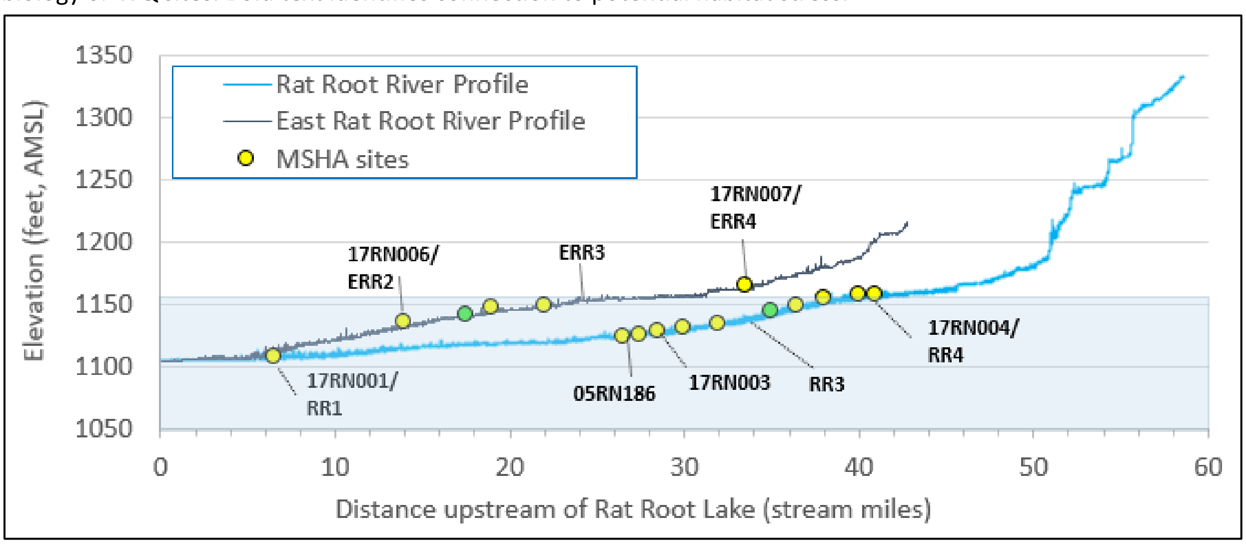
Data suggests that lower DO levels are the result of a variety of factors. DO and stream temperature correlate well in the Rat Root River. As temperatures increase in the summer, stream water has less DO-holding capacity. Low stream velocities and lack of riffle habitat correlate with WQ sites where DO levels are frequently below the 5 mg/L standard which suggests that inadequate mixing and re-oxygenation contribute to low DO. Decomposition occurring in wetlands, within the stream channel itself, and/or within the substrates further lower DO levels. Evidence supporting decomposition include high DOC, TP-DO correlation, and a diminished DO-temperature relationship during low DO (< 5 mg/L) conditions. Isotope and precipitation grid data infer that wetland flow, which can reach low to anoxic levels, is a source of flow to these rivers during the summer months. Lack of daily DO fluctuations suggests that eutrophication is not a primary driver of low DO; rather, lack of sunlight penetration through the turbid and tannin stained water is likely limiting primary production and any DO exchange that occurs through photosynthesis. TP release from wetland and stream sediments during low DO conditions could result in elevated TP in receiving waters.

Continuous DO and temperature data show that abrupt changes in air temperature can lead to equally abrupt inverse changes in DO levels. This warrants further investigation into the potential impacts of climate change on DO. Monitoring of temperature and DO over a longer time period would be necessary to detect such trends. The MPCA has instituted long-term biomonitoring stations for the purpose of detecting climate change impacts (among other things). Although there are no long-term biomonitoring station in the RRRLW, stations are located across the extent of Minnesota's northern border.

## 3.5 Physical habitat findings

Physical habitat conditions were evaluated using MSHA protocols (See Section 2.5). In addition to MSHA data collected during biological monitoring, MSHA was also a component of the September 2019 BANCS survey. MSHA data points are not distributed equally across the full extent of the watershed; rather are densely distributed in some reaches and are scattered throughout others (Figure 18). MSHA data was not collected near the headwaters of either stream. Instead it was focused in the middle to downstream reaches.

**Figure 18. MSHA data sites plotted on Rat Root and East Rat Root Rivers stream profiles.**
MSHA sites (circles) are colored based on their rating: green for "good" and yellow for "fair." The shaded area represents the elevation extent of former glacial Lake Agassiz. Select locations were based on close proximity to biology or WQ sites. Bold text identifies connection to potential habitat stress.



Habitat scores in the Rat Root River range from 48 (rating = “fair”) to 67 (rating = “good”) out of a possible 100 points. Data from a select number of the overall MSHA sites that describe given reaches are shown in Table 5 and Table 6. One out of the eleven stations assessed on the Rat Root River have a MSHA rating of “good”, while the others rate “fair”. Similarly, one out four stations on the East Rat Root River rate “good” and the others rate “fair”.

Of the five subcategories that contribute to the MSHA score, substrate, channel morphology, and instream cover are the most limiting variables (Figure 19). The best scoring stations for each river are positioned at a similar elevation just below the former glacial lake shoreline, which likely relates to the improved scores. The highest score of each of the two rivers are located in reaches with steeper stream slopes that have defined riffle-pool features and diverse instream cover types. Their corresponding elevations (near 1145 feet AMSL) just below the former glacial Lake Agassiz boundary (approximately 1160 feet AMSL) likely contribute to the improved habitat scores. It is conceivable that wave action of the former glacial lake deposited a variety of substrate material near the shoreline and that the steeper slopes are also a remnant feature of the shoreline and geologic transition that helped define it. Lower MSHA scoring sites in the watershed are dominated by fine substrate (silt and clay), generally have slow flow velocity, and lack riffle features. Sparse fish cover is also a limiting factor in Rat Root River WID-635.

**Table 5: MSHA scores and characteristics of select Rat Root River MSHA locations.**
Select locations were based on close proximity to biology or WQ sites. Bold text identifies connection to potential habitat stress.

