Thief River Watershed Total Maximum Daily Load

A description of the restoration measures necessary to bring the Thief River and its tributaries into compliance with Minnesota water quality standards for total suspended solids and *E. coli*.

MINNESOTA POLLUTION CONTROL AGENCY

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Acronyms

AUID	Assessment Unit ID
BMP	Best Management Practice
CFS	Cubic Feet per Second
cfu	colony-forming unit
COD	Chemical Oxygen Demand
CSAH	County State Aid Highway
DNR	Minnesota Department of Natural Resources
DO	Dissolved Oxygen
EPA	U.S. Environmental Protection Agency
EQuIS	Environmental Quality Information System
GW	Groundwater
HSPF	Hydrologic Simulation Program-Fortran
HUC	Hydrologic Unit Code
LA	Load Allocation
Lb	pound
LGU	Local Government Unit
m	meter
mg/L	milligrams per liter
mL	milliliter
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
NPDES	National Pollutant Discharge Elimination System
NWR	National Wildlife Refuge
OP	Orthophosphorus
PTMApp	Prioritize, Target, and Measure Application
RLWD	Red Lake Watershed District
SPI	Stream Power Index
SWAG	Surface Water Assessment Grant
SWAT	Soil and Water Assessment Tool
SWCD	Soil and Water Conservation District
TKN	Total Kjeldahl Nitrogen

TMDL	Total Maximum Daily Load
TP	Total phosphorus
TSS	Total Suspended Solids
USFWS	United States Fish and Wildlife Service
WLA	Wasteload Allocation
WMA	Wildlife Management Area
WRAP	Watershed Restoration and Protection
WRAPS	Watershed Restoration and Protection Strategy
WWTF	Wastewater Treatment Facility

Executive Summary

The Federal Clean Water Act (1972), section 303(d) requires that each State identify impaired waters and develop a restoration study for any waterbody that is deemed impaired by state regulations. A Total Maximum Daily Load (TMDL) study is required by the U.S. Environmental Protection Agency (EPA) as a stipulation of the Clean Water Act. In Minnesota, the Minnesota Pollution Control Agency (MPCA) is tasked with assessing and listing waterbodies that do not meet water quality standards (Minn. R. 7050.022) and developing TMDLs. A TMDL identifies the pollutant sources causing the impairment and calls for pollutant load reductions from those sources. It is a calculation of the maximum amount of pollutant that can enter a waterbody without causing the concentration of the pollutant within the waterbody to exceed water quality standards.

The Thief River Watershed (USGS Hydrologic Unit Code 09020304) is located in northwest Minnesota and is a tributary of the Red Lake River (USGS HUC 09020303) in the Red River of the North Basin (USGS HUC 090203). Most of the watershed area lies within Marshall, Pennington, and Beltrami Counties. A very small portion of the Red Lake Nation Reservation is located within the southeast portion of the watershed. The Thief River itself runs along the western side of the watershed and is joined along the way by a number of tributaries, including the Moose River (Judicial Ditch 21), Mud River (Judicial Ditch 11), Branch 200 of Judicial Ditch 11, Marshall County Ditch 20, and Judicial Ditch 30. There are more than 30 impoundments and reservoirs in the watershed, including the Moose River Impoundment, Lost River Pool, Farmes Pool, the pools of Agassiz National Wildlife Refuge (NWR), and the Thief River Falls Reservoir. Agassiz NWR lies in the center of the watershed. Agassiz Pool, the main pool of the refuge, receives water from the Mud River from the east, Thief River from the north, and some smaller ditches. It discharges to the Thief River to the south.

The number of impairments in the watershed on the 2014 EPA 303(d) list of impaired waters was reduced to just four after three impairments were recommended for delisting during the 2013 assessment and an additional impairment was delisted after additional data collection. The Moose River remains impaired by low dissolved oxygen (DO), and the Mud River remains impaired for DO and *E. coli* bacteria. The analysis of data revealed that the absence of sufficient flow in the Moose River and Mud River had a greater influence upon the ability of the streams to meet the 5 mg/l DO standard than any of the pollutants that have been monitored in those rivers, so TMDLs were not developed for these impairments. The Thief River downstream of Agassiz Pool is listed as impaired by high turbidity. The state's new 30 mg/l Central Nutrient Region total suspended solids (TSS) standard will be used to develop a TMDL to address the turbidity impairment.

The findings of the Thief River Watershed Restoration and Protection Strategy (WRAPS) and other studies completed in the watershed will be used to guide the development of implementation strategies. A full list of these strategies is part of the Thief River WRAPS Report developed concurrently with this TMDL report as part of the Thief River WRAPS project.

This TMDL Report, the WRAPS report, and other technical reports referenced in this document are publicly available on the MPCA website for the Thief River Watershed: https://www.pca.state.mn.us/water/watersheds/thief-river. These and other documents can also be found on watershed-based web pages created for the Thief River by the Red Lake Watershed District (RLWD): http://www.rlwdwatersheds.org/wraps-info.

1. Project Overview

1.1 Purpose

This report establishes TMDLs for rivers and ditches in the Thief River Watershed that are listed on the 303(d) List of Impaired Waters as impaired by high levels of turbidity, high levels of *Escherichia coli* (*E. coli*) bacteria, and low levels of DO. A TMDL is defined as the maximum quantity of a pollutant that a waterbody can receive while meeting the water quality standards for the protection of aquatic life and recreation. This report will also characterize features of the watershed, identify some sources of pollutants that are causing the impairments and call for pollutant load reductions, and make recommendations for future monitoring efforts.

In 2006, Minnesota passed the Clean Water Legacy Act (CWLA) to protect, restore, and preserve the quality of Minnesota's surface waters. As a result, the MPCA established a watershed approach for monitoring, assessment, and the development of TMDLs. One component of that work is to complete TMDLs for the impaired waterbodies within each watershed and develop a watershed-wide TMDL report. This report is intended to fulfill the TMDL requirement. The watershed approach also includes the concurrent creation of a WRAPS report that ultimately recommends a list of strategies for restoring impaired reaches and protecting waterbodies that are currently meeting water quality standards.

1.2 Identification of Waterbodies

The Thief River Watershed (HUC 09020304) is located in northwest Minnesota and is a tributary of the Red Lake River in the Red River of the North Basin. Most of the watershed area lies within Marshall, Pennington, and Beltrami Counties. A very small portion of the Red Lake Nation Reservation is located within the southeast portion of the watershed. The watershed lies within the boundary and jurisdiction of the RLWD. The watershed also lies within the Northern Minnesota Wetlands and Red River Valley ecoregions, and most of the soils in the watershed are poorly drained. The Thief River flows along the western side of the watershed and is fed along the way by tributaries that include the Moose River (Judicial Ditch 21), Mud River (Judicial Ditch 11), Branch 200 of Judicial Ditch 11, Marshall County Ditch 20, and Judicial Ditch 30. There are a number of impoundments in the watershed, including the Moose River Impoundment, Lost River Pool, Farmes Pool, and the pools of Agassiz NWR. Agassiz NWR lies in the center of the watershed. Agassiz Pool, the main pool of the refuge, receives water from the Mud River, Thief River, and some smaller ditches. The pool discharges to the Thief River.

Because it is home to Agassiz NWR and Thief Lake Wildlife Management Area (WMA), the area is productive and important for waterfowl, shorebirds, and migrating birds. The watershed also features productive farmland that is important to the local economy.

The Thief River is a tributary of the Red Lake River, which is a drinking water source for the cities of Thief River Falls (just downstream of the confluence) and East Grand Forks. Water quality in the Thief River directly affects the Thief River Falls Reservoir and the city's water supply. The Minnesota Department of Health has developed source water plans for Thief River Falls and East Grand Forks. One of the currently proposed changes for the MPCA Triennial Standards Review is to change the classification of the Thief River upstream of Thief River Falls from Class 2B (warm water fishery) to Class 1 (drinking water source).

A large amount of data has been collected within the Thief River Watershed by the RLWD, Marshall County, Pennington County Soil and Water Conservation District (SWCD), and the Grygla River Watch condition monitoring programs. Intensive monitoring was conducted throughout the watershed during the 2007 through 2009 Thief River Watershed Sediment Investigation and the coinciding Agassiz NWR Water Quality Study. The watershed was again studied intensively during the Thief River WRAPS (2011 through 2015) and Surface Water Assessment Grant (SWAG 2011-2012) projects.

A total of four water quality impairments are listed on the 2014 EPA 303(d) List of Impaired Waters within the Thief River Watershed (HUC 09020304), and these waters continue to fail to meet water quality standards (Table 1-1 and Figure 1-1). Through the extra data collection facilitated by the Thief River WRAPS Project, the *E. coli* impairment of Branch A of JD21 (09020304-555) from the draft, 2014 303(d) List of Impaired Waters was recommended for delisting and will not be addressed in this report. The Mud River (09020304-507) was also recommended for delisting because it met the *E. coli* standard when assessed both as a unit and at the primary flow monitoring station. However, high concentrations in recent monitoring revealed that a portion of the river, near Grygla, is still impaired by high *E. coli* concentrations, and a TMDL was developed for this waterbody.

The Moose River and Mud River remain impaired by low DO. Improved base flow rates are recommended to improve DO levels in the Moose River and Mud River. Much data analysis work was completed as part of an effort to find a pollutant of concern or other cause of low DO in the Thief River Watershed. Absence of sufficient flow in the Moose River and Mud River greatly impeded the ability of the streams to meet the 5 mg/l DO standard. The influence was greater than that of the pollutants that have been monitored in those rivers, so no TMDLs were developed for these impairments. The Thief River downstream of Agassiz Pool is impaired by high turbidity. The state's new TSS standard was used to develop a TMDL to address the turbidity impairment.

Table 1-1. Impaired Waterways of the Thief River Watershed on the 2014 303(d) List of Impaired Waters

Name	Reach	HUC/AUID Code	Impairment	Listed	Addressed in this TMDL?
Thief River	Agassiz Pool to Red Lake River	09020304-501	Aquatic Life – Turbidity	2006	Yes
~~Thief River~~	~~Agassiz Pool to Red Lake River~~	~~09020304-501~~	~~Aquatic Life – Low Dissolved Oxygen~~	~~2006~~	No**
~~Thief River~~	~~Thief Lake to Agassiz Pool~~	~~09020304-504~~	~~Aquatic Life – Unionized Ammonia~~	~~2006~~	No**
~~Thief River~~	~~Thief Lake to Agassiz Pool~~	~~09020304-504~~	~~Aquatic Recreation – *Escherichia coli*~~	~~2006~~	No**
Moose River	Headwaters to Thief Lake	09020304-505	Aquatic Life – Low Dissolved Oxygen	2006	No*
Mud River	Headwaters to Agassiz Pool	09020304-507	Aquatic Life – Low Dissolved Oxygen	2008	No*
Mud River	Headwaters to Agassiz Pool	09020304-507	Aquatic Recreation - *Escherichia coli*	2014	Yes
~~Branch A of JD21~~	~~Unnamed ditch to Moose River~~	~~09020304-555~~	~~Aquatic Recreation - *Escherichia coli*~~	~~2014~~	No**

*A lack of flow was determined to be the primary cause of this DO impairment instead of a pollutant. No TMDLs were established for this particular impairment.
**Recent data shows that this reach is no longer violating the water quality standard for which it was listed. The reach has been delisted because it is now meeting state water quality standards.

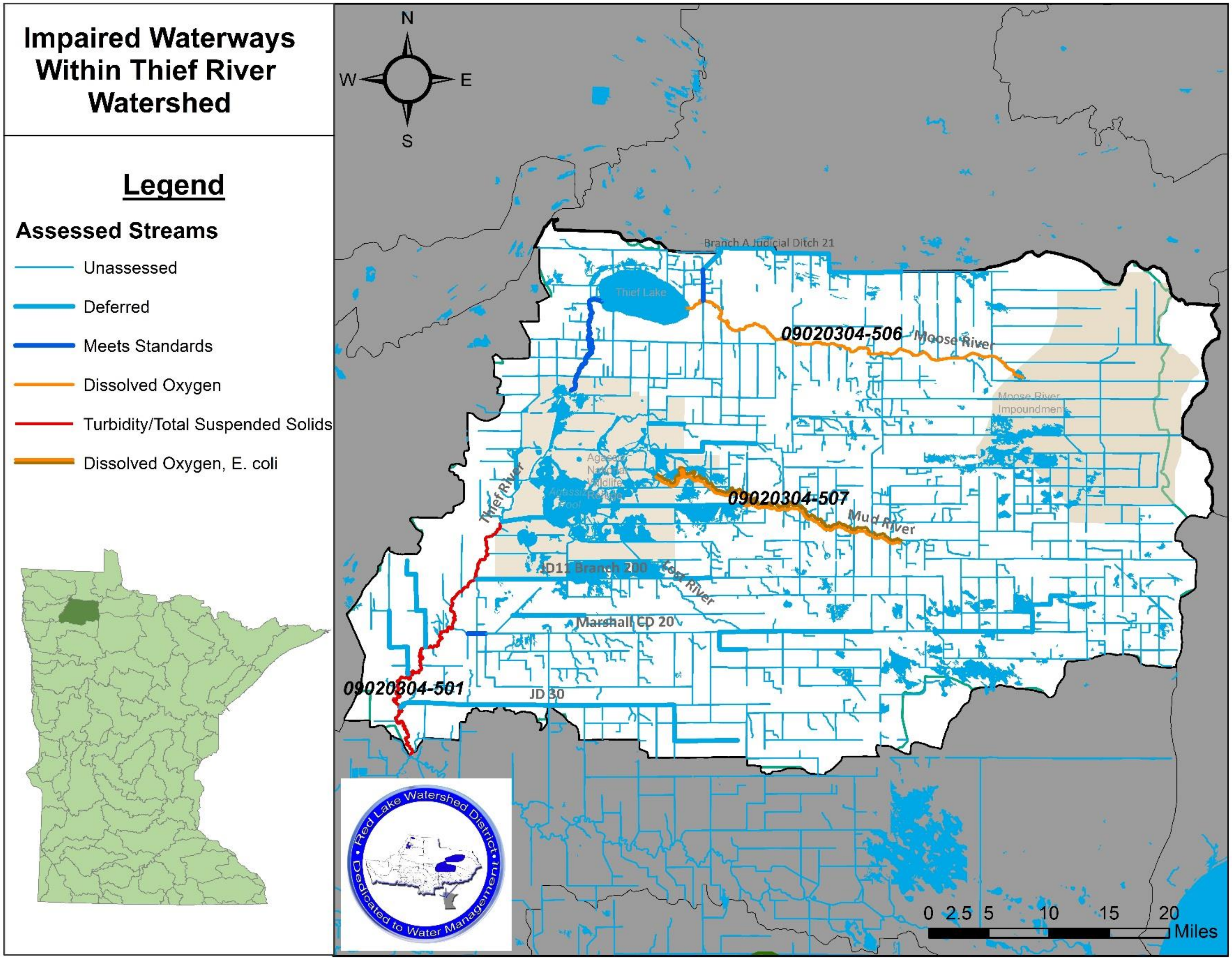


Figure 1-1. Impaired waters in the Thief River watershed (after the recommended *E. coli* delistings)

1.3 Priority Ranking

The MPCA's projected schedule for TMDL completions, as indicated on the 303(d) impaired waters list, implicitly reflects Minnesota's priority ranking of this TMDL. Ranking criteria for scheduling TMDL projects include, but are not limited to: impairment impacts on public health and aquatic life; public value of the impaired water resource; likelihood of completing the TMDL in an expedient manner, including a strong base of existing data and restorability of the waterbody; technical capability and willingness locally to assist with the TMDL; and appropriate sequencing of TMDLs within a watershed.

With the adoption of a watershed approach, the MPCA has adopted a new schedule for the completion of TMDLs. During each year of a 10-year schedule, a portion of the state's watersheds begin an intensive watershed monitoring process. TMDL and WRAPS reports are developed during the third and fourth years of each watershed's WRAPS project following two years of data collection, an assessment of the watershed, and investigation of stressors and pollutant sources. Schedules in Table 1-2 are estimated and indicate when a TMDL may be completed, not when a waterbody will meet its water quality standard. A map that displays the planned years in which each watershed's second round of intensive monitoring is scheduled to start can be found on the MPCA's website: https://www.pca.state.mn.us/water/watershed-approach-restoring-and-protecting-water-quality.

Table 1-2. Schedule for completion of Thief River Watershed TMDLs

Waterbody (AUID)	Reach	Listed	Use Class	Target Start/ Completion	Impairment
Thief River (09020304-501)	Agassiz Pool to Red Lake River	2006	2B, 3C	2011/2016	Aquatic Life - Turbidity
Moose River (09020304-505)	Headwaters to Thief Lake	2006	2B, 3C	No TMDL Required	Aquatic Life – Low Dissolved Oxygen
Mud River (09020304-507)	Headwaters to Agassiz Pool	2008	2B, 3C	No TMDL Required	Aquatic Life – Low Dissolved Oxygen
Mud River (09020304-507)	Headwaters to Agassiz Pool	2008	2B, 3C	2011/2016	Aquatic Recreation – High *E. coli*

2. Applicable Water Quality Standards and Numeric Water Quality Targets

Table 2-1. Applicable water quality standards

Parameter	Use Class	Water Quality Standard	Criteria	Standard's Applicable Time Period
Total Suspended Solids – Central Nutrient Region	2B, 3C	Not to exceed 30 mg/l	Upper 10th Percentile	April 1 – September 30
Escherichia Coli	2B, 3C	126 MPN per 100 ml	Maximum Geometric Mean	April 1 – October 31
		1260	Maximum = 10% of Samples	April 1 – October 31
Dissolved Oxygen	2B, 3C	Daily minimum of 5 mg/l	>90% of daily minimums need to exceed the standard	Open Water Months

Portions of the Thief River failed to meet standards for TSS, *E. coli*, and DO. The state of Minnesota's water quality standards for those parameters are described in Sections 2.1 through 2.4 and summarized in Table 2-1.

The impaired waters within the Thief River watershed have been assigned the 2B and 3C use classes. According to Minnesota statutes, "*the quality of class 2B surface waters shall be such as to permit the propagation and maintenance of a healthy community of cool or warm water aquatic biota and their habitats*." "*These waters shall be suitable for aquatic recreation of all kinds, including bathing, for which the waters may be usable*." The quality of class 3C waters of the state shall be such as to permit their use for industrial cooling and materials transport without a high degree of treatment being necessary to avoid severe fouling, corrosion, scaling, or other unsatisfactory conditions.

2.1 Dissolved Oxygen

DO is required for aquatic organisms to live. When DO drops below acceptable levels, desirable aquatic organisms, such as fish, can be killed or harmed. DO standards differ depending on the use class of the water. The reaches within the Thief River Watershed that were assessed and found to be lacking DO are classified as Class 2B streams.

Class 2Bd, 2B, 2C. Not less than 5 mg/L as a daily minimum

This DO standard may be modified on a site-specific basis according to Minn. R. 7050.0220, subp. 7, except that no site-specific standard shall be less than 5 mg/L as a daily average and 4 mg/L as a daily minimum. Compliance with this standard is required 50% of the days at which the flow of the receiving water is equal to the 7Q10.

The standard for DO is expressed in terms of daily minimums and concentrations generally follow a diurnal cycle. Consequently, measurements in open-water months (April through November) should be made before 9:00 a.m.

A stream is considered impaired if: 1) more than 10% of the "suitable" (taken before 9:00 a.m.) May through September measurements, or more than 10% of the October through April measurements violate the standard; and 2) there are at least three violations.

Because the underlying criterion is that water quality standards can be exceeded no more than 10% of the relevant time, it is important that measurements are a representative sample of overall water quality and are not biased towards certain types of conditions, such as storm events or certain times of the year. The relevant time generally refers not to the entire year, but rather to the usual water quality monitoring portion of the year. The requirement of at least three exceedances helps ensure that the measured data set is sufficiently large to provide an adequate picture of overall conditions.

A designation of "full support" for DO generally requires at least 20 suitable measurements from a set of monitoring data that give a representative, unbiased picture of DO levels over at least two different years. However, if it is determined that the data set adequately targets periods and conditions when DO exceedances are most likely to occur, a smaller number of measurements may suffice for a determination of "full support."

While two waterbodies in the watershed are listed as impaired due to not meeting the DO standard, no TMDL was performed for them, since the impairments are caused by lack of river flow, rather than by pollutants.

2.2 Turbidity

Turbidity is caused by suspended soil particles, algae, etc., that scatter light in the water column making the water appear cloudy. Exceedance of the turbidity standard, especially for prolonged periods, can harm aquatic life. Aquatic organisms may have trouble finding food, gill function may be affected, and spawning beds may be covered.

Turbidity is measured in nephelometric turbidity units (NTU). The standards are shown below:

- 25 NTU, Class 2B and 2Bd waters

The Thief River is classified as a 2B water, so the 25 NTU standard is the standard that was applied when the reach was listed as impaired by high turbidity.

A stream is considered impaired if: 1) more than 10% of the turbidity-related measurements (turbidity, t-tube, TSS) exceed the standard; and 2) there are at least three total exceedances.

Because the underlying criterion is that water quality standards can be exceeded no more than 10% of the relevant time, it is important that measurements are a representative sample of overall water quality and are not biased towards certain types of conditions, such as storm events or certain times of the year. The relevant time generally refers not to the entire year, but rather to the portion of the year in which water quality monitoring usually takes place. The requirements of at least three exceedances helps ensure that the measured data set is sufficiently large to provide an adequate picture of overall conditions.

A designation of "full support" for turbidity generally requires at least 20 suitable measurements from a set of monitoring data that give a representative, unbiased picture of turbidity levels over at least two different years. However, if it is determined that the data set adequately targets periods and conditions when turbidity exceedances are most likely to occur, a smaller number of measurements may suffice for a determination of "full support."

Since the reach was originally listed, the state of Minnesota has adopted water quality standards for TSS and has abandoned turbidity-based assessments. The retired 25 NTU turbidity standard correlates with a TSS concentration of 25 mg/l. The recently adopted TSS water quality standard is 30 mg/l. The newly proposed standard is applicable to the months of April through September instead of the April through October period to which the turbidity standard was applied. An analysis of 2005 through 2014 data (the most recent 10 years) shows that the Thief River has exceeded 25 mg/l of TSS during 28% of measurements. An analysis of the same data shows that the Thief River has exceeded the 30 mg/l proposed water quality standard in 19% of the samples that were collected in 2005 through 2014. Because these exceedance rates are greater than 10%, a TSS TMDL for this reach will be necessary.

2.3 Total Suspended Solids

TSS will be used to address the turbidity impairment. It is a quantifiable standard, which is needed for the calculation of loading capacity, allocations, and reductions. Turbidity is an optical property of water that is useful for on-the-spot assessment of water quality conditions, but needs to be converted to another parameter like TSS to be used. With the adoption of the TSS standard, the state will no longer apply the turbidity standard during official water quality assessments.

The newly adopted TSS standards were adopted at three different levels for three River Nutrient Regions (Figure 2-1). The Thief River lies within the Central Nutrient Region. The TSS standard for the Central River Nutrient Region is 30 mg/l. The TSS standard will be applicable to the months of April through September instead of the April through October period to which the turbidity standard was applied.

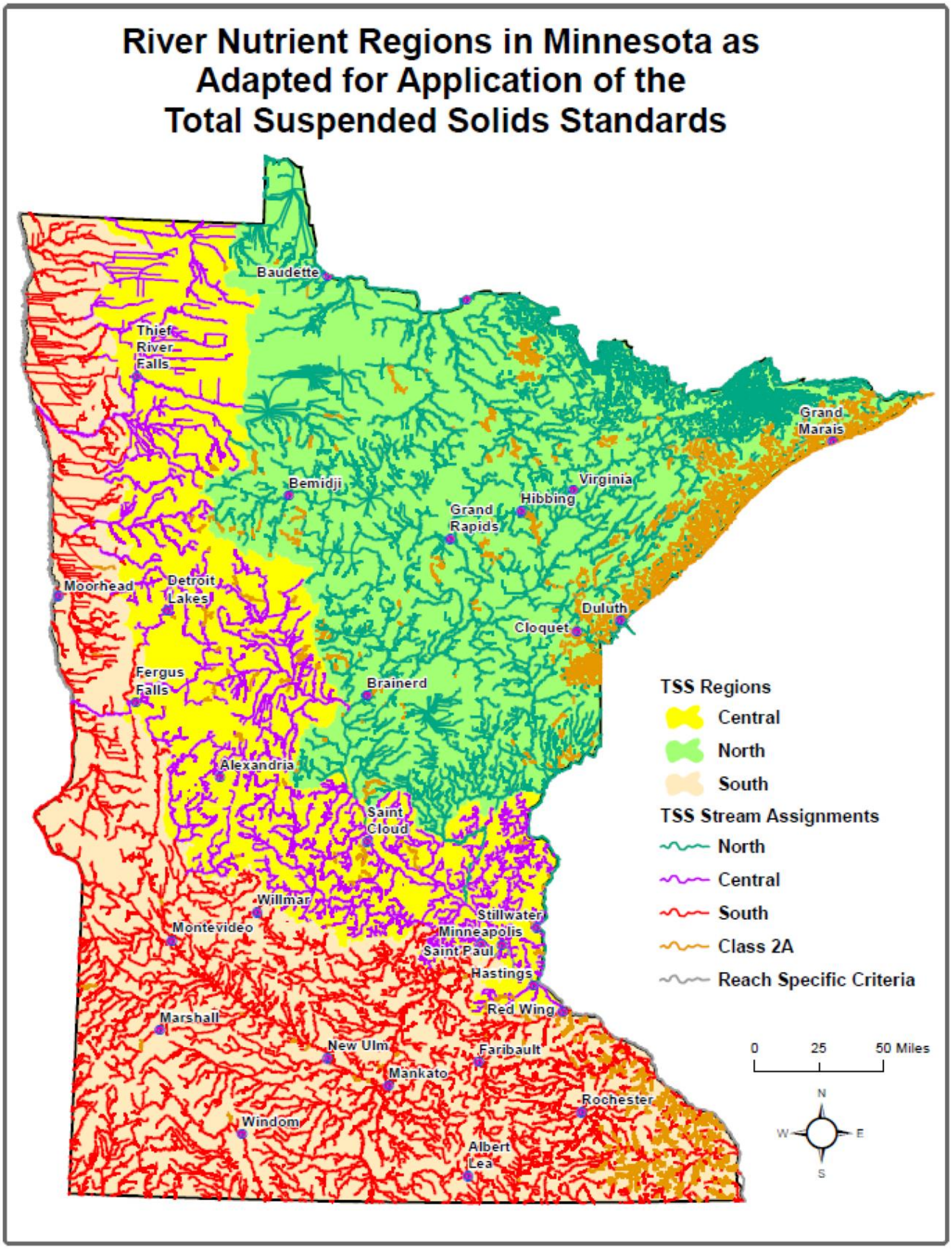


Figure 2-1. Red River Basin River Nutrient Regions as Adapted for Application of TSS Standards

2.4 *Escherichia coli (E. coli)*

The numeric standards in Minn. R. ch. 7050 (Waters of the State) that directly protect for primary (swimming and other recreation where immersion and inadvertently ingesting water is likely) and secondary (boating and wading where the likelihood of ingesting water is much smaller) body contact are the *E. coli* (Escherichia coli) standards shown in Table 2-1. *E. coli* standards are applicable only during the warm months since there is very little swimming in Minnesota in the non-summer months. Exceedances of the *E. coli* standard mean that the recreational use is not being met.

The MPCA uses an *E. coli* standard based on a geometric mean EPA criterion of 126 *E. coli* colony forming units (CFU) per 100 ml. *E. coli* has been determined by the EPA to be the preferred indicator of the potential presence of waterborne pathogens.

There is a considerable amount of *E. coli* data available in Minnesota, and older fecal coliform data. For assessment purposes, only *E. coli* measurements will be used. Exceptions to the exclusive use of *E. coli* data will be made only in special cases, using a ratio of 200 to 126 to convert fecal coliform to *E. coli.*

Data over the full 10-year period are aggregated by individual month (e.g. all April values for all 10 years, all May values, etc.). At least five values for each month is ideal, while a minimum of five values per month for at least three months, preferably between June and September, is necessary to make a determination. Assessment with less than these minimums may be made on a case-by-case basis.

Where multiple bacteria/pathogen samples have been taken on the same day on an assessment unit, then the geometric mean of all the measurements will be used for the assessment analysis.

If the geometric mean of the aggregated monthly values for one or more months exceeds 126 organisms per 100 ml, that reach is considered impaired. In addition, waterbody is considered impaired if more than 10% of individual values over the 10-year period (independent of month) exceed 1260 organisms per 100 ml. This assessment methodology more closely approximates the five-samples-per-month requirement of the standard while recognizing typical sampling frequencies, which rarely provide five samples in a single month and usually only one.

Expert review of the data provides a further evaluation. When fewer than five values are available for most or all months, the individual data are reviewed. In some circumstances where four values are available for some or all months, a mathematical analysis done to determine the potential for a monthly geometric mean to exceed the 126 organisms/100ml standard. All assessments are reviewed by the Watershed Assessment Team (WAT) for each watershed.

Considerations in making the impairment determination include the following:

- Dates of sample collection (years and months)
- Variability of data within a month
- Magnitude of exceedances
- “Remark” codes associated with individual values
- Previous assessments and 303(d) listings

A TMDL was performed for the *E. coli* impairment on the Mud River in the Grygla area.

3. Watershed and Waterbody Characterization

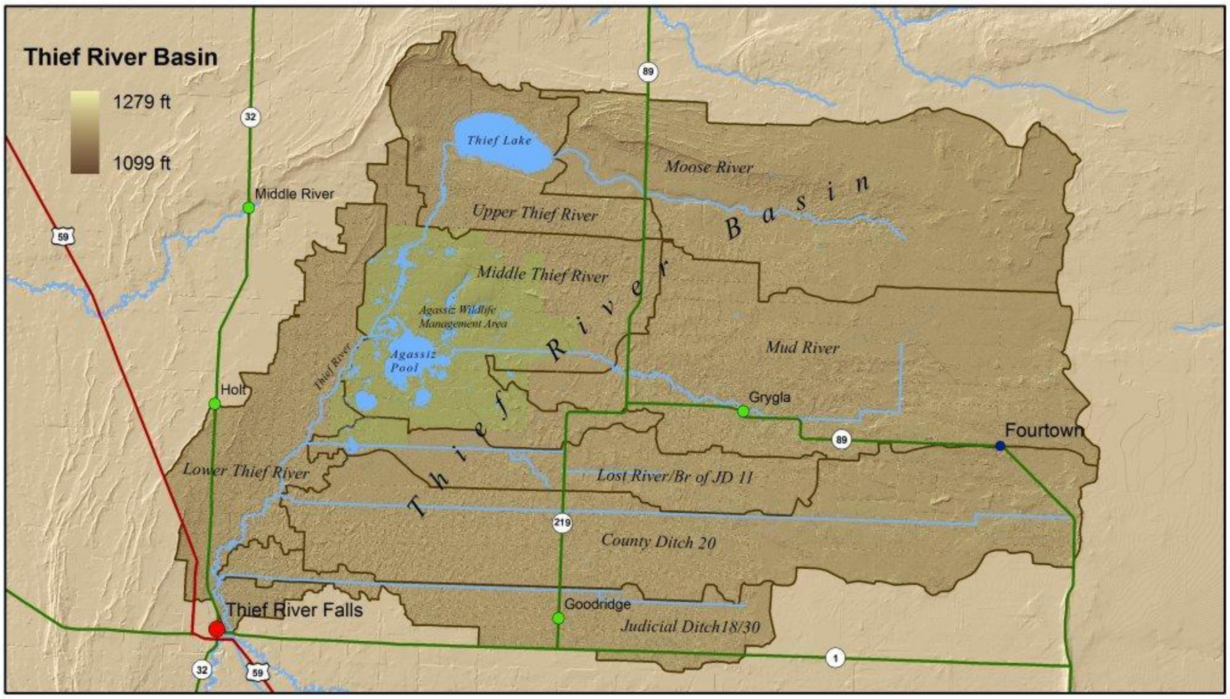


Figure 3-1. Thief River Watershed Map

The Thief River Watershed (Figure 3-1) covers approximately 1090 square miles in northwest Minnesota. The Thief River itself is split into two major reaches. It begins at the outlet of Thief Lake and flows to Agassiz NWR, where the river channel enters and supplies water to Agassiz Pool. A portion of the flow can travel along the northwestern dike of the pool and exits the pool via a relatively new (operational in 2008) northwest outlet structure (Figure 3-2).

Figure 3-2. Aerial view of the northwest outlet of Agassiz Pool that became operational in 2008

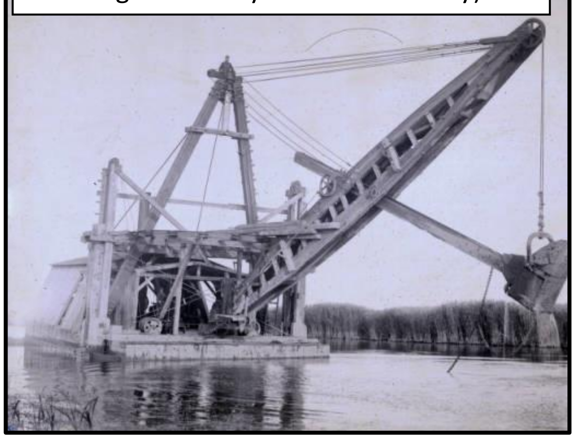
The main tributaries of the Thief River are the Moose River, Mud River, and a series of major ditch systems. The Moose River begins at the outlet of the Moose River Impoundment in the northeastern part of the watershed and flows near the northern edge of the watershed, west, to Thief Lake. Thief Lake is a shallow lake basin that was drained for agriculture in the early 1900s but was restored through the installation of a dam in the 1930s. It is the 15th largest lake in Minnesota.

The Thief River begins at the outlet of Thief Lake. It flows south until it enters Agassiz Pool. Agassiz Pool also receives water from the Mud River (from the east) and other smaller ditch systems. Water is discharged from the primary outlet of Agassiz Pool via two 14-foot wide radial gates (Figure 3-3) and a 2.63-foot screw gate outlet into Judicial Ditch 11 (JD11). After flowing through a 2.3-mile reach of JD11, water re-enters the Thief River.

Figure 3-3. Aerial view of the radial gate outlet of Agassiz Pool along Judicial Ditch 11

Downstream of Agassiz Pool, the Thief River flows south to the city of Thief River Falls where it joins with the Red Lake River within the Thief River Falls reservoir. Within the Thief River Falls Reservoir, the combined waters of the Thief River and the Red Lake River, upstream of the Thief River Falls dam, are used as a source of drinking water for the city of Thief River Falls. The Red Lake River is a major tributary of the Red River of the North.

Floating dredge in 1906 (from the Pennington County Historical Society)



Portions of the Moose River, Mud River, and Thief River were channelized to improve drainage for agriculture. Approximately 96% of the channels in the watershed are man-made or are channelized segments of stream. These dredged reaches are managed as ditch systems by drainage authorities according to Chapter 103E of the State of Minnesota Statutes. The Moose River upstream of Thief Lake and a several-mile reach of the Thief River downstream of Thief Lake are also known as the main branch of Judicial Ditch 21. The Mud River is also known as the main branch of JD 11. State Ditch 83 is a dredged portion of the

Thief River that begins along the western edge of Agassiz NWR and ends downstream of the County State Aid Highway (CSAH) 44 crossing, northeast of Thief River Falls. Remnants of the dredging activities can still be found. Chunks of coal that fueled the floating dredges can be found along the channel bottom of the Thief River and Marshall County Ditch 20. There are only two reaches of significant rivers and streams in the Thief River Watershed that have not been dredged. One section of the upper reach of the Thief River downstream of Judicial Ditch 21 and upstream of State Ditch 83 has not been dredged. The non-channelized reach of the Thief River is downstream of the dredged State Ditch 83 portion of the river.

3.1 Streams

The direct drainage areas and total contributing drainage areas for impaired Assessment Unit ID (AUID) reaches in the Thief River Watershed are listed in the following table. The immediate drainage area is defined as all the land that drains to the specified AUID that does not drain through any other AUID or lake. Watershed areas in Table 3-1 were calculated from the 2009 USGS HUC12 Watershed Boundary Dataset.

Table 3-1.Impaired stream reach direct and total drainage areas.

HUC/AUID Code (09020304-XXX)	Name and Description	HUC10 Subwatershed	Immediate Drainage Area (Acres)	Total Drainage Area (Acres)	Upstream Waterbody (09020304-XXX)
501	Thief River Agassiz Pool to Red Lake River	Lower Thief River	50,230	671,011	Thief River (502) Judicial Ditch 11 (536)
505	Moose River Headwaters to Thief L	Moose River	62,645	125,190	Moose River Impoundment (No AUID)
507	Mud River Headwaters to Agassiz Pool	Mud River	86,918	126,345	Judicial Ditch 11 (526)

The Moose River (09020304-505, Headwaters to Thief Lake) is a tributary of the Thief River that begins at the outlet of the north pool of the Moose River Impoundment and flows west to Thief Lake. The river flows through northwestern Beltrami County and northeastern Marshall County. The water in the Moose River is tea-stained as it flows out of the lowland swamps of the Beltrami Island State Forest. Flow is partially controlled by discharge from a water control structure at the Moose River Impoundment outlet. Much of the Moose River flows within the boundaries of the Thief Lake WMA. The Moose River is a free-flowing stream at the CSAH 54 crossing (S004-211), but gradient decreases, depth increases, and velocity decreases as the river nears Thief Lake. Enough low DO concentrations have been recorded (particularly in the low-gradient portion near Thief Lake) for the reach to be listed as impaired by low DO.

The Moose River was dredged in the beginning of the 20th century and is also known as the main branch of the Judicial Ditch 21 drainage system. The oldest map of JD 21 on hand at the RLWD office was created in 1913. The dredging extended through Thief Lake (draining the lake) to where the Thief River crosses the southern border of Thief Lake Township. When the Thief Lake pool was restored with a dam, water was also pooled within the Moose River (JD 21) channel upstream of the lake.

A significant tributary of the Moose River is Branch A of Judicial Ditch 21 (09020304-555, Unnamed Ditch to Moose River). This ditch system begins within the Wapiti WMA, flows west, and enters the Moose

River near the Thief Lake inlet. The lower reach of that drainage system was impaired by high concentrations of *E. coli*, but recent data collection has shown that it is currently meeting the state water quality standard.

The Mud River (09020304-507, Headwaters to Agassiz Pool) is a significant tributary of the Thief River that begins at the outlet of the south pool of the Moose River Impoundment and flows south, then west to Agassiz Pool. The river flows through the town of Grygla near the upstream end of the 09020304-507 assessment unit. It is also known as the main branch of the Judicial Ditch 11 legal drainage system, which was dredged in the early 1900s. The earliest map of the JD11 drainage system on hand at the RLWD office was created in 1912. The spoil pile from the dredging is still in place along much of the north bank of the river. The assessment unit of concern due to low DO and high *E. coli* levels, 09020304-507, does not fully extend to the actual headwaters of the river. The upstream end of the AUID is approximately 1.6 miles east (upstream) of Grygla. The 10.33 miles of Judicial Ditch 11 channel between the upstream end of 09020304-507 and the outlet of the Moose River Impoundment was split into six additional assessment units during the 2013 assessment process.

The Mud River and Thief River both flow into Agassiz Pool, which then discharges water into the lower reach of the Thief River. The lower reach of the Thief River (09020304-501, Agassiz Pool to Red Lake River), which is impaired by high turbidity levels, begins at the outlet of Agassiz Pool (at the end of the portion of the Judicial Ditch 11 channel between the Agassiz Pool radial gate outlet and the Thief River). Like many other channels within the watershed, a portion of the Thief River was also dredged. That portion of the Thief River is also referred to as State Ditch 83 (Figure 3-4). The dredging stopped at a point within Section 34 of Excel Township, downstream of the current CSAH 44 crossing. As it continues downstream from that point, the channel exhibits a natural pool and riffle pattern until it begins to be affected by backwater from the Thief River Falls dam and reservoir. The city of Thief River Falls pumps its drinking water from a point between the Thief River Falls dam and the confluence of the Thief River and Red Lake Rivers. Therefore, water quality in the Thief River very directly affects the city's drinking water supply.

Other significant legal ditch systems that flow to the Thief River and its tributaries include:

- Marshall County Ditch 28
- Branch 1, JD 11 (09020304-543)
- Branch 200, JD11 (09020304-512, 09020304-511)
- Marshall County Ditch 20 (09020304-510, 09020304-519, 09020304-518, 09020304-517, 09020304-516, 09020304-515, 09020304-514, 09020304-513)
- Judicial Ditch 23
- Judicial Ditch 30/18/13 Drainage System (09020304-509, 09020304-541, 09020304-540,09020304-539, 09020304-538, 09020304-537)

The waters of the Thief River Watershed are conducive to aquatic recreation. The Thief River near Thief River Falls is used for swimming. Kayaking and canoeing are possible on the Thief River, Mud River, and the lower reaches of the Moose River. Frequent road crossings make the streams accessible for aquatic recreation. Waterfowl hunting is another significant form of recreation in the watershed.