Downstream to Upstream

| WID | Station (Year) | MSHA score | Substrate | Instream Cover | Channel Morphology |
|---|---|---|---|---|---|
| Rat Root (WID-635) | 17RN001/RR1 (2017) | 53 - Fair | clay/gravel | **sparse** | **lacks riffle features slow uniform velocity** |
| | 05RN186 (2006)<br>(2019) | 56*[a] – Fair<br>50 - Fair | **silt/clay *[b]** | sparse | **lacks riffle features slow uniform velocity** |
| Rat Root (WID-634) | 17RN003 (2017)<br>(2019) | 60 - Fair<br>54- Fair | silt/clay/gravel | **sparse** | riffle-pool features present |
| | 1 mile us of RR3 (2019) | 67 - Good | silt/gravel | moderate | riffle-pool features present |
| | 17RN004/RR4 (2017)<br>(2019) | 48 – Fair<br>51 - Fair | **silt/clay** | moderate | **lacks riffle/pools slow uniform velocity** |

**Table 6: MSHA scores and characteristics of select East Rat Root River MSHA locations.**

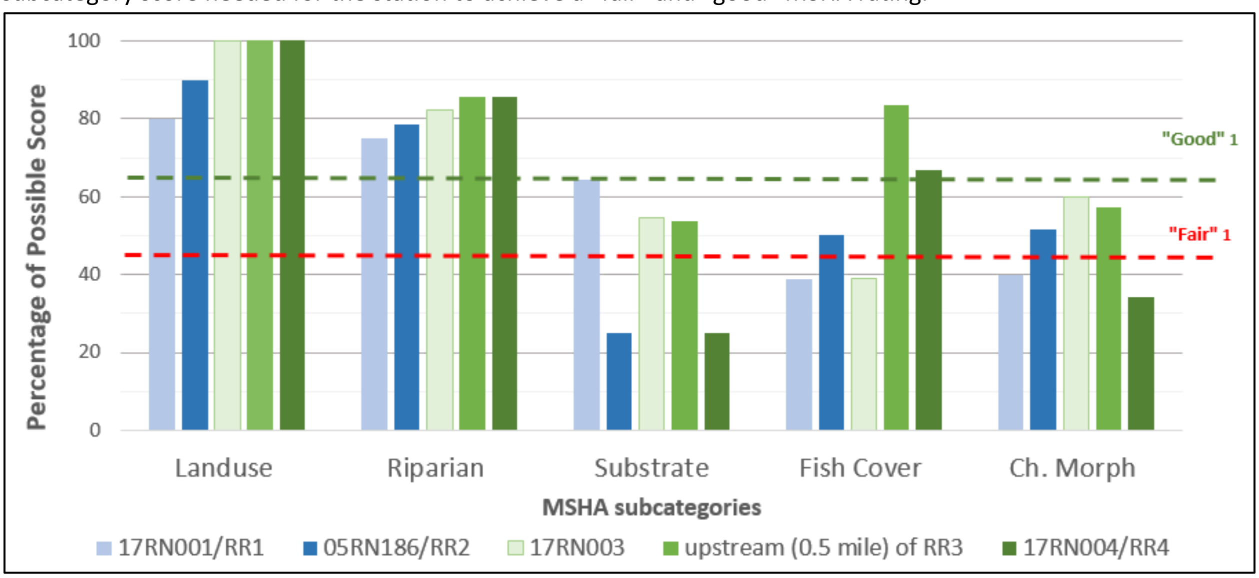
Downstream to Upstream

| WID | Station | MSHA score | Dominant substrate | Instream Cover | Channel Morphology |
|---|---|---|---|---|---|
| East Rat Root (WID-633) | 17RN006/ERR2 | 60 -Fair | gravel/clay | **sparse** | riffle-pool features present |
| | 3.5 miles upstream of ERR2 | 73-Good | sand/clay | moderate | riffle-pool features present |
| | 5 miles upstream of ERR2 | 62-Fair | sand/silt | moderate | riffle-pool features present |
| East Rat Root (WID-632) | 2 miles downstream of ERR3 | 48-Fair | sand/silt | **sparse** | **lacks riffles and deep pools, slow uniform velocity** |
| | 17RN007/ERR4 | 58-Fair | **silt/clay** | **sparse** | **lacks riffles and deep pools, slow uniform velocity** |

Habitat features change between Rat Root River biology sites 17RN003 (upstream) and 05RN186 (downstream), which are located less than three stream miles apart. Because the biological communities' tolerance to WQ and habitat vary between these two stations (See Section 3.1: *Stressor signals from biology*), it is important to consider the differences in observed physical habitat between the sites. Substrates become finer and riffle-pool features diminish longitudinally downstream between the two sites. Comparing 2006 to 2019 data, the MSHA score for the latter is slightly lower, but scores are within a reasonably close range. For both site visits, channel substrate (exclusively silt to silt/clay) is the most limiting factor, followed by channel geomorphology where lack of riffle features and sinuosity combined with slow uniform velocities limit the subcategory score.

Natural factors are likely a primary influence on these variables as stream slope flattens and the geology changes from glacial moraine to glacial lacustrine/till (heavier clay soils) in the vicinity of the sites. An unnamed tributary enters the Rat Root River between the two sites and heavy siltation and embeddedness were noted in the Rat Root River near the tributary outlet during the 2019 habitat surveys. Evidence such as an extensive floodplain near the tributary outlet, clear to tannin-stained appearance, and moderate to extensive stream riparian area suggest that the tributary is a fairly stable channel. The very slow velocities and eddies in the Rat Root River near the tributary outlet likely do not provide enough stream power to transport suspended materials far beyond the outlet during most flow conditions. Currently, there is insufficient tributary data or geomorphology data near the former road crossing to determine if either are contributing to degraded WQ and biology in the reach that is already influenced by natural geologic conditions. Presently, geology and stream power are the primary candidate causes.

**Figure 19. MSHA subcategory scores for select sites on Rat Root River.**
Five of eleven sites with MSHA data are displayed. Displayed sites are representative of distinct habitat reaches. Sites in WID-635 are shown in blue, while sites in WID-634 are shown in green. 1 The minimum percentage of each subcategory score needed for the station to achieve a "fair" and "good" MSHA rating.




## Physical Habitat Summary

Overall habitat conditions in the RRRL Watershed are fair with few respectively small reaches reporting "good" habitat conditions. Substrate, instream cover, and channel morphology are the most limiting variables. The highest scoring site for each of the two rivers are located on steeper stream segments that also have more diverse substrate types. They are located at an elevation 10 to 15 feet below the glacial Lake Agassiz shoreline, which likely contributes to better habitat conditions such as improved substrate size diversity. The “good” habitat sites also corresponded with areas of higher erosion identified in Subsection: *Sources of TSS* of Section 3.3: *Total Suspended Solids*, as the gravel bank material that presumably enhances erosion of isolated banks also contributes (along with a diversity of substrate types) to improved habitat scores. The lowest scoring sites in the Rat Root River are in reaches with extremely flat slopes, fine substrates, slow velocities, and uniform channels that lack defined riffle features. Effects of these conditions on the biological community are most obvious at biological site 05RN186, where fish and/or macroinvertebrate communities show a tolerance to fine substrate, slow stream velocities, and low DO.