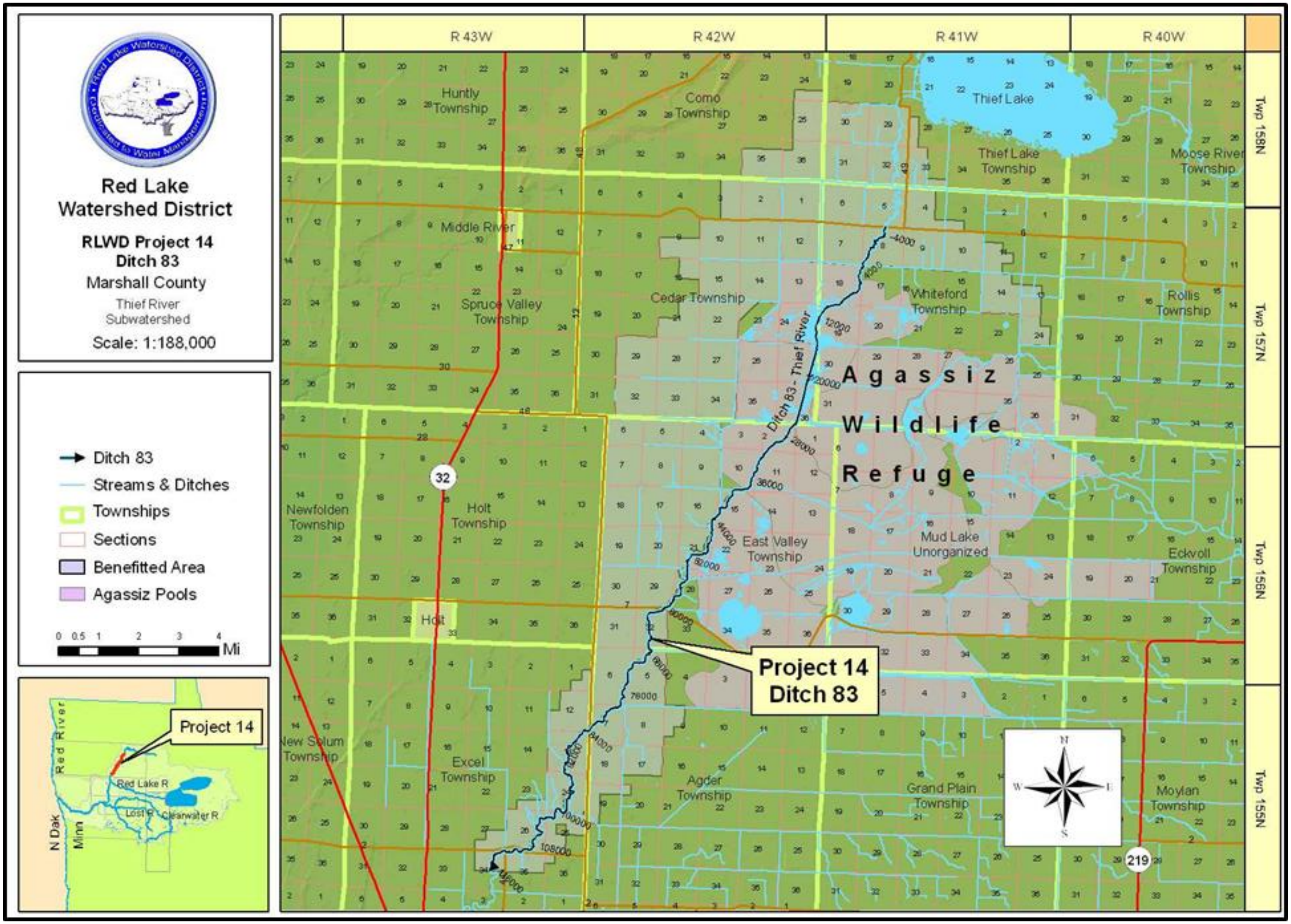


Figure 3-4. State Ditch 83 Portion of the Thief River

3.2 Impoundments and Reservoirs

Hydrologic modification within the Thief River Watershed has had a significant impact upon flows, water quality, aquatic life, aquatic habitat, and the agricultural viability of the land. The drainage-related hydrologic modification made farming possible within this area. Some of the watershed's impoundments were built to address flooding concerns, but most are operated primarily for wildlife habitat management (Figure 3-6). Several of the larger lakes and impoundments within the Thief River Watershed have some form of influence upon water quality within the watershed's impaired stream reaches. The locations of the watershed's most significant impoundments and drainage systems are shown in Figure 3-6.

Moose River Impoundment

The Moose River Impoundment is the largest impoundment operated by the RLWD. The impoundment reduces downstream flood damages by impounding floodwaters in the upper reaches of the watershed. Wildlife and associated recreational benefits are also enhanced by the water retained in the impoundment's pools. It can also be used for streamflow maintenance (a function that needs improvement) and to benefit fire control. The impoundment has two pools. The North Pool discharges to the Moose River (Judicial Ditch 21). The South Pool discharges to the Mud River Subwatershed (Judicial Ditch 11). Other than during runoff events, flow in the Moose River is significantly influenced by the amount of discharge from the impoundment's outlet structure.

Table 3-2. Moose River Impoundment Storage Capacity

Level	Pool	Elevation	Design Storage (ac/ft)	Total Storage (ac/ft)
Top of Dam (Max)	North	1218.0		
	South	1220.0		
Freeboard Flood	North	1217.2	16,250	54,500
	South	1219.3	38,250	
Emergency Spillway	North	1216.0	12,000	36,250
	South	1218.0	24,250	
Gated Pool	North	1215.3	9,750	29,500
	South	1217.4	19,750	
Typical Summer	North	1211.7	2,000	6,000
	South	1213.6	4,000	
Typical Winter	North	1210.5	800	2,600
	South	1212.4	1,800	
Max No-Flood	North	1212.5	3,000	9,000
	South	1214.5	6,000	

Thief Lake

The Thief River begins at the outlet on the west end of Thief Lake, a 7,100-acre marsh that is an important production and tagging area for waterfowl. Thief Lake is a shallow lake with a maximum depth of 7.4 feet. Access to the lake is available through a variety of accesses but is restricted because the lake lies entirely within the Thief Lake WMA. In any year, aquatic recreation is limited by the shallow depths of the lake, severe water level fluctuations, and limited access to the lake due to hunting and waterfowl nesting. Wildlife viewing and hunting are the primary activities for this basin. It is not used for recreational swimming. A landowner at one of the stakeholder meetings stated that Thief Lake supported a fishery at one time prior to when it was drained by Judicial Ditch 21.

Water levels within Thief Lake are managed with a dam approximately 250 yards upstream of CSAH 49. Thief Lake was a natural lake basin prior to European settlement but was dredged and drained for agriculture between 1914 and 1916. The dam was installed by the Department of Conservation in 1931 to restore the pool and restore waterfowl habitat. After spring runoff fills the pool, water is gradually released to get back to normal pool level and provide optimal habitat conditions. The pool is drawn down in the late fall to a winter pool level that is one foot lower than the normal lake level. This provides room for storage of spring runoff.

The Moose River flows into the east end of Thief Lake. The Moose River channel was dredged to create Judicial Ditch 21, the ditch system that once drained Thief Lake. When the dam restored the water levels in the pool, it also raised water levels within the channel upstream of the lake. This created slower flow velocities within a portion of the river that lead to low DO levels due to relatively stagnant water.

Agassiz National Wildlife Refuge

Agassiz NWR is a 61,500-acre complex of wetlands and uplands in the Thief River Watershed (Figure 3-5) that is managed by the USFWS. Agassiz NWR was established in 1937 as Mud Lake Refuge, later renamed in 1961, and has been managed for the primary purpose of supporting breeding and migratory waterfowl (U.S. Fish and Wildlife Service 2005). Agassiz NWR includes 26 impoundments (known variously as lakes, ponds, pools, or moist soil units) and 3 natural lakes. Water is contained within the impoundments by an extensive network of dikes. Water levels can be raised or lowered in any given impoundment by adjusting water control structures at pool outlets. A radial gate outlet discharges water to JD11 and a relatively new stop-log outlet structure discharges water to SD 83.

Sediment infilling has led to a loss of depth and expansion of vegetation within Agassiz Pool. Sediment core and suspended sediment radioisotope analysis suggested that erosion from upland and agricultural fields is the dominant source of sediment entering Agassiz Pool. The USFWS has adopted a strategy of incremental excavation to promote scouring and flushing of sediment in the old JD11 channel within the pool to address the sedimentation. Although necessary for waterfowl management, adverse water quality effects have occurred with this strategy. These adverse effects of this strategy are documented in Section 3.6.

Elm Lake (Farmes Pool) was drained sometime around 1920 by the construction of Branch 200 of Judicial Ditch 11. Multiple agencies cooperated to complete the Elm Lake Project to restore the pool for the purpose of flood control, wildlife habitat, and upstream drainage improvement. Agassiz NWR staff perform the actual operation of the outlet structure.

The Minnesota Department of Natural Resources (DNR) constructed the Lost River Impoundment in the mid-1970s to improve waterfowl habitat. The pool also provides flood control benefits. It receives water from the eastern Branch 200 of JD11 drainage area and discharges water back into Branch 200 of JD11.

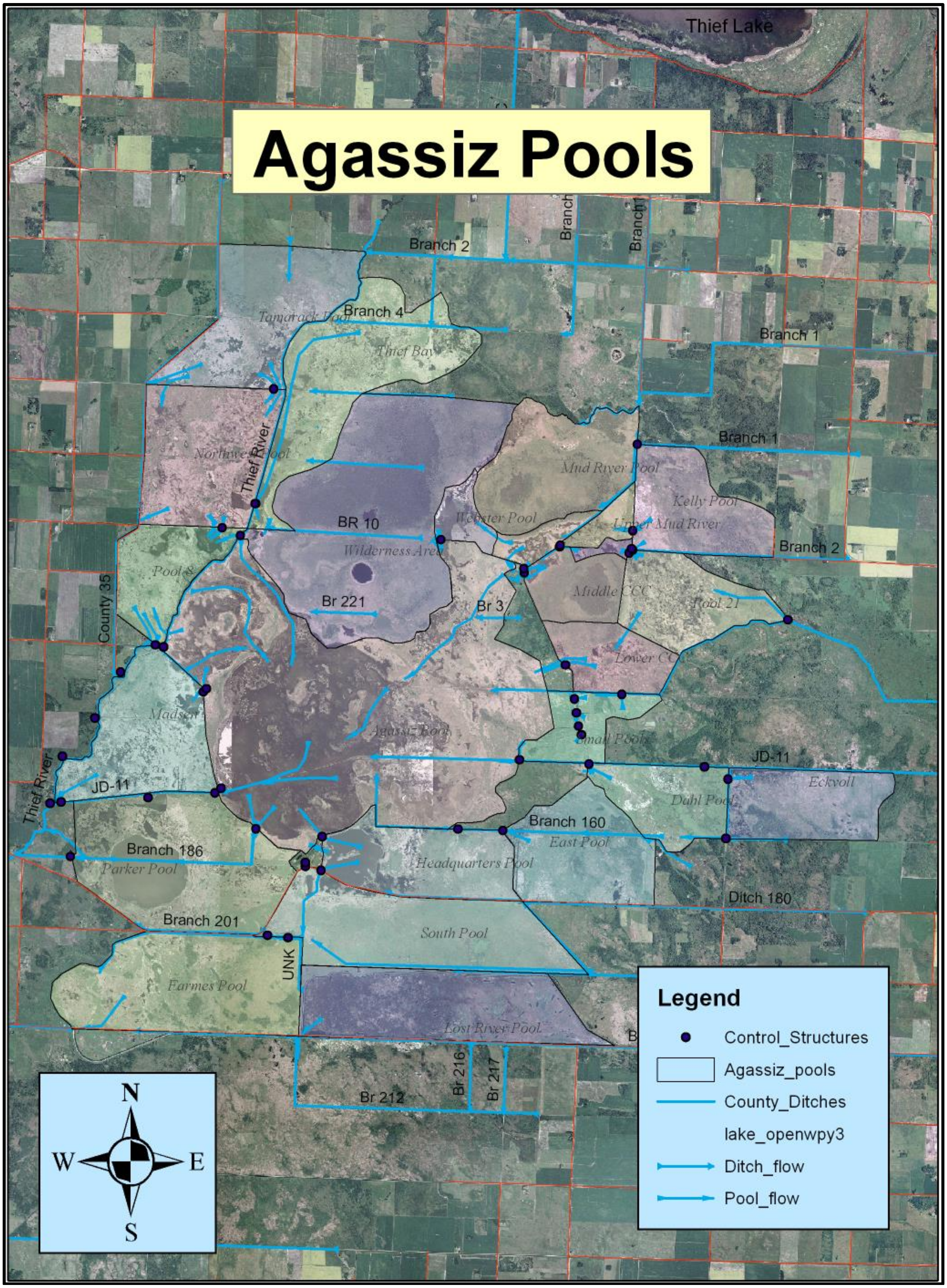


Figure 3-5. Flow Patterns within Agassiz National Wildlife Refuge

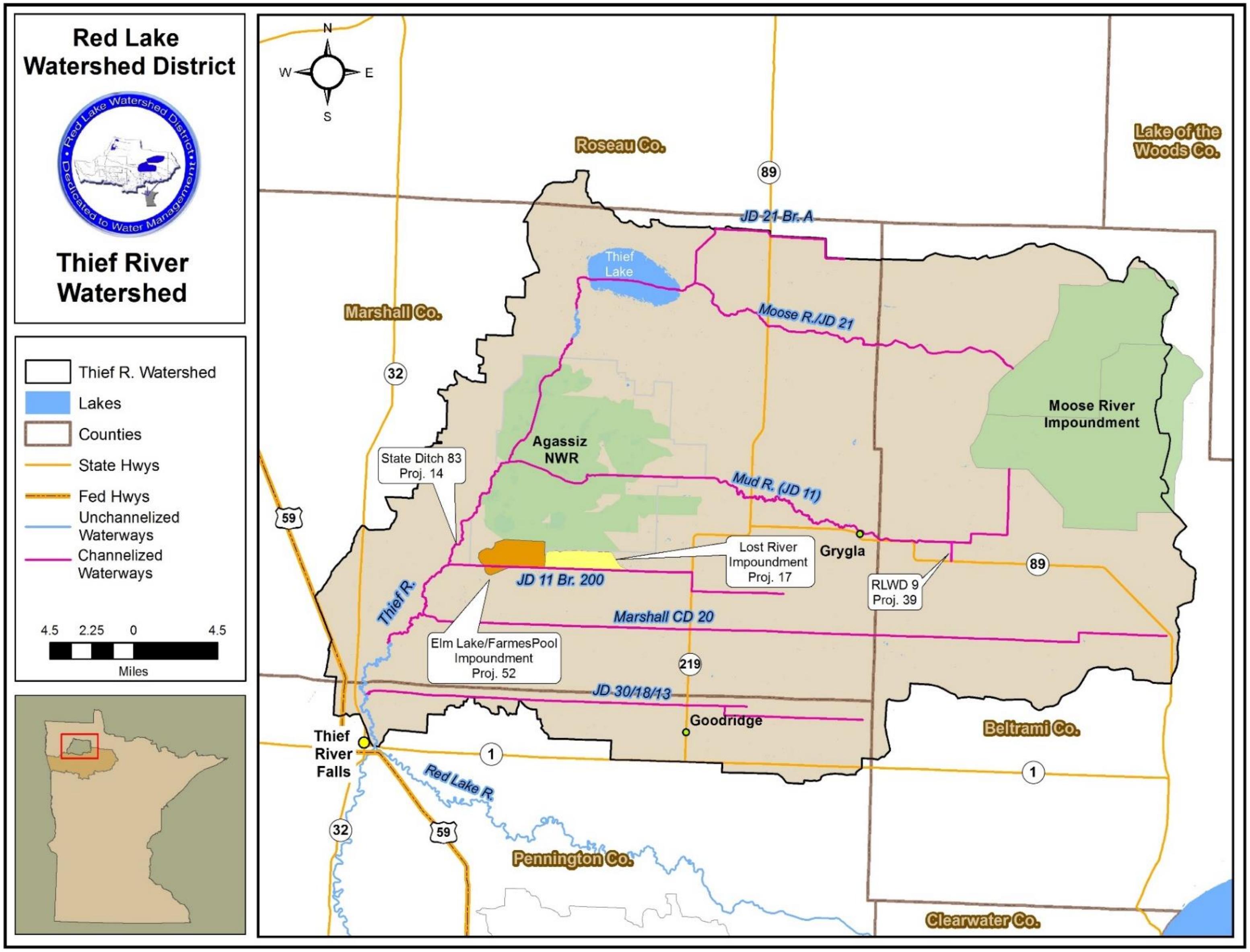


Figure 3-6. Thief River Watershed Impoundments and Major Ditch Systems

3.3 Subwatersheds

The Thief River Watershed (8-digit HUC 09020304) is divided into eight 10-digit HUC subwatersheds. Figure 3-7 is a map of all of the 10-digit HUC watersheds of the Thief River Watershed.

401. Moose River (090203040401)
402. Upper Thief River(090203040402)
403. Mud River (090203040403)
404. Middle Thief River (090203040404) *(Agassiz NWR)*
405. Lost River (090203040405) *(Branch 200 of JD11)*
406. County Ditch 20 (090203040406)
407. Judicial Ditch 18 (090203040407)
408. Lower Thief River (090203040408)

Impairments have been identified in the following 10-digit HUCs:

401. Moose River (090203040401) – shown in Figure 3-8
403. Mud River (090203040403) – shown in Figure 3-10
408. Lower Thief River (090203040408) – shown in Figure 3-9

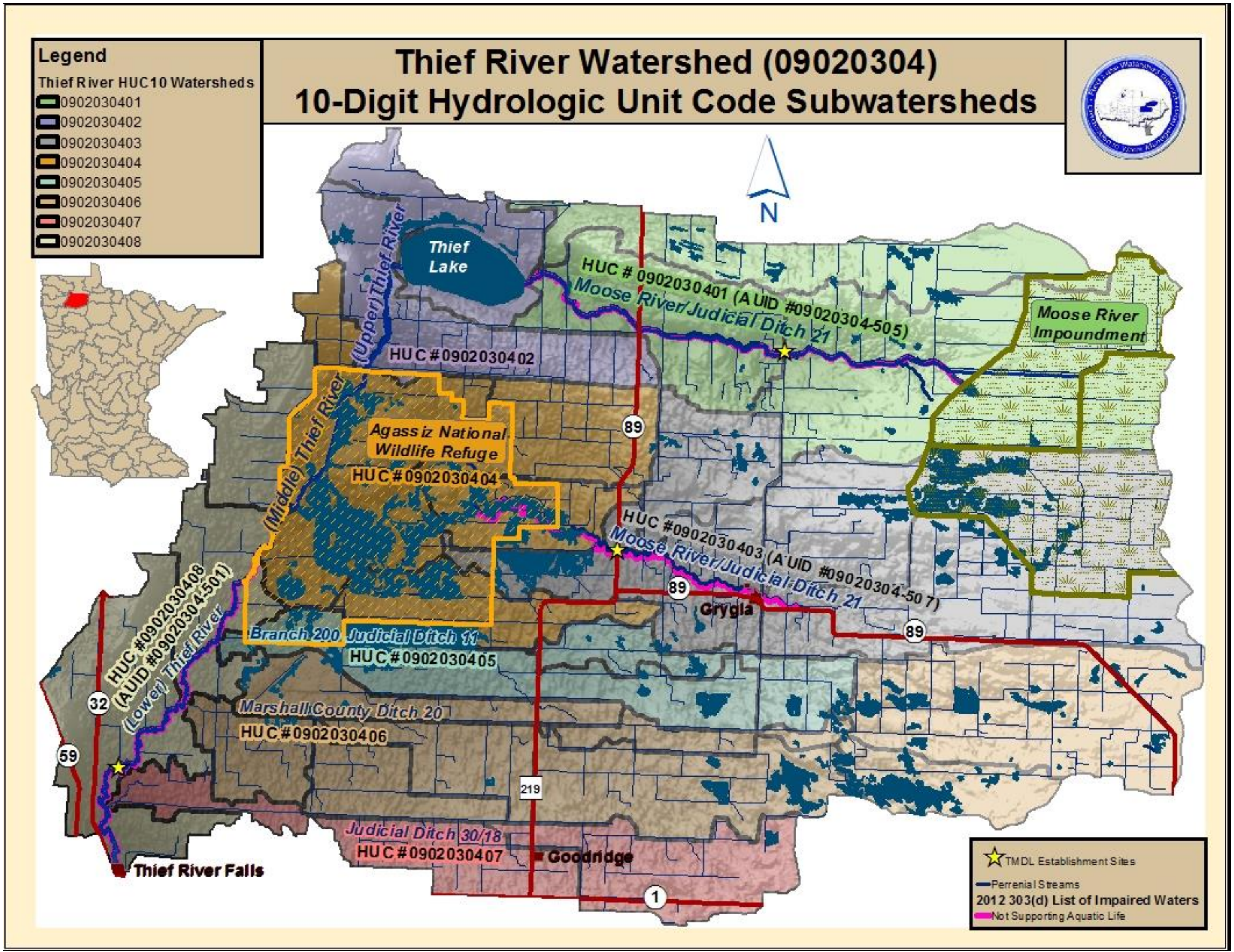


Figure 3-7. 10-digit hydrologic units within the Thief River Watershed

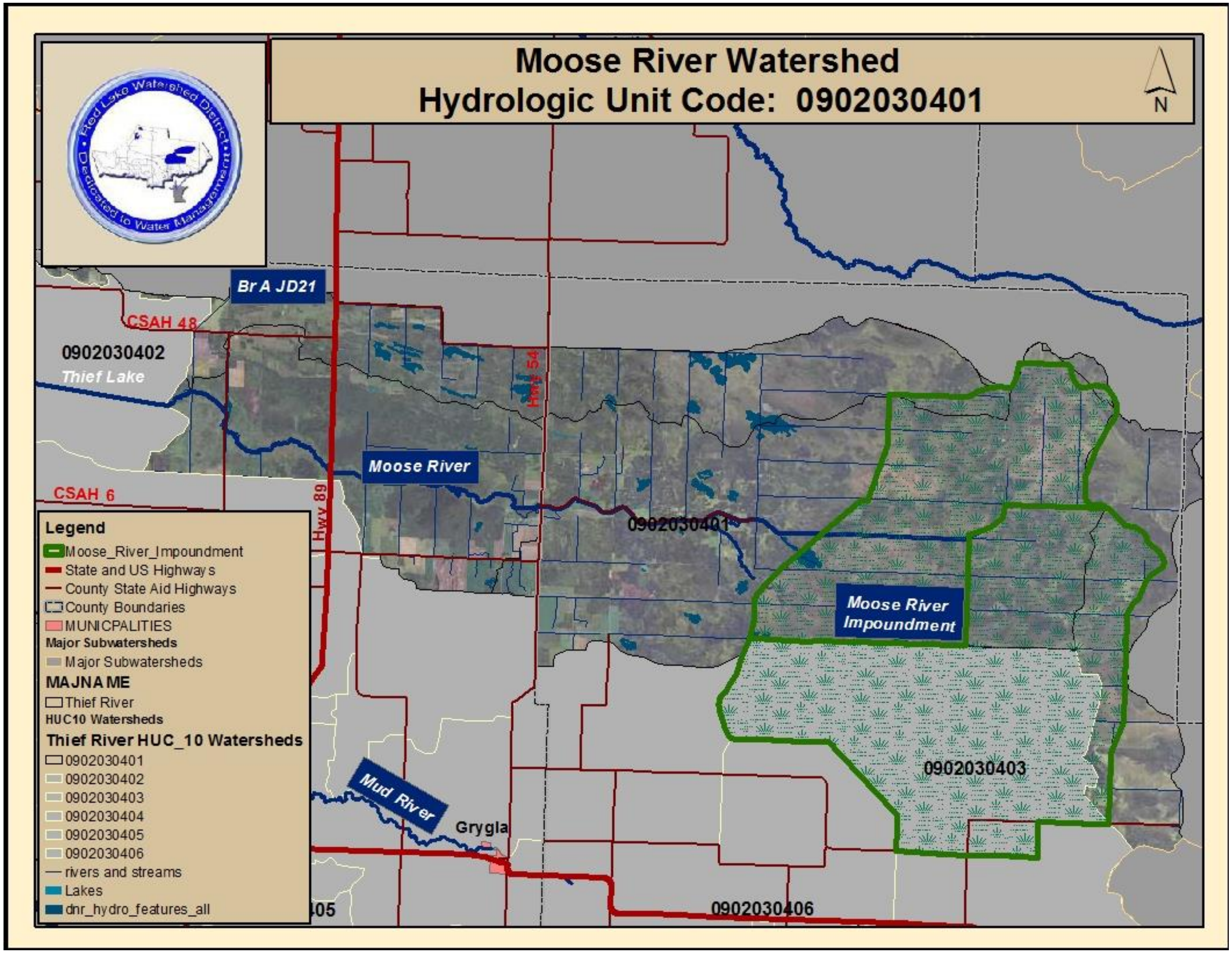


Figure 3-8. Moose River Subwatershed map (HUC #0902030401, AUID #09020304-505)

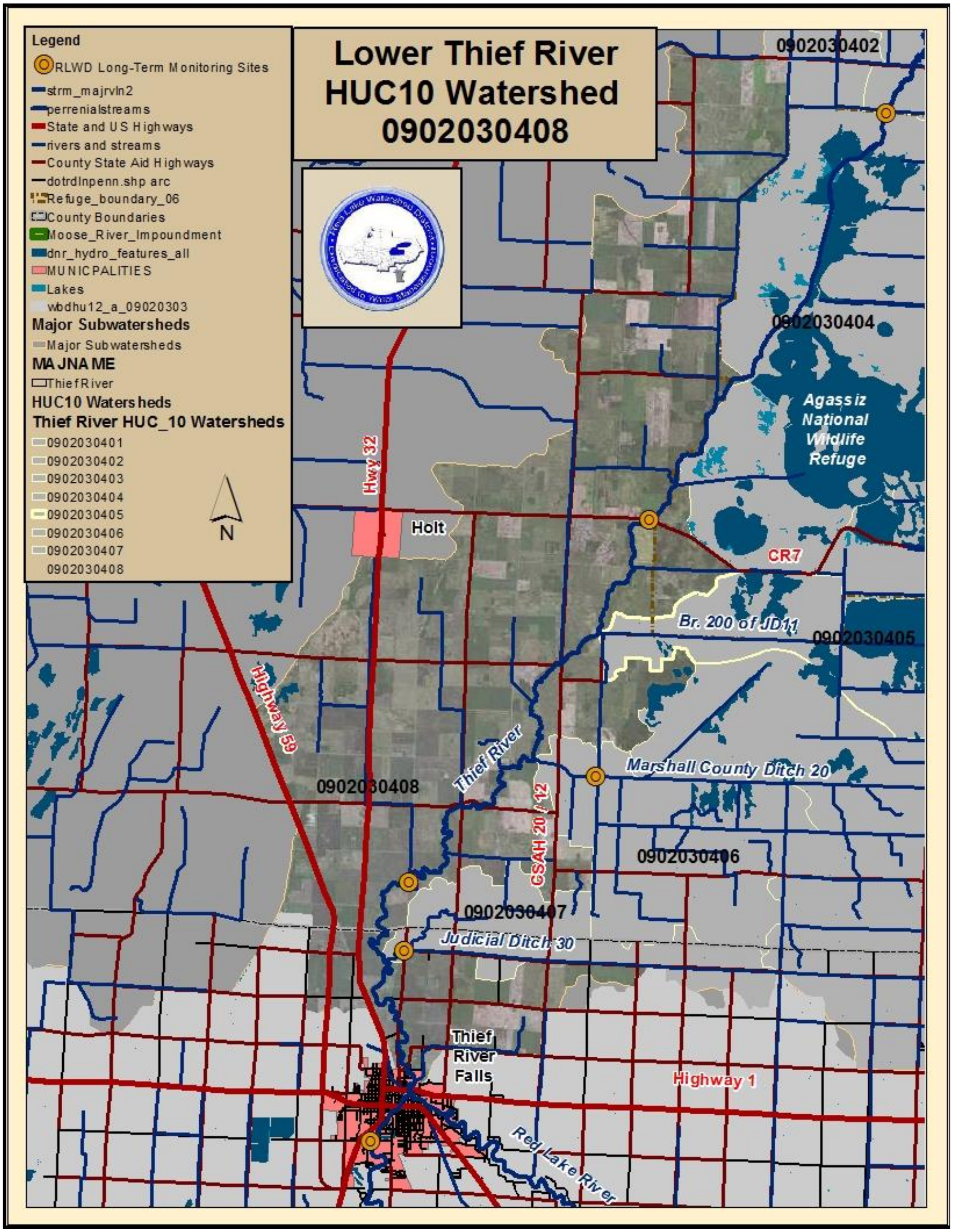


Figure 3-9. Lower Thief River Subwatershed map (0902030408, 09020304-501)

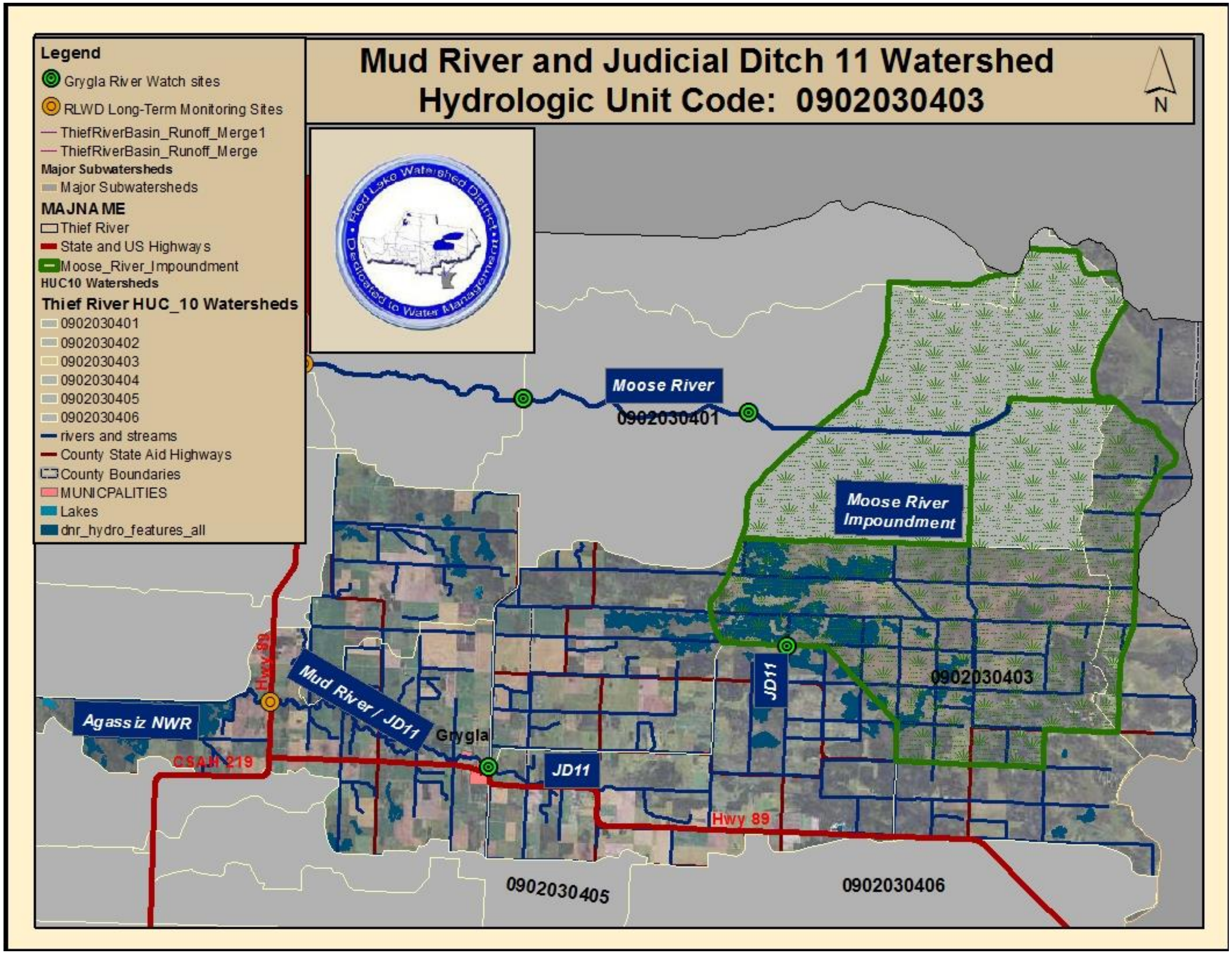


Figure 3-10. Mud River Subwatershed map (0902030403, 09020304-507)

3.4 Land Use

The exact acreages and percentages vary by data source and watershed delineation method, but all land use data (Table 3-3) for the watershed shows that the dominant land uses/covers in the Thief River Watershed are agriculture and wetlands. The largest changes in land use since 2011 are an increase in woody wetlands and a decrease in deciduous forest. Many areas of natural wetlands, grasslands, and forests are in protected status on public lands including refuges, state forests, and WMA s. The distribution of land use types throughout the watershed is shown by Figure 3-11. Smaller-scale maps of the land use within the impaired HUC 10 subwatersheds are shown in Figures 3-12, 3-13, and 3-14.

Table 3-3. Summary of 2001, 2006, and 2011 National Land Cover Database Categories

Thief River Watershed Land Use Summary			
National Land Cover Database Category	**Percent of Watershed 2001**	**Percent of Watershed 2006**	**Percent of Watershed 2011**
Developed, Open Space	2.57%	2.53%	2.57%
Developed, Low Intensity	0.23%	0.23%	0.28%
Developed, Medium Intensity	0.01%	0.01%	0.05%
Developed, High Intensity	0.00%	0.00%	0.00%
Barren Land	0.05%	0.06%	0.06%
Shrub/Scrub	0.25%	0.25%	0.26%
Grassland/Herbaceous	0.72%	0.72%	0.00%
Deciduous Forest	**19.11%**	**5.90%**	**5.97%**
Evergreen Forest	0.55%	0.46%	0.47%
Mixed Forest	0.00%	0.00%	0.00%
Pasture/Hay	7.22%	7.10%	6.87%
Cultivated Crops	**37.01%**	**35.94%**	**36.35%**
Woody Wetlands	3.91%	17.09%	17.06%
Emergent Herbaceous Wetlands	**26.73%**	**28.00%**	**28.36%**
Open Water	1.63%	1.69%	1.69%

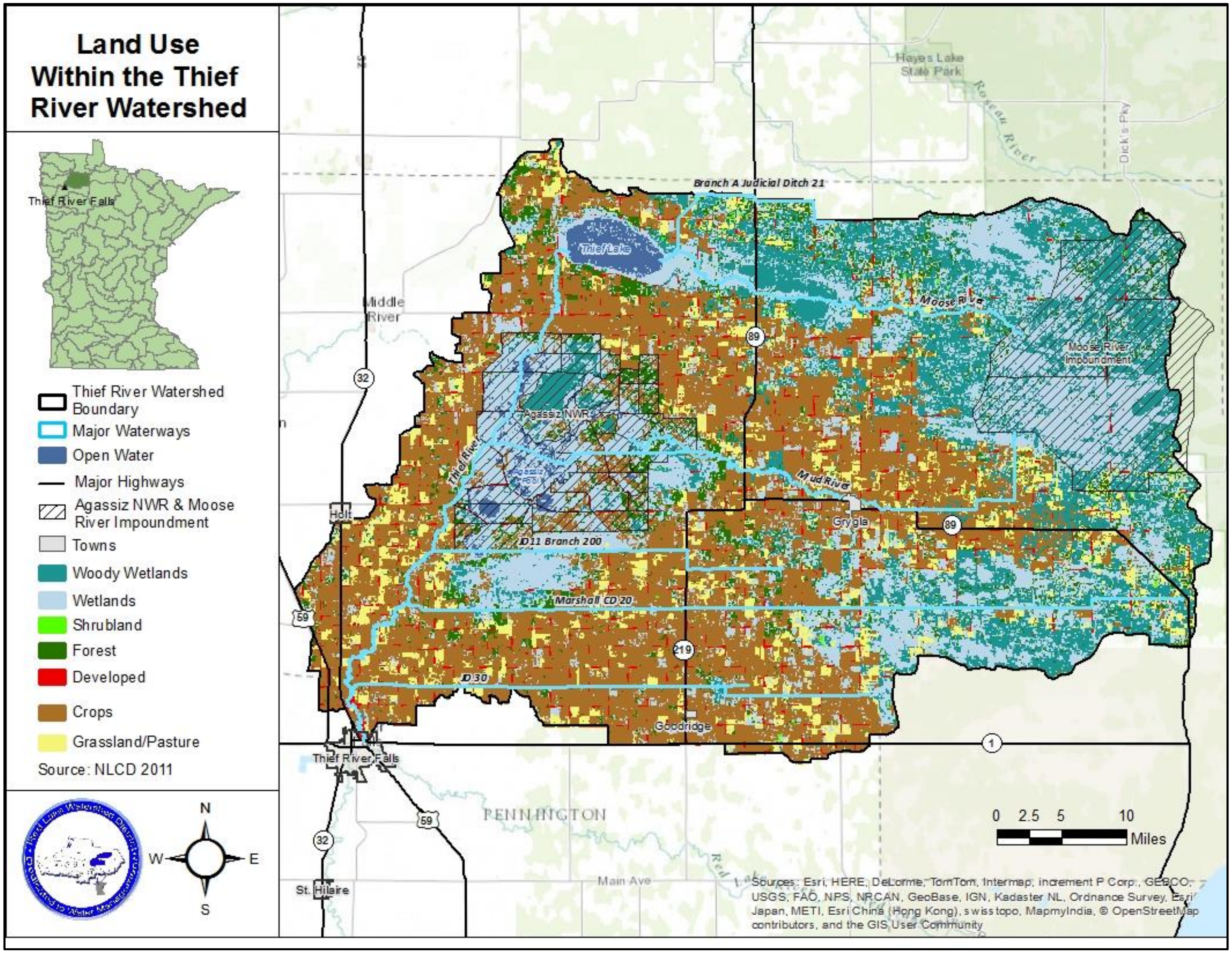


Figure 3-11. Thief River Land Use (2011 National Land Cover Database)

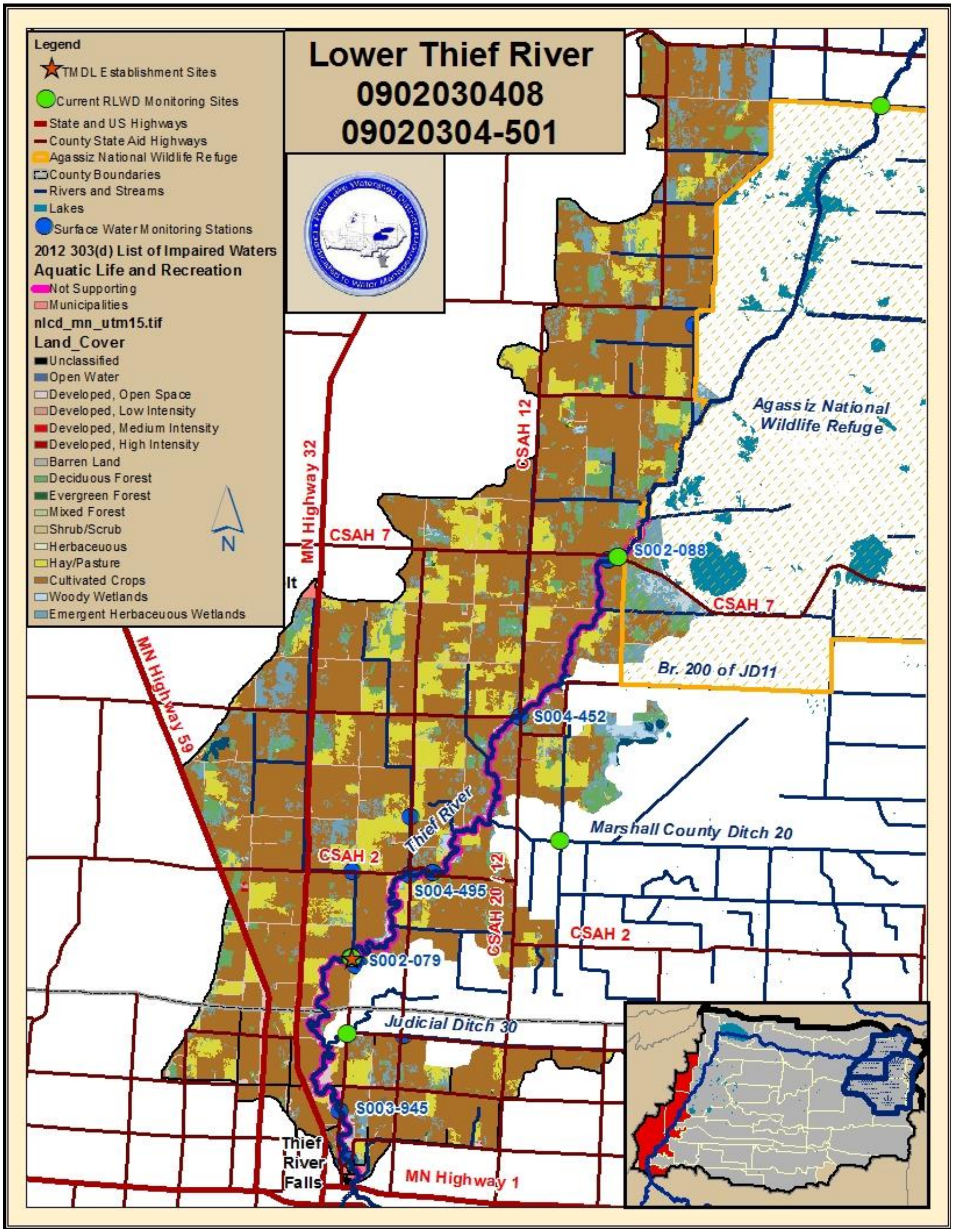


Figure 3-12. Lower Thief River Subwatershed (09020304-501/0902030408) 2011 National Land Cover Database Land Use