The lowest scoring sites in the East Rat Root River are in lower gradient reaches with wetland characteristics. Land use and riparian scores are “good” at all habitat survey sites, which reflects the lack of development in the mostly forested and wetland-dominated watershed.

# 4. Conclusions and Recommendations

## 4.1. Summary of probable stressors

Additional biology, hydrology, and water chemistry information throughout Rat Root River has provided a science-based approach to better understanding the human-induced impacts and natural characteristics of the stream system; some of which prevent it at times from meeting aquatic life standards. Although not impaired, the biological community shows a tolerance to WQ in the downstream to mid-river reaches, where DO and TSS frequently do not meet state standards. This report concludes that low DO, sedimentation, slow flow velocities, mediocre habitat, and to a lesser degree TSS is influencing the biological communities in the Rat Root River. Natural conditions such as low gradient stream channels and glacially-derived clay soils are factors influencing WQ and habitat conditions. Although development is low in the watershed, human impacts over the past century or more have, to some degree, altered watershed and stream health. Conclusions from this report are summarized in Figure 20 and described in more detail under the bulleted items below.

**Figure 20. Summary of evaluated stressors for the Rat Root River.**

Color-code: green = good, yellow= fair, orange = fair to poor, red = poor. *One-sixth of the Altered Hydrology box is colored red and the rest green since only the downstream most- 10 miles out of nearly 60 stream miles of the Rat Root River are affected by dam-influenced backwater.

| Dissolved Oxygen | TP/Eutrophication | TSS and Sedimentation | Habitat | Alt Hydrology |
|---|---|---|---|---|
| **Poor** | **Fair** | **Fair to Poor** | **Fair** | **Poor near outlet, good upstream*** |
| The Rat Root River is not impaired for DO, but DO levels can be very low in summer. Fish and macroinvertebrate assemblages have poor scoring DO metrics. Flat stream slopes and slow flows (poor aeration) combined with in-channel and wetland decomposition contribute to low DO. | TP concentrations are high during low-DO periods, when it is most easily converted to a soluble form. Elevated TP is likely a product of decomposition. Response variables suggest eutrophication is not a problem in the river; however TP loading could affect water quality in downstream receiving waters. | TSS and sedimentation are elevated in the downstream WID. Biological communities show slight tolerance to TSS (macroinvertebrates) and clearer tolerance to fine bed sediment (fish and macroinvertebrates). Along with prolonged suspension under low-flow disturbance, TSS can also be elevated by high-flow TSS sourcing (runoff and/or erosion) in some reaches. | Most of the watershed has fair habitat, besides reaches near the former glacial lake shoreline where scores are improved. Slow uniform flow, lack of riffle-pool features, poor in-stream cover, and dominantly fine substrate limit aquatic habitat in the Rat Root River. | The dam on Rainy lake causes backwater in the lower ten miles of the Rat Root River. The fish community meets IBI thresholds, but metrics indicate a tolerance to slow flow as well as a tolerance to flow response variables: sedimentation and low DO. |

- **Biological scores**, both fish and macroinvertebrates, are poorest in the middle reaches of the Rat Root River in a stream segment that includes the upstream end of WID-635 and the downstream end of WID-634. Biology is not listed as impaired because the lowest scores are from site 05RN186, which was sampled in 2006 and outside of the 10-year period used in assessments, as well as consideration of the potential influence of natural conditions on biology at the two mid-river sites. Fish-IBI scores near the river outlet and in the headwaters are good, above the IBI thresholds, indicating healthier and more diverse fish communities in those reaches. Macroinvertebrate data are not available near the river outlet. Future collection and evaluation of macroinvertebrate data in the lower river are needed to fully assess the health of WID-635.

On the East Rat Root River, fish scored good in the downstream WID and excellent in the upstream WID. Macroinvertebrates in the downstream WID scored fair, just above the respective IBI threshold.

- **Altered hydrology** contributes to naturally inadequate streamflow in Rat Root River WID-635. Gage data analysis shows that spring to late summer streamflow in the downstream 10 miles is influenced by water level management on Rainy Lake and suggest that level management to some extent has influenced streamflow changes in the system over the past century. Another study concluded that floods that occurred in 1950s era (amplified by early-century land clearing) also changed the system in ways that influenced downstream hydrology. Farther upstream on WID-635, beyond the downstream controls, stream velocity is also slow to stagnant for much of the summer season. Although lower flow velocities are a natural consequence of the low-gradient conditions in the upstream part of the WID, remnants and pilings of a bridge on the former Galvin Line crossing (downstream of MN State Highway 217) were identified as another potential control on flows.

  The low gradient condition of this subwatershed naturally limits water movement, which can lead to poorer habitat, increased sedimentation, high wood occurrence rates, and low DO conditions. Altered hydrology exacerbates these natural conditions. In regards to lake level management, much work has been done over the past decade to improve the balance of shared ecological, flood control, and hydropower uses of the waters, which is reflected in the current level management guidelines.

  It is suspected that lack of flow to effectively transport sediment, clean gravel, and supply adequate oxygenated water has negatively impacted walleye spawning in the downstream portion of the river, which has declined over the past half-century. Other indicators in the biological community show that slow velocity conditions, as well as various flow-dependent conditions such as low DO and sedimentation, negatively influence the biological community. Despite these conditions, the Fish-IBI score at the downstream-most site meets the expected threshold for the Northern Streams fish class and reflects an overall healthy community. Farther upstream, streamflow influence on the biological assemblage is more apparent, where there is an increased community tolerance to slow flow.

- **Total suspended solids** is poorer than state standards periodically in reaches of the Rat Root River and East Rat Root River. The highest exceedances occur in the East Rat Root River upstream of Koochiching County Highway 3 and second highest in the Rat Root River reach that spans the MN State Highway 217 crossing. TSS mostly meets the standard upstream of glacial Lake Agassiz geology influence and exceeds it downstream on both rivers. Just downstream of the glacial lake shoreline, TSS exceeds mostly during low to moderate flows and is likely caused by prolonged suspension of easily disturbed silt and clay-dominant bank and bed sediments. The TSS-streamflow relationship at Rat Root River mid-river site suggests upstream fine sediment supply or sheer stress is too low to cause erosion proportionate to increasing flow. Farther downstream on the Rat Root River, TSS exceeds the standard during low, moderate, and high flows indicating that both disturbance under low to moderate flows and event-driven TSS loading during high flows contribute to elevated TSS. TSS levels near the outlet are highest during the spring season when vegetation on the landscape is still dormant.

Areas of bank erosion were observed in both the Rat Root River and East Rat Root River, although in the Rat Root River erosion is mostly limited to isolated banks. A longer stretch of erosion was identified near the upstream end of WID-633 on the East Rat Root River and may be the upstream extent of incision identified near Ericsburg, Minnesota by Ellen River Partners (2008).

Although the fish community in the Rat Root River does not show TSS influence, it is observed in the macroinvertebrates in WID-635. Influence from sedimentation, a product of elevated TSS, is observed in both fish and macroinvertebrate communities in WID-635. The MPCA continues to investigate the TSS standard in relation to biological health, particularly in areas of low disturbance and in reaches associated with high-clay soils and glacial lake bed geology.

- **Sedimentation** is caused by excess fine sediments and/or the inability of a stream to transport sediment downstream. Sedimentation is influenced by variables such as TSS, altered hydrology, and stream instability; and can result in degraded aquatic habitat. Fine glacially derived soils, lack of flow velocity (likely both natural and human influenced), and flat stream slopes create the right conditions for sedimentation to occur in WID-635 of the Rat Root River. Both fish and macroinvertebrates there show tolerance to fine sediment.
- **Dissolved oxygen** is poorer than state standards frequently July through September in low gradient reaches of the Rat Root River. DO conditions are better and meet state standards in the East Rat Root River. The most severe low-DO reach of the Rat Root River spans the MN State Highway 217 crossing, where DO concentrations can drop to harmful levels. Biology in the downstream to mid-watershed (all of WID-635 and the downstream end of WID-634) show a tolerance to low DO. Data suggests that decomposition occurring both in wetlands and the stream channel itself is a primary cause of low DO; and lack of physical mixing through riffle-type features inhibits re-oxygenation of low DO waters. Lack of daily fluctuations in DO is the main supporting evidence that eutrophication is not the cause of low DO in the Rat Root River; although, low nitrate levels, lack of agricultural development, and no visible signs of algal blooms also support this assessment. TP release under low DO conditions is documented and elevated TP loading in the Rat Root River could result in higher TP levels in receiving waters.

  Data supports that DO is influenced by stream temperature and large swings in ambient air temperature. Maintaining overhead cover is important in mitigating negative changes in stream temperature and DO levels. While much of the stream riparian is in good condition throughout the watershed, there are areas where stream riparian clearing, aging/dying trees, and beaver-influenced areas have resulted in lack of overhead cover.
- **Physical habitat** conditions are considered fair throughout Rat Root River and East Rat Root River with habitat scores slightly higher near the former glacial lake shoreline in both rivers. Habitat limitations are inadequate fish cover, slow moving water, predominant fine substrate and lack of substrate variety, sometimes limited depth variability, and poor to fair channel development (lack of riffle features). Improved scores near the glacial lake line are due to more

diverse substrate, a variety of flow velocities, more fish cover, and better channel development. While many of these habitat limitations are natural, overhead and in-stream cover are variables that can easily be impacted by instream activity and land use within the stream riparian. Maintaining healthy in-stream wood and overhead riparian cover can help protect habitat conditions from declining and may improve habitat conditions in some reaches. In wetland-dominated reaches, increasing overhead cover may not be feasible.

- **Climate change susceptibility** is a concern for this watershed. If stream temperatures increase with a warming climate, it is expected that DO conditions will worsen as a result of less DO-holding capacity in stream water as well as increase microbial activity and decomposition. Lower DO levels over extended time periods could result in more TP release from wetland soils and stream substrates. Stream flow is another concern as slow flow velocities are an identified stressor for this watershed and influence other parameters of concern such as sediment and wood transport and DO levels. Other unknown climate vulnerabilities include riparian vegetation susceptibility to warming, changes in weather patterns, and resulting changes in the hydrological budget (severe runoff, extreme low flows, drought, etc.). Planning for climate resiliency and climate change mitigation is important in current and future watershed management of the RRRL Watershed.

## 4.2. Recommendations

Future planning for improving WQ and reducing stressors to biological communities within the RRRLW should focus on actions that protect and enhance the stream riparian, improve physical habitat, protect stream temperatures from a warming climate (which will help mitigate a continued decline in DO), and reduce sedimentation. Recommended actions to restore and protect stream health fall under five categories: stream shoreline and riparian zone management, best forest management practices, in-stream restoration and management, future monitoring, and watershed education. Recommendation are described in Table 7 and Table 8. Local and regional resource managers are encouraged to select, prioritize, and add to these recommendations based on local watershed management plans and goals.

**Table 7: Recommended actions to restore and protect stream health in the Rat Root River and East Rat Root River Subwatersheds.**

Blue rows = stream shoreline/riparian management, Pink = forestry management, Purple = in-stream management. Recommendations in blue and pink rows are based off of BMPs described in NRCS 2021, MFRC 2012, DNR 2021b, and PSU 2021b.

| Practice | Watershed health benefit | Location |
|---|---|---|
| **Establish/maintain permanent vegetation along the stream corridor that includes a variety of grass, trees, and shrubs.** | Modify stream temperature, filter sediment and nutrient runoff, provide aquatic and wildlife habitat, and stabilize stream banks and shorelines. | Watershed-wide. Consider initial focus on un-vegetated shorelines in a reach that extends from the MN State Hwy 217 crossing upstream to a few miles beyond the County Road 29 stream crossing. |
| **Preserve and restore native vegetation on shorelines and throughout the watershed.** | Provide diverse and healthy aquatic and upland habitats. Maintain stream temperatures, filter sediment and nutrient runoff, and stabilize stream banks and shorelines | Watershed-wide |
| **Encourage forestry practices that are protective of the stream riparian and water quality and adhere to MFRC Guidelines.** | Reduce the potential for negative environmental impacts resulting from timber harvesting and other forest-management activities on all forest lands. | Watershed-wide |
| **Diversify tree species, emphasizing longer-lived conifers and climate change resiliency in species selection.** | Improve forest health, provide diverse and healthy upland habitats that can withstand climate change. Provide longer-term shoreline sustainability benefits when implemented within the stream riparian. | Within forested areas watershed-wide, especially within the stream riparian area. |
| **Work with private land owners to develop Forest Stewardship Plans.** | Improve forest health, provide diverse and healthy upland habitats that can withstand climate change. Provide longer-term shoreline sustainability benefits when implemented within the stream riparian. | Within forested areas watershed-wide, especially within the stream riparian area. |
| **Remove bridge and pilings at former trail crossing with consideration of removal methods that will not negatively impact stream stability.** | Increase stream velocity, reduce sedimentation, and prevent further warming of stream temperature which can effect DO holding capacity and the rate of microbial respiration. | latitude 48.409797°, longitude -93.365305°, Downstream (1 mile) of MN State Highway 217 |
| **Assess and allow for a healthy amount of wood to establish naturally in the stream channel.** Removal of large structures causing sedimentation and backwater issues should be considered in the context of full ecological impacts and benefits. | Provides diverse and healthy aquatic habitat, diversifies flow velocities, and encourages scouring of gravels and riffle-pool development. | Watershed-wide |