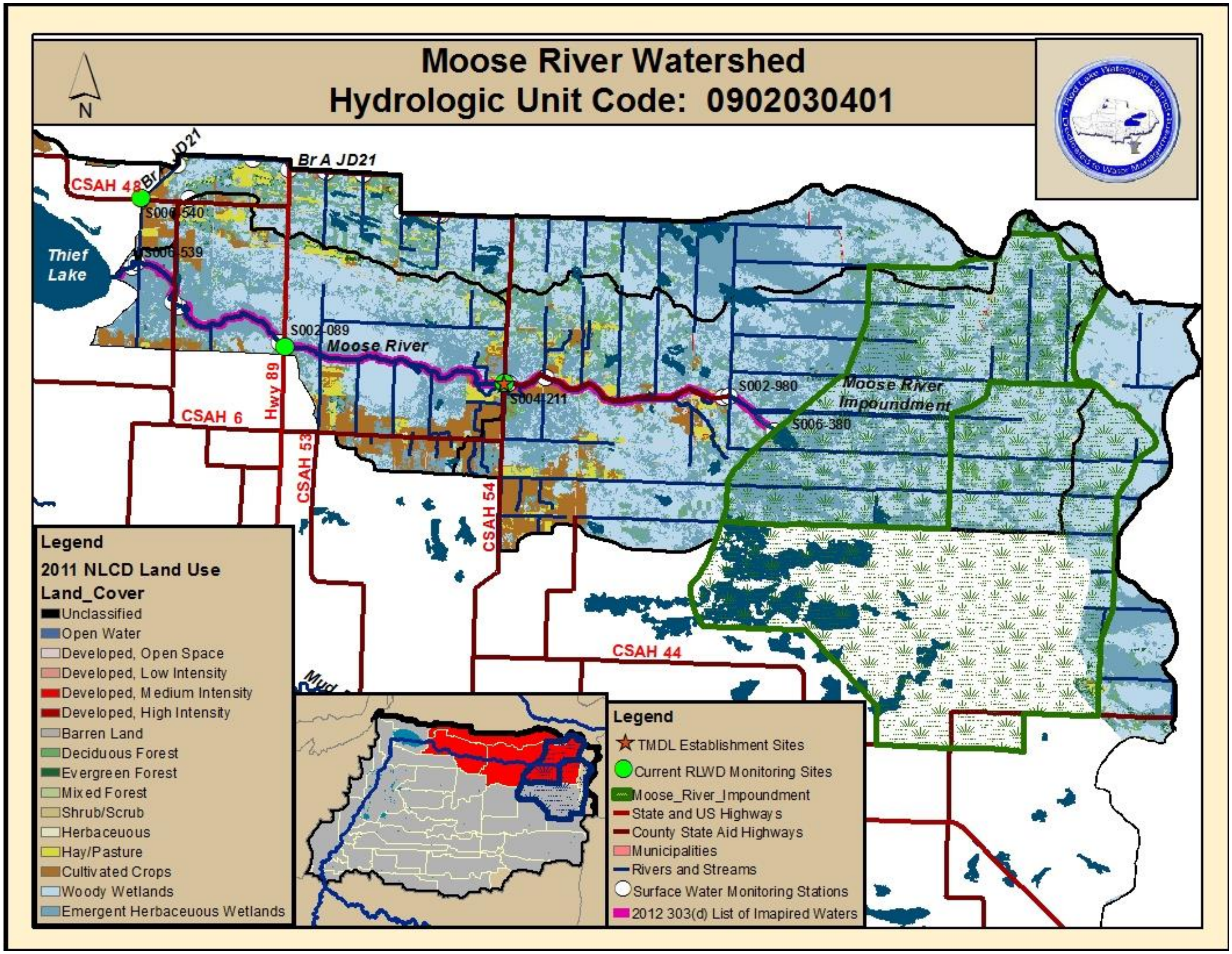


Figure 3-13. Moose River Subwatershed (09020304-505/0902030401) 2011 National Land Cover Database Land Use

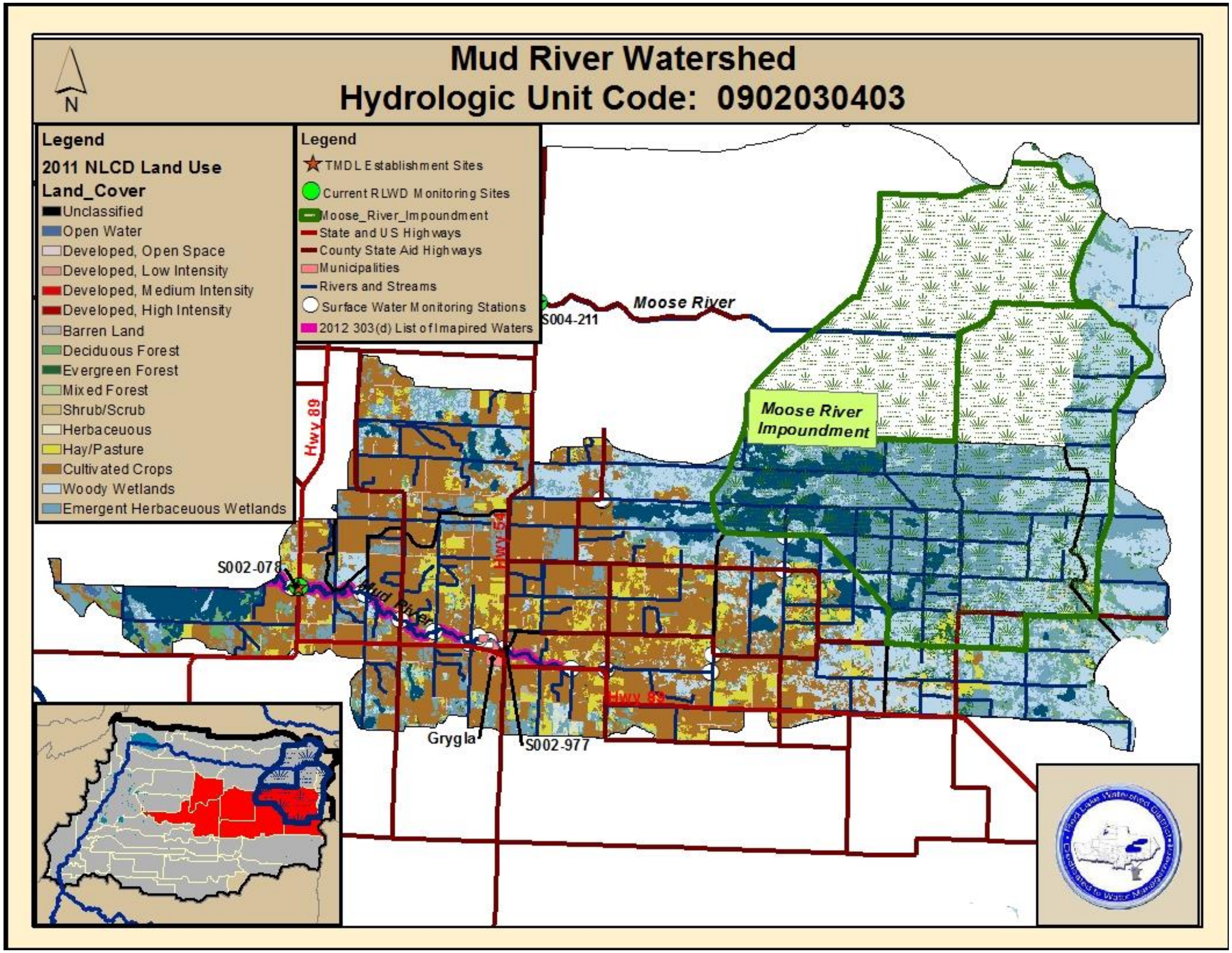


Figure 3-14. Mud River Subwatershed (09020304-507/0902030403) 2011 National Land Cover Database Land Use

3.5 Current/Historic Water Quality

Monitoring Efforts

A substantial amount of water quality data collection has been accomplished in the Thief River Watershed by multiple organizations.

- The Thief River, Moose River, Mud River, Marshall County Ditch 20, and Judicial Ditch 30 are monitored regularly by the RLWD's long-term monitoring program (1980 to present). Field measurements and samples are collected during a minimum of four site visits each year.
- The Grygla River Watch program monitors sites on the Moose River, Mud River/JD11, and Marshall County Ditch 20 on a semi-monthly schedule during the open water season (2002 to present).
- Continuous water quality data has been collected at nine sites, total, for the Thief River Watershed Sediment Investigation and the Thief River WRAPS Project. Multiple years of continuous DO data are available for some sites.
- The United States Fish and Wildlife Service (USFWS) and United States Geological Survey collected continuous water quality data from at least 5 sites in and around Agassiz NWR. Intensive sampling was also conducted at those sites.
- Intensive sampling has been conducted in the watershed for the state's Watershed Pollutant Load Monitoring program (S002-079, S002-088, and S002-078).
- Fieldwork for a geomorphological assessment was conducted in 2011 and 2012.
- Biological sampling was conducted in the watershed in 2011.
- Flow has been monitored at nine strategic sites. Long-term data is available at the 05076000 USGS gage from 1909 through the present. Monitoring began at additional sites in 2007 and continues through the present through the MPCA/DNR Cooperative Stream Gaging network (two sites), RLWD, and USFWS.
- Monitoring took place for the Thief River Watershed Assessment Monitoring SWAG project in 2012 and 2013.
- Visit http://www.rlwdwatersheds.org/tr-docs to download/read reports from previously completed studies in the Thief River Watershed.

Waterbody Assessments

The Thief River Watershed was one of the last watersheds assessed (2013 assessment) prior to the application of the Tiered Aquatic Life Use (TALU) water quality standards. Several ditches were assessed for water quality parameters relating to the protection of aquatic life, but not officially listed as impaired. Table 3-4 summarizes the official results of the assessment.

Some of the waterbodies in the Thief River Watershed are impaired by mercury. However, this TMDL report does not cover toxic pollutants. For more information on mercury impairments see the statewide mercury TMDL at: http://www.pca.state.mn.us/index.php/water/water-types-and-programs/minnesotas-impaired-waters-and-tmdls/tmdl-projects/special-projects/statewide-mercury-tmdl-pollutant-reduction-plan.htmL.

In 2013, 31% of stream miles were assessed for aquatic recreation and 25% of Thief River stream miles were assessed for aquatic life by the MPCA. Factors influencing these low percentages include:

- Channelized reaches were not formally assessed for aquatic life. Water quality problems (DO and turbidity) and low index of biotic integrity scores were identified in some of those reaches, but impairments were deferred until the adoption of TALU standards.
- Approximately 24 miles of stream assessment units in the Thief River Watershed lie within pools and impoundments.
- Monitoring efforts have been focused on sites located near pour points of 10-digit HUCs. Monitoring of upstream segments is typically limited unless problems are discovered at the pour point monitoring sites.
- Several ditch systems were split into numerous assessment units. Monitoring results from primary monitoring sites were only applied to relatively small assessment units in some cases (particularly Marshall County Ditch 20, Judicial Ditch 11, and the Judicial Ditch 30/18/13 drainage system).
- Some of the assessment units are intermittent county road ditches that have not been of interest to local, long-term monitoring programs.

During the 2013 assessment process, conventional water chemistry parameters were still assessed using existing standards, but not made official. Water chemistry data sets for the reaches on the draft 2014 List of Impaired waters were assessed for this report in 2015 by applying existing (*E. coli*, pH, DO, un-ionized ammonia) standards and the newly adopted TSS standard to data collected during the years of 2005 through 2014. The complete assessment, including the watershed's other assessment units, can be found in the Thief River WRAPS.

Table 3-4. Official impairments and recommended delistings that resulted from the 2013 water quality assessment

River/Ditch Name	Assessment Unit ID	Reach Description	2013 Water Quality Assessment Results
Thief River	09020304-501	Agassiz Pool to Red Lake R	Turbidity Impairment
Thief River	09020304-501	Agassiz Pool to Red Lake R	Recommended Delisting for Dissolved Oxygen and *E. coli*
Thief River	09020304-504	Thief Lk to Agassiz Pool	Recommended Delisting of Ammonia and *E. coli* Impairments
Moose River	09020304-505	Headwaters to Thief Lk	Dissolved Oxygen Impairment
Unnamed Ditch (Branch A of JD21)	09020304-555	Unnamed ditch to Moose R	Draft *E. coli* impairment
Mud River	0902304-507	Headwaters to Agassiz Pool	Dissolved Oxygen and Draft *E. coli* Impairments

As shown in Table 3-5, the assessment of 2007-2016 data indicates that the delisted reaches and reaches recommended for delisting (AUID 504 and AUID 555) still meet water quality standards. As a complete unit, the AUID 507 portion of the Mud River meets the *E. coli* standards. However, site-specific analysis shows that the river is failing to meet the *E. coli* standard within the city of Grygla. Therefore, the MPCA decided not to recommend delisting of the Mud River *E. coli* impairment. There is cause for concern about potential future impairments that are based upon biological sampling data. There is cause for concern about TSS concentrations in the Mud River after the exceedance rate is now greater than 10% after the 2016 sampling season.

Table 3-5. Results of an assessment of 2007-2016 Water Quality Data

Assessment of 2007-2016 Thief River Watershed Water Quality Data Impaired and Previously-Impaired Waters									
River/ Stream/ Ditch	**AUID (Last 3 Digits)**	**Reach Description**	**Miles**	**Days With Data**	**Fish IBI (2013 Results)**	**Macro-invertebrate IBI (2013 Results)**	**Total Suspended Solids**	**Dissolved Oxygen**	**E. coli Bacteria**
Thief River	501	Agassiz Pool to Red Lake R	21.96	712	Sup	P	Imp	P	Sup
Thief River	504	Thief Lk to Agassiz Pool	7.9	229	Sup	Sup	Sup	Sup	Sup
Moose River	505	Headwaters to Thief Lk	23.35	184	P	Sup	Sup	Imp	Sup
Mud River	507	Headwaters to Agassiz Pool	20.01	290	Sup	P	P	Imp	Imp
Unnamed Ditch (Branch A of JD21)	555	Unnamed ditch to Moose R	1.7	70	Sup	Sup	Sup	Sup	Sup
Imp	Impaired. The reach is officially listed as impaired for this parameter and 2005-2014 data supports that listing.								
P	Potentially impaired reach in need of Protection efforts. 2005-2014 data provides evidence that the reach is too frequently violating the standard for this specific parameter, but the reach is not currently listed as impaired. It may have been deferred until TALU standard adoption, the standard may have been newly adopted in 2015, water quality conditions may have changed, or good IBI scores may override poor water chemistry data.								
Sup	Supporting. Current data indicates that the reach is meeting the standard for this parameter and supports the respective designated use.								

3.5.1 Turbidity and Total Suspended Solids in the Thief River

The reach of the Thief River that flows from the outlet of Agassiz Pool in Agassiz NWR to the Red Lake River (Figure 3-15) is listed as impaired by high turbidity on the 303(d) List of Impaired Waters. High turbidity levels have been observed during spring runoff, storm events, and during drawdowns of Agassiz Pool. The 2013 State water quality assessment found that turbidity levels still supported the original 2006 listing and “15% of data values collected since exceed the standard.”

Since the reach was originally listed, the state of Minnesota has adopted water quality standards for TSS and has abandoned turbidity-based assessments. The new TSS standard provides a similar level of water quality protection. The Thief River also fails to meet the TSS standard, just as it failed to meet the turbidity standard. Reach-wide and site-specific rates of exceedance are shown in Table 3-6. The extent of the impairment at the 30 mg/l level is not so extreme that there would be no hope for restoration. In AUID 09020304-501, 15% of samples were >30 mg/l in 2007-2016, which is a 3% decrease from the rate (18%) that was calculated from the 2005 through 2014 data.

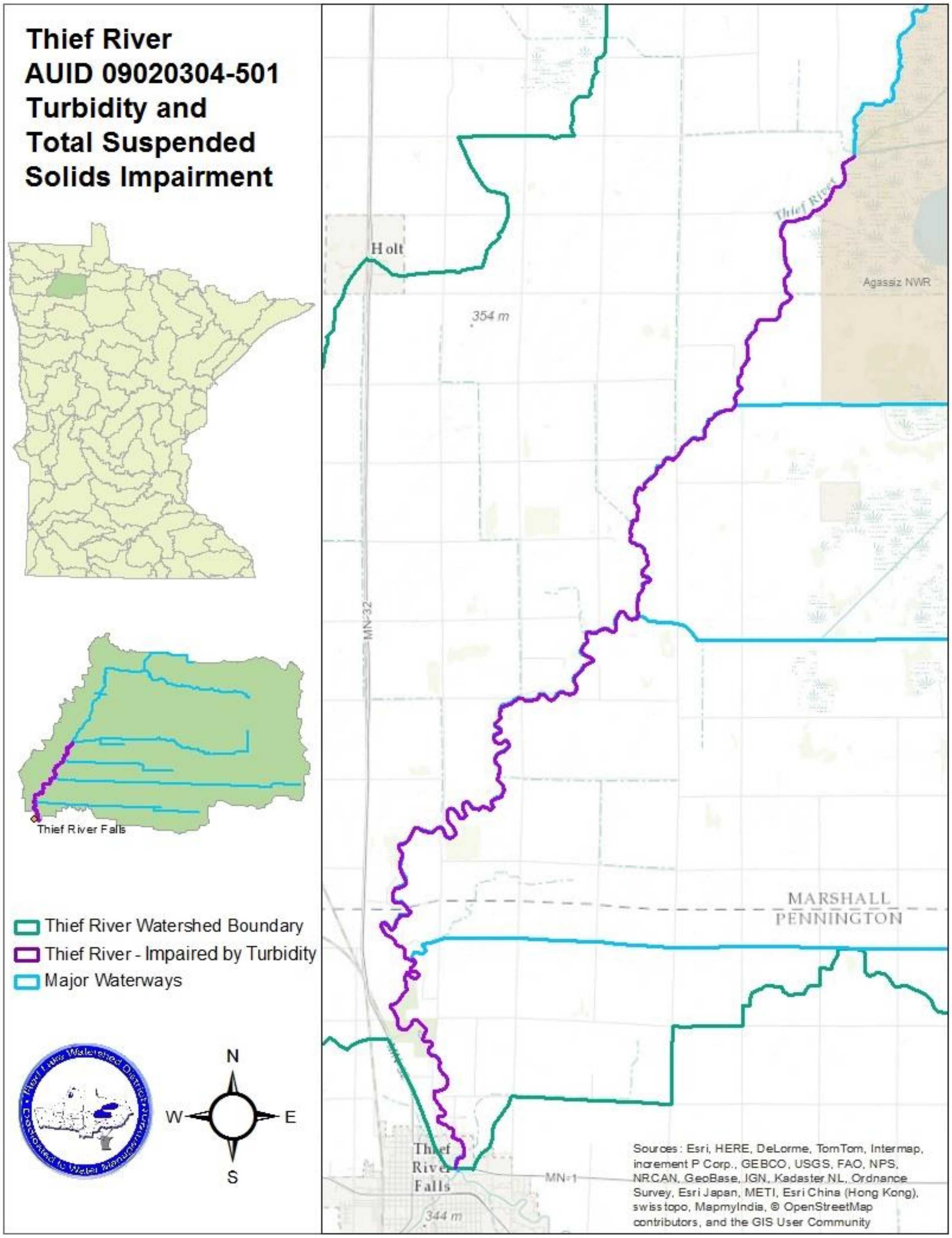


Figure 3-15. Map of the reach of the Thief River that is impaired by turbidity (and TSS).

Table 3-6. Thief River TSS assessment statistics

Lower Thief River (09020304-501) Total Suspended Solids Assessment April - September data from 2007-2016 at sites with >10 Measurements							
	Road	Site ID	n	# of Exceedances	Exceedance Rate	Average	90th Percentile
Upstream ---------------- Downstream		All	354	53	15.0%	20.0	36.0
	County Road 7	S002-088	164	40	24.4%	31.8	60.0
	CSAH 12	S004-052	24	0	0.0%	10.5	19.4
	County Road 44	S004-495	19	0	0.0%	10.5	24.0
	140th Ave NE	S002-079	253	66	26.1%	23.1	48.6
	Dewey Ave	S003-945	48	1	2.1%	12.8	22.6

The new 30 mg/l standard seems to be appropriate for this reach of the Thief River. Data from the turbidity-impaired reach of the Thief River (Agassiz Pool Outlet to the Red Lake River) was analyzed to determine a relationship between turbidity and TSS. The comparison of simultaneously collected TSS and turdbidity measurements in Figure 3-16 shows that the 30 mg/l TSS standard provides a similar level of protection as the turbidity standard once did.

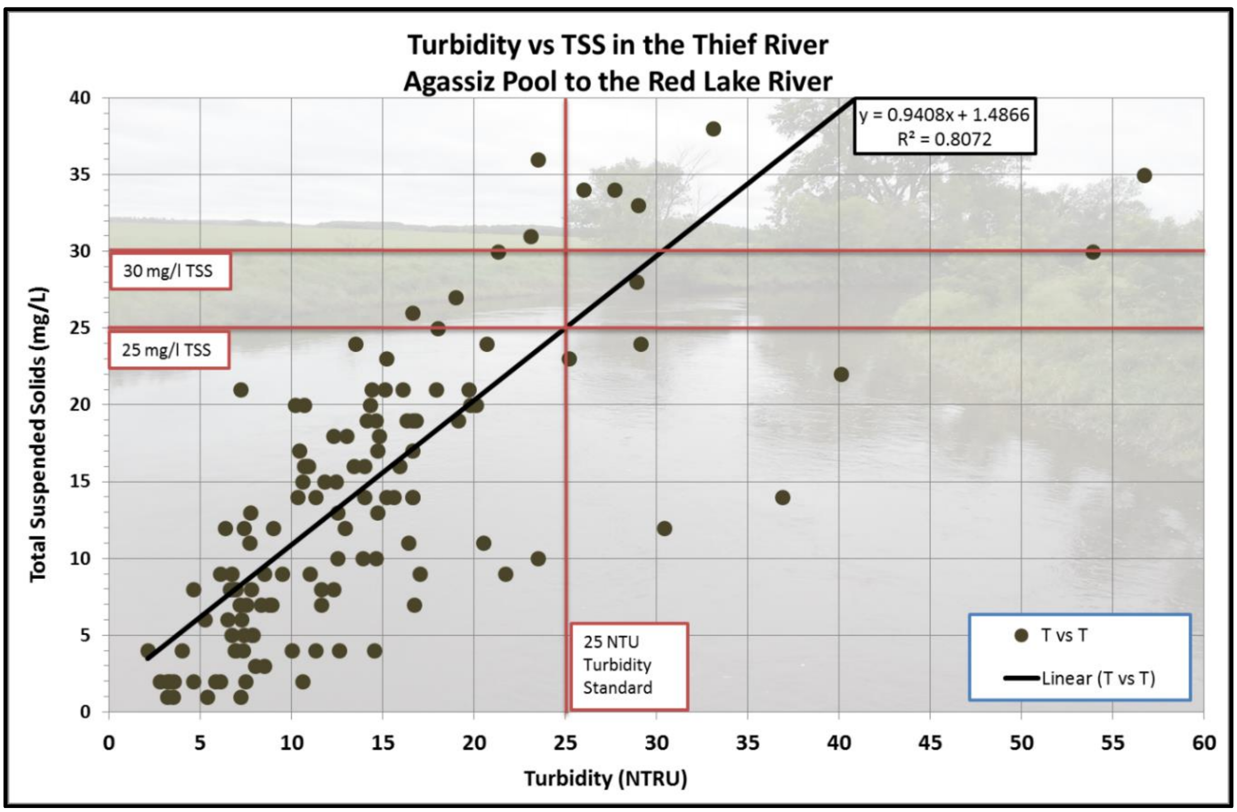


Figure 3-16. Turbidity vs. TSS in the Thief River Watershed.

3.5.2 Dissolved Oxygen in the Mud River

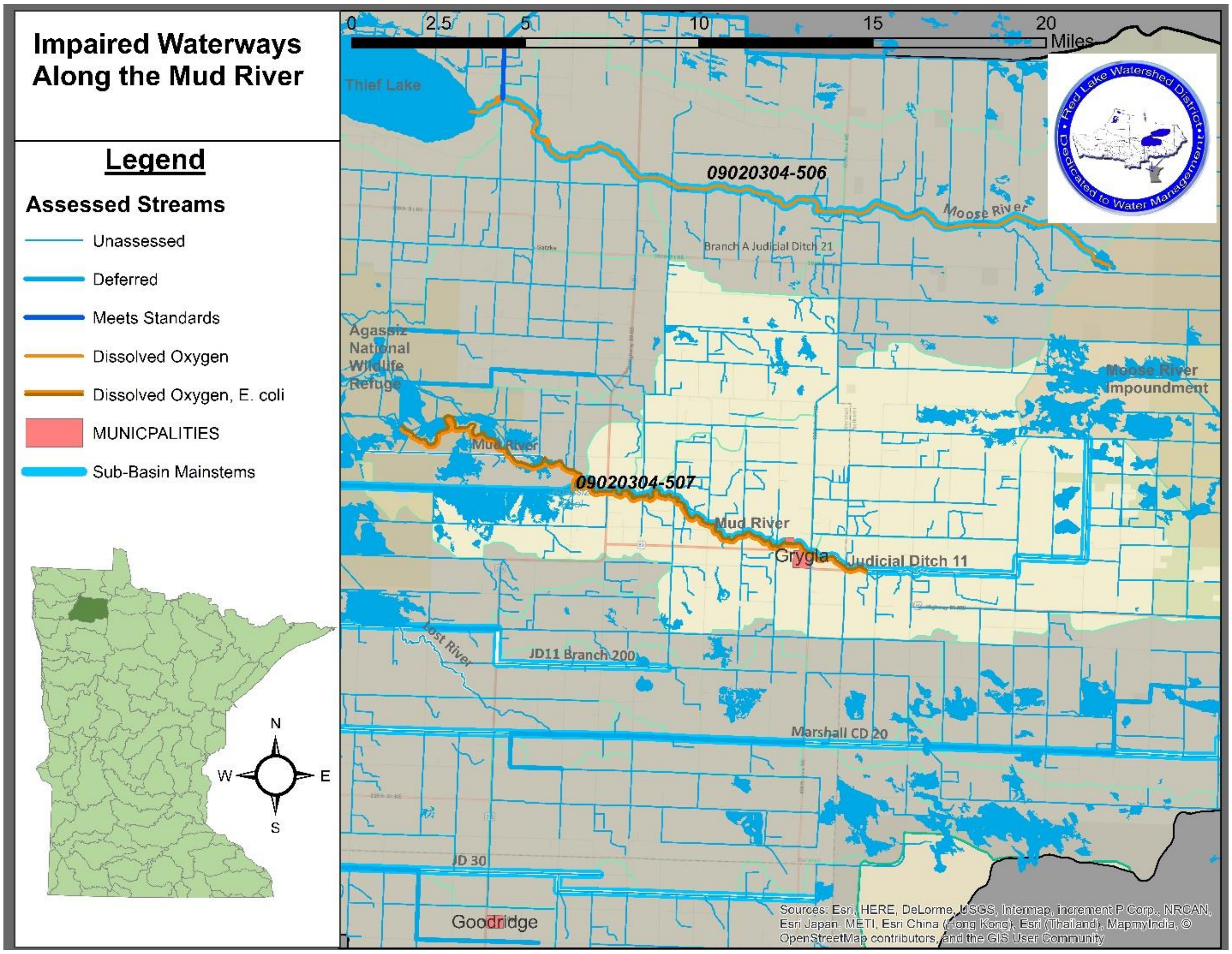


Figure 3-17. Map of the Mud River dissolved oxygen and *E. coli* impairments

The Mud River (Figure 3-17) was first listed as impaired by low DO on the 2008 303(d) List of Impaired Waters, based on data collected from 1997 through 2006. The assessment results improved during the 2009 assessment (1999 through 2008 data), but the reach remained listed as impaired. The river was nearly delisted during the 2013 assessment, but the high frequency of low DO levels recorded by DO loggers in 2012 increased the rate of violation of the standard above the 10% threshold for determination of impairment.

Abnormally low flows in 2012 led to the increased frequency of low DO readings. There were only three or four days in May and June of 2012 with daily minimums below the standard. Beginning in July 2012, conditions became dry, which was very bad for DO levels. The Mud River channel even went dry at one point. That was the only recorded instance in which the Mud River channel had been dry. DO was not measured while the channel was dry, but the conditions in a river that is progressing toward a dry channel are extremely poor for aquatic life. Table 3-8 shows that the discrete data meets the standard, but the continuous DO record contained a higher percentage of low daily minimum DO readings.

A robust monitoring dataset is available for the Mud River. The remote location of the watershed; however, impedes the ability to visit monitoring sites and collect DO data prior to 9 a.m. The scheduling of water quality sampling on any given day in this area is limited by the holding time for *E. coli* samples and the time at which samples are typically delivered to the laboratory by an overnight delivery service.

Sampling typically commences after 11 a.m. to avoid exceeding the *E. coli* holding time. Local volunteer monitoring programs may have the capability of collecting pre-9:00 a.m. data points (no sample collection), but the quantity has been insufficient for an assessment based solely upon pre-9:00 a.m. discrete data. To measure actual daily minimums, local agencies have deployed sondes to record DO at 30-minute intervals in 2007, 2008, 2009, 2012, and 2015. The results of site-specific assessment of 2005 through2014 data are shown in Table 3-7.

Table 3-7. Assessment of 2005-2014 dissolved oxygen levels in the 09020304-507 reach of the Mud River and individual sites with >10 measurements.

Mud River (09020304-507) Assessment of Daily Minimum Dissolved Oxygen Values 2005-2014 data from sites with >10 Measurements								
	Road	**Site ID**	**DO Assessment Method**	**# of Daily Minimums**	**# of Low DO (<5 mg/l)**	**Low DO Rate**	**Average Daily Minimum**	**10th Percentile of Daily**
Upstream ---------------- Downstream	All		DO12_All	227	4	1.8%	9.7	6.9
			DO5_All	164	4	2.4%	9.0	6.6
			DO5_9am	12	0	0.0%	7.9	6.2
			DO5_9am +	16	4	25.0%	6.9	3.8
			C+D_9am	357	79	22.1%	6.4	4.1
	CSAH 54	S002-977	DO12_All	34	1	2.9%	9.3	6.0
			DO5_All	25	1	4.0%	9.1	6.0
			DO5_9am	0	0	IF	IF	IF
			DO5_9am +	1	1	IF	IF	IF
	State Highway 89	S002-078	DO12_All	199	3	1.5%	9.8	7.1
			DO5_All	143	3	2.1%	9.0	6.7
			DO5_9am	12	0	0.0%	7.9	6.2
			DO5_9am +	15	3	20.0%	7.0	3.8
			C+D_9am	357	79	22.1%	6.4	4.1

DO12 = All discrete dissolved oxygen measurements from all 12 months of January through December

DO5 = Dissolved oxygen over the 5 summer months of May through September (% <5 mg/l)

DO5 9am = Dissolved oxygen measurements collected during the months of May through September prior to 9am

DO5 9am + = Dissolved oxygen measurements collected during the months of May through September prior to 9am **plus** any low readings observed during those months (daily minimum would definitely fall below 5 mg/l if any measurement during the day is <5 mg/l).

C+D_9am = An assessment all **c**ontinuous monitoring data points from May through September that were recorded prior to 9 am and all **d**iscrete data points used for the DO5_9am assessment. The two datasets overlap on days in which both discrete and continuous measurements were recorded.

IF = Insufficient data for a water quality assessment

The influence of the 2012 data upon the assessment results was tested by leaving the 2012 data out of the assessment. Table 3-8 shows that removing the 2012 monitoring data would significantly lower the percentage of days in which DO levels were lower than 5 mg/l. The frequency of low DO readings drops to an acceptable level in nearly every subset of the data. Comparing the following table to the preceding table (Table 3-7) shows that nearly 85% of the low DO levels recorded in 2005 through 2014 occurred within one year, in 2012.

Table 3-8. An assessment of 2005-2014 Mud River dissolved oxygen data without data from the dry year of 2012.

Mud River (09020304-507) Assessment of Daily Minimum Dissolved Oxygen Values
2005-2011 and 2013-2014 data (Nothing from 2012) from sites with >10 Measurements

	Road	Site ID	DO Assessment Method	# of Daily Minimums	# of Low DO (<5 mg/l)	Low DO Rate	Average Daily Minimum	10th Percentile of Daily Minimums
Upstream ---------------- Downstream	All		DO12_All	199	4	2.0%	9.5	7.0
			DO5_All	146	4	2.7%	8.8	6.6
			DO5_9am	12	0	0.0%	7.9	6.2
			DO5_9am +	6	4	IF	IF	IF
			C+D_9am	235	12	5.1%	7.1	5.8
	CSAH 54	S002-977	DO12_All	29	1	3.4%	9.0	6.3
			DO5_All	23	1	4.3%	8.7	5.9
			DO5_9am	0	0	IF	IF	IF
			DO5_9am +	1	0	IF	IF	IF
	State Highway 89	S002-078	DO12_All	174	3	1.7%	9.6	7.0
			DO5_All	126	3	2.4%	8.9	6.7
			DO5_9am	12	0	0.0%	7.9	6.2
			DO5_9am +	15	3	20.0%	7.0	3.8
			C+D_9am	235	12	5.1%	7.1	5.8

DO12 = All discrete dissolved oxygen measurements from all 12 months of January through December

DO5 = Dissolved oxygen over the 5 summer months of May through September (% <5 mg/l)

DO5 9am = Dissolved oxygen measurements collected during the months of May through September prior to 9am

DO5 9am + = Dissolved oxygen measurements collected during the months of May through September prior to 9am **plus** any low readings observed during those months (daily minimum would definitely fall below 5 mg/l if any measurement during the day is <5 mg/l).

C+D_9am = An assessment all **c**ontinuous monitoring data points from May through September that were recorded prior to 9 am and all **d**iscrete data points used for the DO5_9am assessment. The two datasets overlap on days in which both discrete and continuous measurements were recorded.

IF = Insufficient data for a water quality assessment

Continuous DO data was collected in 2015 by the RLWD as part of a separate effort to investigate the conditions that have led to periodic blue-green algae blooms in the Mud River in Grygla. All the 2015 DO readings during site visits were good. However, assessment results did not change significantly because there were too many days with daily minimums that dropped below 5 mg/l. The continuous & discrete pre-9 a.m. assessment for the entire reach was improved slightly (approximately one percentage point), but the complete dataset still indicates an impairment due to low DO.

The MPCA biological monitoring staff sampled fish and macroinvertebrates in the 09020304-507 reach of the Mud River ("Headwaters to Agassiz Pool") prior to the 2013 assessment. The reach was not officially assessed due to channelization, but results were reported in the Thief River Watershed Monitoring and Assessment Report. Fish IBI scores on this reach fair to good. Macroinvertebrate scores ranged from poor to fair. The reach will be assessed for aquatic life during the 2023 assessment because TALU standards have now been adopted by the state.

3.5.3 *E. coli* in the Mud River

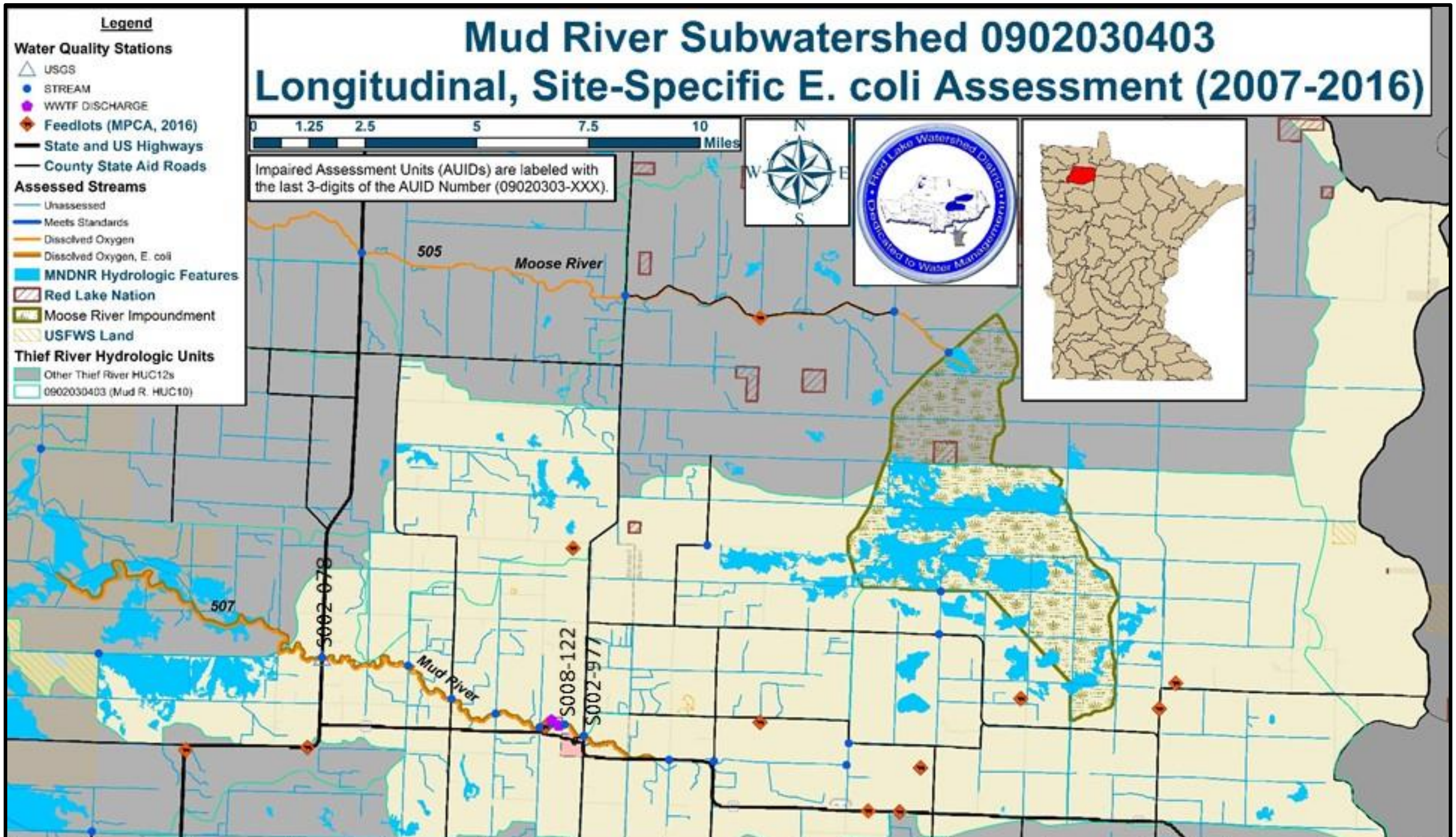
Bacteria sampling has been conducted in the Mud River since 1990. The frequency of sampling increased significantly in 2001. Fecal coliform samples were collected from 1990 through 2007. *E. coli* samples have been collected from 2005 through the present. Sufficient data for a full *E. coli* assessment of summer months wasn't accumulated until after the 2009 monitoring season. The watershed was assessed in 2013. During the 2013 assessment (2003 through 2012 data), the Mud River reach number 09020304-507 (as shown in Figure 3-17) was found to be exceeding the 126 MPN/100ml standard for monthly geometric mean

E. coli concentrations during the months of July and October. Results of the MPCA's data assessment are found in the Stream Assessment Transparency Documentation for the 2013 assessment year: "July just exceeded the standard with 128 MPN/100ml and October was well above the standard with 179 MPN/100ml." "Individual exceedances were less than 10% with a maximum observation of 2420 MPN/100ml recorded on three separate occasions."

Table 3-9. History of reach-wide assessment statistics of the Mud River AUID 09020304-507. Formal assessments were conducted in 2007, 2009, and 2013.

History of Mud River *E. coli* Monthly Geometric Means							
Monthly E. coli Geomean 2007-16 Data	Monthly E. coli Geomean 2006-15 Data	Monthly E. coli Geomean 2005-14 Data	Monthly E. coli Geomean 2005-13 Data	Monthly E. coli Geomean 2005-12 Data	Monthly E. coli Geomean 2005-11 Data	Monthly E. coli Geomean 2005-10 Data	Monthly E. coli Geomean 2005-09 Data
14.6	14.6	16.9	16.9	16.9	17.5	14.3	
29.1	27.1	27.7	27.7	25.4	24.0	29.2	29.2
86.0	86.6	91.7	91.6	91.6	100.9	86.5	82.9
115.39	**115.37**	**116.4**	**125.6**	**128.7**	**167.8**	102.8	102.8
101.5	87.1	78.3	78.3	82.8	109.9	101.7	105.2
67.0	64.9	42.6	42.6	40.6	40.6	38.8	38.8
93.8	**86.7**	**101.3**	**101.3**	**126.2**	**179.0**	**239.9**	**394.7**

Mud River *E. coli* from 2005 through 2014 was assessed during the Thief River WRAPS process. The monthly *E. coli* geometric means for this reach had dropped far enough for the reach to meet the *E. coli* water quality standard. Table 3-9 shows how monthly geomeans have changed over time along the 09020304-507 AUID. The official 2013 assessment used data from 2005 through 2012. The October and July geometric means decreased after 2013 sampling (125.6 for July and 101.3 for October) and then again after 2014 sampling (116 for July and 101 for October). The geomeans were even lower at the S002-078 (Highway 89) water quality station that was primary long-term monitoring site, a flow monitoring site, and the most likely target location for TMDL calculations. The reach was recommended for delisting. During the delisting process, a site-specific impairment was found at sampling sites near Grygla (S002-977 and S008-122). Intensive sampling of the Mud River at Grygla began in 2015 in response to a blue-green algae problem. The data from those two years, along with a few earlier samples from other investigative and longitudinal sampling efforts, met minimal data requirements. The data from S002-977 and S008-122 revealed that August (275 MPN/100ml) and September (244 MPN/100ml) exceeded the 126 MPN/100ml *E. coli* standard. The downstream, primary long-term water quality and flow monitoring site (S002-078) still met the standard. So, the TMDL was written for the CSAH 54 crossing (S002-977) in Grygla. Figure 3-18 shows the difference in monthly *E. coli* geomeans between the Highway 89 crossing and the Grygla sites.