**Table 8: Recommendations for monitoring (green-shaded rows) and outreach (purple-shaded rows) in the Rat Root River and East Rat Root River subwatersheds.**

| Monitoring/Outreach Activity | Description/Intent | Location |
|---|---|---|
| **Effectiveness** | Monitor the effectiveness of past and future stream restoration and riparian area enhancement projects as well as the effects of BMPs implemented on the landscape. | Watershed-wide at past and future project locations. |
| **Geomorphic assessment of stream bank stability** | Using DNR-approved methods, determine stream bank stability and potential degree of aggradation or sedimentation at locations of interest. | As deemed necessary by local resource managers. Suggest locations at the three locations identified in the Assessments of stream bank stability and bank erosion subsection of Section 3.3: Total suspended solids |
| **Additional erosion survey using BANCS methodology** | Using DNR-approved methods, continue the BANCS survey in areas with potentially high bank erosion inputs. | Suggest locations identified in the erosion survey such as the East Rat Root River between CSAH3 and Rainy Lake as well as gullies (Rat Root WID-634) and tributaries that appear unstable or at-risk based on aerial imagery or visual observations |
| **Climate change monitoring** | Consider on-going monitoring of DO and water temperature | Watershed-wide. Rat Root River WID-635 = high priority |
| **Other monitoring gaps** | Role of sediment-oxygen-demand in low DO reaches | Rat Root River WID-635 |
| **Education and outreach for pollutant-reduction activities** | Educate and/or assist private landowners in forest, pasture, and overall healthy riparian area and watershed management. | Watershed-wide |
| **Education and outreach for pollutant-reduction activities** | Educate land owners and stakeholders about the current state of the watershed, identified stressors, future threats (e.g. climate) to stream health, and the importance of watershed protection. | Watershed-wide |
| **Plan and manage for climate resiliency and climate mitigation** | Explore and incorporate actions and conservation planning specific to climate change being developed by various agencies at the Federal, State, and Local levels | Watershed-wide |

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# Appendix A: Supporting Data and Analyses

**Table 9: Summary of Rat Root River stressors that required (or did not require) further evaluation.**

| Stressor | Candidate cause identification | |
|---|---|---|
| | Summary of available information | Required further evaluation |
| Temperature | The Rat Root River is a warmwater stream that experiences normal temperature values. | No |
| Physical habitat | Rat Root River shows visual indications of insufficient instream habitat, bank erosion, and sedimentation. | **Yes** |
| TSS (Total Suspended Solids) | Total suspended solids (TSS) in the Rat Root River exceeded the applicable state standard (15 mg/L) for 40% of WQ samples. | **Yes** |
| Low dissolved oxygen and/or Eutrophication | Discrete and/or continuous dissolved oxygen (DO) observations were below the applicable state standard (5 mg/L). Total phosphorus values regularly exceed the eutrophication standard for the northern region (0.05 mg/L). Chlorophyll-a levels varied from low to elevated beyond the applicable state standard. No algal blooms have been documented. | **Yes** |
| Nitrate-nitrite, Ammonia | Nitrate-nitrite concentrations in the watershed were below the lab detection limit for 76% of 107 samples. Unionized ammonia is meeting aquatic life use over the assessment period (50 samples in 2017). Row-crop agriculture accounts for <1% of land area in the RRRLW. | No |
| pH | pH values were within the state standard range (6.5-8.5) for 99% of observations measured between 2014 and 2018. | No |
| Chloride | Chloride is meeting aquatic life use over the assessment period. There were no exceedances of the standard during the assessment period (20 samples in 2017). | No |
| Flow Alteration and Connectivity | The Fort Francis International Falls dam on Rainy River controls water levels on Rainy Lake and potentially outflow from the Rat Root River. Bog wetlands are ditched in the downstream drainage area of Rat Root River Subwatershed. Stream crossing occurrence is low. Wood jams and beaver dam occurrence are moderate to high in reaches. | **Yes** |

**Figure 21: Comparison of HSPF-simulated flows and observed flows at Rat Root River site RR2, 2018-2019**

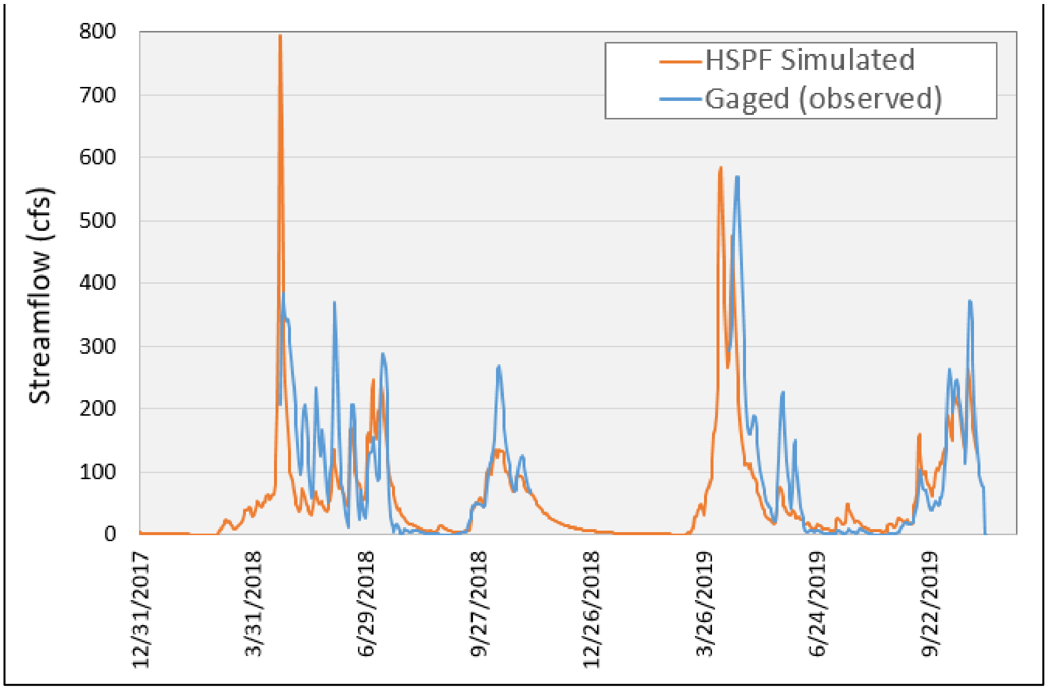



**Figure 22: Isotopes of oxygen (del O) and hydrogen (deuterium, del D) in stream water collected at Rat Root River WQ sites RR1 and RR2 and East Rat Root River WQ sites ERR2 and ERR3**