Site ID:	S002-078	S008-123	S008-139	S008-132	S004-212	S008-122	S002-977	S008-140	S008-124	S008-133	S008-141	S002-090	S002-978
AUID (09020305-XXX)	507	507	507	507	507	507	507	526	526	526	525	522	521
Street/Road:	Hwy 89	360th Ave NE	CSAH 53 (370th Ave)	380th Ave NE	CSAH 10	Grygla City Park	CSAH 54	Dylan Rd NW	Flintlock Rd NW	Gunpowder Rd NW	Outpost Rd NW	CSAH 44	Moose R. Imp. Outlet
May Geomean:	29.1	IF	IF	IF	IF	IF	IF	IF	IF	IF	IF	IF	IF
June Geomean:	89.2	IF	IF	IF	IF	IF	IF	IF	IF	IF	IF	IF	IF
July Geomean:	111.4	IF	IF	IF	IF	IF	IF	IF	IF	IF	IF	IF	IF
August Geomean:	57.1	IF	IF	IF	IF	183.0	271.4	IF	IF	IF	IF	IF	IF
September Geomean:	36.1	IF	IF	IF	IF	141.8	421.5	IF	IF	IF	IF	IF	IF
Total # of May-September Days with Samples:	68	1	1	1	6	16	16	2	2	2	1	2	2

IF = <5 samples

Figure 3-18. Mud River longitudinal, site-specific *E. coli* assessment statistics for 2007-2016 data

3.5.4 Dissolved Oxygen in the Moose River

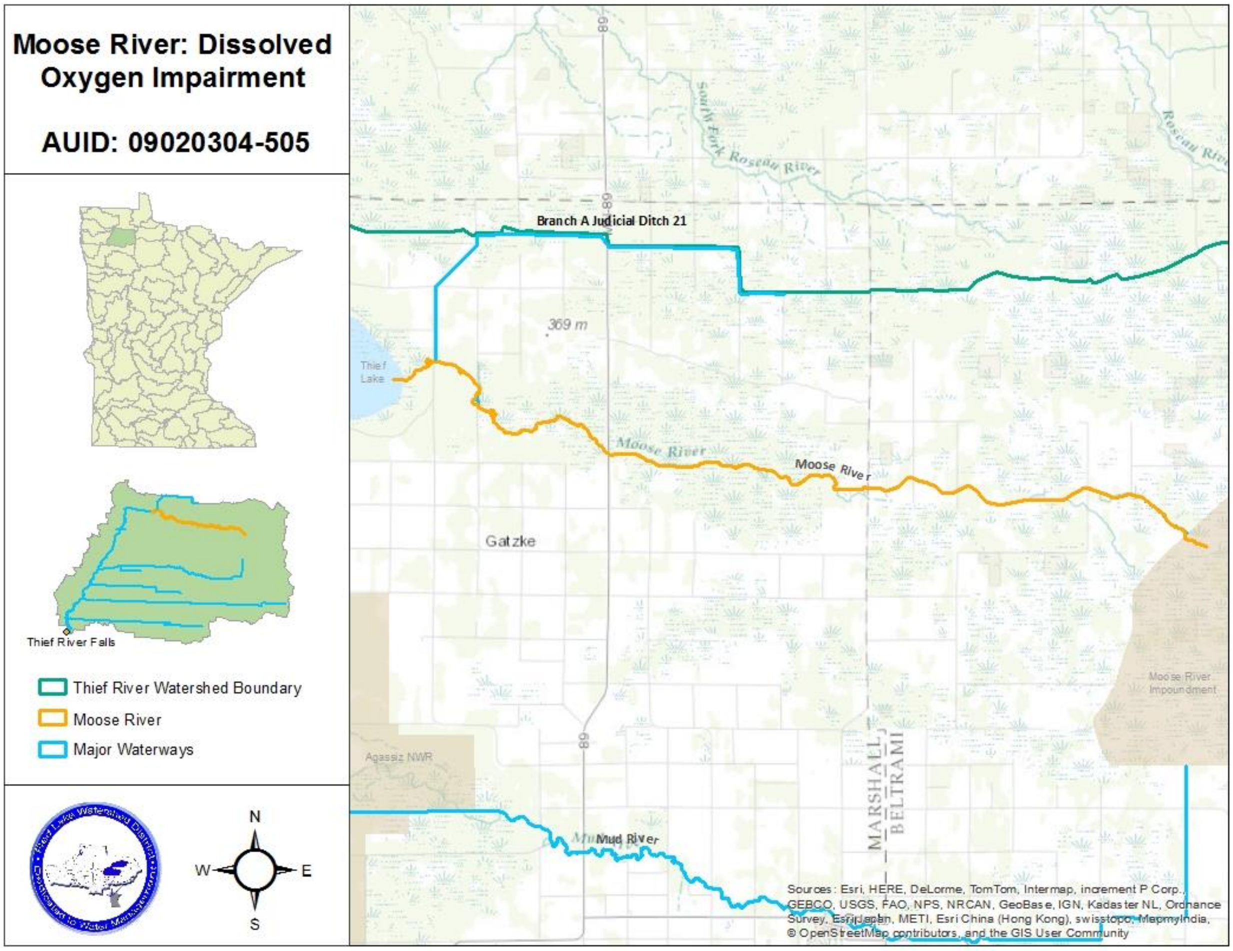


Figure 3-19. Map of the Moose River dissolved oxygen impairment

The Moose River (Figure 3-19) has been monitored at the Highway 89 crossing (S002-089) since 1984. Additional sites have been monitored in recent years. CSAH 54 (S004-211) is the furthest downstream free-flowing crossing for which a flow rating curve has been developed. The earliest data available from that site was collected by the Marshall County Water Planner in 2001. The 2013 Stream Assessment Transparency Documentation noted that current DO results indicate an improvement since the 2006 impairment listing. However, pre-9 a.m. discrete DO data was insufficient (only eight days with measurements prior to 9 a.m.) to fully determine whether supporting conditions are presently occurring. The MPCA recommended maintaining the previous low DO impairment listing. Only 7.5% of all DO measurements from the Moose River were below 5 mg/l. The percentage was also lower than the impairment threshold when the summer months of May through September were examined (9.1%). Forty measurements were collected during colder weather months (October through April) and only one of those measurements collected from 2003 through 2012 was less than 5 mg/l. Stagnant water during the low flows of 2012 may have contributed to the high frequency of low DO concentrations. 2012 deployments of DO loggers yielded higher rates of low DO levels than what has been found in the discrete record and previous DO logger deployments. An updated (2005 through 2014 data) assessment of current DO concentrations in the Moose River is detailed in Table 3-10.

Table 3-10. Site-by-Site Moose River Dissolved Oxygen Assessment

Moose River (09020304-505) Assessment of Daily Minimum Dissolved Oxygen Values 2005-2014 data from sites with >10 Measurements								
	Road	**Site ID**	**DO Assessment Method**	**# of Daily Minimums**	**# of Low DO (<5 mg/l)**	**Low DO Rate**	**Average Daily Minimum**	**10th Percentile of Daily Minimums**
Upstream ↑ ---------------- Downstream ↓	All		DO12_All	145	14	9.7%	8.2	5.1
			DO5_All	111	13	11.7%	7.5	4.8
			DO5_9am	2	0	IF	IF	IF
			DO5_9am +	15	13	86.7%	4.3	1.8
			C+D_9am	144	85	59.0%	4.7	2.1
	All Minus S006-539		DO12_All	132	10	7.6%	8.5	5.3
			DO5_All	98	9	9.2%	7.9	5.2
			DO5_9am	2	0	IF	IF	IF
			DO5_9am +	11	9	81.8%	4.5	2.1
			C+D_9am	144	85	59.0%	4.7	2.1
	All Minus S006-539 and continuous data from S002-980		C+D_9am	141	64	45.4%	5.1	2.1
	Moose River Impoundment Outlet	S006-380	DO12_All	13	0	0.0%	9.1	7.9
			DO5_All	10	0	0.0%	8.8	7.7
			DO5_9am	0	0	IF	IF	IF
			DO5_9am +	0	0	IF	IF	IF
	Moose River Rd NW	S002-980	DO12_All	42	0	0.0%	8.9	6.1
			DO5_All	31	0	0.0%	8.2	6.0
			DO5_9am	0	0	IF	IF	IF
			DO5_9am +	0	0	IF	IF	IF
	County State Aid Highway 54	S004-211	DO12_All	84	2	2.4%	10.0	7.1
			DO5_All	64	2	3.1%	9.5	6.9
			DO5_9am	2	0	IF	IF	IF
			DO5_9am +	4	2	IF	IF	IF
			C+D_9am	141	64	45.4%	5.2	2.2
	State Highway 89	S002-089	DO12_All	56	6	10.7%	7.7	5.0
			DO5_All	37	5	13.5%	6.6	4.7
			DO5_9am	0	0	IF	IF	IF
			DO5_9am +	5	5	IF	IF	IF
	300th Ave NE	S006-539	DO12_All	19	5	26.3%	6.0	4.4
			DO5_All	19	5	26.3%	6.0	4.4
			DO5_9am	0	0	IF	IF	IF
			DO5_9am +	5	5	IF	IF	IF

DO12 = All discrete dissolved oxygen measurements from all 12 months of January through December

DO5 = Dissolved oxygen over the 5 summer months of May through September (% <5 mg/l)

DO5 9am = Dissolved oxygen measurements collected during the months of May through September prior to 9am

DO5 9am + = Dissolved oxygen measurements collected during the months of May through September prior to 9am **plus** any low readings observed during those months (daily minimum would definitely fall below 5 mg/l if any measurement during the day is <5 mg/l).

C+D_9am = An assessment all **c**ontinuous monitoring data points from May through September that were recorded prior to 9 am and all **d**iscrete data points used for the DO5_9am assessment. The two datasets overlap on days in which both discrete and continuous measurements were recorded.

IF = Insufficient data for a water quality assessment. Only sites with 10 or more days of data wre assessed individually.

DO levels are generally better at the upper, free-flowing sites (Highway 54, S004-211) than they are at sites in the lower portion of the river (Highway 89, S002-089), where flows are affected by backwater from Thief Lake (Figure 3-20). Trend analysis in the Thief River WRAPS shows that water quality has been improving in the Moose River (Table 3-11).

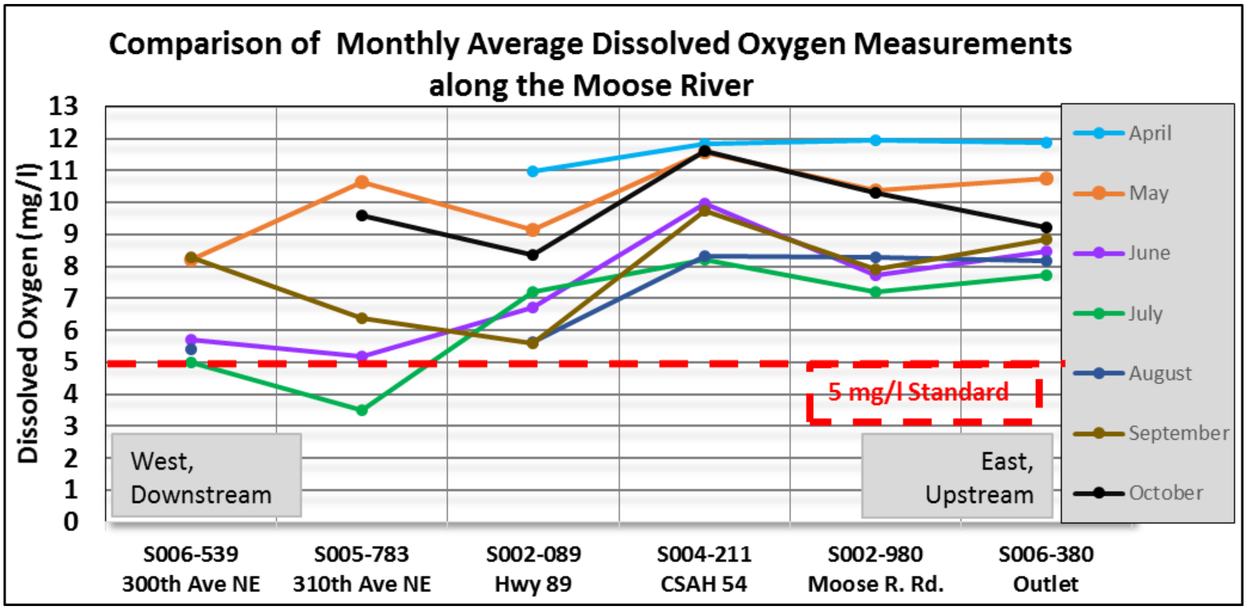


Figure 3-20. Longitudinal chart of monthly average dissolved oxygen levels recorded at sites along the Moose River

Table 3-11. Water quality trends in the Moose River

Trends of Seasonal Averages Using Seasonal Mann-Kendall Analysis				
Moose River Highway 89 Crossing Site S002-089	Total Suspended Solids	Dissolved Oxygen	Total Phosphorus	E. coli
Years	1998-2014	1984-2014	1984-2014	2005-2014
Annual Average	↓	↑ +	↓	↓
April	X	X	↓	X
May	X	X	↓	X
June	↓ -	↑	X	X
July	↓ -	↑	↓	X
August	↓	↑	X	X
September	X	X	↓	X
October	↓ -	X	↓	↓
November - March	X	X	X	No data
X = No Trend				
↑ = Upward Trend (Getting Better)				
↓ = Downward Trend (Improvement)				
↑ + = Strong Upward Trend (Getting Significantly Better)				
↓ - = Strong Downward Trend (Significant Improvement)				

3.6 Pollutant Source Summary

Because of the attention that the watershed has received in recent years, multiple resources detail water quality conditions, known sources of water quality problems, potential water quality problems, water quality modeling results, and suggestions for implementation projects. For DO impairments, the extensive collection of data from the watershed was utilized to identify causes of low DO levels. Soil and Water Assessment Tool (SWAT) and Hydrologic Simulation Program – Fortran (HSPF) models have been developed for the watershed to identify sources of water quality problems. SWAT modeling results can be viewed at the following address: http://www.redlakewatershed.org/waterquality/TRW_Report.pdf. The use of these models will be discussed in Section 3.6.1.2.

3.6.1 Turbidity/Total Suspended Solids in the Lower Thief River

The load duration curve (LDC) for the Thief River at County Road 77 shows that high TSS concentrations occur during high flows in this reach of the river. Nonpoint sources are the dominant source of water quality problems related to sediment and turbidity. No point sources discharge directly to this reach. As with any river, there are typical sources of sediment occurring along the channel (streambank erosion, overland erosion, etc.). Monitoring data has shown that the conditions in the Thief River downstream of Agassiz NWR to be worse than those in either the Thief River or the Mud River upstream of the refuge. Scouring and movement of sediment from Agassiz Pool during drawdowns has been identified as a cause of worsening TSS levels in the Thief River. A 2012 USGS report (Nustad 2012) found that “outflow sites had significantly greater suspended-sediment concentrations than inflow sites.”

3.6.1.1 Regulated Sources

Construction and Industrial Stormwater

Construction and industrial stormwater are regulated by the MPCA through National Pollutant Discharge Elimination System (NPDES) permits. Unlike WWTF permittees, there is no publicly information available about the requirements of the permits, the level of adherence to those permits, or the amount of pollutants that run off an individual permittee’s property. Because current loading and permitted loading numbers are not available, the significance of construction and industrial stormwater will need to be estimated based on the amount of activity in the watershed. The drainage area of the Thief River is encompassed by Pennington County, Marshall County, and Beltrami County. Wasteload allocations (WLAs) were calculated with permitting data from those counties, as described in Section 4.1.3.

Insufficient Buffers

There is significant room for improvement in the completeness and the quality of riparian buffers along the Thief River and its tributaries. Multiple examples of the consequences of poor riparian buffers have been documented with georeferenced photos. Two of those examples are shown in Figure 3-21. Riparian buffers are now required by law along public waterways and public drainage systems in the state of Minnesota. Governor Mark Dayton's landmark buffer initiative was signed into law in 2015 and amended in 2016. The law establishes new perennial vegetation buffers that are an average of 50 feet wide along public waters, and an average of 16.5 feet wide along public ditches that will help filter out phosphorus, nitrogen, and sediment. The new law provides flexibility and financial support for landowners to install and maintain buffers.

Figure 3-21. Photos of erosion problems that could be prevented by implementation of the 16.5-foot buffer requirement.

Permits are now required to install tile drainage systems within the RLWD (which includes the Thief River Watershed). The water coming out of tile drainage systems in the Thief River Watershed is generally very low in suspended solids. However, the erosive power of drainage water downstream after it leaves the pipe is the main way that tiling could have a negative effect upon TSS concentrations in receiving waters. The permitting rules state, "All subsurface tile drainage systems must protect from erosion and include RLWD approved erosion control measures."

There are few feedlots remaining in the Thief River Watershed. Feedlots within Marshall and Pennington County are regulated by county officers. Feedlot Program staff at the Detroit Lakes MPCA office also regulate feedlots in the area.

3.6.1.2 Non-permitted Sources

Nonpoint sources of sediment pollution within the watershed of the Thief River vary from one part of the watershed to another. Studies have identified stream bank erosion, overland erosion from agricultural fields, and the flushing of sediment from Agassiz Pool as significant sources of sediment in the lower Thief River. The Thief River watershed has been intensively studied since 2007. In that time, many general and specific problem areas have been identified within the watershed. The entire reach of the Thief River has been explored via canoe/kayak and eroding stream banks have been documented. A geomorphic assessment was conducted along the reach.

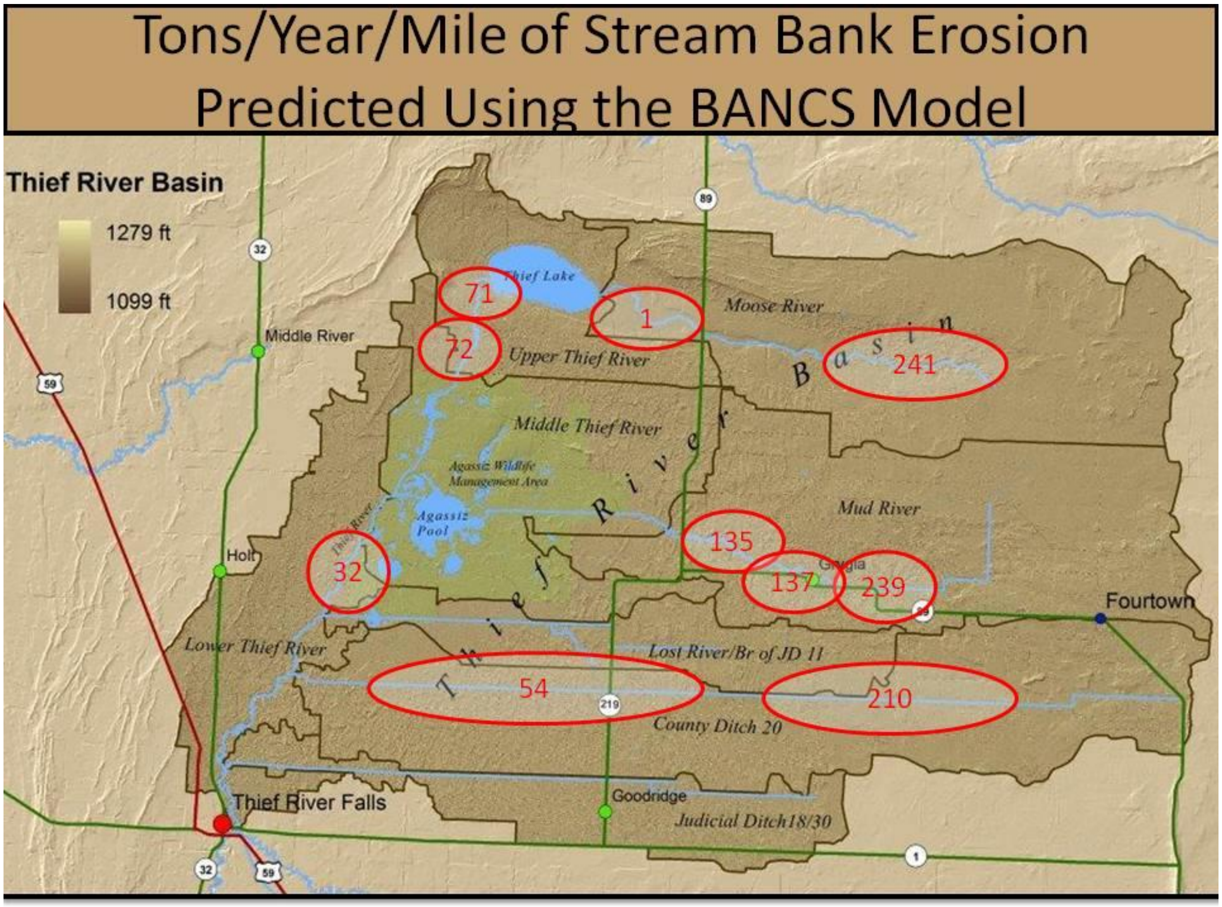


Figure 3-22. BANCS Model stream bank erosion predictions from the Thief River Watershed Fluvial Geomorphology Report. The circles and ovals encompass the reaches that were evaluated. The values inside the ovals are the predicted erosion rates (tons/year/mile).

The DNR staff used the Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS) data that was collected during the Thief River Watershed Geomorphic Assessment, to estimate stream bank erosion rates using a Bank Assessment for Nonpoint Source Consequences of Sediment (BANCS) Model. The BANCS model is a quantitative method of estimating stream bank erosion rates. The BANCS modeling results for the Thief River Watershed are shown in Figure 3-22.

Discharge from impoundments can abruptly and significantly raise flow rates within receiving channels. When decisions are made to release water from a pool, it has been historically released with the goal of getting the pool down to the target elevation as quickly as possible. The water coming out of most impoundments is usually not high in sediment (Moose River Impoundment, Thief Lake, Brandt Impoundment, and Farmes Pool). However, the volume of water released can have significant erosive power.

Agassiz Pool

Agassiz Pool, however, has proven to be a source of sediment-laden water during drawdown periods. Research conducted by Houston Engineering and the Pennington SWCD indicates that two-thirds of the sediment flowing into the Refuge's main pool is deposited there when the water that enters the pool loses velocity, and drawdowns flush a portion of that deposited sediment out of the pool. The amount of sediment leaving this impoundment is greater than typical impoundments due to:

- A radial gate outlet
- Increased frequency of full drawdowns
- Remnants of JD11 that concentrate flow
- Maintenance and cleaning of the old JD11 channel by the USFWS that causes flushing of sediment downstream.

The radial gate outlet opens from the channel bottom. This allows more movement of water within the lower channels, gullies, and highly erodible soil/muck within the pool. The USFWS has recently adopted a strategy that removes sediment from Agassiz Pool through flushing and scouring that is facilitated by incremental cleanup of the old JD 11 channel within Agassiz Pool, breaches in the ditch berm, and multiple drawdowns during the course of several years. Recent excavation by the USFWS within the old JD11 channel has exacerbated high sediment concentrations exiting Agassiz Pool. As USFWS staff have excavated sediment from the water-filled old JD11 channel to the berms, uncontrolled sediment has flushed downstream. Additionally, following excavation headcutting of the channel has occurred during drawdowns, sending additional sediment downstream. Trend analysis in the Thief River WRAPS report shows strong upward trends in TSS concentrations. Recent increases in TSS concentrations have occurred since the USFWS initiated the maintenance excavation of the old JD11 channel in 2012. Multiple specific instances in which discharge from Agassiz Pool has negatively affected downstream water quality have been documented with observations and monitoring data.

In the late fall of 2009, the USFWS opened the radial gate outlet of Agassiz for an extended drawdown period and the turbidity was very high in the Thief River downstream of Agassiz Pool for an extended period. There was extensive gully formation, sloughing, and erosion within Agassiz Pool along the old JD 11 channel. A thick layer of organic sediment was deposited downstream.

Sediment Deposition along the Thief River

In August of 2012, Agassiz NWR began drawing down Agassiz Pool by releasing water through their water control structures at a rate of up to 1,200 CFS. This greatly increased turbidity in the river and affected the quality of drinking water in Thief River Falls. The RLWD and the MPCA both received complaints about the taste and odor of the drinking water in the city of Thief River Falls during the Agassiz Pool drawdown. RLWD staff verified the complaints by taste-testing the water. During the drawdown, there was a very strong chlorine-like taste that made the water virtually undrinkable. Shortly after the drawdown was over, the city's tap water improved dramatically. The daily mean discharge in the Thief River near Thief River Falls increased from 64 CFS to 629 CFS on August 2nd, near the beginning of the drawdown. On August 6, 2012, the daily mean discharge at the USGS gauge (05076000) had decreased to 241 CFS. Monitoring on August 6, 2012 found that the turbidity at the County Road 7 Bridge near Agassiz NWR was 25.1 NTRU, which is almost equal to the former 25 NTU turbidity standard. Prior to the more recent maintenance excavation of the old JD11 channel within Agassiz Pool, the data suggests that moderation of flows during pool discharge (keeping flows at or below the 241 CFS observed on August 6, 2012) would help reduce sediment concentrations, turbidity levels, and sedimentation in the Thief River.

Longitudinal samples were collected along the lower reach of the Thief River from CSAH 7 to Long's Bridge during a storm event on May 20, 2013 (Figure 3-23). Turbidity gradually increased from upstream to downstream with a significant exception. The turbidity reading at the CSAH 7 Bridge (S002-088, closest crossing to the outlet of Agassiz Pool) was 216.2 FNU. The turbidity at the next crossing downstream, CSAH 12 (S004-052), was 24.0 FNU. It was unusual to see turbidity (and TSS) decrease that greatly from an upstream site to a downstream site. This indicated that a large amount of sediment was being discharged from the Agassiz Pool outlet(s) and much of that sediment was being deposited along the Thief River between the two crossings. Relatively large, dark-colored particles were visible in the CSAH 7 sample, but not in samples from other sites. These larger particles likely fell out of suspension rather quickly.

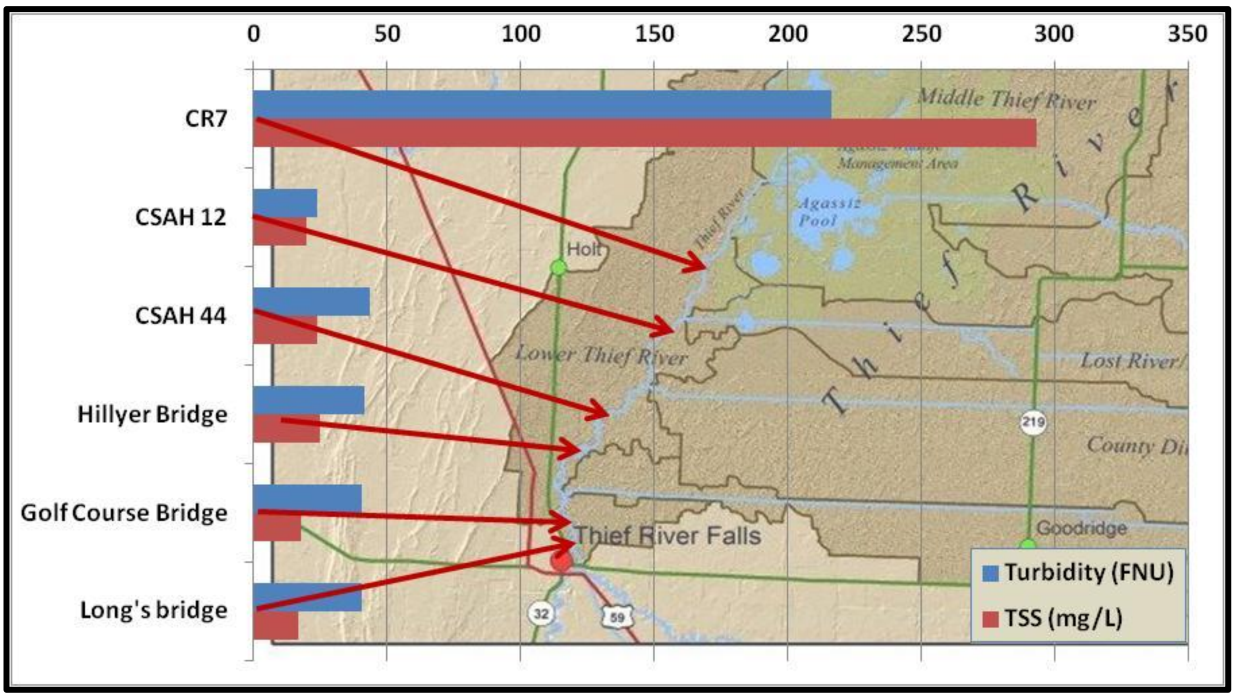


Figure 3-23. Longitudinal turbidity and TSS levels during a May 20, 2013 runoff event

Water quality in the Thief River was monitored during the Agassiz Pool drawdown in 2013 (Figure 3-24). Water quality was satisfactory when it was tested slightly after the peak flow level during the discharge period. However, turbidity levels increased to record highs as water levels receded. On August 19, 2013, turbidity levels were recorded at 398.8 FNU and transparency was only 2.5 cm. Conditions were worsening on the receding limb of the hydrograph. A similar, but more detailed, pattern was observed when the Thief River was intensively sampled during the 2015 late-summer drawdown of Agassiz Pool. TSS concentrations spiked during the receding limb of the hydrograph once again (Figure 3-25).

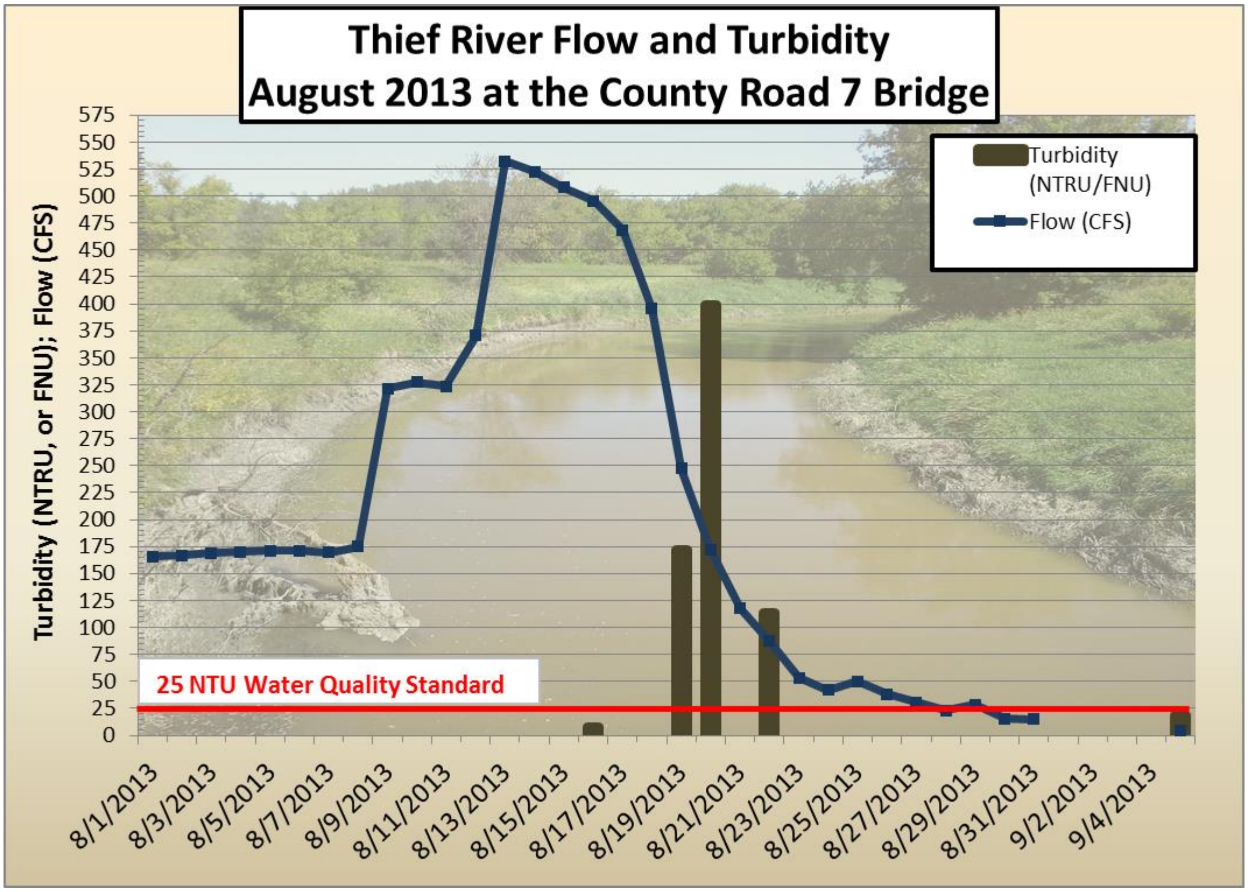


Figure 3-24. 2013 intensive sampling of the lower Thief River

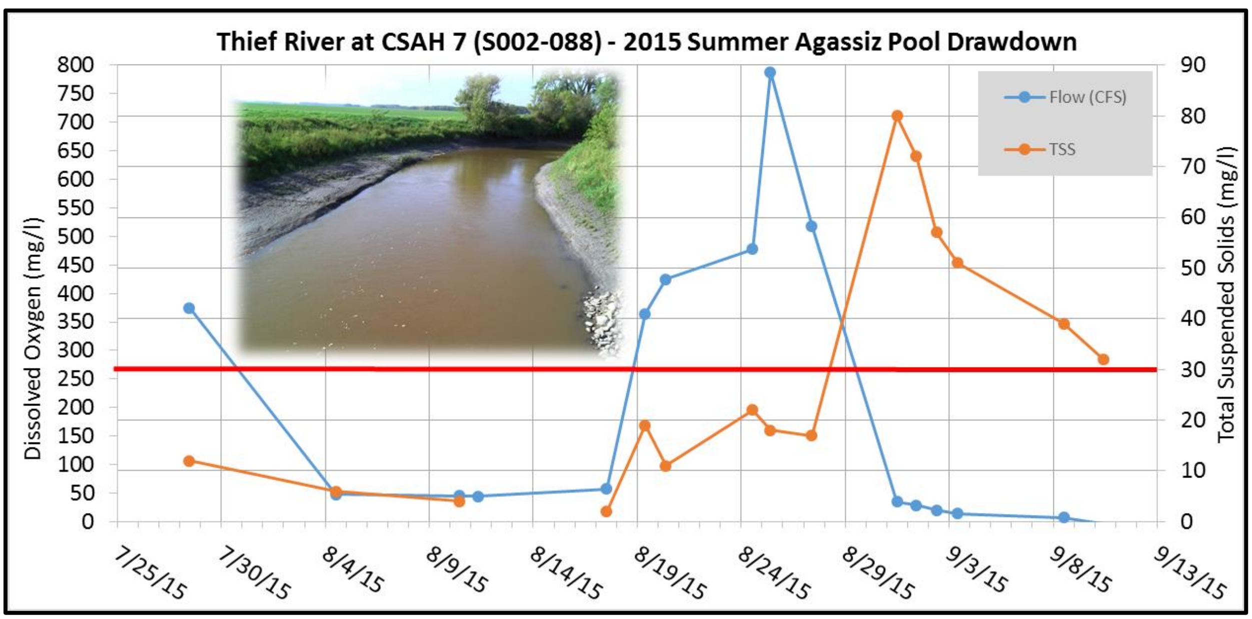


Figure 3-25. 2015 intensive sampling on the Thief River during the Agassiz Pool Drawdown

Prior to the adoption of a new strategy for managing sediment within Agassiz Pool, monitoring data indicated that moderation of flows would be desirable for minimizing spikes in turbidity and TSS in the Thief River during Agassiz Pool drawdowns. Flashy flows in river channels can increase erosion rates. The cleaning of JD 11 for the purpose of flushing and the increased frequency of full drawdowns has raised turbidity and TSS levels in the Thief River to new extremes (2013 and 2014 maximums shown in Figure 3-26) and has generated high sediment concentrations as water levels recede within the pool.

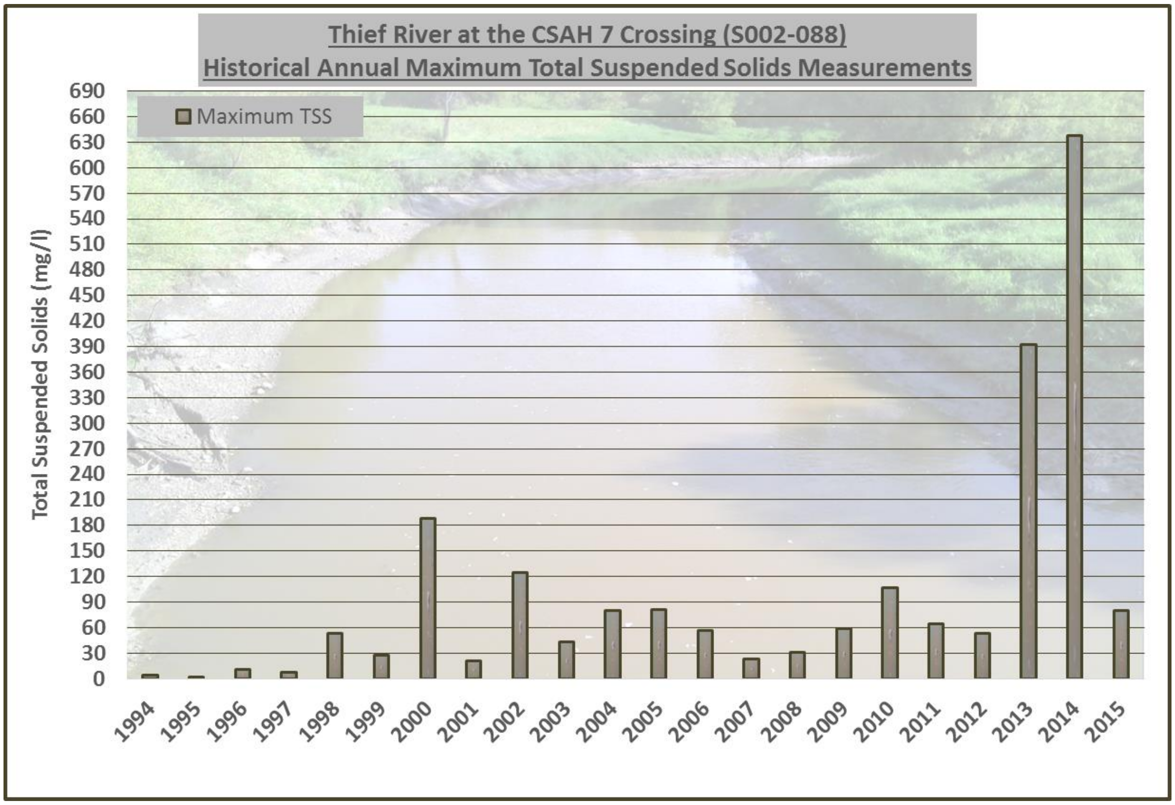


Figure 3-26. Historical annual maximum total suspended solids concentrations

A 2012 report from the USFWS describes the scouring process that occurs within Agassiz Pool during drawdowns. The report provides information that explains why TSS concentrations increase as flow rates flow rates decrease. Large gullies formed within Agassiz Pool as water flowed to the open portion of the JD11 channel during the 2012 drawdown. "The drawdown within the pool caused significant disturbance to emergent wetland vegetation and substrate in the immediate vicinity of the Ditch 11 Outlet. The head differential created between water surface elevations in the main ditch system extending upstream of the Ditch 11 Outlet and water surface elevations within Agassiz Pool appear to have created velocities sufficient to flatten vegetation and scour multiple networks of channels." High velocity sheetflow occurred as "water levels in the ditch began to drop lower than the surrounding pool water level. The sheetflow had velocities sufficient to flatten large areas of vegetation and undoubtedly transport large volumes of unconsolidated organic substrate from these areas of the pool." Excavation and head cutting will open up more of the old JD11 channel within Agassiz Pool. The sediment scoured from the channel will not be the only sediment that travels downstream. As more of the JD11 channel is excavated, the head differential (Figure 3-28) that occurs during sheetflow would be occurring along a longer reach of open channel. The scouring within the pool (Figure 3-27) described in the *Assessment of Water Quality Conditions: Agassiz National Wildlife Refuge, 2012* report could increase as that open channel is lengthened.

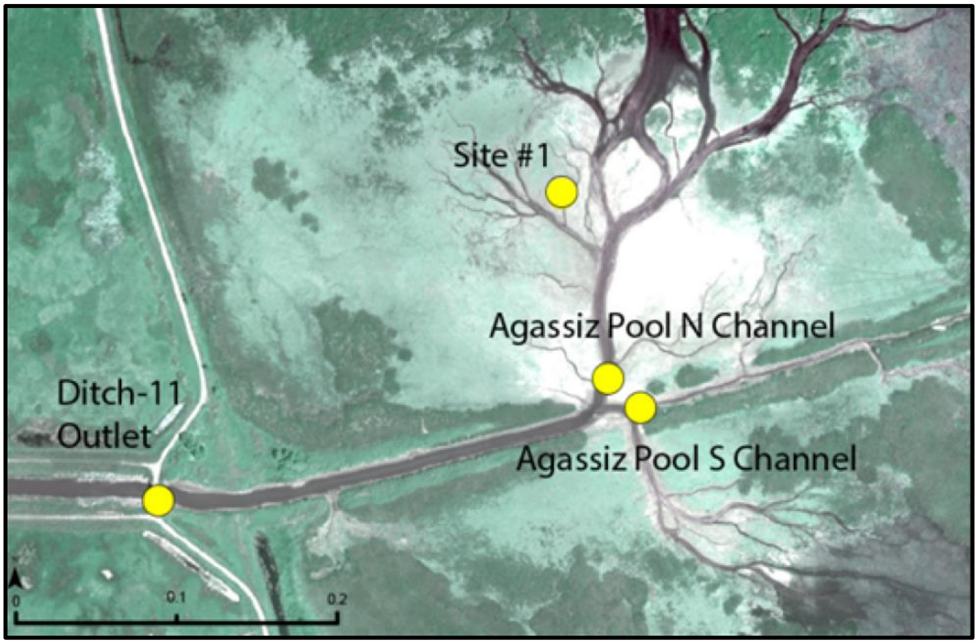


Figure 3-27. Scouring of sediment and gully formation within Agassiz Pool (Eash 2012)

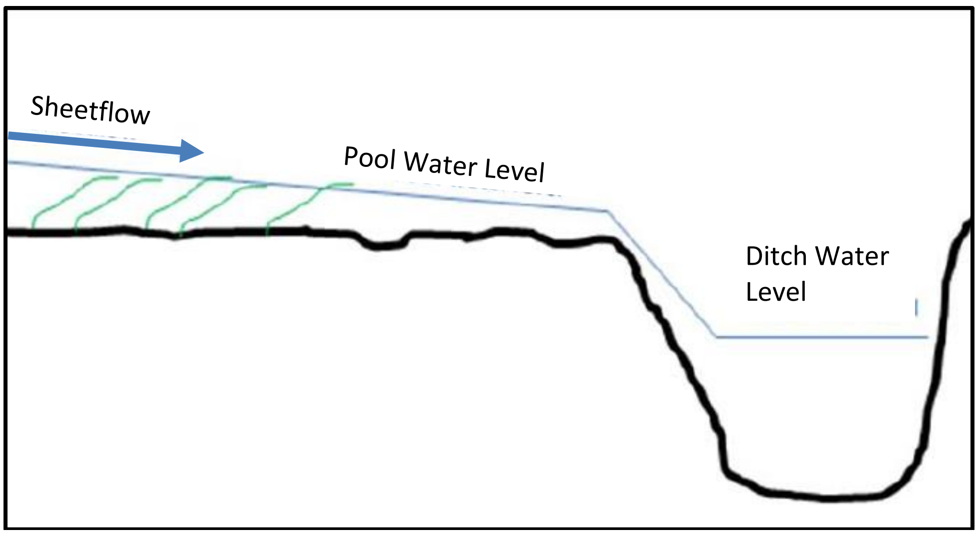


Figure 3-28. Diagram of hypothetical water surface profile within Agassiz Pool during periods of sheet flow (Eash 2012).