Samples plot along the GMWL, and become more enriched in isotopes (continuously plot more to the right) as the seasons shift from spring to late summer. Beginning in late-June, samples plot more noticeably below the GMWL as surface water sources of streamflow (e.g. wetlands) undergo increased evaporation. Isotopes are measured using the Del notation (δ), the parts per thousand enrichment or depletion of oxygen and hydrogen isotopes in sample water relative to the isotopic standard for water (Vienna Standard Mean Ocean Water (VSMOW)).

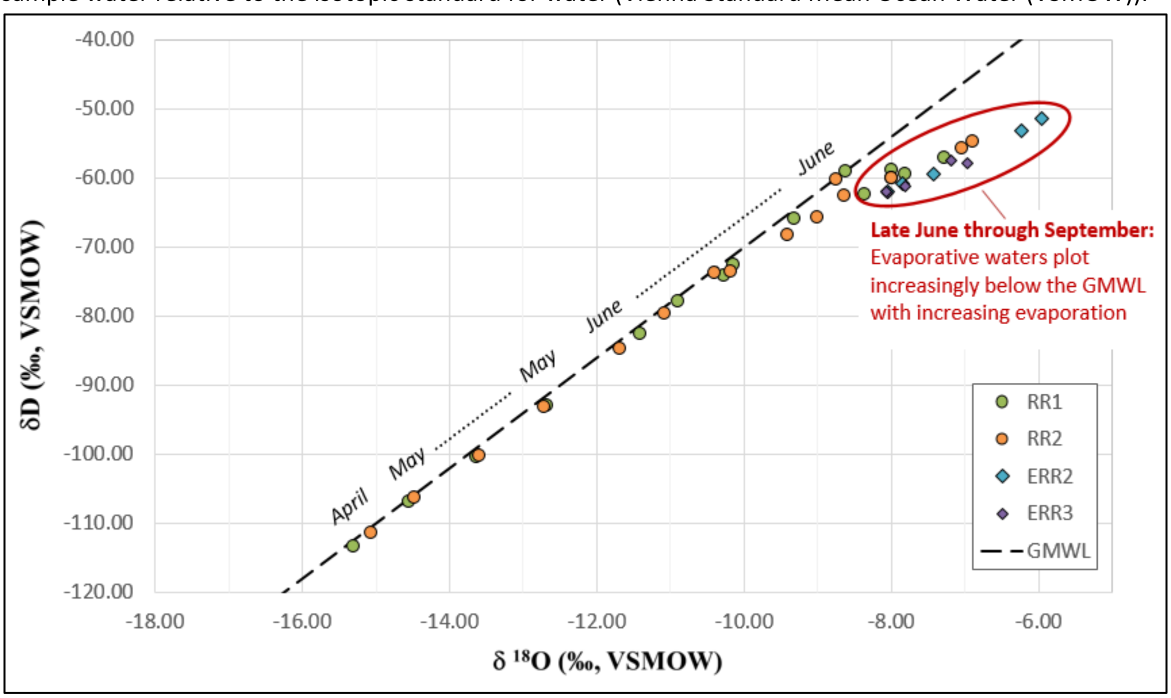
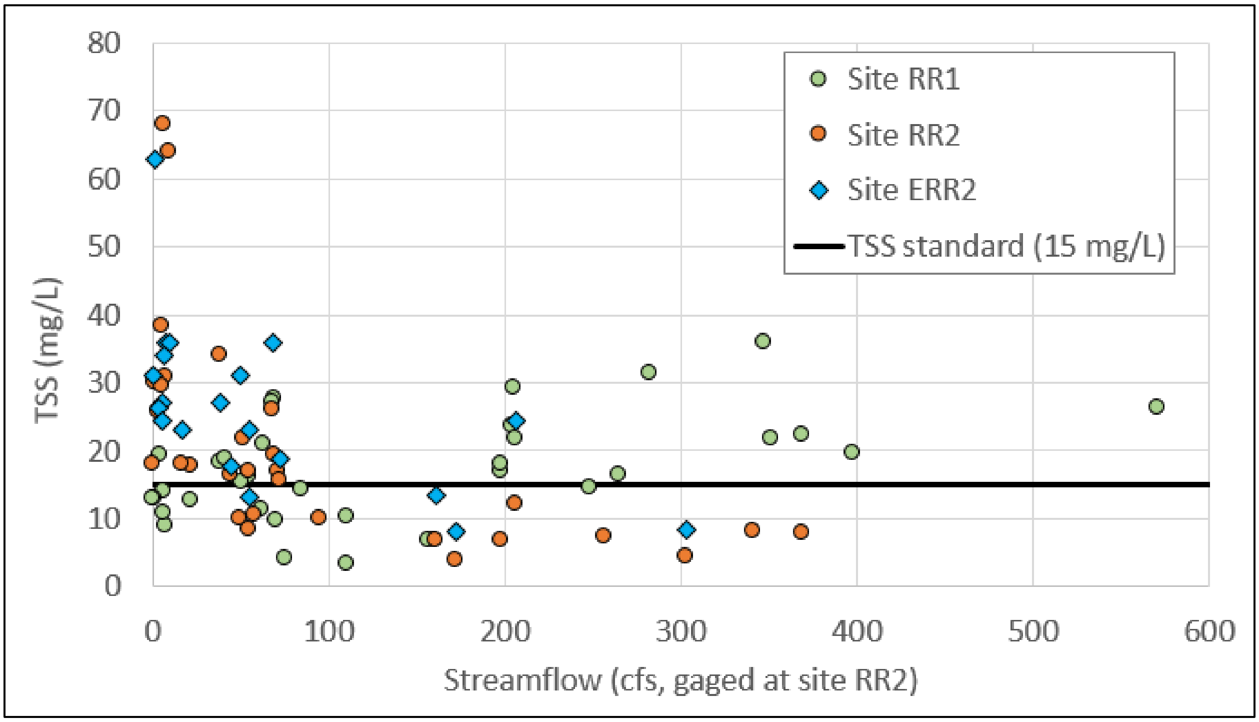


**Figure 23: TSS at WQ site RR1, RR2, and ERR2 plotted with streamflow measured at site RR2 (gage 74033003).** TSS at site RR1 exceeds the 15 mg/L at low to high flows; whereas TSS exceeds the standard at RR2 and ERR2 most frequently at flows less than 70cfs. High flow samples for ERR2 are limited. This analyses assumes that flows at sites RR1 and ERR2 concurrently experience a similar flow regime as RR2 and is not meant to infer that the exact flow value observed at RR2 applies to those locations.