Other Sources of Erosion and Sedimentation

Reducing the effects of sediment erosion upon all the waterways in the Thief River Watershed will be beneficial for accomplishing the goals of this TMDL. The amount of sediment coming into Agassiz Pool, for example, influences the amount of sediment available to be scoured out of Agassiz Pool and moved downstream. The pool receives water from the Thief River, Mud River, and some other smaller drainage systems. Both the Thief River and the Mud River meet their respective TSS water quality standards. The sediment inputs from the Thief River may have been partially reduced by the new northwest outlet structure that allows a portion of the flow from the river to bypass the pool. The Mud River even meets a more protective standard of 15 mg/l. Even if the rivers are meeting the standard, moving water still moves sediment. A study that analyzed core samples in Agassiz Pool found that most of the sediment in Agassiz Pool was coming from upland erosion. The lower Mud River (downstream of Grygla) is fairly stable, but it is carrying a high, sandy bedload from the upper watershed. Bedload consists of sediment particles that, although not suspended, are transported along the bed of the river. The Mud River upstream of Grygla is channelized (Main JD 11) and there is a lack of buffers and higher erosion rates (239 tons/year/mile) in this reach.

A visual inspection of the watershed has identified ditches that have little to no vegetation establishment in the channel and/or on/along the banks. The navigable channels within the watershed have been surveilled via canoe or kayak. Some channels like the county/judicial ditches and a portion of the Moose River were visually inspected by driving along roads that parallel the channel. Erosion and other potential sources of pollutants were documented in georeferenced photographs. Runoff from bare soil is another source of sediment in ditches that are carrying turbid water to the Thief River and its tributaries. Occasionally, plumes of sediment entering the Thief River and its tributaries from township ditches due to recent cleaning and a lack of vegetation were observed.

High flows and poor water quality in the Thief River have already caused multiple instances of high trihalomethanes (a potentially harmful disinfection byproduct) in Thief River Falls' drinking water during runoff events and Agassiz Pool drawdowns. The city of Thief River Falls has been subjected to increased scrutiny by the Minnesota Department of Health because the disinfection byproducts have occasionally spiked to a level of imminent concern. High turbidity/TSS and high total organic carbon (TOC) in source water are considered to be significant factors that lead to this drinking water quality issue. The difference in water clarity between the Thief River and Red Lake River is evident in Figure 3-29.

Figure 3-29. Sediment plumes from the Thief River entering the Red Lake River and the Thief River Falls Reservoir.

Streambank and overland erosion are sources of sediment in the Thief River. Previously completed reports help identify the general sources of sediment and the areas with the worst erosion problems.

Erosion, Sedimentation, Sediment Yield Report

The *Erosion, Sedimentation, Sediment Yield Report: Thief and Red Lake Rivers Basin, Minnesota* was completed by the USDA Natural Resources Conservation Service (NRCS) in cooperation with the Marshall-Beltrami SWCD, Pennington SWCD, and other local, state, and federal agencies in April of 1996. The study created a sediment budget to help local agencies find solutions to sedimentation problems within public wildlife areas and the Thief River Falls Reservoir. Sediment sources were identified and quantified. Although knowledge of the watershed has expanded since the completion of this report, it involved rigorous data collection and measurement of erosion rates. Findings of the study have influenced local water planning. The report is available online:

http://www.redlakewatershed.org/projects/Erosion%20Sedimentation%20Sediment%20Yield%20Report.pdf.

Findings of the report included:

- The Thief River and Red Lake River watersheds were split into eight subbasins for evaluation. The watershed area that drains to the Thief River from the west was the "evaluation unit" with the highest gross erosion per square mile.
- 65% (24 river miles) of the streambanks are eroding along the Thief River. Over 60% of this erosion is considered severe.
- Only 15% (nine miles) of the streambanks along the Red Lake River are eroding.
- The more extensive streambank erosion on the Thief River may be explained in part by greater water level fluctuations. The channel is not as wide as the Red Lake River, yet it has a larger uncontrolled drainage area than the Red Lake River.
- Of the total annual gross erosion of approximately 2.8 million tons, only about 53,900 tons of sediment is yielded to the ditches and streams annually. The rest is deposited on land.
- Of the 53,900 tons of sediment yielded to streams:
    - 58% (31,200 tons) is from streambank erosion
    - 22% (11,700 tons) is from sheet and rill erosion
    - 14% (7,900 tons) is from wind erosion
    - 5% (2,700 tons) is from ditch bank erosion
    - 1% (400 tons) is from classic gully erosion
- The average annual rate of deposition in the Thief River Falls reservoir was estimated at 5,330 tons over the 1966 through 1990 time period.
- Future options for reduced sedimentation (Several stream stabilization projects have already been completed as of the publishing of this report):
    - Land treatment
    - Return cropland to permanent grass cover
    - Accelerate the application of conservation tillage, crop residue use, field shelterbelts, and filter strips
    - Accelerate the installation of grade stabilization structures and side-water inlets
    - Adequately revegetate legal drains after their cleanout
    - Structural measures
    - Streambank stabilization measures
    - Trap sediment before it is yielded to the reservoir
    - Dredging the reservoir

        - Cost estimated at over 1 million dollars (in 1996 – it would be much more today)
        - 25-year project life
    - Combine dredging with periodic drawdown of the reservoir
    - Combine dredging of the reservoir and land treatment measures
    - Do nothing: Water quality conditions would gradually become worse
- Conclusions of the Erosion Sedimentation and Sediment Yield Report:
    1. Even though 98% of the gross erosion (total mass of erosion from the soil surface) occurs on cropland, this kind of erosion accounts for only 37% of the sediment yielded (net erosion) to ditches, streams, and the reservoir (only a fraction of eroded sediment is deposited into a waterbody). Soil erosion on cropland causes more damage on-site by reducing soil productivity, damaging growing crops, losing fertilizers and chemicals, and reducing net income.
    2. Wind erosion accounts for 94% of the gross erosion but only 14% of the sediment yield to streams, ditches, and the reservoir.
    3. The major source of sediment yielded to streams and ditches is from streambank and ditch bank erosion (63%).
    4. Current sediment deposited in the reservoir accounts for about 18% of the total volume. Annual deposition over the past 24 years amounts to 5,330 tons (RLWD data). Future depositions are expected to be less, unless current sediment accumulations are removed and CRP acreage is returned to crop production.
    5. Even though sediment yield values are considerably lower than in other parts of the state and nation, considerable local interest exists, especially among the recreationalists and city officials in Thief River Falls, for reducing the sediment yield to the reservoir. Similar interest also exists for the WMAs.
    6. Opportunities exist for using the sediment budget to determine impacts of various treatment scenarios.

Watershed Modeling and Analysis

A SWAT model was created for the Thief River watershed during the Thief River Watershed Sediment Investigation. The model identified the areas of land within the watershed that are most likely contributing the greatest sediment and nutrient yields (Figure 3-30). The potential effectiveness of best management practices (BMPs) was also evaluated by the model (Figure 3-31).

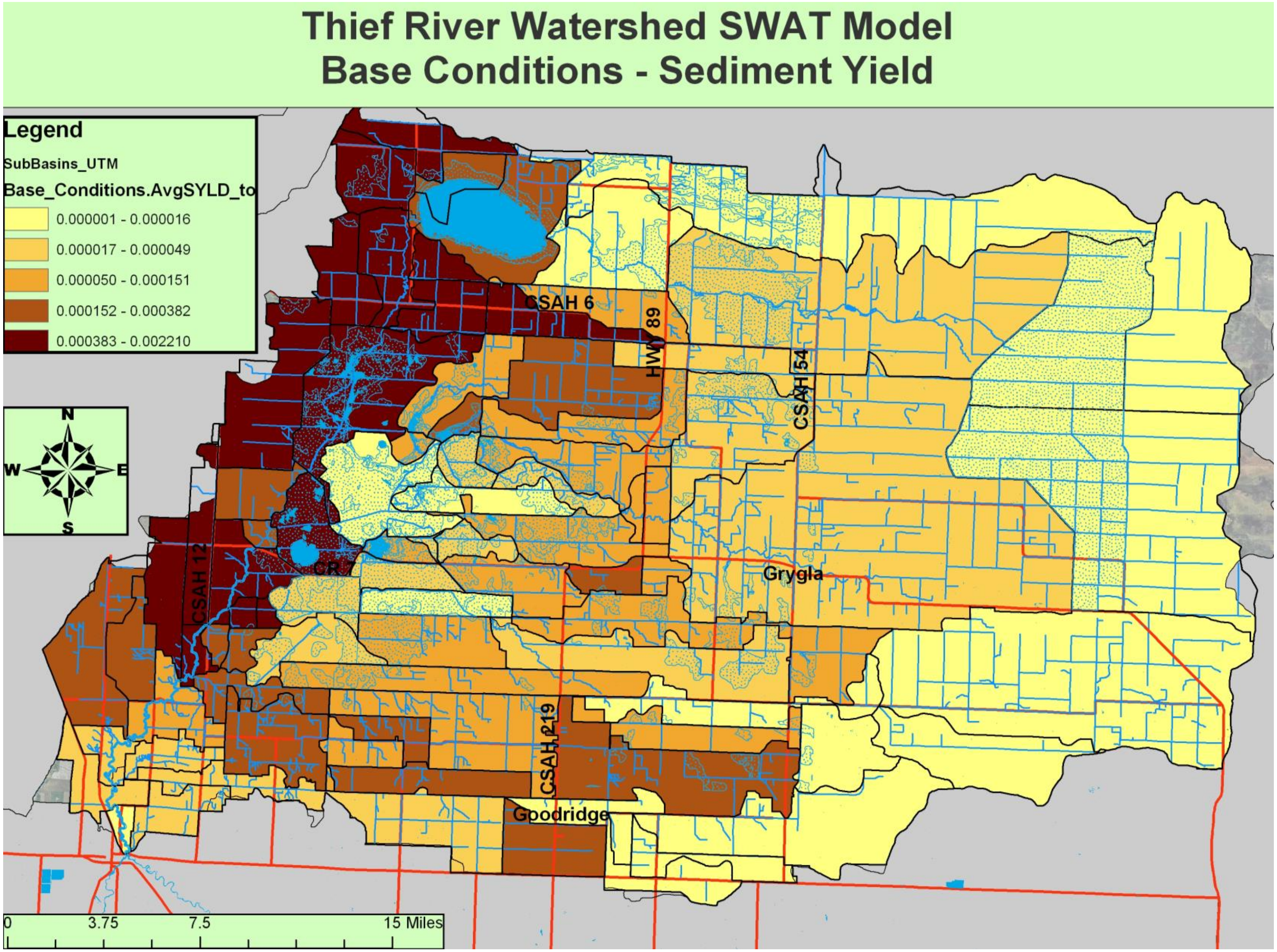


Figure 3-30. SWAT-modeled sediment yield from the sub-basins of the Thief River Watershed (2000-2009 modeling period)

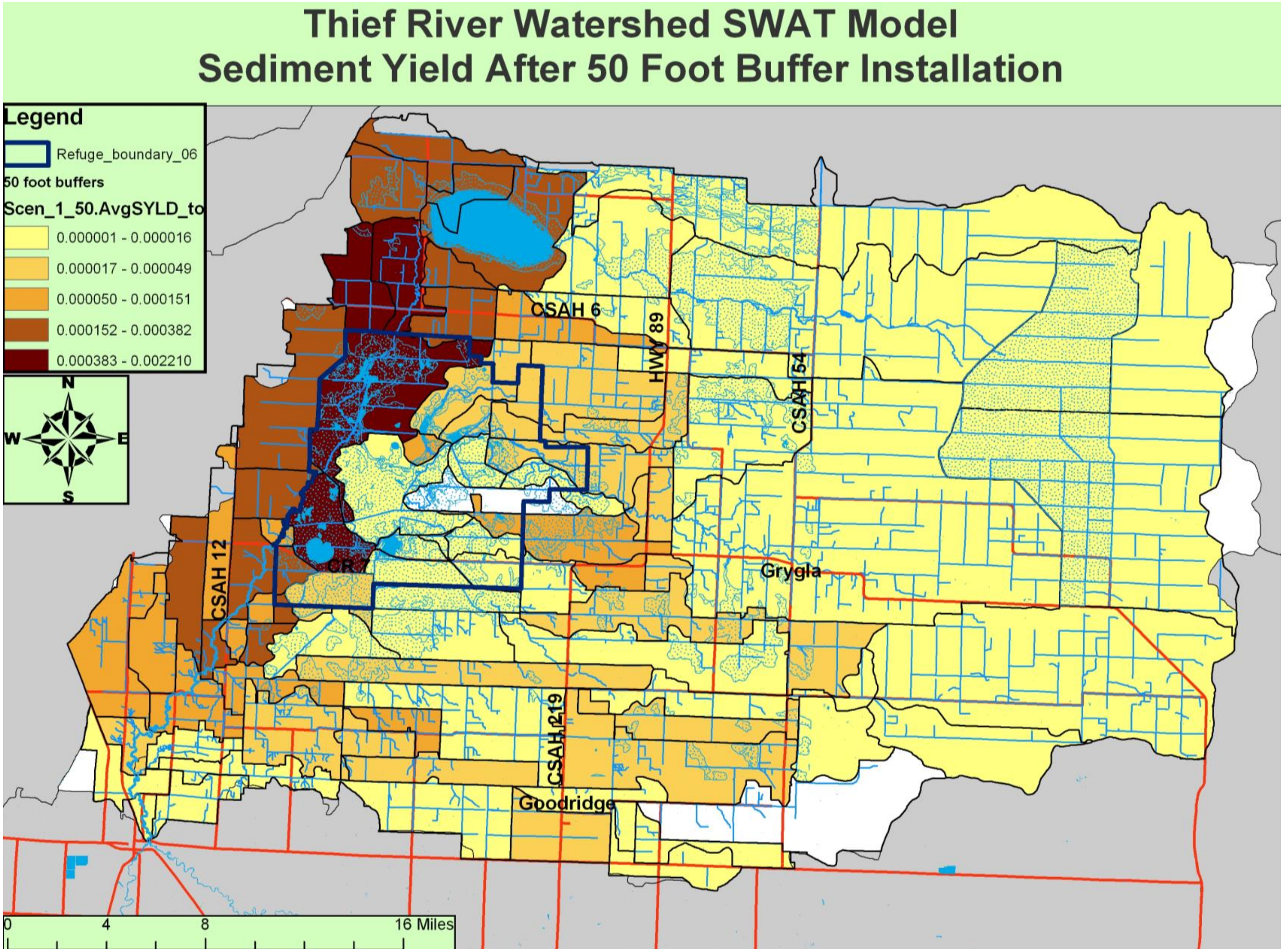


Figure 3-31. SWAT-modeled sediment yields for the sub-basins of the Thief River Watershed with 50-foot buffers.

HSPF is a computer model used for the simulation of hydrology and water quality for natural and manmade water systems. The model incorporates nonpoint and point flows and water quality loading by simulating the processes on pervious and impervious land surfaces and in streams or impoundments. Pervious areas are simulated using the PERLND module; impervious areas are simulated using the IMPLND module; and in-stream hydraulics and water quality processes are simulated using the RCHRES module. HSPF is a continuous model using an hourly time-step and typically outputting information on a daily time-step. Meteorological, point source, and other data, as well as outputs, are stored as time series in a binary Watershed Data Management (WDM) file. HSPF is part of the EPA's Better Assessment Science Integrating point and Non-point Sources (BASINS) suite of tools and is utilized using WinHSPF. Figure 3-32 highlights the areas that are most in need of projects to reduce sediment yields.

The fieldwork for a geomorphologic assessment of the Thief River Watershed was conducted in 2011 and 2012. A report on the results of the assessment was completed in 2015. This work identified individual stream banks as well as larger reaches of the Thief River and some of its tributaries along which significant erosion is occurring. The results of this work can be used to target areas for erosion control projects. The report can also be used to guide decisions about the type of erosion control strategies that are implemented. The report can be viewed by using the following link: http://redlakewatershed.org/waterquality/Thief%20R%20Geomorphology%20Report%20Nov2015.pdf.

Desktop analysis of the watershed has yielded information on the locations of many points within the watershed that could be contributing to water quality problems. Stephanie Klamm, DNR Hydrologist, created "Stressor" shapefiles in which potential sources of pollutants and other notable features in the Thief River watershed are marked. Four categories of features were marked: erosion, livestock, dams, and ditches. A stream power index (SPI) analysis of the watershed has been completed. The SPI analysis used LiDAR-derived digital elevation models and other inputs to identify the points on the landscape that are most susceptible to gully erosion, as shown in Figure 3-33.

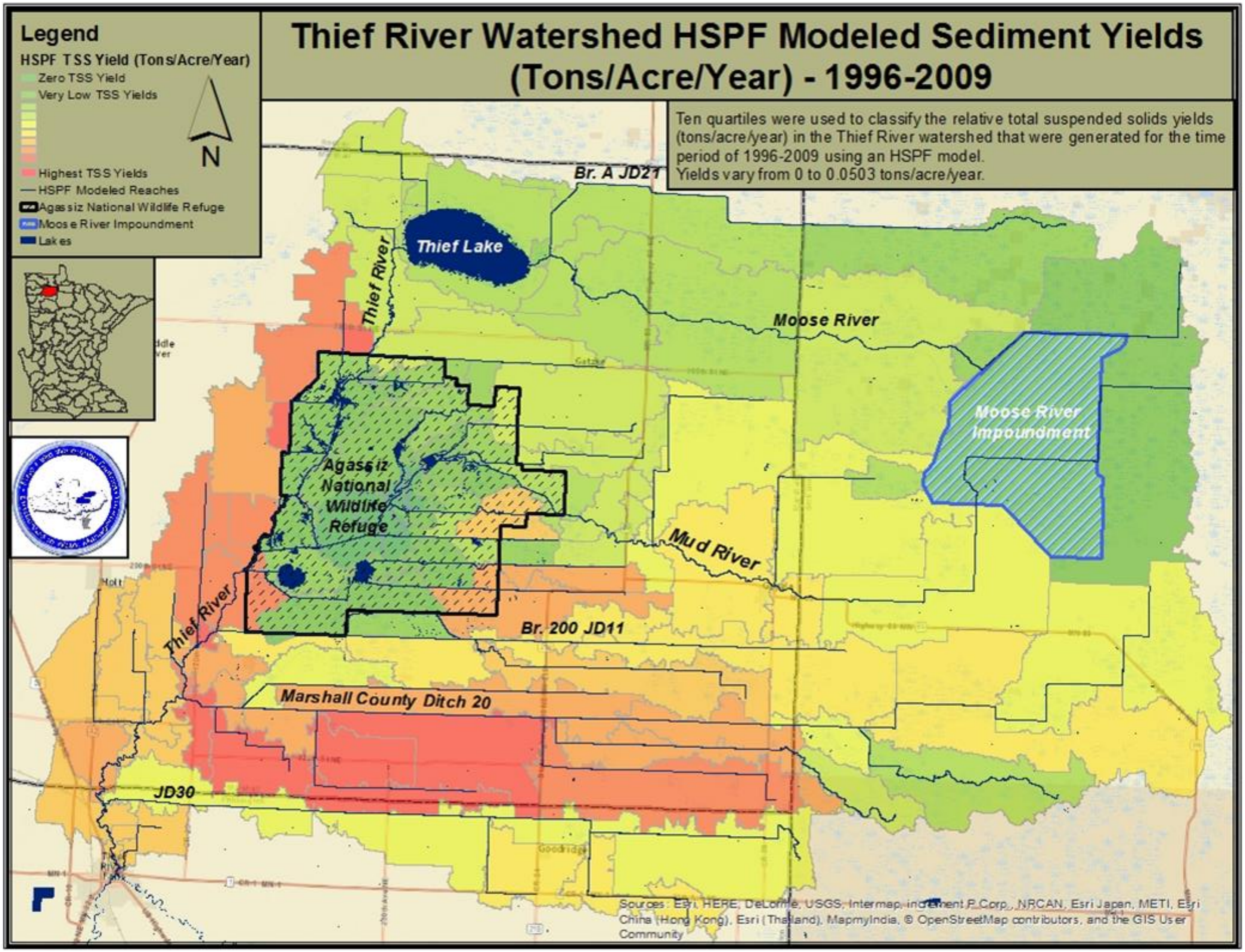


Figure 3-32. Thief River Watershed HSPF-Modeled Total Suspended Solids Yields (Tons/Acre/Year)

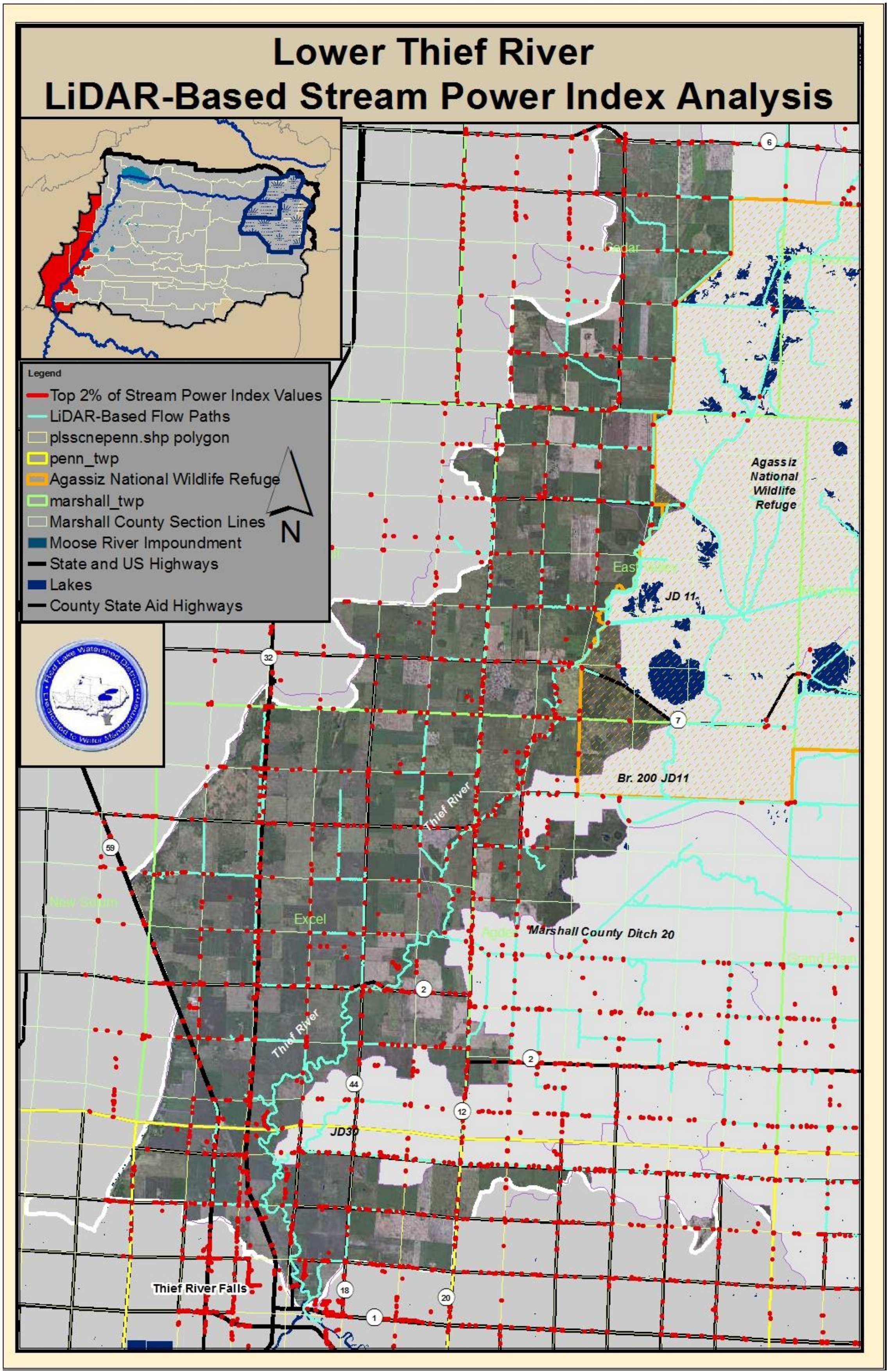


Figure 3-33. Lower Thief River Watershed high erosion potential based upon the top 2% of stream power index values.

3.6.2 *E. coli Bacteria* in the Mud River

The Mud River AUID 09020304-507, when assessed as a combined unit, meets the *E. coli* standard. The reach was proposed for delisting. A site-specific assessment; however, found that a portion of the river is still failing to meet the standard. Two locations along the Mud River have sufficient data for a site-specific analysis. One site is the primary long-term water quality and flow monitoring site at the Highway 89 crossing (S002-078). The *E. coli* data from that site meets the water quality standard. The other location is the city of Grygla. Two stations within one mile of each other in Grygla have been intensively sampled in recent years to investigate a blue-green algae problem. The *E. coli* data collected during that sampling activity revealed a site-specific impairment at the city of Grygla. Both sites are located upstream of the Grygla WWTF. Longitudinal sampling efforts have also indicated that major sources of *E. coli* in the Mud River are located upstream of Grygla. Cattle and birds have been confirmed as nonpoint sources of *E. coli* pollution in the Mud River. Microbial source tracking analysis found that human waste is polluting the river as much as or more than cattle or birds.

3.6.2.1 Permitted Sources

The wastewater treatment facility (WWTF) for the town of Grygla discharges downstream of the area impaired for *E. coli* so the WWTF is not considered a source of the impairment.

However, due to the discovery of human fecal DNA markers in the Mud River at Grygla, failing septic systems are a suspected source of *E. coli* bacteria. Septic system inspection in within the 090203040302 and 090203040303 HUC12 subwatersheds is recommended.

There are few feedlots remaining in the Thief River Watershed. Feedlots in the Mud River Subwatershed are shown in Figure 3-34. A single feedlot; however, can still cause an *E. coli* impairment. The location and types of sources that are causing the *E. coli* impairment of the Mud River have been narrowed down through longitudinal sampling and microbial source tracking. Ruminant fecal DNA markers have been found within the impaired portion of the Mud River and livestock operations are located upstream of that location. There are also some livestock operations that aren’t represented by points on the map. Most of the drainage area of S002-977 is located within Beltrami County and that county does not have an official county feedlot officer. Feedlot Program staff at the Detroit Lakes MPCA office regulate feedlots in the area.

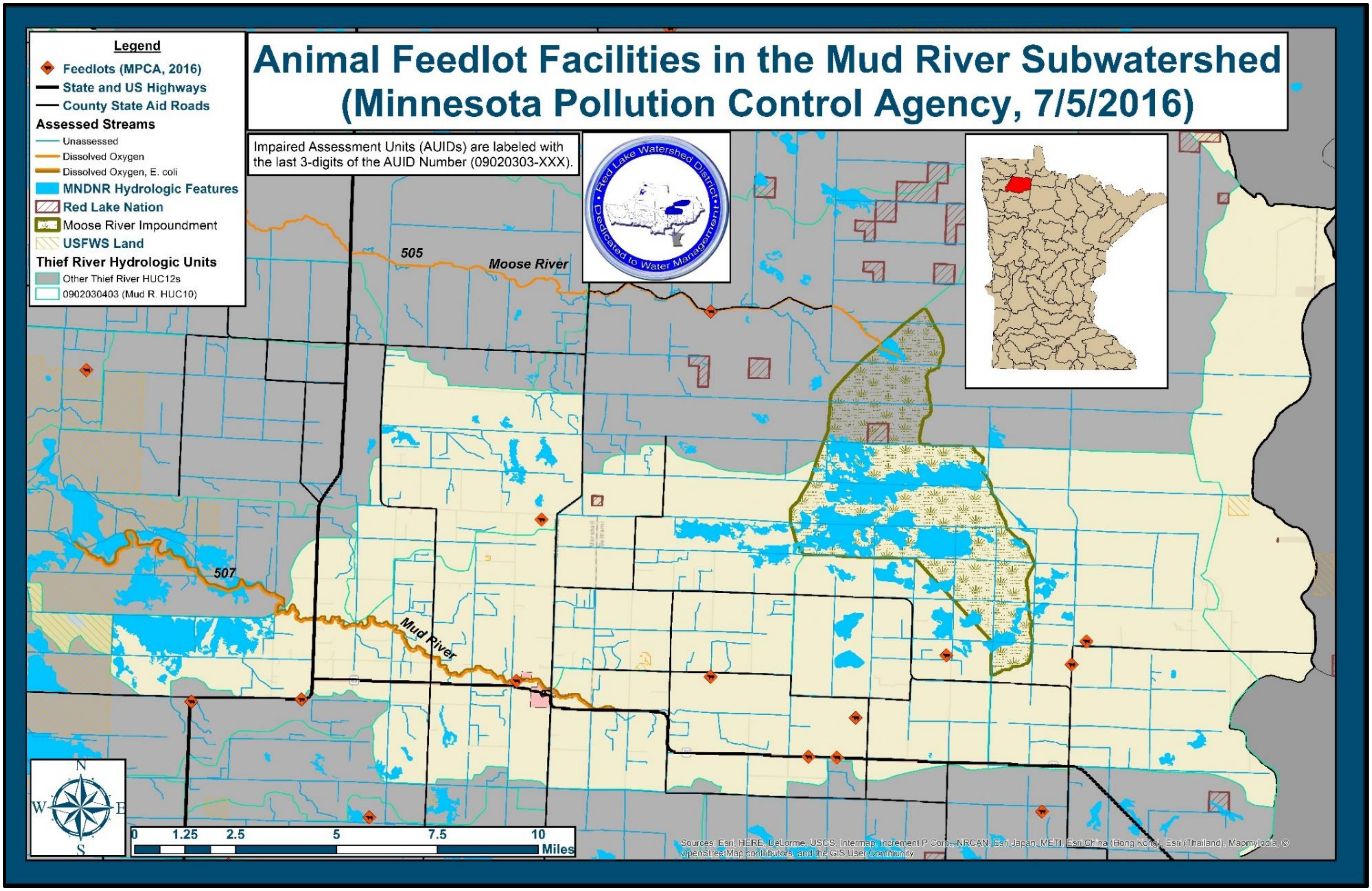


Figure 3-34. Registered feedlots in the Mud River Subwatershed

3.6.2.2 Non-permitted Sources

In addition to failing septic systems, livestock and birds (cliff swallows under bridges and within box culverts) have been identified as sources of *E. coli* in the Mud River. Natural background sources also contribute, minimally, to the *E. coli* concentrations found in the river.

Aerial photos (Figure 3-35) show that there are some livestock operations along the Mud River upstream of Highway 89. Kayak stream reconnaissance identified sites where livestock are accessing the river downstream of Grygla.

Figure 3-35. Livestock operation along the Mud River upstream of Grygla (1.3 miles east of town on Highway 89) that could be directly contributing to periodic high *E. coli* concentrations.

At the time of the 2009 longitudinal samples, a livestock operation was still in operation downstream of 370th Avenue Northeast (CSAH 53) that likely contributed to high *E. coli* concentrations during runoff events. In addition to contributing to *E. coli* concentrations, cattle access to the river had caused stream bank instability. The operation and cattle access to the river appears to have continued through 2011 (at least), based upon aerial photos. In spring 2013 aerial photos, the operation no longer appeared to be active. The most recent, 2015 aerial photos indicated the presence of livestock near buildings, but there was no evidence of livestock access to the river. The banks of the river have revegetated where they had been bare and eroding. The recently lessened impact from the livestock operation near CSAH 53 coincides with the recent decrease in *E. coli* concentrations at the lower end of the subwatershed. The livestock in Section 28 of Valley Township also appeared to negatively affect *E. coli* concentrations.

Figure 3-36. 370th Ave NE livestock operation active in 2011 (left) and no longer active in 2015 (right).

A former member of the Marshall-Beltrami SWCD board shared data that was collected in 1996 by the Marshall-Beltrami SWCD (not available in Environmental Quality Information System; EQuIS). Some of the sites bracketed suspected fecal coliform sources such as cliff swallows within a box culvert and a livestock operation. Fecal coliform concentrations didn't change much from upstream to downstream of the feedlot unless there was a runoff event. During one runoff event, fecal coliform increased greatly from 329 col/100ml upstream the feedlot to "too numerous to count" downstream of the feedlot on May 29, 1996.

Table 3-12. Microbial Source Tracking Fecal DNA sampling results

Date	Site Name	S-Code	E. coli (CFU/100ml)	Analysis Requested	Quantification (Copies/100mL)	DNA Analytical Results	Contribution to Fecal Pollution
6/18/2014	Mud R. @ Hwy. 89	S002-078	95.9	Bird Fecal ID	<LOQ	Positive (Trace)	Potential Contributor
6/18/2014	Mud R. @ Hwy. 89	S002-078	95.9	Cow Bacteroidetes ID		Absent	
6/18/2014	Mud R. @ Hwy. 89	S002-078	95.9	Goose Bacteroidetes ID		Absent	
6/18/2014	Mud R. @ Hwy. 89	S002-078	95.9	Human Bacteroidetes ID 1		Absent	
6/18/2014	Mud R. @ Hwy. 89	S002-078	95.9	Human Bacteroidetes ID 2		Absent	
6/24/2014	Mud R. @ Hwy. 89	S002-078	920.8	Bird Fecal ID	<LOQ	Present (Trace)	Potential Contributor
6/24/2014	Mud R. @ Hwy. 89	S002-078	920.8	Cow Bacteroidetes ID		Absent	
6/24/2014	Mud R. @ Hwy. 89	S002-078	920.8	Goose Bacteroidetes ID		Absent	
6/24/2014	Mud R. @ Hwy. 89	S002-078	920.8	Human Bacteroidetes ID 1		Absent	
6/24/2014	Mud R. @ Hwy. 89	S002-078	920.8	Human Bacteroidetes ID 2		Absent	
7/18/2017	Mud R. @ Grygla	S008-122	62	Bird Fecal ID		Not Detected	
7/18/2017	Mud R. @ Grygla	S008-122	62	Ruminant Bacteroidetes ID	Low, Not Quantified	Detected	Potential Contributor
7/18/2017	Mud R. @ Grygla	S008-122	62	Beaver Fecal ID		Not Detected	
7/18/2017	Mud R. @ Grygla	S008-122	62	Goose Bacteroidetes ID		Not Detected	
7/18/2017	Mud R. @ Grygla	S008-122	62	Human Bacteroidetes ID 1	1.76E+02	Detected	Contributes at low levels
7/18/2017	Mud R. @ Grygla	S008-122	62	Human Bacteroidetes ID 2		Not Detected	

Microbial Source Tracking samples were collected from the Mud River at Highway 89 and JD21 at CR48 on June 18 and June 24, 2014. Microbial source tracking is a method for identifying the type of animal that is the source of fecal coliform and *E. coli* pollution. The samples were analyzed by a lab in Florida (Source Molecular) that specializes in this testing. *E. coli* samples were also collected and sent to RMB Environmental Laboratories in Detroit Lakes to learn the concentration of *E. coli* bacteria at the time of sampling.

Longitudinal surveys of *E. coli* concentrations were collected along the Mud River between Highway 89 and Highway 54 on:

- June 4, 2009 (152.3 CFS of flow at S002-078)
- August 4, 2009 (9.7 CFS of flow at S002-078)
- August 20, 2009 (39.8 CFS of flow at S002-078)
- June 3, 2014 (325 CFS of flow at S002-078)
- July 17, 2017 (9.5 CFS of flow at S002-078)

These dates represented different flow levels. The August 20, 2009, sampling followed a recent rainstorm and had relatively high flow for that time of the year.

In the August 2009 set of longitudinal samples (Figure 3-37), the *E. coli* concentrations were high on the east (upstream) side of Grygla, so that indicates the presence of *E. coli* sources upstream of CSAH 54.

Longitudinal *E. coli* samples were collected along the Mud River near Grygla in September 2013, after high concentrations of *E. coli* near the Grygla lagoons were reported. The results did not reveal high *E. coli* concentrations downstream of the lagoons. Rather, the highest concentration was at the CSAH 54 crossing (S002-977) on the east (upstream) side of town. This is the third set of longitudinal samples that suggested the presence of significant *E. coli* sources upstream of Grygla.

The June 3, 2014, longitudinal sampling event (Figure 3-38) followed a runoff event. Despite the recent rain, runoff, and relatively high flows, *E. coli* concentrations were all below the chronic standard of 126 CFU/100ml. *E. coli* concentrations did increase from upstream to downstream, though, and there were some points where there were relatively significant increases in *E. coli*. The lowest bacteria levels were found where JD 11 (headwaters of the Mud River) leaves Moose River impoundment (which was discharging at the time). This indicates that the impoundment is not a likely source of the high *E. coli* readings that are sometimes found in the river.

On July 17, 2017, longitudinal samples (Figure 3-39) were collected between the outlet of the Moose River Impoundment and the Grygla City Park. The *E. coli* concentration leaving the impoundment was very low (9.8 MPN/100ml). Concentrations rose above the 126 MPN/100ml at the Flintlock Road crossing and peaked at the Dylan Road crossing. The concentration at CSAH 54 was 166.4 MPN/100ml. There was a decrease between CSAH 54 and the Grygla City Park.

High *E. coli* concentrations were found at the Hwy 54 crossing of the Mud River in Grygla, which indicates that there are sources upstream of there that would also need to be addressed.

A common finding among longitudinal sampling upstream of Grygla is that the origin of the impairment is not the Moose River Impoundment because concentrations have been low at the outlet of the impoundment.

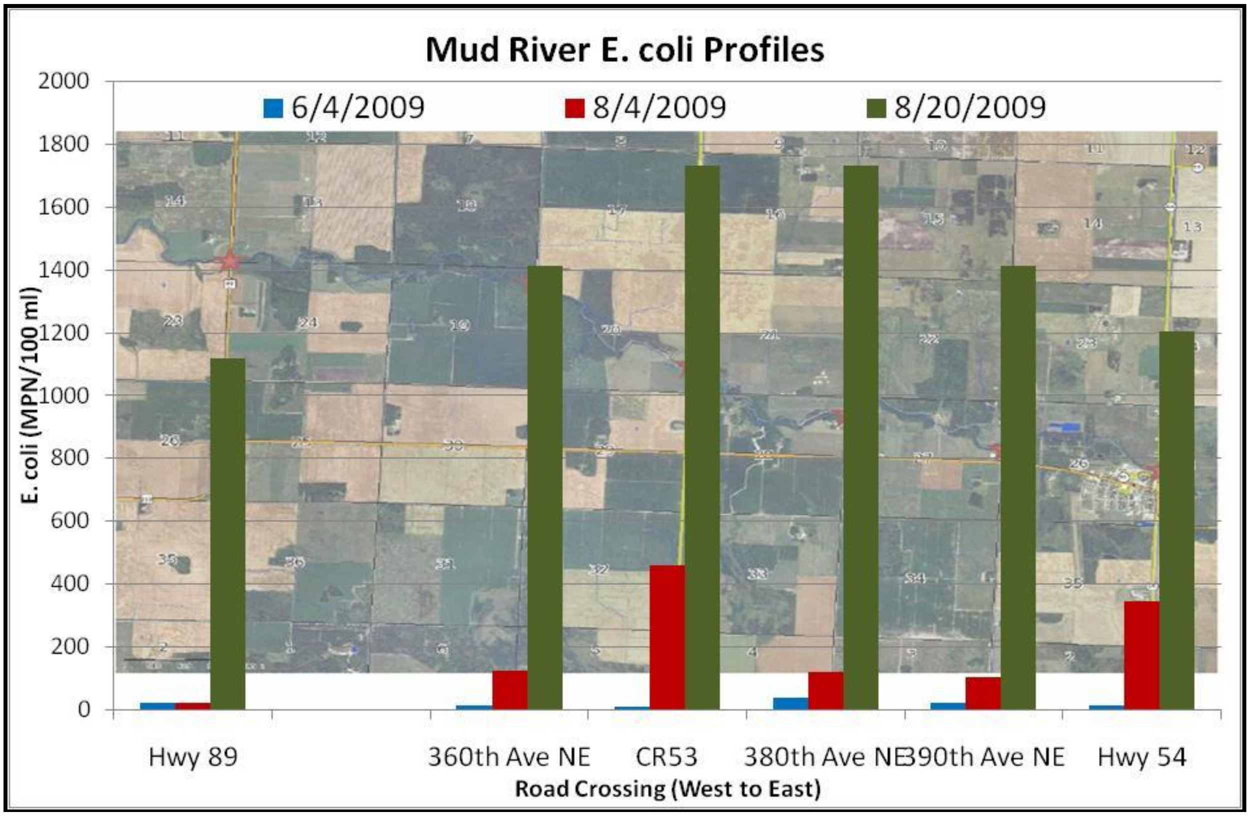


Figure 3-37. 2009 Longitudinal *E. coli* Sampling along the Mud River.

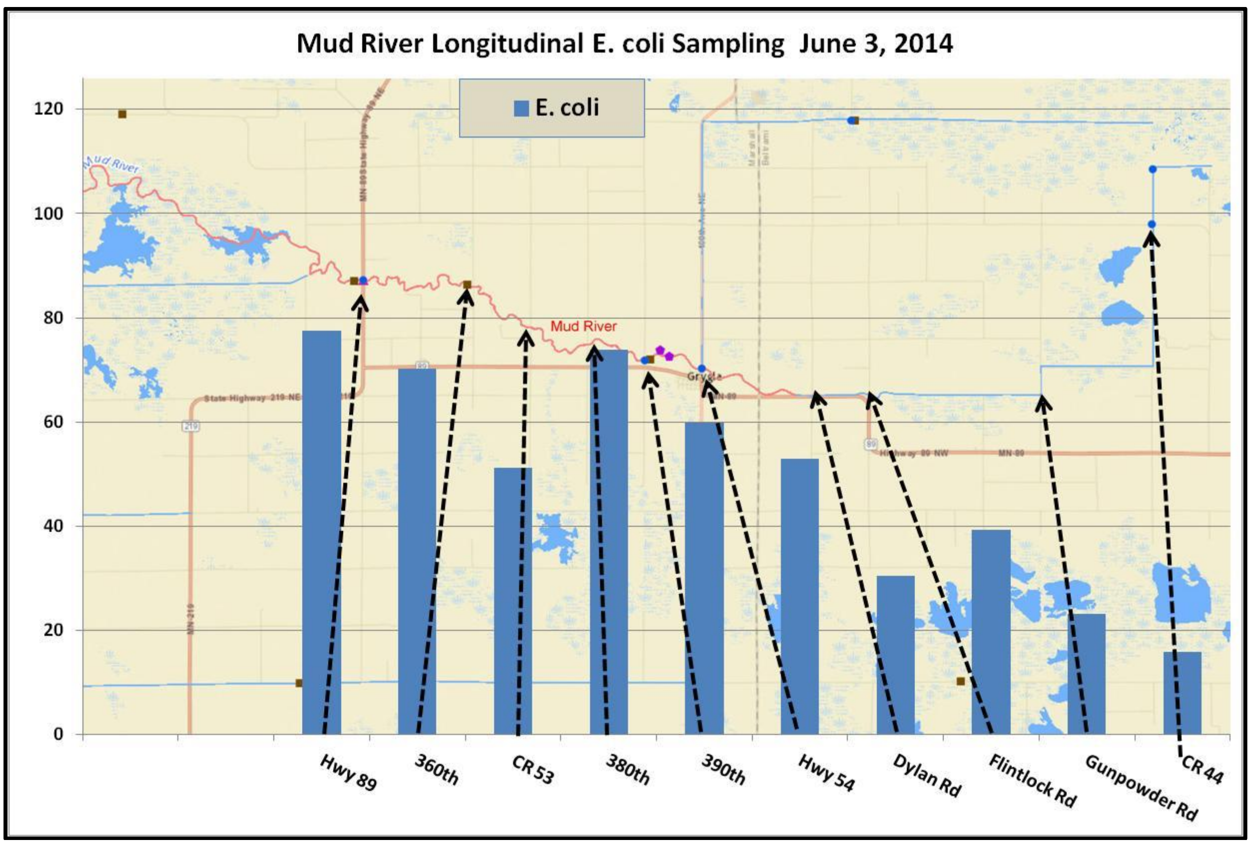


Figure 3-38. June 3, 2014 longitudinal *E. coli* sampling results along the Mud River

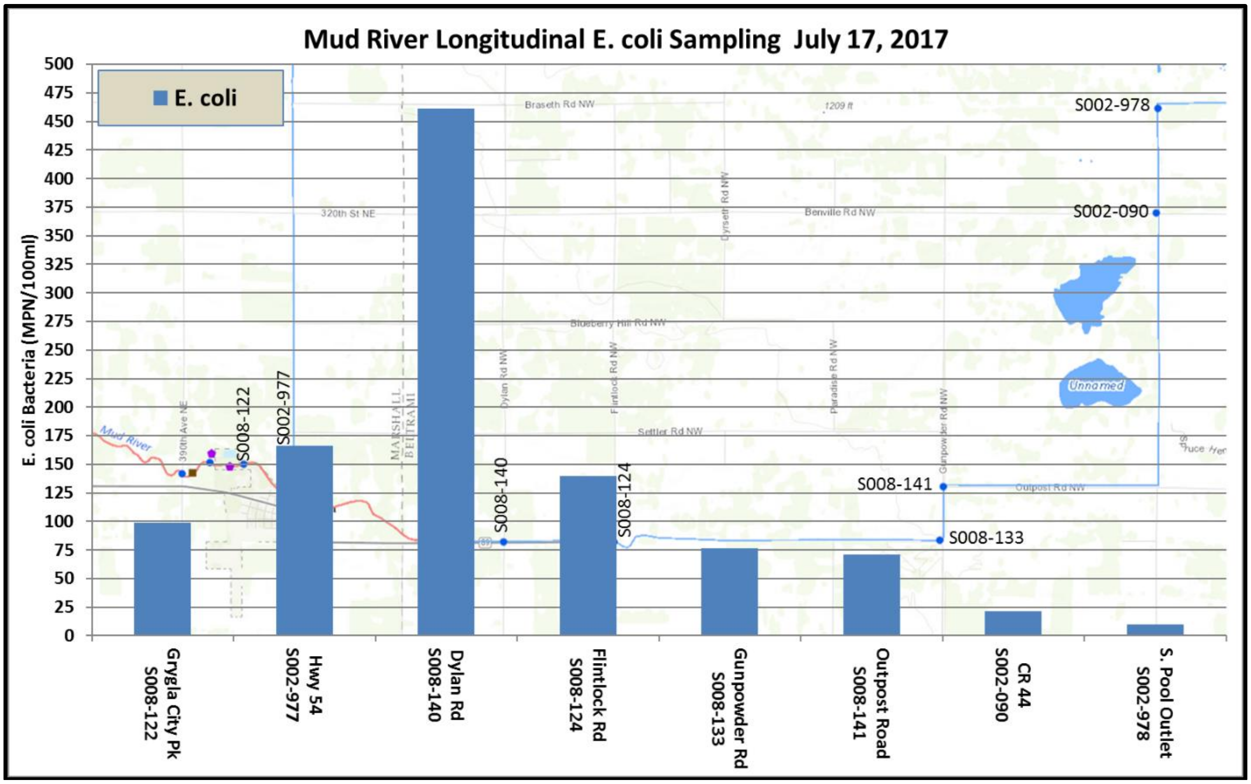


Figure 3-39. July 17, 2017 longitudinal *E. coli* sampling results along the Mud River upstream of Grygla.

3.6.3 Low Dissolved Oxygen (DO) in the Mud River

Two potential causes of low DO in the Mud River were identified, investigated further, and compared to see which is more likely to be the primary cause of the problem.

Water quality data from the Mud River was analyzed in an attempt to identify a quantifiable pollutant of concern that can be used to write a TMDL and compute load allocations (LAs) for the Mud River. A regression analysis of paired DO and pollutant concentrations for the Mud River did not identify useful relationships except for chemical oxygen demand (COD). DO levels appear to decrease as COD levels increase.

A lack of flow due to dry conditions and/or a lack of discharge from the South Pool of the Moose River Impoundment also negatively affect DO levels. Nearly all of the low daily minimum DO levels recorded in the river occur when there is a minimal amount of flow from the Moose River Impoundment (<4 CFS, see Table 3-13) and/or low flow (<15 CFS) in the Mud River at State Highway 89 (S002-078). Data analysis also indicated that the Mud River would meet the <5 mg/l water quality standard for DO in the months of May through September if at least 5 cubic feet per second (CFS) of flow is maintained in the river at the S002-078 monitoring site. In Table 3-14, the DO standard is violated at lower rates with each progressive increase in minimum flow.

Table 3-13. Mud River dissolved oxygen levels compared to Moose River Impoundment operations and flow

Analysis of All Mud River (09020304-507) Low Daily Minimum Dissolved Oxygen Levels (<5 mg/l) Low Dissolved Oxygen Record Were Compared to: Moose River Impoundment South Pool Discharge, Flow at S002-078, and Rainfall					
% of Low DO Recorded During Zero Flow	% of Low DO Recorded During <1 CFS of Flow	% of Low DO Recorded During <4 CFS of Flow	% of Low DO Recorded During <10 CFS of Flow	% of Low DO Recorded During <15 CFS of Flow	% of Low DO with Impoundment Gates Mostly Closed (<4 CFS)
14.3%	24.2%	59.3%	80.2%	91.2%	87.9%

Table 3-14. Flow-based assessment of dissolved oxygen in the Mud River

Mud River (09020304-507) Assessment of Daily Minimum Dissolved Oxygen Values 2005-2014 data from sites with >10 Measurements and >0 CFS and Unknown Flow Rates						
Site ID	DO Assessment Method	# of Daily Minimums	# of Low DO (<5 mg/l)	Low DO Rate	Average Daily Minimum	10th Percentile of Daily Minimums
All Sites	DO12_All (>0 CFS)	221	4	1.8%	9.6	7.0
	DO5_All (>0 CFS)	163	4	2.5%	8.9	6.5
	DO5_9am (> 0 CFS)	12	0	0.0%	7.9	6.2
	C+D_9am (>0 CFS)	340	66	19.4%	6.5	4.3
	C+D_9am >1 CFS	320	56	17.5%	6.6	4.3
	C+D_9am (>5 CFS)	268	24	9.0%	6.9	5.2
DO12 = All discrete dissolved oxygen measurements from all 12 months of January through December (%						
DO5 = Dissolved oxygen over the 5 summer months of May through September (% <5 mg/l)						
DO5 9am = Dissolved oxygen measurements collected during the months of May through September prior to 9am						
C+D_9am = An assessment all continuous monitoring data points from May through September that were recorded prior to 9 am and all discrete data points used for the DO5_9am assessment. The two datasets overlap on days in which both discrete and continuous measurements were recorded.						
IF = Insufficient data for a water quality assessment						

Low DO levels only occur in the Mud River when water temperatures are greater than 10 degrees Celsius. In open water conditions, sub-5 mg/l DO concentrations and average temperatures >10 degrees Celsius have only been recorded in the months of May through September. Low concentrations have been measured under the ice during a limited number of site visits. April is the month with the highest average flow rates. Water temperatures during the month of April are lower than 10 degrees Celsius, so DO levels are sufficient during that month. The daily minimum concentrations of DO, on average, are lowest in July during the open water months (Figure 3-40).

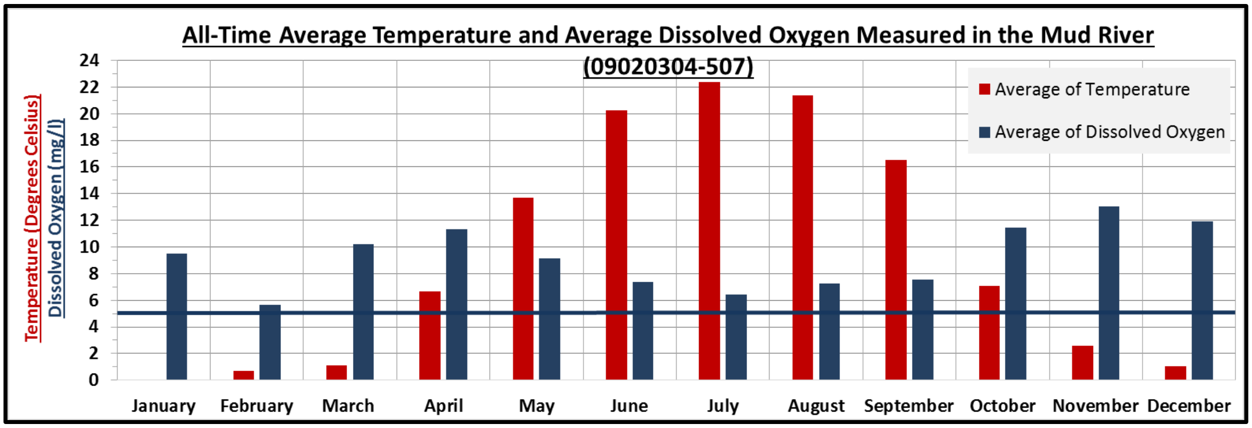


Figure 3-40. Monthly average temperatures and dissolved oxygen concentrations in the Mud River

No low DO levels have been recorded during flows of 32.43 to 184.4 CFS (top 10% to 40%) of flows (Figure 3-41). The following table shows the results of an assessment of a DO dataset that has been filtered to only include dates in May through September for which flow data exists. Results for each flow regime show that some improvement is needed in each flow regime except for "high flows." The high percentage of water quality standard violations in the low flow regimes demonstrate the negative effect that conditions of low-to-no flow within the Mud River have upon DO levels in the river. A LDC for desired DO levels (Figure 3-42) visually demonstrates the increased rate of low DO levels that occurs at lower flows.

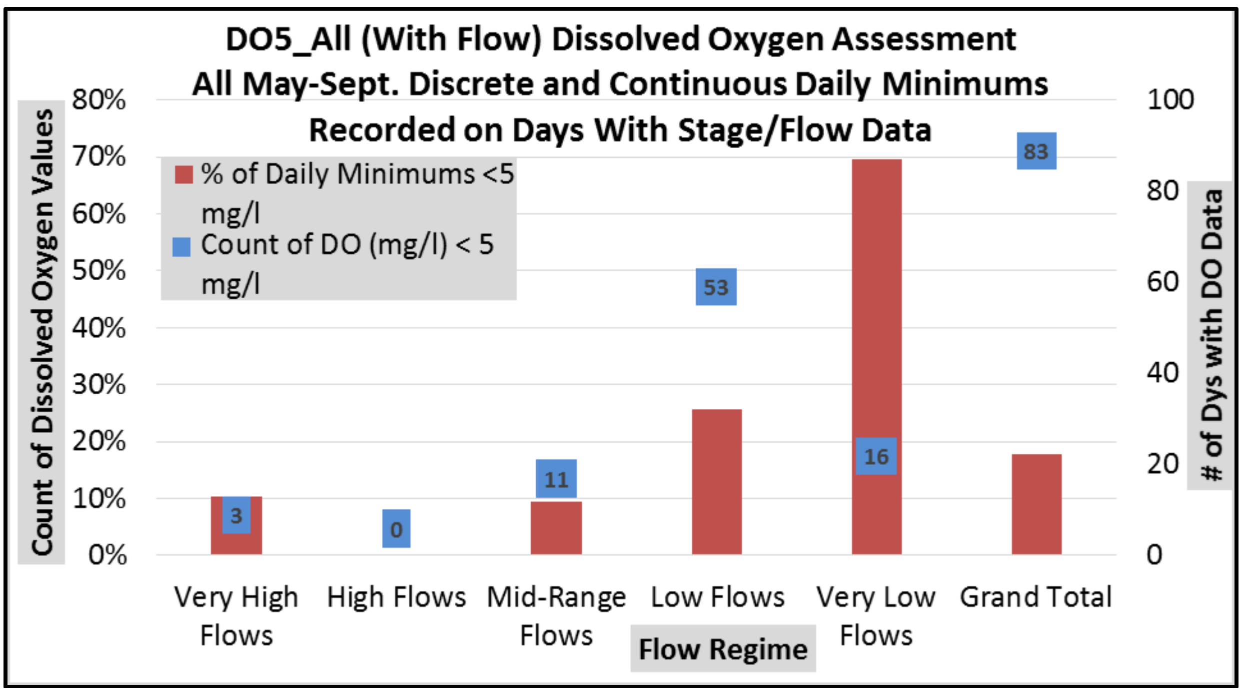


Figure 3-41. DO5_All assessment by flow regime

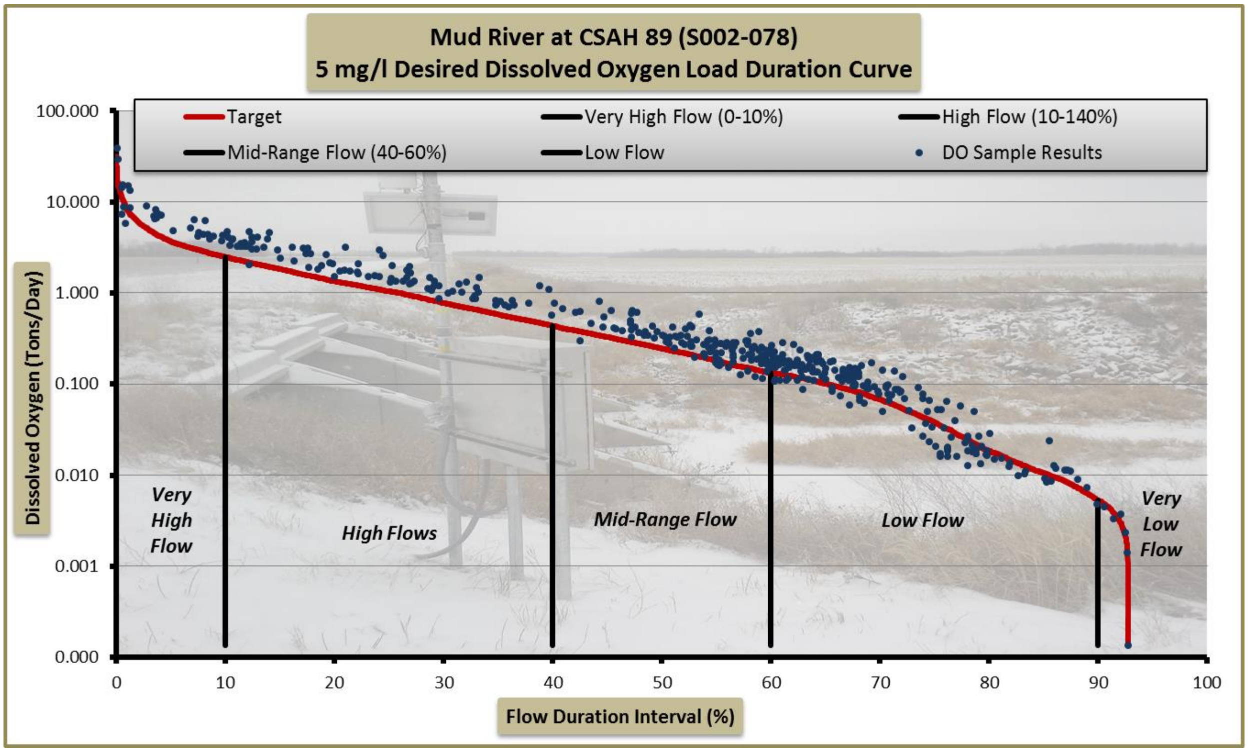


Figure 3-42. Mud River desired dissolved oxygen load duration curve

The two potential causes of the DO impairment were discussed among local and state agency staff to make a decision about how to address the Mud River DO impairment in this TMDL. Although the statistical connection with COD is a relatively good correlation between DO and a pollutant (R^2 = 0.68) compared to other TMDLs, most of the evidence (Table 3-15) pointed to lack-of-flow as the primary cause of low DO concentrations in this reach of the Mud River. Therefore, no TMDL for COD will be written. Development of a “flow TMDL” for the DO impairment (using flow as a surrogate) could be done but has not been attempted before in Minnesota. Instead, recommendations are made in the WRAPS report for the augmentation of base flows to improve DO conditions. General reductions in pollutants could reduce oxygen demand within the channel, but specific requirements are not justifiable compared to the influence of flow. Reductions of sediment and nutrients are also recommended as protection strategies in the Thief River WRAPS.

Table 3-15. A list of facts that support each candidate cause of low dissolved oxygen in the Mud River.

Weight of Evidence for Potential Causes of Low Dissolved Oxygen Levels in the Mud River (09020304-507)		
	Chemical Oxygen Demand	**Flow**
1	There is a good negative correlation between COD an Daily Minimum DO	The COD/DO correlation is based upon a limited number of samples.
2	There is a good positive correlation between COD and BOD	A precedent for a COD TMDL to address low dissolved oxygen in a river was not found.
3	WWTF that discharges water with high concentrations of BOD	The WWTF usually does not discharge during low flows.
4	There are three low DO readings that occurred during Very high flows	Violations during Very HIgh or High flows are rare.
5	Basing the TMDL upon a pollutant would provide nutrient runoff reduction benchmarks and increase the impetus for water quality improvement projects in the subwatershed.	Removing data from 2012, an abnormally dry year, improves the assessment results enough for the reach to meet the standard. Nearly 85% of the low DO levels recorded in 2005-2014
6		The reach would have been delisted without a large number of violations that occurred during the minimal flow of 2012.
7		Dissolved oxygen levels are sufficient to meet the DO standard if flow is greater than 5 CFS at Hwy 89. Removing the lowest of flows from the dataset improves the assessment results.
8		The rate of violations of the DO standard is greatest in the lowest of flow regimes.
9		A means for achieving the goal of >5 CFS has been identified (utilization of the water stored between summer and winter pool elevations)
10		After reviewing the evidence, there was a consensus among State and local/regional staff that flow should be used instead of COD.
11		The dissolved oxygen water quality standard is met if only measurements taken during >5 CFS of flow are included in the assessment.

3.6.3.1 Permitted Sources

No water allocation/appropriation regulations have been applied to the Mud River. Discharge rarely occurs during periods of low flow. A pollutant-based TMDL is not being written to address this impairment.

3.6.3.2 Non-permitted Sources

Flow rates outside of runoff events are heavily influenced by the operation of the outlet of the South Pool of the Moose River Impoundment. The impoundment is managed by the RLWD under the authority provided in Minn. Stat. ch. 103D. Flow from the Moose River Impoundment is minimal after the summer pool elevation is reached.

The land in the Mud River Watershed is extensively drained. Agricultural drainage can reduce infiltration and negatively affect base flows. Some research suggests that subsurface drainage, a popular practice in the Mud River Watershed, could have some positive effect upon base flows. Some branches of JD 11 are draining areas that are not used for agriculture. The water quality is excellent in those ditches because they are draining land that has been minimally disturbed. However, that drainage may be limiting the amount of infiltration that may be occurring in those areas. A better understanding of soils and groundwater patterns in the area through further study could help lead to improvements in water storage and more natural base flow augmentation.

3.6.4 Low Dissolved Oxygen (DO) due to Lack of Flow in the Moose River

Analysis of existing water quality data for the Thief River WRAPS project failed to reveal a usable, negative correlation between a pollutant concentration (e.g. TP, COD, etc.) and DO concentrations within the Moose River Subwatershed. Data indicates that the Moose River DO impairment is primarily caused by a lack of base flow. Loads were not calculated for this TMDL because the most likely cause of the impairment is not a pollutant.

Most of the DO readings that were available for the 2005 water quality assessment that led to the 2006 impairment listing were collected at the Highway 89 crossing of the Moose River (S002-089) where gradient is low and water can become stagnant. The gradient of the Moose River is greater upstream at the CSAH 54 crossing (S004-211). Only two discrete DO readings below 5 mg/l have been recorded at the CSAH 54 crossing during the most recent 10 years of monitoring (2005 through 2014).

Moose River DO measurements (discrete measurements and daily minimums from the continuous data) were also plotted on a chart along with a flow duration curve in order to visualize the relationship between flow and DO. A flow duration curve (Figure 3-43) was created by calculating the probability of exceedance of all of the measured levels of flow at S004-211. The probability of exceedance of a flow level of zero was approximately 81%. Daily minimum DO measurements were matched with daily average flow and flow exceedance probability values using date values. Flow data was available for many, but not all of the dates in which DO was measured. Many of the violations of the DO standard appeared to occur when there was no measurable flow in the river at the CSAH 54 (S004-211) monitoring site (red box on Figure 3-37). Violations of the DO standard appeared to be much less frequent during higher flows. The channel of the Moose River is still holding stagnant water at the sampling reference points at CSAH 54 (S004-211) and Highway 89 (S002-089) when flows fall to zero CFS. At CSAH 54, the channel is shallower downstream than it is near the culvert where samples, discrete field measurements, and DO logger deployments were conducted. At Highway 89, the Moose River is influenced by the Thief Lake Dam. The channel was deeply dredged in the early 20^{th} century and is now ponded by backwater from Thief Lake whether there is measurable flow or not. Figure 3-47 shows the flat gradient upstream of Thief Lake.

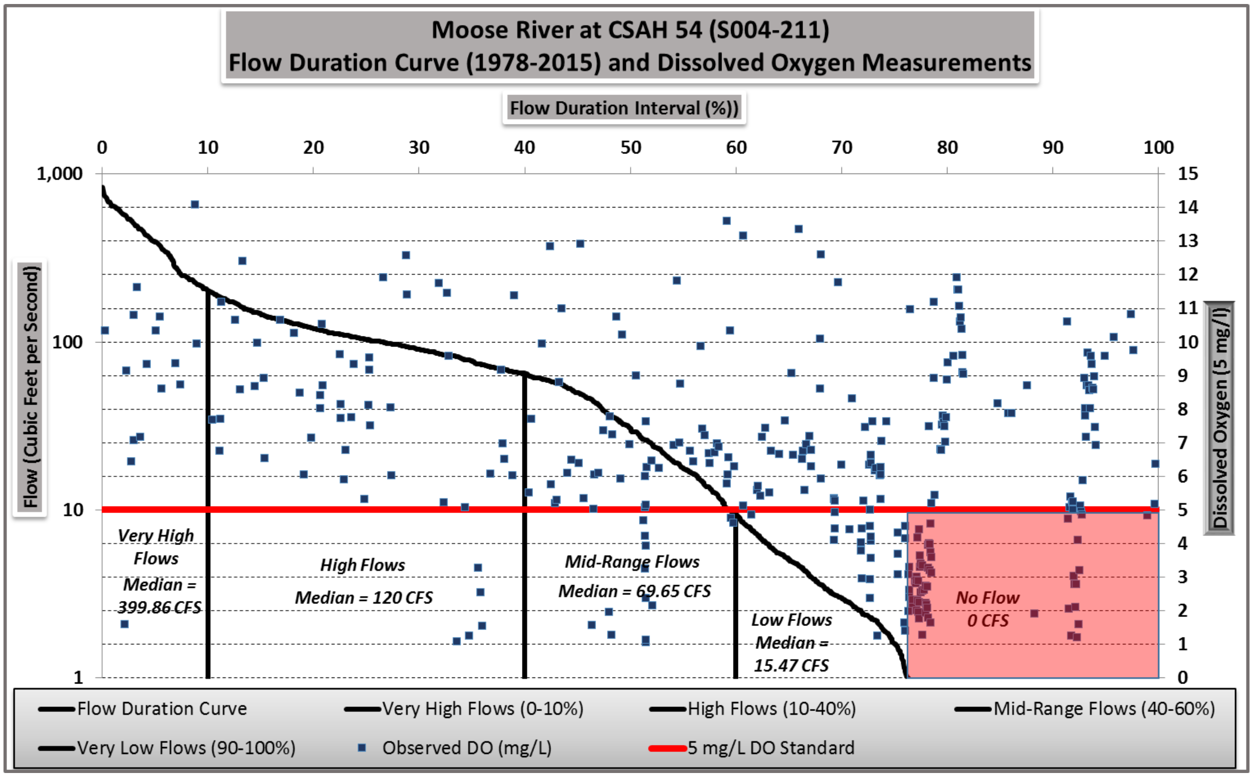


Figure 3-43. Moose River flow duration curve and dissolved oxygen measurements

An assessment of a subset of DO measurements that includes days in which flow was known to be greater than 0 CFS yielded satisfactory results. This analysis found that the free-flowing portions of the river meet the standard as long as there is some measurable flow in the channel.

The dataset used for the analysis consisted of all discrete, in-situ measurements recorded and stored in the State's EQuIS water quality database. It also included continuous DO data collected at CSAH 54 crossing of the Moose River (S004-211) in 2009 and 2012. Continuous DO data was reviewed and edited with Aquarius software to ensure that only high-quality data was used to assess water quality conditions. Daily average flow values from continuous and discrete stage records were used to calculate flow values for as many of the DO measurements as possible. Daily DO and flow data were combined.

The DO data from the Moose River seems to meet the State water quality standard (<10% of the measurements are less than 5 mg/l) when the following conditions are met.

- Flow is known to be greater than 0 CFS at the CSAH 54 crossing of the Moose River (S004-211).
- Data from the ponded 300th Ave crossing (S006-539) is excluded from the analysis. The S006-539 site is not representative of most of the Moose River channel.

In the tables below, subsets of the data from the Moose River were analyzed to learn more about the influence of flow upon DO values. The 2005 through 2014 discrete data was filtered so that it did not include site S006-539 where water is ponded and the channel is essentially an extension of Thief Lake. Five of the nineteen daily minimum values recorded in the ponded water at site S006-539 were lower than the 5 mg/l DO standard. Therefore, removing that site from the analysis has a significant impact upon the assessment results. Data was then filtered to only include the days with flow greater than zero. After filtering the dataset in this manner, the frequency at which the DO standard was violated decreased to acceptable levels.

Note that discrete and continuous data sets overlap. The number of daily minimums in the "Discrete and Continuous" category in Table 3-16 will not equal the sum of the "Discrete" and "Continuous" categories because there are some days in which both discrete and continuous data were collected. Those days in which both DO (at any site other than S006-539) and stage/flow (at CSAH 54) were recorded form a subset of the entire DO dataset. The days in which there was flow and flow was greater than zero form another, smaller subset.

Table 3-16. Moose River Flow-Based 2005-2014 Dissolved Oxygen Assessment, all sites except S006-539

Moose River Flow-Based 2005-2014 Dissolved Oxygen Assessment

All sites except S006-539 (Thief Lake Inlet). Continuous data from 2009 and 2012 at site S004-211 (CSASH 54). Flow recorded at site S004-211.

Dissolved Oxygen Data was filtered for seasons and flow.		All Daily Minimum DO Values			All Days with both Minimum DO and Average Flow Values			Daily Minimum DO from Days with Flow > 0 CFS		
		Total #	# < 5 mg/l	Rate (%)	Total #	# < 5 mg/l	Rate (%)	**Total #**	**# < 5 mg/l**	**Rate (%)**
DO12_All	Discrete Data	132	10	7.6%	107	7	6.5%	64	2	3.1%
	Continuous Data	157	65	41.4%	88	13	14.8%	35	2	5.7%
	Discrete & Continuous	265	73	27.5%	171	18	10.5%	91	4	4.4%
DO5_All	Discrete Data	98	9	9.2%	79	6	7.6%	46	2	4.3%
	Continuous Data	143	65	45.5%	74	13	17.6%	31	2	6.5%
	Discrete & Continuous	220	72	32.7%	132	17	12.9%	70	4	5.7%
DO5_9am + Any May-Sept. <5	Discrete Data	11	9	81.8%	7	6	IF	2	2	IF
	Continuous Data	140	65	46.4%	71	13	18.3%	28	2	7.1%
	Discrete & Continuous	149	72	48.3%	76	17	22.4%	30	4	13.3%
DO5_9am Only	Discrete Data	2	0	IF	1	0	IF	0	0	IF
	Continuous Data	140	65	46.4%	71	13	18.3%	28	2	7.1%
	Discrete & Continuous	147	65	44.2%	76	13	17.1%	28	2	7.1%

DO12 = All discrete dissolved oxygen measurements from all 12 months of January through December (% of daily minimums < 5 mg/l)
DO5 = Dissolved oxygen over the 5 summer months of May through September (% <5 mg/l)
DO5 9am = Dissolved oxygen measurements collected during the months of May through September prior to 9am plus any low readings observed during those months (daily minimum would definitely fall below 5 mg/l if any measurement during the day is <5 mg/l).
IF = Insufficient data to conduct an assessment

The frequency at which the DO standard is violated is further decreased, as shown in Table 3-17, if analysis is limited to the free-flowing CSAH 54 monitoring site (S004-211).

Table 3-17. Assessment of dissolved oxygen conditions at the CSAH 54 crossing of the Moose River (S004-211) with and without flow.

Moose River Flow-Based 2005-2014 Dissolved Oxygen Assessment at Site S004-211

Continuous data from 2009 and 2012 at site S004-211. Discrete data from site 2004-211 from 2005 through 2014. Flow recorded at site S004-211.

Dissolved Oxygen Data was filtered for seasons and flow.		All Daily Minimum DO Values			All Days with both Minimum DO and Average Flow Values			Daily Minimum DO from Days with Flow > 0 CFS		
		Total #	# < 5 mg/l	Rate (%)	Total #	# < 5 mg/l	Rate (%)	**Total #**	**# < 5 mg/l**	**Rate (%)**
DO12_All	Discrete Data	84	2	2.4%	78	2	2.6%	42	1	2.4%
	Continuous Data	157	65	41.4%	88	13	14.8%	35	2	5.7%
	Discrete & Continuous	219	66	30.1%	144	14	9.7%	70	3	4.3%
DO5_All	Discrete Data	64	2	3.1%	60	2	3.3%	31	1	3.2%
	Continuous Data	143	65	45.5%	74	13	17.6%	31	2	6.5%
	Discrete & Continuous	188	66	35.1%	115	14	12.2%	56	3	5.4%
DO5_9am Only	Discrete Data	2	0	IF	1	0	IF	0	0	IF
	Continuous Data	152	64	42.1%	84	13	15.5%	32	2	6.3%
	Discrete & Continuous	154	64	41.6%	85	13	15.3%	32	2	6.3%
DO5_9am + Any May-Sept. <5 mg/l	Discrete Data	4	2	50.0%	3	2	66.7%	1	0	IF
	Continuous Data	153	65	42.5%	84	13	15.5%	32	2	6.3%
	Discrete & Continuous	156	66	42.3%	86	14	16.3%	32	2	6.3%

DO12 = All discrete dissolved oxygen measurements from all 12 months of January through December (% of daily minimums < 5 mg/l)
DO5 = Dissolved oxygen over the 5 summer months of May through September (% <5 mg/l)
DO5 9am = Dissolved oxygen measurements collected during the months of May through September prior to 9am
IF = Insufficient data to conduct an assessment

3.6.4.1 Permitted Sources

There are no permitted wastewater discharges within this watershed. No pollutant-based TMDLs have been written. No water allocation/appropriation permits have been issued to withdraw water from the Moose River.

3.6.4.2 Non-permitted Sources

Low DO levels in the Moose River are found in the summer months of June through September and under the ice in winter months. Under the ice in the winter, water becomes stagnant and low in DO. Winter fish kills have occurred along the Moose River and its tributary ditch, Branch A of JD 21 when suckers get trapped in the upper reaches during the winter and are eventually frozen into the ice.

Moose River DO levels have been acceptable during the spring when water temperatures are cool and there is sufficient flow during the most recent 10 years. The rate at which low DO levels are recorded in the Moose River during the open-water season increases during the summer months and peaks in August (Figure 3-44). Warmer water temperature and more stagnant flow (Figure 3-45) likely contribute to the problem during the late summer. Flows in the Moose River are also low in August (Figure 3-45).

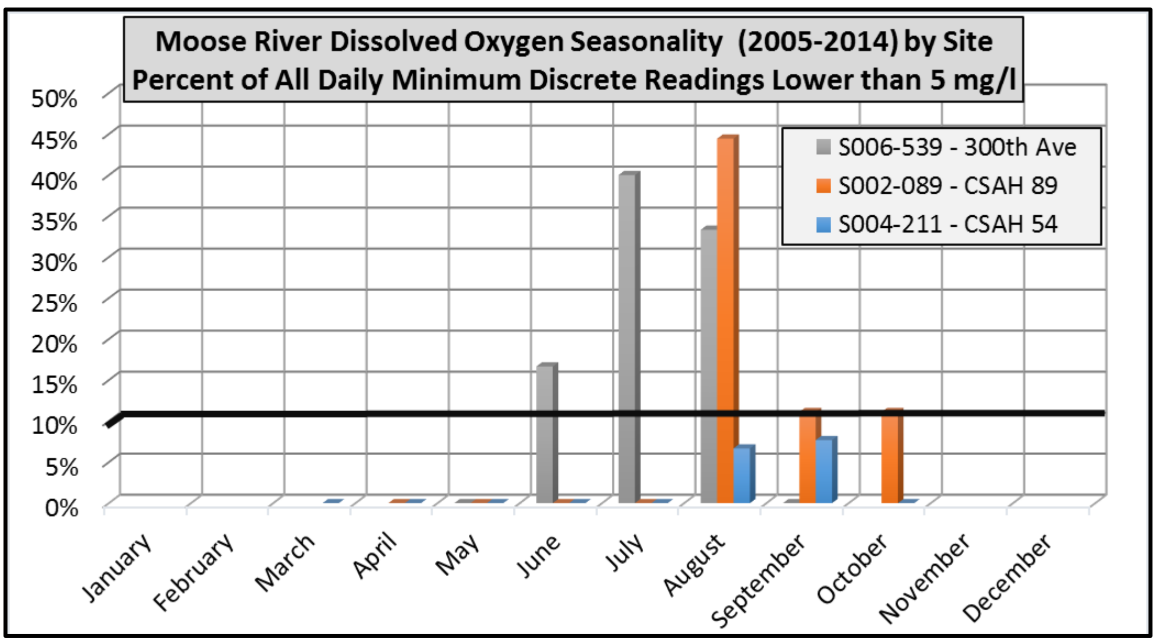


Figure 3-44. Site-specific seasonality of dissolved oxygen along the Moose River.

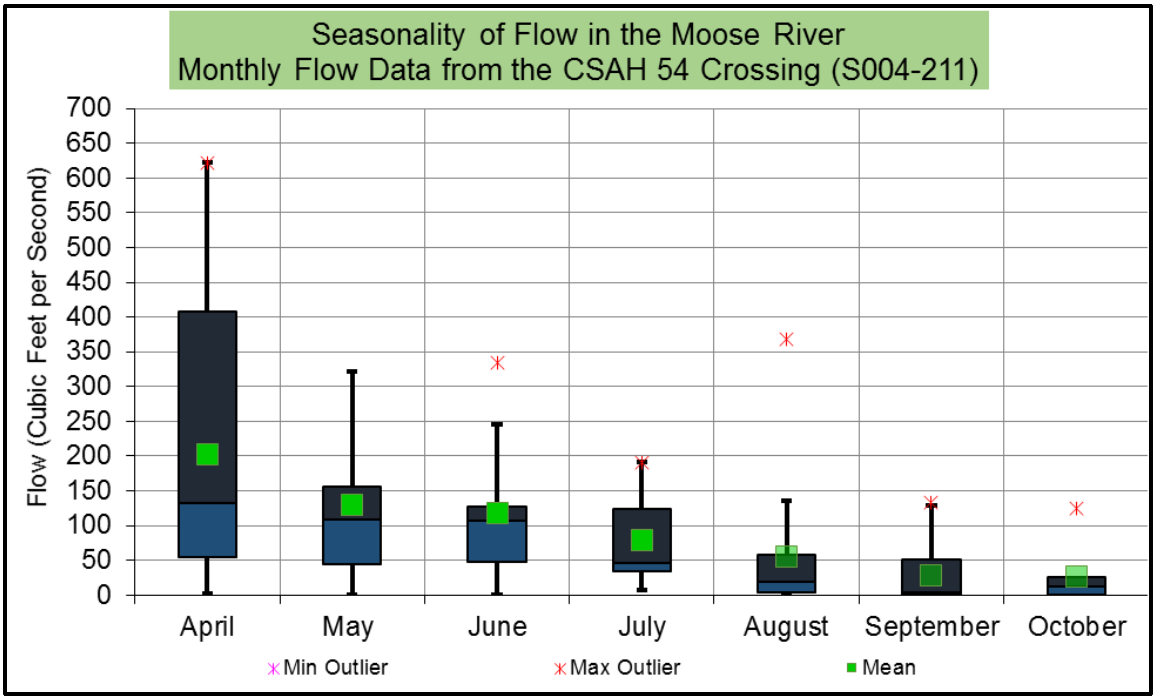


Figure 3-45. Seasonality of flow in the Moose River - an analysis of monthly flow data from the CSAH 54 (S004-211) monitoring site.

There are conditions in the Moose River drainage area that contribute to low DO levels. Spatially, data shows that low DO readings occur most frequently at the sites on the lower, western end of the reach where water is more stagnant and ponded within the channel due to historical dredging of the channel and backwater from Thief Lake (Figure 3-46). Early 1900s newspapers describe broad marshes along Thief River tributaries prior to the drainage project that created JD 21 (Moose River). Currently, the Moose River begins at the outlet of the Moose River Impoundment, a very large wetland. Toward the lower end of the reach, the gradient of the river flattens as it enters the Thief Lake WMA (Figures 3-47 and 3-48).

Figure 3-46. Ponded water at the 300th Ave NE crossing of the Moose River. Note the pondweed accumulating in the photo on the right.

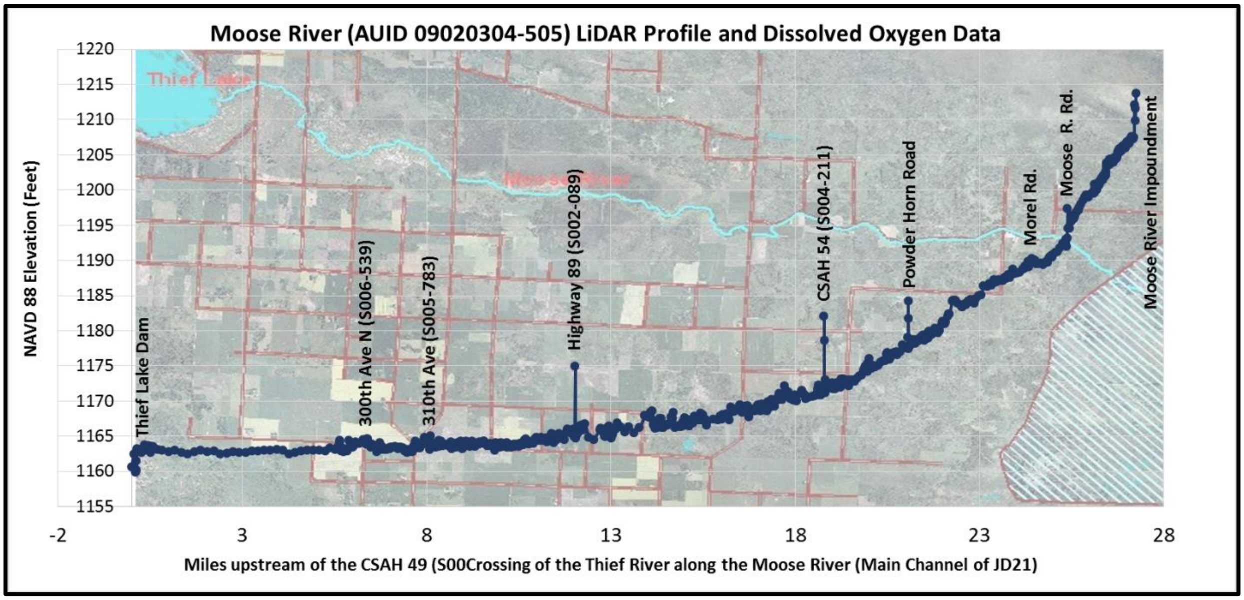


Figure 3-47. Moose River elevation profile (data generated using the International Water Institute LiDAR Viewer website)

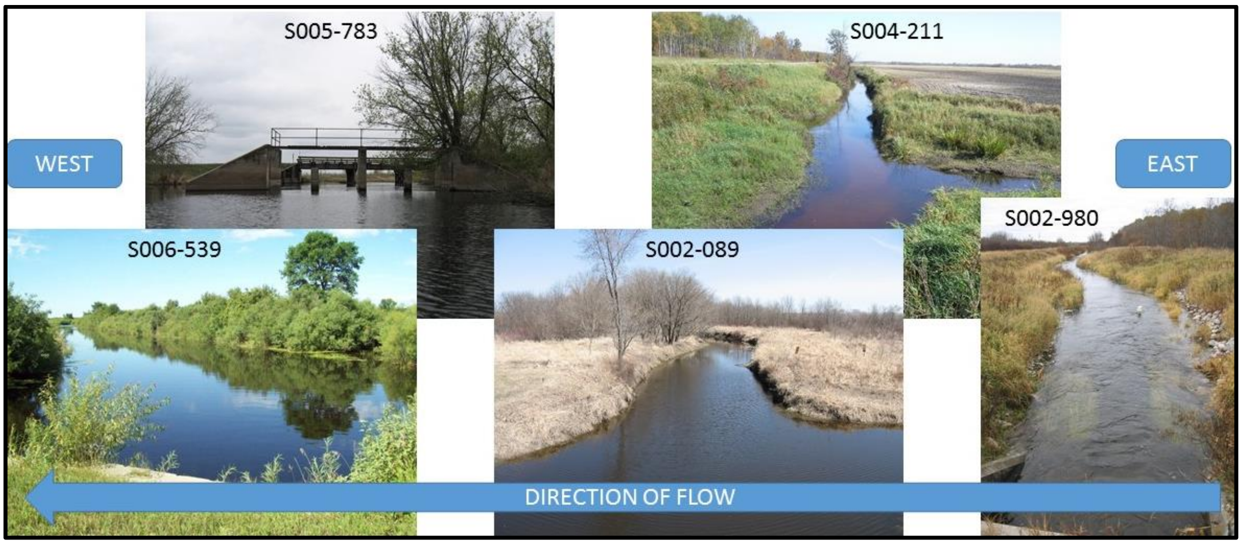


Figure 3-48. Photos of monitoring sites along the Moose River showing changes in slope and channel depth.