# Appendix B: Detailed TIV analyses

## B.1. Rat Root River Fish tolerance indicators

### DO tolerance, fish

The fish samples show multiple lines of evidence of the influence of low DO concentrations, particularly the two downstream sites (17RN001 and 05RN186), which are in WID-635. There, the DO TIV scores are both poorer than the class average, are at very low percentiles within their class, and the probability of the fish communities collected from these sites coming from a DO standard-meeting reach is below 50%. The DO TIV scores for the two upstream sites (within WID-634) are higher, as is the probability of coming from a DO standard-meeting stream. Additionally, site 17RN004 (Low Gradient fish class) is above the TIV average and at a high percentile within its class, suggesting the DO is at good levels for a low gradient stream in the upper part of the Rat Root River. Not a single low-DO Intolerant species was found at any of the four sites. All four sites' communities are skewed toward low-DO Tolerance in terms of taxa present and percentage of individuals.

### TSS tolerance, fish

There is little to no evidence in the fish data of stress from TSS. Results of the various metrics are mixed. The community TSS Index score is better than the class average at the lower two sites and moderately poorer than the class average farther upstream at 17RN003. All sites have TSS TIV Index scores that have a very high probability of coming from a TSS standard-meeting stream. Collectively at all four sites, the number of both TSS Tolerant and Intolerant individuals was low.

### Fines tolerance, fish

The three more-downstream sites all score poorer than the class average, with the Fines TIV score degrading longitudinally from upstream to downstream. The two downstream-most sites score at a very low percentile for the Northern Streams class. The upstream-most site, 17RN004, has a Fines TIV score that is much better than the Low Gradient class average and at a high percentile ($89^{th}$) for the class. This analysis suggests that there is either significant deposition of fine sediment that increases moving in a downstream direction, or that there are natural differences in substrate types based on local surficial geology (See Section 3.3: *Total Suspended Solids findings*).

### Flow Velocity tolerance, fish

For the Flow Velocity TIV score, a higher number indicates a fish community that prefers higher flow velocity and a lower number indicates a fish community that prefers lower flow velocity. The most upstream and downstream Rat Root River sites have Flow TIV scores that are relatively close to the appropriate class average, with the downstream site slightly below the class Northern Streams class median, and the upstream site being above Low Gradient class median. The middle two sites have Flow TIV scores substantially below the class average, with both being at very low percentiles. This suggests that the fish community is being influenced negatively by very slow flow velocities, especially at the middle two sites, and to a lesser degree at the farthest downstream site. These findings contrast with stream gradient data (Table 12), which show a longitudinal slope decline from upstream to downstream and observations at 17RN001 where backflow is observed and further explained in Section 3.2: *Hydrology findings*.

**Table 10: Fish community Tolerance Index Values (TIVs) for Rat Root River biology sites.**
For DO and Flow Velocity, a higher index score is better, while for TSS and Fines, a lower index score is better. "Percentile" is the rank of the index score within the appropriate fish stream class, (2019 version). "Prob." is the probability (ver. 2018) a community with this score would come from a stream reach with DO or TSS that meet the standards. Bold print indicates the metric score poorer than the average, depending on expected response with increased stress.

| Site | Date | Parameter | TIV Index score | Class avg./median | Percentile in class | Prob. as % |
|---|---|---|---|---|---|---|
| 17RN001 | 8/22/2017 | DO | **6.61** | 7.00/7.11 | **20** | **41.8** |
| 05RN186 | 8/1/2006 | DO | **6.22** | 7.00/7.11 | **7** | **19.0** |
| 17RN003 | 7/25/2017 | DO | **6.91** | 7.00/7.11 | **35** | 62.9 |
| 17RN004 | 7/24/2017 | DO | 6.89 | 6.21/6.16 | 86 | 61.2 |
| 17RN001 | 8/22/2017 | TSS | 13.24 | 13.71/12.96 | **43** | 88.1 |
| 05RN186 | 8/1/2006 | TSS | 12.47 | 13.71/12.96 | 63 | 89.7 |
| 17RN003 | 7/25/2017 | TSS | **14.50** | 13.71/12.96 | **23** | 85.1 |
| 17RN004 | 7/24/2017 | TSS | 14.56 | 14.99/13.36 | **35** | 84.9 |
| 17RN001 | 8/22/2017 | Fines | **59.10** | 46.72/46.38 | **7** | -- |
| 05RN186 | 8/1/2006 | Fines | **58.09** | 46.72/46.38 | **10** | -- |
| 17RN003 | 7/25/2017 | Fines | **49.21** | 46.72/46.38 | **38** | -- |
| 17RN004 | 7/24/2017 | Fines | 49.25 | 58.26/58.79 | 89 | -- |
| 17RN001 | 8/22/2017 | Flow velocity | **0.580** | 0.651/0.595 | **47** | -- |
| 05RN186 | 8/1/2006 | Flow velocity | **0.334** | 0.651/0.595 | **8** | -- |
| 17RN003 | 7/25/2017 | Flow velocity | **0.371** | 0.651/0.595 | **11** | -- |
| 17RN004 | 7/24/2017 | Flow velocity | 0.383 | 0.331/0.302 | 69 | -- |

**Table 11. Metrics involving low-DO and TSS for the sampled fish communities at 17RN001 (year 2017), 05RN186 (year 2006) and 17RN003 (year 2017).**

| Parameter | Site | # Intolerant Taxa* | # Very Intolerant Taxa | # Tolerant Taxa* | # Very Tolerant Taxa | % Intolerant Individuals | % Tolerant Individuals |
|---|---|---|---|---|---|---|---|
| Low DO | 17RN001 | 0 | 0 | 4 | 1 | 0.0 | 55.0 |
| Low DO | 05RN186 | 0 | 0 | 4 | 3 | 0.0 | 50.9 |
| Low DO | 17RN003 | 0 | 0 | 7 | 5 | 0.0 | 18.1 |
| Low DO | 17RN004 | 0 | 0 | 10 | 7 | 0.0 | 30.4 |
| TSS | 17RN001 | 1 | 1 | 1 | 0 | 1.1 | 0.6 |
| TSS | 05RN186 | 0 | 0 | 0 | 0 | 0.0 | 0.0 |
| TSS | 17RN003 | 1 | 1 | 0 | 0 | 0.2 | 0.0 |
| TSS | 17RN004 | 0 | 1 | 0 | 0 | 7.1 | 0.0 |