The percentage of DO values that violate the standard exceeds the 10% impairment threshold at the two significant monitoring sites that are influenced by Thief Lake backwater (S006-539 and S002-089), but not at the free-flowing CSAH 54 (S004-211) monitoring site. Longitudinal measurements made on the same day show significant differences in DO levels throughout the reach (Figure 3-49). DO levels have been satisfactory at the outlet of the Moose River impoundment.

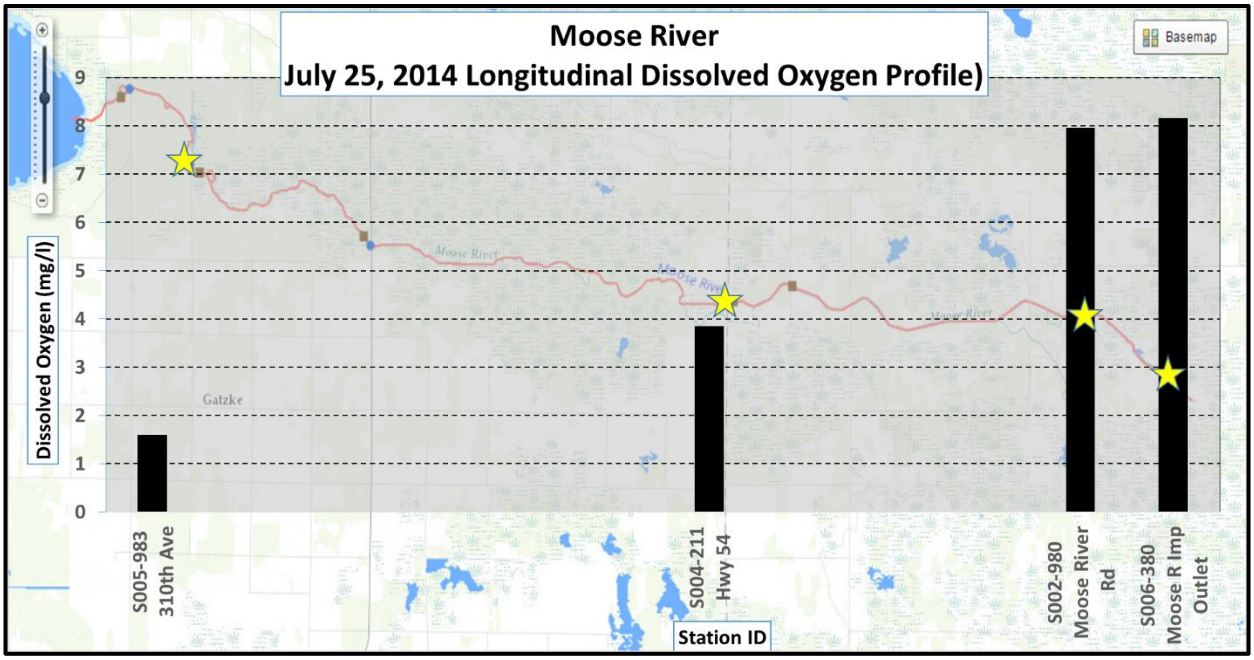


Figure 3-49. Snapshot of longitudinal dissolved oxygen concentrations along the Moose River.

All the low DO levels recorded in the most recent 10 years of monitoring were compared to flow levels at CSAH 54, rainfall amounts, and the amount of discharge at the outlet of the Moose River Impoundment. At least 86% of the low DO levels occurred while there was low flow or no flow in the river. More than 97% of the low DO readings occurred while the impoundment's gates were closed or were allowing only a minimal amount of discharge (<2 CFS). In one case, continuous DO logger data revealed that discharge from the impoundment appeared to improve DO levels at CSAH 54 (S004-211). On July 25, 2012, DO levels were very low (1.85 mg/l) in the early morning hours. It rained that day and the gates were opened at 9:30 a.m. DO levels improved to acceptable levels in time for the 9:00 a.m. reading (5.45 mg/l).

To adequately protect aquatic life, future planning of the operation of the Moose River impoundment needs to consider maintenance of base flow in the operation plan of the impoundment's outlet. Water can be slowly released throughout the late summer months. Considerations include:

- There is no set date for when gates are closed and flow is restricted in the late summer. The timing is based on coordination with other pools (Thief Lake, Agassiz Pool) in the watershed.
- Reasons for the summer pool elevation:
    - Nesting: Nesting is usually done by the end of July, when gates are typically closed.
- There is a 1,200 acre-feet (52,272,000.5322 ft^3) difference (2,000 acft. minus 800 acft.) in the amount of storage between the summer pool and winter pool levels in the north pool.
- According to hydrographs, flow in the Moose River drops significantly in the beginning of August (Figure 3-50). Supplemental flow could start in August.
- The Moose River Impoundment has been drawn down to the winter pool target elevation in late October over a short period of time (eight to nine days).
- There is a total of 92 days (7,948,800 seconds) from August 1st through October 31st.

- Without factoring in evapotranspiration or rainfall, a constant flow of 6.576 CFS would drain the 1,200 acre feet of storage between the summer and winter pools over a period of 92 days.
- There will be dry years, like 2012, when there is not enough water available.
- On typical years, there should be a sufficient supply of water within the North Pool of the Moose River Impoundment to supplement base flow in the Moose River through the months of August, September, and October.

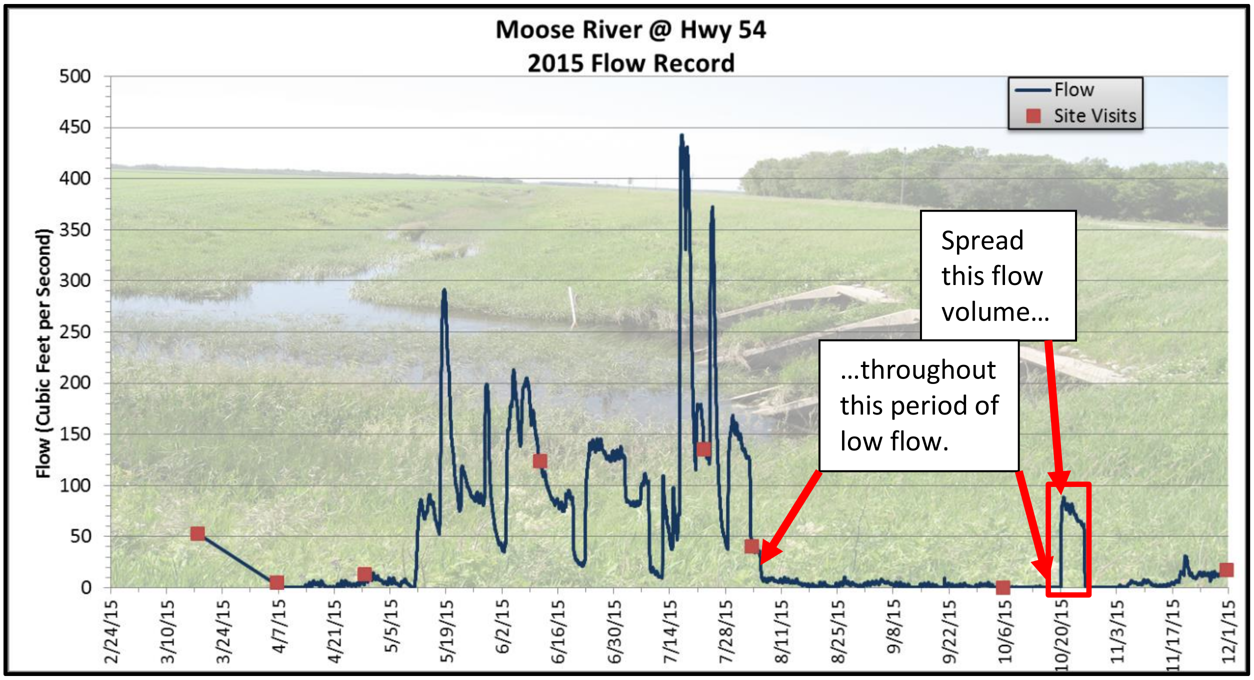


Figure 3-50. Moose River hydrograph and proposed remedy for low flows and low dissolved oxygen.

Sediment and nutrient reduction goals will still help improve conditions for aquatic life and recreation, even though they are not part of the TMDL. Strategies to address pollutants and improve aquatic habitat in the Moose River Subwatershed are identified in the Thief River WRAPS.

4. TMDL Development

TMDLs are developed based on the following equation:

TMDL = LC = ∑WLA + ∑LA + MOS + RC

Where:

LC = loading capacity, or the greatest amount of a pollutant a waterbody can receive and still meet water quality standards;

WLA = Wasteload allocation, or the portion of the loading capacity allocated to existing or future permitted point sources;

LA = load allocation, or the portion of the loading capacity allocated for existing or future nonpoint sources and natural background sources;

MOS = margin of safety, or accounting for any uncertainty associated with attaining the water quality standard. The MOS may be explicitly stated as an added, separate quantity in the TMDL calculation or maybe implicit, as in a conservative assumption (EPA 2007);

RC = reserve capacity, or the portion of the TMDL that accommodates for future loads;

4.1 Total Suspended Solids in the Thief River (AUID 09020304-501)

4.1.1 Loading Capacity Methodology

The EPA defines loading capacity as “the greatest amount of loading that a water can receive without violating water quality standards.” The loading capacity provides a reference that helps guide pollutant reduction efforts needed to bring a water into compliance with the standards. The LDC method is based upon an analysis that encompasses the cumulative frequency of historic flow data over a specified period. Because this method uses a long-term record of daily flow volumes the full spectrum of known allowable loading capacities is represented by the resulting curve. The entire LDC represents the TMDL and is what is ultimately approved by the EPA. In this case, a long history of flow data is available from a USGS gauging station (05076000 near S002-079). In the TMDL summary table for this reach (Table 4-1), five points on the LDC are depicted (the midpoints of the designated flow zones). The lowest flow regime (90% to 100% exceedance probability) is typically labeled “very low.” In the Thief River, more than 10% of the daily average measured flows have been zero CFS. Therefore, the “low flow” regime smaller than the typical 30% that it comprises (60% to 90%) and the “very low (no flow)” regime is larger than its typical 10% in the Thief River TMDL. The median flow of each “low flow” regime is the median flow within the range of non-zero flows that have an exceedance probability greater than 60%. The median flow of each “very low (no flow)” flow regime is zero because every flow value is zero within those regimes.

Average daily flow records for the Thief River at the 05076000 USGS gauging site (S002-079 water quality monitoring station) were compiled. Flows were ranked from highest to lowest. Average daily flow values were assigned a flow rank value. The probability of exceedance of each average daily flow value was calculated as a percentage. A flow duration curve was created by plotting probability of exceedance (X-axis) against the flow level (logarithmic Y-axis). Using the allowable concentration of 30 mg/l, flow duration curve data, and conversion factors, an LDC (Figure 4-1) was developed to show the allowable tons per day of sediment for each level of flow along the curve. The LDC data was used to determine the median loading capacity for each flow regime. The median load for the "low flow" regimes was calculated in a manner similar to the median flow level calculation that is described in the previous paragraph. Loads for each "very low (no flow)" regime are zero because all flow values in those regimes are zero.

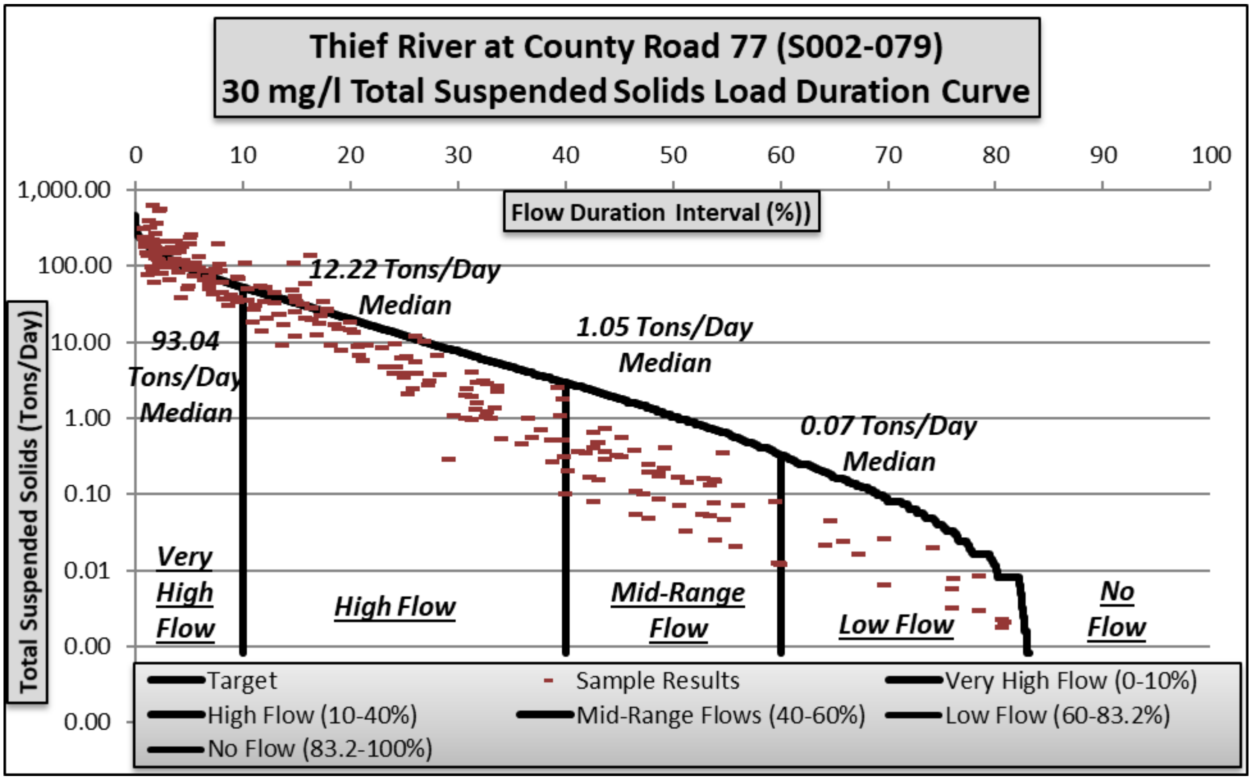


Figure 4-1. Thief River at County Road 77 (S002-079, USGS gauge 05076000) Total Suspended Solids Load Duration Curve (30 mg/l Standard)

4.1.2 Load Allocation Methodology

Portions of the total loading capacity were reserved for WLAs (if any), reserve capacity, and a MOS. The remaining loading capacity for each flow regime is the LA. The LA includes nonpoint pollution sources that are not subject to permit requirements, as well as natural background sources of sediment from upland areas and in-channel sources.

The EPA does not require the specification of natural background sources in a TMDL report, but existing reports were reviewed in an attempt to find information that could be used to create separate allocations for natural background and nonpoint sources. The primary focus of water quality research in the watershed has been upon anthropogenic sources. That research has been successful in connecting anthropogenic sources of pollutants with excessive TSS and turbidity. Insufficient research; however, has been conducted within the watershed for the purpose of defining or allocating natural background sources. The St. Croix Watershed Research Station analyzed sediment cores from Agassiz Pool, but the analysis of sedimentation rates was limited to the history of the refuge (post-1940) and did not determine pre-settlement rates. “Because Agassiz Pool had been drained and extensively farmed prior to creation of the Refuge, the early (pre-Refuge) part of the sediment record has largely been destroyed, thus the dating efforts focused on post-Refuge history.” (Schottler 2011, p. 4)

Under Minnesota’s CWLA, natural background is defined as: “*Natural background” means characteristics of the waterbody resulting from the multiplicity of factors in nature, including climate and ecosystem dynamics, that affect the physical, chemical, or biological conditions in a waterbody, but does not include measurable and distinguishable pollution that is attributable to human activity or influence. (Minn. Stat. 114D.15, 2006)*

Natural background and natural sources are important considerations. Natural background levels of sediment should be considered during implementation as better information becomes available. The estimation of pre-settlement sediment loading would be challenging due to the altered hydrology of the watershed. River channels, drainage flow paths, and impoundments have been constructed and have been incorporated into existing water quality models. Estimation of current natural background loading could be more feasible as modeling tools are further developed. HSPF modeling tools are being developed to facilitate the modeling of BMP implementation. A best-case scenario could possibly be tested with the HSPF model by simulating the effect of a 100% implementation of BMPs throughout the watershed upon water quality in existing flow paths.

Additionally, Minn. R. ch. 7050, Waters of the State defines natural causes as: *“Natural causes” means the multiplicity of factors that determine the physical, chemical, or biological conditions that would exist in a waterbody in the absence of measurable impacts from human activity or influence.* (Minn. R. 7050.0150, subp. 4N)

The current loading estimates were calculated by finding the average TSS concentration for each flow regime with the help of a LDC. TSS data collected during the years of 2005 through 2014 (most recent 10 years) was used to assess and represent current conditions at S002-079. Flow rates and flow regime values were assigned to each average daily TSS data point. Average TSS concentrations were calculated for each flow regime. Load reduction recommendations for each flow regime were calculated by subtracting the LA from the current load.

4.1.3 Wasteload Allocation Methodology

There are no WWTFs, MS4s or other regulated stormwater that discharge directly to this AUID. The only WWTF in the total drainage area of this AUID discharges to the Mud River in Grygla. It is separated from this reach of the Thief River by Agassiz Pool.

Regulated Construction and Industrial Stormwater

NPDES-permitted construction stormwater must be given a WLA for TMDLs that are established for TSS and other pollutants. Industrial stormwater must also receive a WLA if facilities are present in the drainage area of an impaired AUID. The Industrial Stormwater Multi-Sector General Permit is also utilized by the MPCA to manage compliance with a TMDL. The MPCA has issued construction and industrial NPDES permits within each of the counties through which the Red Lake River flows. Construction and industrial activity comprise a small percentage of the land area in the watershed, so the allocations for these two activities were combined in the WLA calculations for this TMDL. Construction permitting data from Marshall, Pennington, and Beltrami Counties were acquired from the

MPCA. Those are the three counties that encompass the drainage area of the Thief River. Beltrami County permitting is heavily influenced by the city of Bemidji, which lies within the Mississippi River watershed and isn't relevant to this rural watershed TMDL. The stormwater permits from the city of Bemidji (76% of the permits and 72% of the permitted area in the county) were removed from the Beltrami County permitted acreage. The remaining permits were used to more representatively calculate the Beltrami County portion of the Thief River construction and industrial stormwater WLA. For each county, industrial stormwater LAs were estimated by using land area percentages that were identical to the percentage that were calculated for construction stormwater permits. The average annual acreage was calculated by dividing the total acreage under construction by the number of unique start date years. That average annual acreage within each county was divided by the total acreage of the county to calculate the density of construction stormwater activity as a percentage of land area (Table 4-1) that was applied to the loading capacity (LC) using the following equation:

Construction and Industrial Stormwater WLA = (% of Land Area) x (LC – MOS)

Table 4-1. Calculation of construction and industrial stormwater land use percentages

Thief River at S002-079 Stormwater WLA calculations	Pennington County	Marshall County	Beltrami County	Totals
Construction Stormwater - Avg. Annual Land Area (ac)	39.02	45.60	45.62	130.24
Total County Land Area (ac)*	395,520	1,160,320	1,955,840	3,511,680
Construction Stormwater as a % of Land Area	0.010%	0.004%	0.002%	0.004%
Industrial Stormwater % (= Const. Stormwater %)	0.010%	0.004%	0.002%	0.004%
Total % Industrial and Construction Stormwater WLA	0.020%	0.008%	0.004%	**0.008%**

4.1.4 Margin of Safety

The statute and regulations require that a TMDL include a MOS to account for any lack of knowledge concerning the relationship between load and WLAs and water quality (CWA §303(d)(1)©, 40 C.F.R. §130.7©(1)). An explicit MOS equal to 10% of the loading capacity was applied to each flow regime. The explicit 10% MOS accounts for:

- Uncertainty in the observed daily flow record
- Uncertainty in the observed water quality data.
- Allocations and loading capacities are based on flow, which varies from high to low. This variability is accounted for using the five flow regimes and the LDCs.
- The variability in pollutant concentrations at any given flow.
- Heterogeneity of pollutants throughout the water column.

The large amount of water quality and flow data that has been collected in the watershed contributes to confidence in the TMDL calculations. Due to the high level of confidence in the data, there does not appear to be a need for an MOS that is greater than the 10% fraction that has been commonly used in comparable TMDLs in the State of Minnesota.

4.1.5 Seasonal Variation

The seasonality of TSS concentrations in the Thief River downstream of Agassiz Pool (09020304-501) was examined on a monthly basis (Figures 4.3 and 4.4) and by examining a LDC (Figure 4-1).

Exceedances of the TSS standard in the lower Thief River appear to mainly occur during the highest 20% of flows at the downstream end of the reach. The critical flow regimes were very high flows (top 10% of flows in which 41.2% reduction is necessary) and high flows (Top 10% to 40% of flows in which a 23.3% reduction is necessary). TSS concentrations have typically been highest during the months of April, May, and August. The timing of these higher concentrations can be attributed to spring runoff (April), storm runoff (May and other summer months), and discharge from Agassiz Pool (May, August).

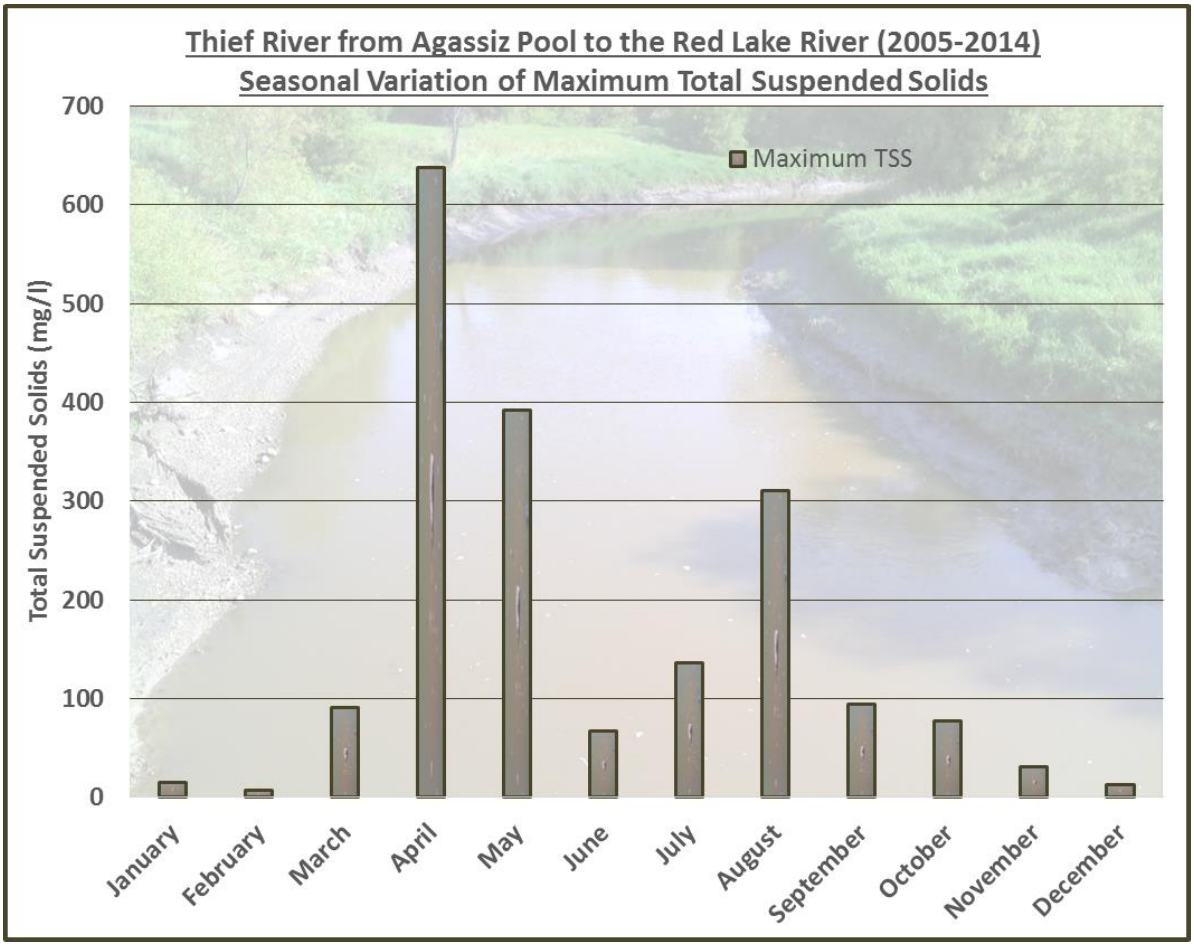


Figure 4-2. Monthly maximum TSS concentrations in the Lower Thief River (09020304-501)

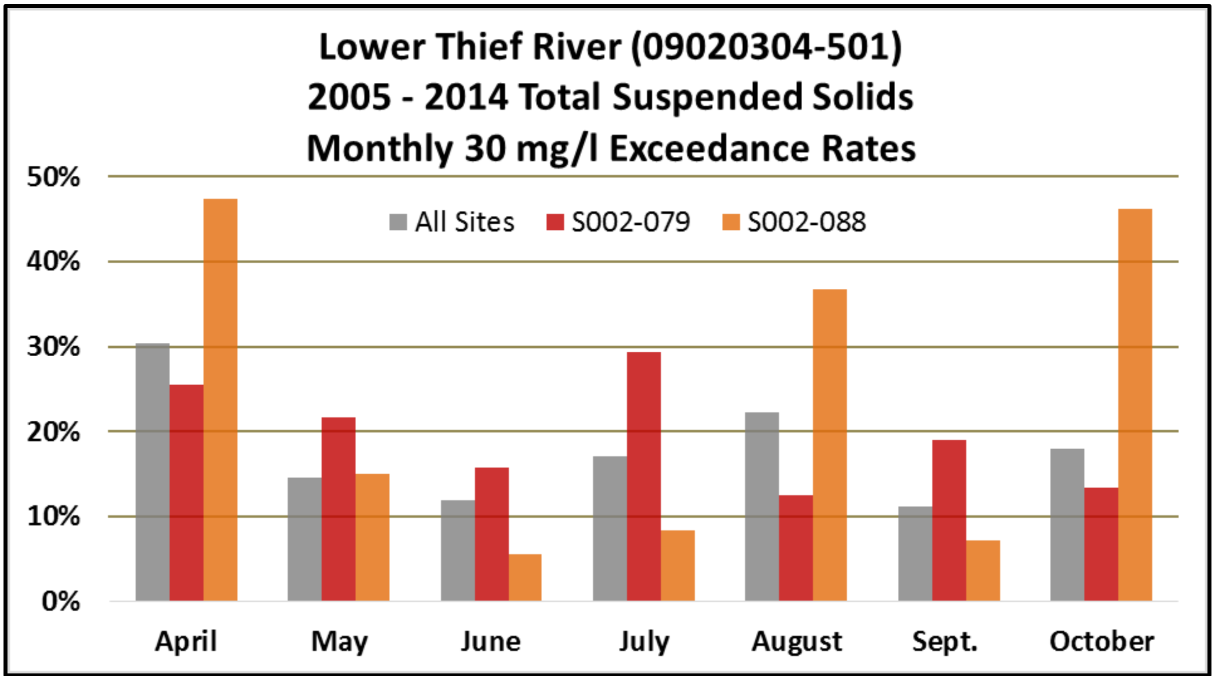


Figure 4-3. Monthly rates at which the 30 mg/l TSS standard is exceeded in the Lower Thief River (09020304-501)

4.1.6 Reserve Capacity

A reserve capacity of 0% was reserved for future development in this watershed. Very little (if any) future urban development is planned in this agricultural watershed. Implementation goals will focus on lessening the impact of agricultural practices. This follows a precedent for setting the reserve capacity to zero in other agricultural watershed TMDLs within the Red River Basin.

4.1.7 TMDL Summary

Table 4-2 shows the computed loading capacity, allocations, and recommended reductions for TSS loads (tons/day) in the Thief River at the USGS gauging station at the County Road 77 (140th Avenue, S002-079, USGS #05076000) crossing. Reductions in sediment loads are recommended for two wetter flow regimes of very high flows and high flows. In other words, the rate of exceedance of the 30 mg/l TSS standard needs to be significantly reduced when flows are greater than 36 CFS at the 05076000 USGS gauging station. Overall sediment reduction needs are shown in Table 4-3.

Table 4-2. Thief River (09020304-501) TSS TMDL summary table for site S002-079.

EQuIS Site ID: S002-079 USGS Site ID: 05076000 Total Suspended Solids Standard: 30 mg/l Drainage Area (square miles): 985 % MS4: 0.00% Total WWTF Design Flow (mgd): 0.00	Loading Capacity and Load Allocations for Total Suspended Solids in the Thief River at Marshall County Road 77 (AUID 09020304-501, Station S002-079)				
	Duration Curve Zone				
	Very High	High	Mid	Low	Very Low (No Flow)
TMDL Component	Values Expressed as Tons per Day of Sediment				
TOTAL DAILY LOADING CAPACITY*	93.04	12.22	1.05	0.07	0.00
Wasteload Allocation**					
Permitted Wastewater Treatment Facilities	0	0	0	0	0
NPDES Permitted MS4 Communities	0	0	0	0	0
NPDES Permitted Livestock Facilities	0	0	0	0	0
Construction and Industrial Stormwater	0.01	0.00	0.00	0.00	0.00
Reserve Capacity	0.00	0.00	0.00	0.00	0.00
Daily Load Allocation	83.73	11.00	0.94	0.06	0.00
Daily Margin of Safety	9.30	1.22	0.11	0.01	0.00
	Values Expressed as Percentages of the Total Loading Capacity				
TOTAL MONTHLY LOADING CAPACITY	93.04	12.22	1.05	0.07	0.00
Wasteload Allocation					
Permitted Wastewater Treatment Facilities	0%	0%	0%	0%	0%
NPDES Permitted MS4 Communities	0%	0%	0%	0%	0%
NPDES Permitted Livestock Facilities	0%	0%	0%	0%	0%
Construction and Industrial Stormwater	0.008%	0.008%	0.008%	0.008%	0.008%
Reserve Capacity	0%	0%	0%	0%	0%
Load Allocation	89.992%	89.992%	89.992%	89.992%	89.992%
Margin of Safety	10%	10%	10%	10%	10%
MEDIAN FLOW*	1150.00	151.00	13.00	0.50	0.00
FLOW DURATION INTERVAL OF MEDIAN FLOW	5%	25%	50%	71.60%	91.60%
*The flow record from USGS Gauge 05076000 was used to develop flow zones and loading capacities. **Wasteload Allocations are rounded to the nearest 2 digits (1/100th of a ton)					

Table 4-3. Lower Thief River Annual Load Reduction Calculation for site S002-079

Thief River near Thief River Falls (AUID 09020304-501, Site S002-079) TSS Load Reductions	Very High Flow	High Flow	Mid-Range Flow	Low Flow	Very Low (No Flow)	Annual Total
Current Daily Load (tons/day)	142.39	14.33	0.21	0.01	0	6782.546654
Load Allocation (tons/day)	83.73	11.00	0.94	0.06	0.00	4334.344924
Load Reduction (tons/day)	58.66	3.33	-0.73	-0.05	0	
% of Flows Represented	10.00%	30.00%	20.00%	23.20%	16.80%	100%
Number of Days Represented	36.50	109.50	73.00	84.67	61.33	365
Annual Load Reduction (tons/year)	2141.09	364.64	0.00	0.00	0.00	**2,505.73**
Total Current Load	5197.24	1569.14	15.33	0.85	0	6782.56
% Reduction	**41.2%**	**23.2%**	0.0%	0.0%	0.0%	**36.9%**

4.2 *E. coli* bacteria in the Mud River (AUID 09020304-507)

4.2.1 Loading Capacity Methodology

The LDC method, as described in Section 4.1.1, was used to calculate an *E. coli* TMDL for the Mud River. *E. coli* standards are met at the primary flow monitoring site on the Mud River (S002-078 at Highway 89, but the Mud River remains impaired by *E. coli* bacteria in the city of Grygla. There are two monitoring sites within the city of Grygla, S008-122 and S002-977 that show a site-specific *E. coli* impairment. The two sites are located 0.64 miles apart and are both located upstream of the Grygla WWTF. Most of the

E. coli data has been collected at S008-122, which has been intensively monitored to investigate a blue-green algae problem. Site S008-122 (along a Grygla City Park) lacks a reference point for stage measurements. Therefore, the TMDL was calculated for the CSAH 54 crossing of the Mud River (S002-977) that is equipped with a wire weight gauge. Stage and flow have not been regularly monitored at either of those sites, other than stage measurements during site visits to S002-977. Therefore, flow data simulated with the Thief River HSPF model was used to create an LDC and calculate TMDLs. The flow record was creating using the daily sums of simulated flows from HSPF reaches 237 (JD 11 upstream of CSAH 54) and 241 (Branch 95 of JD 11). The flow data was simulated for the years 1996 through 2016.

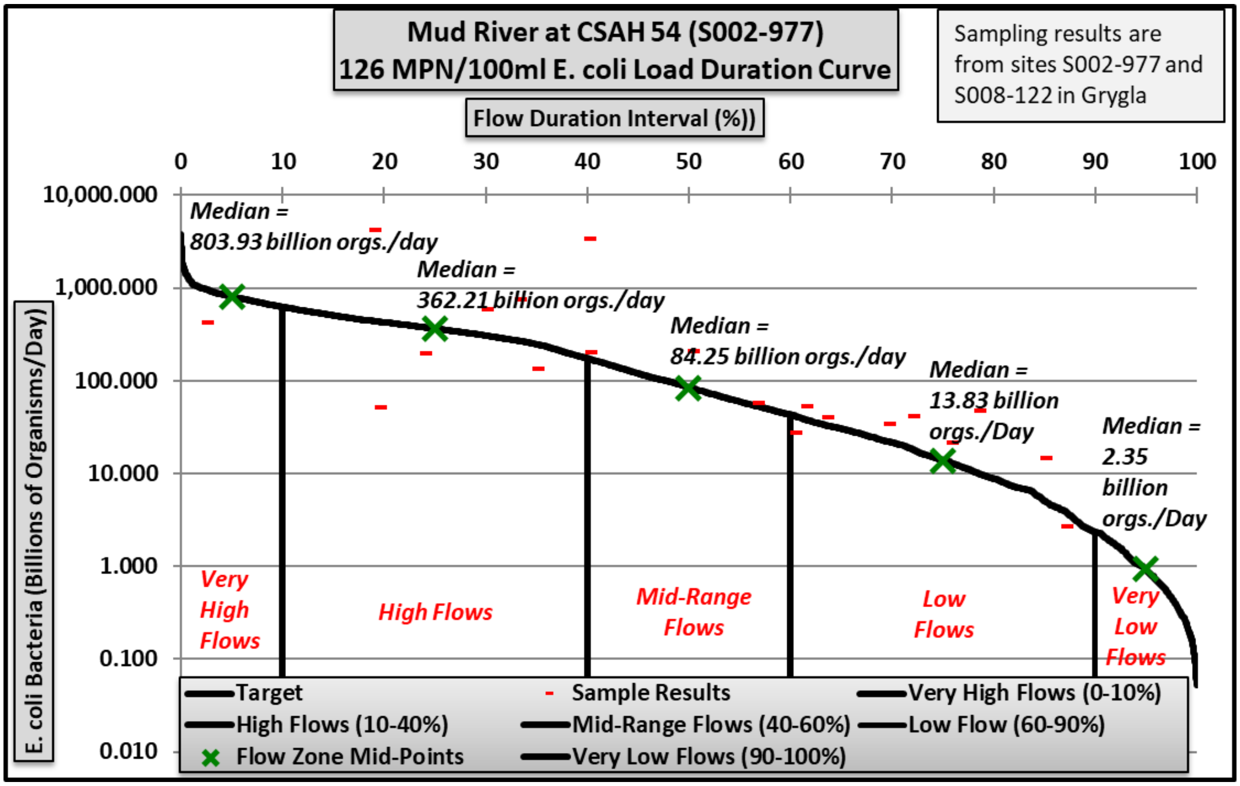


Figure 4-4. Mud River at CSAH 54 (S002-977) in Grygla *E. coli* Load Duration Curve (126 MPN/100mL Standard)

After the simulated average daily flow record was compiled, flows were ranked from highest to lowest. Average daily flow values were assigned a flow rank value. The probability of exceedance of each average daily flow value was calculated as a percentage. This created the information needed to create a flow duration curve by plotting probability of exceedance (X-axis) against the flow level (logarithmic Y-axis). Using the allowable concentration of 126 MPN/100mL and conversion factors, an LDC was developed (Figure 4-5) to show the allowable billions of organisms per day for each level of flow along the LDC. The LDC data was used to determine the median loading capacity for each flow regime. Only a small percentage of flows (3.04%) fell into the very low flow regime because 6.96% of the daily flow values were zero CFS (no flow, dry conditions).

4.2.2 Load Allocation Methodology

Portions of the total loading capacity were reserved for WLAs (if any), reserve capacity, and a MOS. The remaining loading capacity for each flow regime is the LA. The LA includes nonpoint pollution sources that are not subject to permit requirements, as well as natural background sources of sediment from upland areas and in-channel sources.

The EPA does not require the specification of natural background sources in a TMDL report. There has been speculation that some natural sources (beaver and birds) have contributed to *E. coli* concentrations in the Mud River. Microbial source tracking analysis identified the presence of bird fecal DNA markers, but only in trace amounts. Beaver fecal DNA markers were not detected. Therefore, there is no evidence to suggest that the impairment is caused by natural background sources, and a separate allocation was not made for natural background sources.

The current loading estimates were calculated by finding the geometric mean *E. coli* concentration for each flow regime with the help of a LDC. *E. coli* data collected during the years of 2007 through 2016 (most recent 10 years) from sites S008-122 and S002-977 was used to assess and represent current conditions in the Mud River at Grygla. Flow rates and flow regime values were assigned to each *E. coli* sampling date, where possible. Geometric mean *E. coli* concentrations were calculated for each flow regime. Load reduction recommendations for each flow regime were calculated by subtracting the LA from the current load.

4.2.3 Wasteload Allocation Methodology

There are no WWTFs that discharge upstream of S002-977. The Grygla WWTF discharges to AUID 09020304-507, but downstream of the portion of the Mud River that is exceeding the *E. coli* standard. Therefore, WLAs were not calculated for this reach.

4.2.4 Margin of Safety

The statute and regulations require that a TMDL include a MOS to account for any lack of knowledge concerning the relationship between load and WLAs and water quality (CWA §303(d)(1)©, 40 C.F.R. §130.7©(1)). An explicit MOS equal to 10% of the loading capacity was applied to each flow regime. The explicit 10% MOS accounts for:

- Uncertainty in the observed daily flow record.
- Uncertainty in the observed water quality data.
- Allocations and loading capacities are based on flow, which varies from high to low. This variability is accounted for using the five flow regimes and the LDCs.
- The variability in pollutant concentrations at any given flow.
- Heterogeneity of pollutants throughout the water column.

4.2.5 Seasonal Variation

Exceedances of the *E. coli* standard occur during the late summer and throughout a broad range of flows. When the 09020304-507 AUID of the Mud River is assessed as a complete unit (2007 through 2016 data), the months with the highest geometric mean concentrations are July (115.4 MPN/100mL) and August (99.3 MPN/100mL). The assessment results at the primary long-term flow and water quality monitoring site (S002-078) are similar to the results from the reach as a whole. The July geometric mean *E. coli* concentration at S002-078 is 111.4 MPN/100mL. The concentration is high enough for concern but does not exceed the impairment threshold. The somewhat elevated July geomean at S002-078 is the result of two high concentrations (547.5 and 2098 MPN/100mL) that were recorded in July of 2011. No July exceedances of the 126 MPN/100mL standard have been recorded at S002-078 since 2011.