**Table 12. Reach gradient for the four Rat Root River biological monitoring sites.**

| Site | Gradient (% slope) |
|---|---|
| 17RN001 | 0.001 |
| 05RN186 | 0.480 |
| 17RN003 | 0.620 |
| 17RN004 | 0.080 |

## B.2. Rat Root River Macroinvertebrate tolerance indicators

### DO tolerance, macroinvertebrates

Macroinvertebrate community TIV Index scores shown in Table 13 and individual TIV metrics in Table 14 indicate some, influence from low DO concentrations at 05RN186 and no influence from low DO at the upstream site 17RN003, which were sampled in 2006 and 2017 respectively. The DO TIV Index score is slightly better than the class average at 05RN186 (55$^{th}$ percentile) and much higher than the average (85$^{th}$ percentile) at 17RN003. The probability (56%) of the sampled communities coming from a DO standard-meeting site at 05RN186 is neither good nor poor and at 17RN003 (71%) is fairly good. The community at the downstream site is skewed toward taxa and percentage of individuals that are low-DO Tolerant, whereas the community at the upstream site is skewed toward taxa and percentage of individuals that are low-DO intolerant, though the percentage of the sample made up of the respective tolerant and intolerant-leaning individuals is not high at either site.

### TSS tolerance, macroinvertebrates

In contrast to fish community observations, macroinvertebrate TSS TIV Index scores and individual metrics suggest that TSS is influencing the macroinvertebrate community at both 05RN186 and 17RN003. Macroinvertebrate community TIV scores and individual metric scores are similar between the two sites. The TIV scores are substantially poorer (14$^{th}$ -16$^{th}$ percentiles) than the class average and the probability of the community coming from a standard-meeting site is somewhat low (37% to 38%). Although the community taxa is only moderately skewed toward the presence of TSS Tolerant taxa, the percent of individuals that are TSS Tolerant is high. Considering all of these analyses together, it appears that TSS is a parameter that is influencing the structure of the macroinvertebrate community.

### Fines tolerance, macroinvertebrates

The Fines tolerance indicators suggests that there is less fine particulate sediment at site 17RN003 than at 05RN186 or that streambed conditions changed between 2006 and 2017. The Fines TIV Index scored poorer than the class average, and at the 37$^{th}$ percentile at site 05RN186. The macroinvertebrate community there is highly skewed toward Fines Tolerant taxa in terms of both number of taxa and percent of individuals. At 17RN003, the community TIV was slightly better than the class average, and ranks at the 58$^{th}$ percentile. The macroinvertebrate community is skewed toward Fines Intolerant taxa, both in terms of number of species, and to a more slight degree with the percent of individuals. At site 05RN186, Fines Tolerant taxa outnumbered Fines Intolerant taxa 10 to 1. Conditional probability is not available for percent fines. These statistics suggest that much of the stream bed at 05RN186 is composed of fine particulate material which is influencing the macroinvertebrate community structure.

## Flow Velocity tolerance, macroinvertebrates

The Flow Velocity TIV Index was poorer than the class average at both sites, scoring at the 31st percentile at 05RN186 and the 42nd percentile at 17RN003. The downstream macroinvertebrate community is fairly skewed toward taxa that prefer slow flow, both in terms of number of species, as well as percent of individuals; whereas the community at the upstream site is not. These statistics show evidence that flow speeds (in this case very slow moving water) is a factor that shapes the macroinvertebrate community. Comparing the two macroinvertebrate sites suggests that there is higher general flow velocity at site 17RN003 than at 05RN186 or that flow conditions differed between 2006 and 2017.

**Table 13. Macroinvertebrate community Tolerance Index Values (TIVs) for Rat Root River biology sites.** For DO and Flow Velocity, a higher index score is better, while for TSS and Percent Fines, a lower index score is better. “Percentile” is the score rank within the stream class. “Prob.” is the probability a community with this score would come from a standard-meeting reach. Bold print indicates the metric score is poorer than the average, depending on expected response with increased stress.

| Parameter (year) | TIV Index | Class avg./median | Percentile in class | Prob. as % |
|---|---|---|---|---|
| **05RN186 (2006)** | | | | |
| DO | 6.55 | 6.30/6.49 | 55 | 56 |
| TSS | **15.31** | 13.63/13.77 | **16** | **38** |
| Fines | **50.44** | 48.55/48.90 | **37** | -- |
| Flow velocity | **0.412** | 0.498/0.474 | **31** | -- |
| **17RN003 (2017)** | | | | |
| DO | 7.09 | 6.30/6.49 | 85 | 71 |
| TSS | **15.40** | 13.63/13.77 | **14** | **37** |
| Fines | 47.84 | 48.55/48.90 | 58 | -- |
| Flow velocity | **0.448** | 0.498/0.474 | **42** | -- |

**Table 14. Macroinvertebrate metrics involving DO, TSS, Fines, and Flow Velocity at 05RN186 (year 2006) and 17RN003 (year 2017).**

| Parameter | # Intolerant Taxa*a | # Very Intolerant Taxa | # Tolerant Taxa*a | # Very Tolerant Taxa | % Intolerant Individuals | % Tolerant Individuals |
|---|---|---|---|---|---|---|
| **05RN186** | | | | | | |
| DO | 2 | 0 | 8 | 4 | 0.6 | 4.4 |
| TSS | 3 | 1 | 7 | 2 | 0.9 | 50.1 |
| Fines | 1 | 0 | 10 | 6 | 0.3 | 9.5 |
| Flow vel. | 4*b | 3*b | 0*b | 0*b | 1.2*b | 0.0*b |
| **17RN003** | | | | | | |
| DO | 6 | 2 | 1 | 0 | 5.1 | 1.0 |
| TSS | 5 | 1 | 7 | 1 | 4.1 | 42.7 |
| Fines | 5 | 2 | 1 | 0 | 3.2 | 1.0 |
| Flow vel. | 1*b | 1*b | 3*b | 1*b | 0.3*b | 1.9*b |

*aIncludes # of Very Intolerant or Very Tolerant taxa as part of the count. *b For flow velocity, Intolerant means taxa that prefer very slow moving water and Tolerant means taxa that prefer fast moving water.