Late summer monitoring further upstream; however, discovered that *E. coli* levels are still consistently high near the city of Grygla. At the sampling sites in Grygla (S008-122 and S002-977), the monthly geometric means for August (275.2 MPN/100mL, 10 days with data) and September (244.4 MPN/100mL, five days with data) exceed the 126 MPN/100mL standard. Most of the monitoring activity at those sites has taken place in August and September because the late summer was targeted for the intensive, investigative monitoring of a blue-green algae problem.

Exceedances of the *E. coli* standard have occurred during high flows, mid-range flows, and low flows at S002-977 and S008-122. No samples have been collected during very low flows or dry conditions at S002-977 or S008-122. The highest concentrations (1,203.3 and 2,419.6 MPN/100mL) of *E. coli* have occurred during high flows. Exceedances have most frequently occurred, however, during low and mid-range flows (80% of samples have been greater than 126 MPN/100mL in each of those flow regimes). No exceedances have been recorded during very high flows. It is important to note that the mid-range and low flow regimes are the most commonly sampled flow regimes. Only five samples, total, have been collected during high and very high flows at S002-977 and S008-122.

4.2.6 Reserve Capacity

A reserve capacity of 0% was reserved for future development in this watershed. Very little (if any) future urban development is planned in this agricultural watershed. Implementation goals will focus on SSTS compliance and lessening the impact of agricultural practices. This follows a precedent for setting the reserve capacity to zero in other agricultural watershed TMDLs within the Red River Basin. The WWTF is located downstream of the point at which this TMDL was established. Future growth of the city of Grygla should not have a direct impact on this TMDL. Future growth should still be mindful of the need to protect the rest of the Mud River is in need of protection from *E. coli* pollution as to not lose ground on improvements that have been made in *E. coli* concentrations at S002-078.

4.2.7 TMDL Summary

Table 4-4 shows the computed loading capacity, allocations, and recommended reductions for *E. coli* loads (billions of organisms/day) in the Mud River at the S002-977 water quality monitoring station at the CSAH 54 Bridge. Reductions in *E. coli* loads are recommended for the high, mid-range, and low flows. Overall *E. coli* load reduction needs are shown in Table 4-5.

Table 4-4. Mud River (09020304-507) *E. coli* TMDL summary table for site S002-977.

1996-2016 HSPF flow rates from reaches 237 and 241 were used to develop flow regimes & loading capacities Drainage Area (square miles): 133.81 *E. coli* Standard: 126 MPN/100ml %MS4 Urban: 0.00 Total WWTF Design Flow (mgd): 0.00	**AUID 09020304-507 Mud River at CSAH 54 (S002-977) Loading Capacity and Load Allocations for *E. coli* Duration Curve Zone**				
	Very High	**High**	**Mid-Range**	**Low**	**Very Low**
Values expressed as billions of organisms per day					
TOTAL DAILY LOADING CAPACITY	**803.93**	**362.21**	**84.25**	**13.83**	**0.93**
Median Flow	260.79	117.50	27.33	4.49	0.30
Median Flow Exceedance	5%	25%	50%	75%	95%
Wasteload Allocations					
NPDES Permitted WWTF	--	--	--	--	--
NPDES Permitted MS4 Communities	--	--	--	--	--
NPDES Permitted Livestock Facilities	--	--	--	--	--
Reserve Capacity	--	--	--	--	--
Daily Load Allocation	**723.54**	**325.99**	**75.82**	**12.45**	**0.84**
Daily Margin of Safety	80.39	36.22	8.43	1.38	0.09
Values expressed as percentages of the total daily loading capacity					
Wasteload Allocations					
NPDES Permitted WWTF	--	--	--	--	--
NPDES Permitted MS4 Communities	--	--	--	--	--
NPDES Permitted Livestock Facilities	--	--	--	--	--
Reserve Capacity	--	--	--	--	--
Load Allocation	90%	90%	90%	90%	90%
Margin of Safety	10%	10%	10%	10%	10%

Table 4-5. Lower Thief River Annual Load Reduction Calculation for site S002-079

Mud River (09020304-507) Annual *E. coli* Load Reductions	**Very High Flow**	**High Flow**	**Mid-Range Flow**	**Low Flow**	**Very Low Flow**	**Annual Total**
Current Geometric Mean Daily Load (billions of orgs/day) for Flow Regime	420.76	453.02	69.50	24.41	No Data	
Load Allocation (billions of orgs/day)	723.54	325.99	75.82	12.45	0.84	
Load reduction (billions of orgs/day)	-	127.03	-	11.96	-	
% of Flows Represented	10%	30%	20%	30%	10%	100%
# of Days Represented	36.5	109.5	73.0	109.5	36.5	365
Annual Load Reduction (billions of orgs/yr)	-	13,909.79	-	1,309.62	-	**15,219.41**
Total Current Load	15,357.74	49,605.69	5,073.50	2,672.90	No Data	72,709.83
Percent Reduction	0.0%	**28.0%**	0.0%	**49.0%**	0.0%	**20.9%**

5. Future Growth Considerations

5.1 New or Expanding Permitted MS4 WLA Transfer Process

No Municipal Separate Storm Sewer Systems (MS4s) exist within the Thief River Watershed, and none are expected to develop in the future.

5.2 New or Expanding Wastewater

The MPCA, in coordination with the EPA Region 5, has developed a streamlined process for setting or revising WLAs for new or expanding wastewater discharges to waterbodies with an EPA approved TMDL (MPCA 2012). This procedure will be used to update WLAs in approved TMDLs for new or expanding wastewater dischargers whose permitted effluent limits are at or below the instream target and will ensure that the effluent concentrations will not exceed applicable water quality standards or surrogate measures. The process for modifying all WLAs will be handled by the MPCA, with input and involvement by the EPA, once a permit request or reissuance is submitted. The overall process will use the permitting public notice process to allow for the public and EPA to comment on the permit changes based on the proposed WLA modification(s). Once any comments or concerns are addressed, and the MPCA determines that the new or expanded wastewater discharge is consistent with the applicable water quality standards, the permit will be issued and any updates to the TMDL WLA(s) will be made.

No new or expanding wastewater dischargers are anticipated within the direct drainage area of the 09020304-501 reach of the Thief River For more information on the overall process visit the MPCA's TMDL Policy and Guidance webpage.

6. Reasonable Assurance

None of the impairments described in this document are extreme in nature. Restoration of these reaches should be feasible.

Partnerships among local governmental units, state and federal agencies aid the success of implementation efforts. The following is a list of those governments and agencies:

- Marshall SWCD
- Pennington SWCD
- Beltrami SWCD
- RLWD
- NRCS
- USFWS
- DNR
- MPCA
- Minnesota Board of Water and Soil Resources (BWSR)

Figure 6-1. Minnesota Water Quality Framework

The findings from the Thief River Watershed TMDL and the restoration and protection strategies from the Thief River WRAPS will be incorporated into local county water management plans. Additional information regarding local water management plans is found in Section 8.2.6. Strategies will be especially helpful during the development of the Thief River One Watershed One Plan (1W1P) local water planning effort that was started during the summer of 2017. The Minnesota BWSR 1W1P process will incorporate restoration and protection strategies of the Thief River TMDL and WRAPS into the 1W1P document. The listing of implementation activities within a local water management plan such as a 1W1P plan will improve the likelihood of those projects being funded by states grant funds.

In addition to commitment from local agencies, the state of Minnesota has also made a commitment to protect and restore the quality of its waters. In 2008, Minnesota voters approved the Clean Water, Land, and Legacy Amendment to increase the state sales tax to fund water quality, habitat, and cultural improvements. The interagency Minnesota Water Quality Framework (Figure 6-1) illustrates the cycle of assessment, watershed planning, and implementation to which the state is committed. Funding to support implementation activities under this framework is made available through BWSR, an agency that has awarded grant funding to the RLWD in the past.

The findings of the geomorphology work that was completed by the DNR in the Thief River Watershed is being used to guide future implementation efforts. This work identified stream banks with high erosion potential and made recommendations for improving stream channel stability. Local agencies have already completed some projects in the Thief River that fixed problem areas identified during the geomorphologic assessment work.

- Erickson Group Project: http://www.bwsr.state.mn.us/cleanwaterfund/stories/factsheets/Pennington_ThiefRiver.pdf
- Halvorson Streambank Stabilization Project: http://www.bwsr.state.mn.us/cleanwaterfund/stories/factsheets/Pennington_Streambank.pdf

Planning tools have been developed to help target and prioritize projects that will reduce the amount of pollutant loading throughout the watershed.

- International Water Institute’s Water Quality Decision Support Tool
- HSPF modeling results can be used to identify targeted projects with measurable outcomes on the landscape. HSPF modeling results are featured in the Thief River WRAPS Report.
- SPI GIS layers have been developed for the watershed. These have been developed using LiDAR-derived topographic data and show the points on the landscape in which the risk of erosion due to the power of flowing water is the greatest.
- The International Water Institute, BWSR, and Houston Engineering collaborated to create a tool for estimating the water quality benefits of practices that treat nonpoint sources of pollutants for a select few watersheds in the state of Minnesota. The Prioritize, Target, and Measure Application (PTMApp) can be used to prioritize resources, target specific fields for conservation practices and BMPs, and measure expected water quality improvements. Under the guidance of International Water Institute staff, RLWD staff have been applying the PTMApp development process to the Thief River Watershed. Visit the Red River Basin Decision Information Network

website to learn more about PTMApp: http://www.houstoneng.com/ptmappnewtechnologytoprotectourmostpreciousresource/.

Ongoing professional and volunteer monitoring programs will provide the data needed to measure the success of restoration and protection efforts.

Minnesota’s Buffer Law that was signed into law by Governor Dayton in June 2015 was amended by the Legislature and signed into law by Governor Dayton on April 25, 2016. Minnesota's buffer law establishes new perennial vegetation buffers of 50 feet along public waters and 16.5 feet along ditches. The law provides flexibility and financial support for landowners to install and maintain buffers. Many segments of streams and ditches have been poorly buffered due to landowner choice, “grandfathering” status of old ditches that are not subject to current rules, and incomplete enforcement. This law will provide the means and support needed to fix those problems and significantly improve and protect water quality.

7. Monitoring Plan

This section describes on-going monitoring efforts in the watershed, and recommendations for possible additional monitoring, contingent upon availability and prioritization of resources.

On-going Monitoring Efforts

The RLWD has been collecting samples in the Thief River Watershed since 1980. Some new sites that were monitored for the Thief River Watershed Sediment Investigation were added to the RLWD long-term monitoring program. The monitoring program (Figure 7-1) collects data from the significant waterways within the watershed, including multiple reaches of the Thief River, the Mud River, Moose River, Marshall CD 20, and JD 30. Field measurements of DO, temperature, turbidity, specific conductivity, pH, and stage are collected during each site visit (if there is water). Four rounds of samples are also collected and analyzed for total phosphorus (TP), orthophosphorus (OP), TSS, total dissolved solids, total Kjeldahl nitrogen, ammonia nitrogen, nitrates + nitrites, and *E. coli* at most of the sites. For the past few years, biochemical oxygen demand (BOD) analysis has been added for the sites that are located on reaches that have had low DO levels. BOD was replaced with COD analysis in 2014 because too many BOD levels were too low to be measured. Sampling months are alternated each year with the goal of collecting at least five samples per calendar month within a 10-year period.

River Watch is a volunteer monitoring program that gives high school students the opportunity to collect water quality data. This data is collected using the same methods that are used by professionals and is stored in EQuIS along with all other data that is collected within the watershed. Grygla High School has an active River Watch program. The Thief River Falls River Watch program is active periodically but is currently inactive. Reviving this program and keeping it active is a recommended goal. The Grygla River Watch team has sampled at the following sites (as of 2016):

1. S002-979 – CD20 at CSAH 54
2. S002-977 – Mud River at CSAH 54
3. S002-978 – Mud River at the Moose River Impoundment (S Pool) outlet to JD11
4. S002-980 – Moose River at Moose River Forest Road
5. S006-380 – Moose River at the Moose River Impoundment (N Pool) outlet to JD21
6. S005-783 – Moose River at 310th Av NE
7. S004-211 – Moose River at CSAH 54
8. S002-078 – Mud River at CSAH 89

The Pennington SWCD collects monthly samples from the Thief River at the “Golf Course Bridge” monitoring site (S003-945).

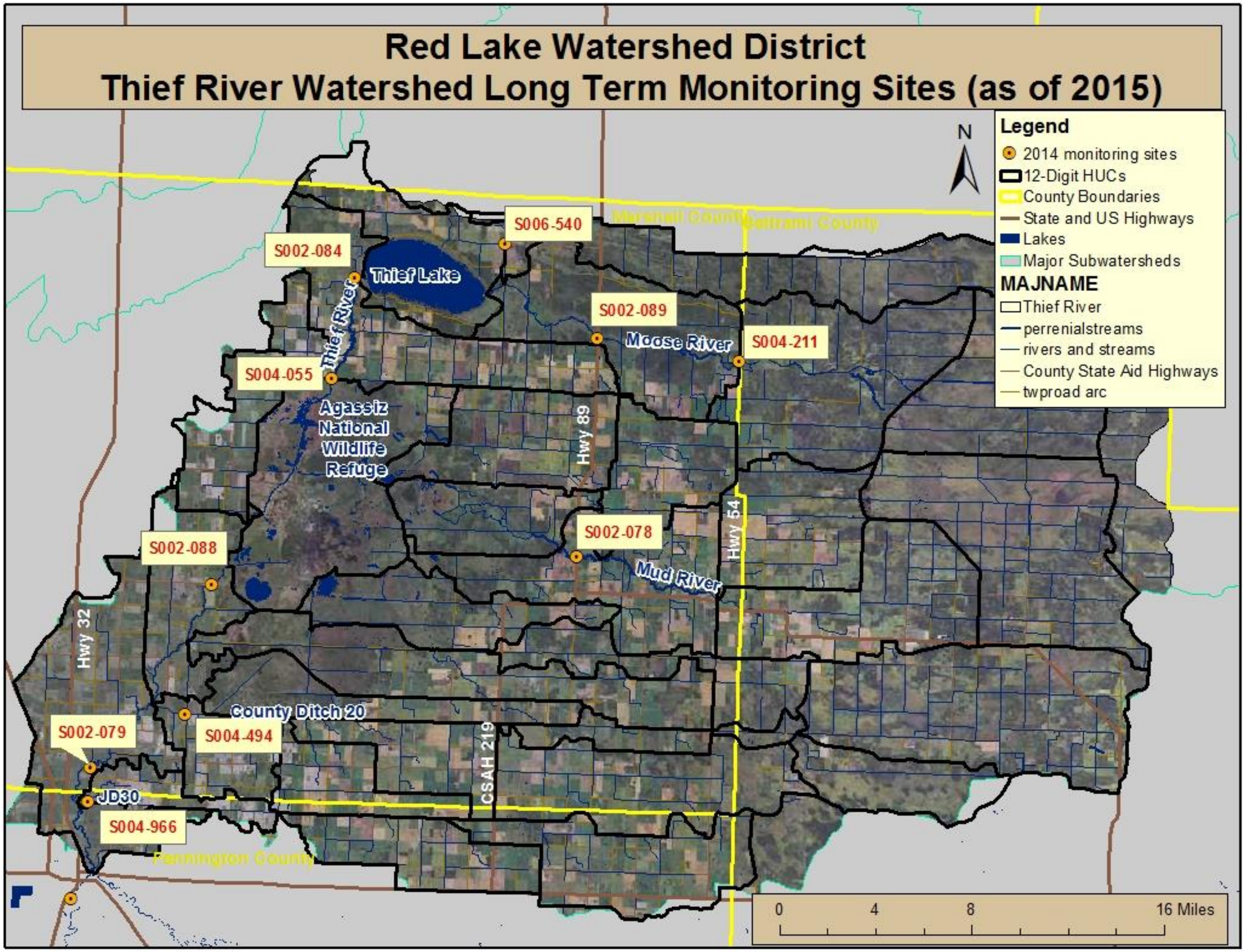


Figure 7-1. Long term monitoring sites within the Thief River Watershed

The Thief River Monitoring site (S002-079) that is co-located with the USGS gauging station, the Thief River site near Agassiz NWR (S002-088), and the Mud River site at Highway 89 (S002-078) have been intensively monitored for other projects, including the MPCA's Major Watershed Pollutant Load Monitoring Network. Frequent sampling should continue for the MPCA's Major Watershed Pollutant Load Monitoring program. The International Water Institute has worked with the MPCA to sample the Thief River at S002-079, Thief River at S002-088, and Mud River at S002-078.

Flow monitoring is conducted using real-time gauge installations on the Thief River and Mud River. The Thief River has two real-time gauges. One is the USGS Gauge 05076000 at the 140th Avenue Northeast crossing of the Thief River, north of the city of Thief River Falls. The other is located at CSAH 7, near Agassiz Refuge, and is monitored by a MPCA and DNR cooperative gauge at site S002-088. The Mud River is also monitored by a MPCA/DNR cooperative gauging system at the Highway 89 crossing of that river (S002-078), west of Grygla. Other significant reaches of the watershed are monitored with HOBO water level loggers by the RLWD. The locations of flow monitoring stations are shown in
Figure 7-2.

Possible Additional Monitoring Needs

The RLWD has conducted multiple intensive watershed monitoring projects in recent years that have involved continuous water quality monitoring. Several grant/contract funded projects have left the RLWD very well equipped for continuous DO monitoring. Additional continuous DO monitoring should be conducted in the Mud River as soon as time allows. The DO impairment on that reach could be considered borderline. The reach may have been delisted if not for the poor DO levels recorded during the dry year of 2012.

The low DO impairment of the Mud River should be monitored to see if conditions improve. Continuous DO records will be needed to get a pre-9:00 a.m. record of daily minimum DO that can be used to accurately assess the conditions in the river. Longitudinal continuous DO monitoring along the Mud River could effectively characterize the origins of low DO problems within the river. A continuous DO record near the outlet of the Moose River impoundment would provide more information about the influence of impoundment discharges upon DO.

Potential aquatic life impairments on channelized reaches of the Thief River were deferred during the 2013 assessment. Now that TALU standards have been adopted by the state of Minnesota, these reaches will be assessed during the 2023 assessment process. Basic water quality data and biologic data will likely be collected in 2021 and 2022.

June is an important month for the monitoring of *E. coli* concentrations within Branch A of JD21. Additional investigation of the watershed may help with further identifying the sources of *E. coli* along the ditch and to watch for signs of regression back to an impaired condition.

Additional intensive sampling during runoff events and Agassiz Pool drawdowns will help shed light upon the causes of water quality problems in the watershed. Ditch systems on the east side of Agassiz NWR should be sampled during runoff events (Marshall County Ditch 35, Branch B of Marshall County Ditch 28).

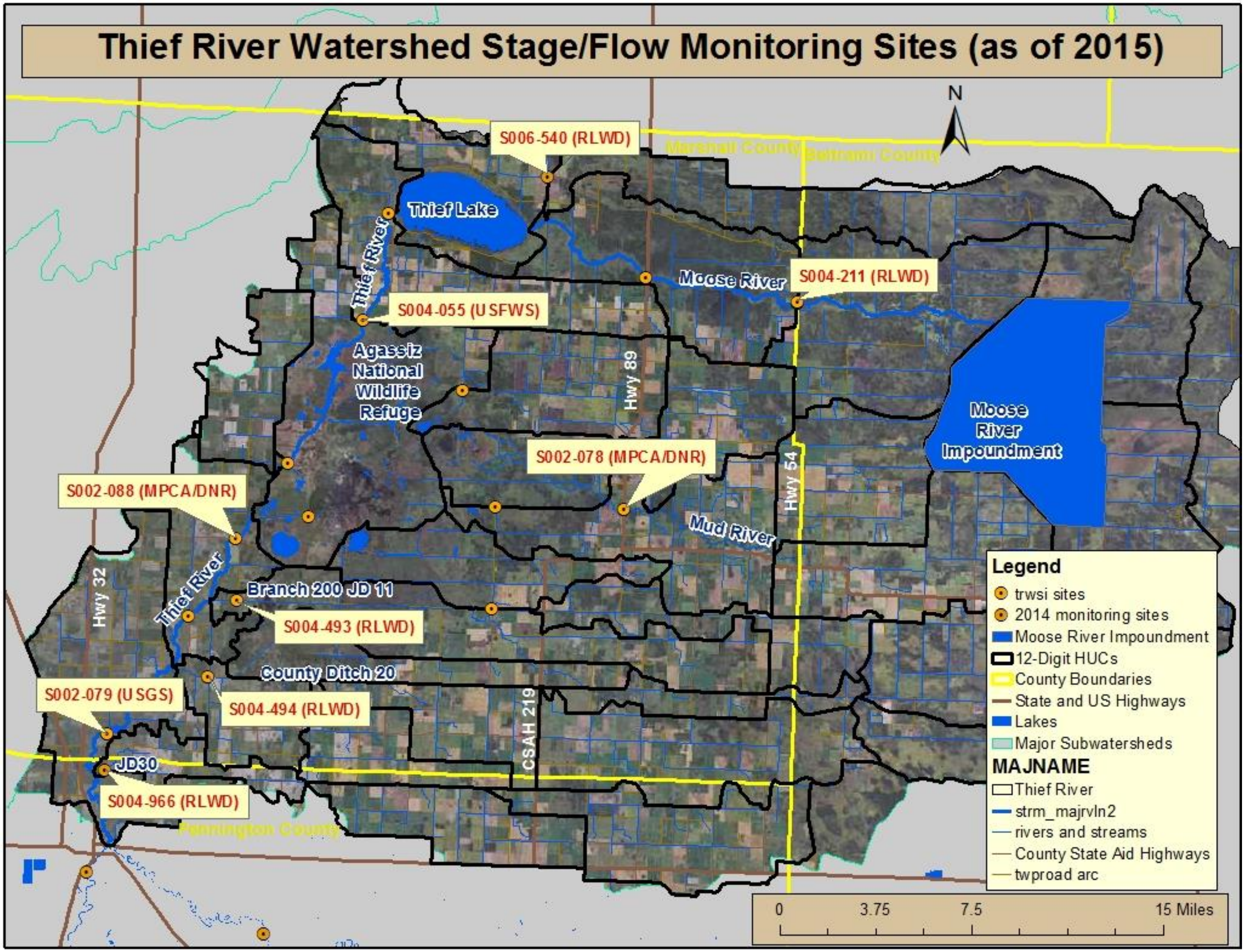


Figure 7-2. Stage and flow monitoring sites in the Thief River Watershed

8. Implementation Strategy

Implementation strategies for the Thief River watershed have been developed through extensive field reconnaissance, collaboration with local and state agencies, stakeholder involvement, multiple water quality studies, and the use of watershed modeling tools. The strategies in this TMDL focus on water quality improvement along impaired reaches. Additional strategies are discussed in the Thief River WRAPS Strategy Report. Below is a summary of the suggested strategies needed to achieve restoration goals in the watershed:

- Improve and maintain buffers along the Thief River and its tributaries. Establish riparian brush, trees, and other deep-rooted vegetation.
- Consider alternative to the flushing of sediment from Agassiz Pool to the Thief River.
- Limiting Agassiz Pool discharge during non-emergency releases to 250 CFS or less.
- Improve base flows in the Moose River and Mud River during the late summer months by modifying the operations of the Moose River Impoundment discharges.
- Implement agricultural BMPs to reduce soil erosion and sedimentation.
- Continue long-term monitoring efforts.
- Utilize the recommendations of the Thief River Watershed Fluvial Geomorphology Report as guidance for future implementation projects and ditch maintenance.
- Restoration of meandering channels with floodplain access will reduce sedimentation and improve habitat.
- Utilize models, tools, site visits, and inventories to implement targeted BMPs to control upland erosion. Those practices include, but are not limited to side water inlets, alternative side water inlets, cover crops, and crop residue management.
- Install and renovate field windbreaks to reduce wind erosion.
- Continue and further develop education and outreach activities.
- Install BMPs and storage to moderate runoff rates to reduce in-channel erosion.
- Inspect septic systems and help homeowners bring failing systems into compliance.
- Limit cattle access to watercourses.
- Minimize runoff from feedlots.

8.1 Permitted Sources

8.1.1 MS4

There are no MS4s in the Thief River Watershed. Therefore, no implementation strategies were developed for MS43s in the Thief River Watershed.

8.1.2 Wastewater

The only WWTF in the Thief River Watershed is the Grygla WWTF. There are no impairments downstream of the WWTF, so no changes in its permit conditions are warranted. The MPCA is in charge of enforcing wastewater treatment regulations. Local government units (LGUs) can monitor the operation of the facility by monitoring water quality downstream of the WWTF outlet, or at the outlet of the WWTF if a problem is suspected.

8.1.3 Construction Stormwater

The WLA for stormwater discharges from sites where there is construction activity reflects the number of construction sites greater than one acre expected to be active in the watershed at any one time, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in the State's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). If a construction site owner/operator obtains coverage under the NPDES/State Disposal System (SDS) General Stormwater Permit and properly selects, installs and maintains all BMPs required under the permit, including those related to impaired waters discharges and any applicable additional requirements found in Appendix A of the Construction General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL, although minimal if any urban development is expected to occur in this watershed. All local construction stormwater requirements must also be met.

8.1.4 Industrial Stormwater

If a facility owner/operator obtains an appropriate NPDES/SDS Permit and properly selects, installs, and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the LAs in this TMDL although there are no industrial stormwater sources within this watershed. All local stormwater management requirements must also be met.

Though not a regulatory requirement, stormwater inlets in the town of Grygla should be protected from spills (Figure 8-1).

Figure 8-1. Stormwater inlet near an agricultural supply company in Grygla

8.2 Non-Permitted Sources

TSS concentrations within the Thief River need to be reduced through erosion (channel and overland) prevention efforts/BMPs, modification of ditch maintenance strategies, water management that reduces peak flows, and acceptance of a philosophy that limits natural resource management actions to those that avoid downstream "degradation, risk to health or safety, or other undesirable and unintended consequences" (National Environmental Policy Act of 1969, Section 101). Specific strategies are listed in the WRAPS report throughout the days of the year in which the top 40% of flow is occurring, a total load reduction of a little more than 2,500 tons/year is desired.

Implementation of the requirements of Minnesota's Buffer Law, enacted in 2015 and amended in 2016, will provide much-needed protection of riparian corridors that will help stabilize streambanks and reduce sediment delivery from overland runoff. The Buffer Law will protect Minnesota's water resources from erosion and runoff pollution by establishing perennial vegetative cover adjacent to Minnesota's waters. The buffer width will be an average of 50 feet on public waters. The buffer width will be a minimum of 16.5 feet on public ditches. Buffer widths on other waters will be determined by SWCDs. The Thief River SWAT model predicted that improvements to buffers in the Thief River Watershed could result in significant reductions of sediment yields.

Sources of *E. coli* bacteria in the Mud River need to be addressed (see Sections 8.2.4 and 8.2.5 for more detail).

8.2.1 Stream and Ditch Bank Erosion

Figure 8-2. Photos of actively eroding streambanks along the Thief River

Limiting Agassiz Pool discharge during non-emergency releases to 250 CFS or less should help limit the frequency of high TSS readings caused by streambank erosion resulting from high discharge flows.

Prioritizing and targeting eroding streambanks to implement stabilization projects is another key strategy. Erosion sites throughout much of the watershed have been photographed and marked with GIS coordinates (examples shown in Figure 8.2).

The Thief River Fluvial Geomorphology Report recommends stabilization of the Lower Thief River channel as the preferred method of reducing sediment loading from in-channel erosion. A current example of such a project is project that is being planned by the Pennington SWCD with the purpose of halting the formation of a cut-off channel across a meander of the Thief River upstream of the Thief River Golf Club (Figure 8.3). If the River cuts through this meander, the gradient of the river will be increased and that could lead to more streambank erosion upstream. This “causeway” construction project will complement a streambank stabilization project that has recently been completed.

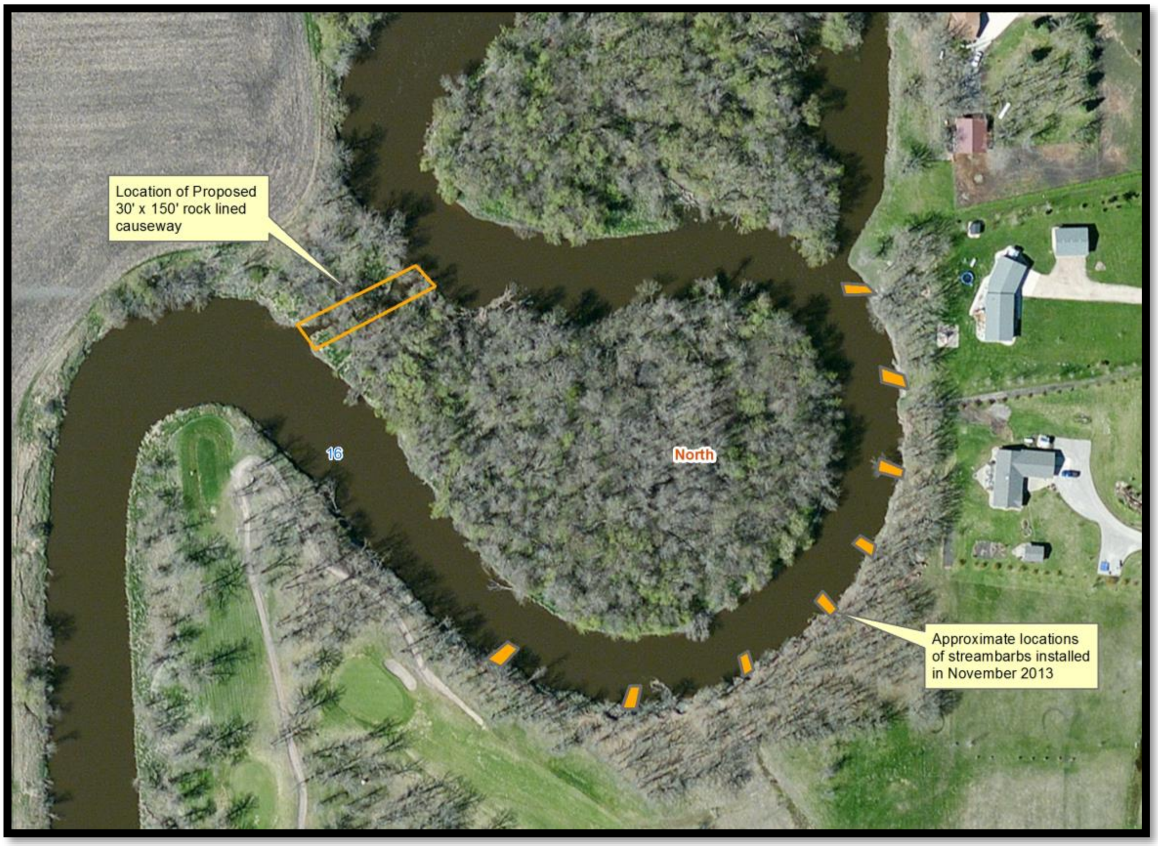


Figure 8-3. Example Pennington SWCD erosion control projects along the Thief River

The Thief River Watershed Fluvial Geomorphology Report also makes several recommendations for the other impaired reaches in this watershed:

- Moose River
  - Identify upland sources of sediment and lessen the contribution of excessive sediment to the river channel.
  - The upstream portion of the Moose River would benefit from riparian buffer improvements.
  - Maintain the condition of the downstream segment of the Moose River.
  - Flatten spoil piles to increase floodplain capacity if stability problems do arise.
- Mud River
  - Identify upland sources of sediment and lessen the contribution of excessive sediment to the river channel.
  - Utilize SPI GIS layers to identify priority areas.
  - Maintain and improve riparian buffers.
  - Maintain the existing condition of the channel and riparian buffers.

- Assess whether or not the river is currently in a stable form prior to initiating a new clean-out.
- Create setbacks within the riparian zone to minimize future problems with the Thief River encroaching upon development.

8.2.2 Agricultural and Overland Erosion

The establishment of a continuous buffer along the Mud River (JD 11) channel should result in water quality improvements (Houston Engineering 2010). There are reaches of the Mud River/JD11 channel where land is being cultivated up to the edge of the bank, leaving no buffer. The quality of the buffer also makes a difference. The stream channel along the 09020304-507 reach of the Mud River is "very highly dependent on robust stream bank vegetation to remain stable" (Friedl 2015).

BMP strategies aimed at reducing runoff during spring and summer storm events should be a goal within the Mud River Watershed. Establishment of a buffer along the Mud River will reduce the amount of sediment entering Agassiz NWR. Reducing sediment inputs to Agassiz Pool would decrease the need for maintenance activities in the old JD11 channel and, in turn, the amount of sediment that can be moved downstream into the Thief River during Agassiz Pool discharges.

Re-meandering the Mud River as it enters the Agassiz NWR is a project idea that has been discussed. This project could reduce the amount of sediment entering Agassiz Pool from the Mud River drainage system and improve aquatic habitat within the lower end of the river if done correctly. Improvements should be made to the quality of the riparian corridor of the rest of the Mud River channel to optimize the preservation of DO levels and optimize aquatic habitat.

Figure 8-4. Utilization of Stream Power Index results to plan side water inlet installations

Georeferenced photographs of erosion problems can be taken while traveling throughout the watershed. Compiling and sharing photos of erosion problems in the watershed can help maximize the number and degree of actions that are taken to address erosion problems. Runoff events in the spring and early summer are good opportunities for finding gully erosion problems before they become hidden by crops and other vegetation growth. Inspection of the watershed and watershed models (SPI, PTMApp) can be used to identify locations where side water inlets should be installed to prevent gully erosion like what is shown in the following photos in Figure 8-4.

8.2.3 Agassiz Pool Sediment Management

Agassiz Pool is managed by the USFWS. This limits the ability of state or local agencies to alter practices within the refuge. Monitoring data and reports published by the USFWS indicate that water and sediment management within the pool has the effect of increasing TSS concentrations downstream of the pool. The refuge has been implementing management practices that disturb sediment and allow that sediment to move downstream causing TSS concentrations that exceed water quality standards. The USFWS's primary responsibility is to manage for waterfowl and is concerned that sediment accumulation within the pool is causing a disappearance of waterfowl habitat. However, attempts to improve habitat for waterfowl have a side effect of degrading downstream conditions for aquatic life and public drinking water supplies. Preferably, the USFWS will alter pool management practices voluntarily. Sharing of information, cooperation, and efforts to reduce sediment inflows from the Mud River and Thief River to Agassiz Pool may aid that process. Ideally, 'win-win' solutions can be identified. Regardless of USFWS actions, one way to limit the amount of sediment discharged from Agassiz Pool may be reduction of the amount of sediment entering the pool.

One potential project involves re-routing the Mud River into its original, meandering channel. This project should minimize sediment deposition within the in-pool portion of JD11 and potentially eliminate the need for further excavation within that submerged channel. If possible, water from the Mud River could be routed through a smaller pool prior to entering Agassiz Pool. Ideally, the smaller pool could be engineered to allow for sediment deposition and removal (with proper disposal of excavated sediment). The acquisition/compilation of funding for preliminary engineering expenses to assess the feasibility of this potential project is one of the first steps that can be taken.

The northwestern outlet of Agassiz Pool allows a portion of floe from the Thief River to pass through the pool and deposit less sediment within the pool. Although the upper reach of the Thief River meets TSS standards, multiple opportunities for sediment reduction have been identified. Buffers and side water inlets along ditches are needed. There are actively eroding streambanks that can be stabilized. The geomorphology report recommended moving spoil banks along the Thief River to allow floodplain access, which should dissipate some of the erosive power of high flows.

The Mud River currently meets that 30 mg/L TSS standard and most of the time meets the more stringent North River Region standard of 15 mg/L. Local water planning efforts will use 15 mg/L as the target for protection as to not allow degradation of the Mud River and protect Agassiz Pool from additional sedimentation. Multiple studies have found that sediment from the Mud River (an east-to-west flowing stream) has caused degradation of habitat within Agassiz Pool in the past.

8.2.4 Stormwater

Grygla is the only community within the watershed in which stormwater is suspected to be contributing pollutants to an impaired waterway. (Stormwater outlets in the city of Thief River Falls flow into the Red Lake River.) Options should be explored for addressing stormwater runoff within the city of Grygla to address the localized *E. coli* impairment. Sampling of stormwater outlets during runoff events is also recommended to confirm or eliminate stormwater runoff as a potential source of *E. coli*.

8.2.5 Grazing Management

SWCDs, with assistance from state agencies, will work to implement projects that limit or exclude the access of livestock to waterways. They will strive to ensure that all feedlots are up to date and comply with regulations, and for ones that do not meet the regulations, they will work with the landowner to get compliance. Runoff should also be minimized from feedlots that are not located directly on an impaired waterway, especially those that are located near ditches that flow to impaired waterways.

This strategy will be implemented watershed-wide, but extra attention is required for the impaired reach of the Mud River (507). This effort is needed to delist the existing impairment and to ensure that unimpaired waters continue to meet standard. Although there are some livestock operations downstream of Grygla at which livestock access to the river can be reduced, the Mud River remains impaired by high *E. coli* due to sources upstream of Grygle. Microbial source tracking has found ruminant (livestock) fecal DNA markers in samples collected at Grygla. There is a livestock operation along the Mud River upstream of Grygla in which livestock have access to the stream and from which runoff would contribute to *E. coli* concentrations. All livestock operations on land that drain to the Mud River between Flintlock Road and Grygla should be targeted for grazing management and other BMPs to minimize runoff and minimize livestock access to stream/ditch channels.

8.2.6 Septic System Compliance

SWCDs will conduct septic system inventories to identify non-compliant septic systems. Out-of-compliance systems shall be brought into compliance in a timely manner. County ordinances could be updated to include point of sale septic inspections. Local agencies will also help homeowners get low interest loans for septic system updates. Inspection of septic systems in the Mud River subwatershed should be a priority due to the findings of the microbial source tracking analysis. Septic systems upstream of Grygla are contributing to the *E. coli* impairment in the Mud River. Failing systems need to be identified and upgraded. Utilize cost-share funding or Clean Water Partnership 0% loans, where possible to ease the financial burden for homeowners.

8.2.7 Strategies from Local Water Management Plans

Local water management plans include objectives, goals, and strategies for addressing water quality issues in the Thief River Watershed. The existing local plans include the RLWD 10-Year Plan, Pennington County Local Water Management Plan, Marshall County Local Water Management Plan, and the Beltrami County Local Water Management Plan. During the summer of 2017, the planning process started to consolidate these plans into one plan for the Thief River Watershed through BWSR’s 1W1P process.

The Pennington County 2010-2020 Comprehensive Local Water Management Plan includes actions aimed at addressing water quality problems in the Thief River Watershed:

- Assist landowners and government entities with the reduction of water and wind erosion
- Work with the county and watershed districts to identify problem reaches and to ensure watershed, county, township, and private drainage systems adequately address drainage needs to support agriculture without threatening water quality.

- Monitor the quality of surface water in Pennington County.
- Assist landowners with compliance of the county shoreland, sewage, wastewater treatment, and floodplain ordinances to help protect water resources.
- Educate the public about water and soil stewardship and encourage BMPs.
- Coordinate and cooperate with other agencies and jurisdictions on plans and projects.
- Address Federal List 303(d) impaired waters by actively participating in the development and implementation of TMDL plans for impaired waters of Pennington County.
- Address high sediment volumes affecting the reservoir for Thief River Falls.
- Address high hydrogen sulfide within the reservoir for Thief River Falls.
- Educate citizens about the importance of source water protection.

Steps to address soil erosion, sedimentation, and other water quality issues were incorporated into the Marshall County Water Plan. The plan includes strategies to accomplish the objectives of understanding the sources of sediment and nutrients in the Thief River Watershed and for the reduction of sediment and nutrient loads within the watershed.

The Beltrami County Water Plan includes objectives and strategies to address erosion, sedimentation and low DO levels within the Thief River Watershed.

- Manage ditch banks and stream banks to reduce erosion losses.
    - Improve regular maintenance and increase extent of native vegetation in the network of ditch banks throughout the watershed.
    - Encourage landowners to utilize present and future cost-share and grant programs to provide buffers between areas of cropland and streams and ditches.
- Conduct research on the cause and origin of observed DO impairments and consequences for downstream nutrient enrichment.
    - Develop and implement appropriate remediation steps.
- Address concerns of marginal lands coming out of CRP and put back into crop production.
- Address concerns of marginal lands coming out of pasture and hay land due to any additional depopulation of cattle herds as a result of bovine tuberculosis.

The RLWD 10-Year Overall Plan contains action items for improving water quality and aquatic habitat in the Thief River Watershed:

- Improve fish habitat in the Mud, Moose and Thief Rivers and their tributaries.
- The RLWD will actively collaborate with the DNR, USFWS, USDA NRCS, USACE, MPCA, Marshall County Water Planner, and the SWCDs to seek to implement projects that reduce agricultural and bank erosion and improve water quality.

- The RLWD will seek partnerships with landowners, SWCD and USDA NRCS to implement BMPs that reduce agricultural erosion and slow water down. Landowners will be discouraged from farming ditches.
- The RLWD will seek out grant opportunities to conduct an erosion and water quality assessment on the entire course of the Thief River (accomplished through the Thief River Watershed Sediment Investigation and Thief River WRAP projects).

8.2.8 WRAPS Strategy Tables

RLWD, DNR, SWCD, BWSR, and the MPCA staff collaborated to compile a list of restoration and protection strategies that can be used in planning for improving water quality throughout the Thief River Watershed. The full list of strategies can be found in the Thief River WRAPS Strategy document.

8.3 Cost

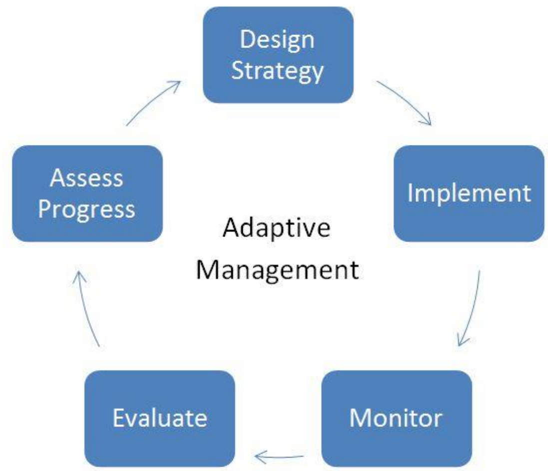
Restoration options for rivers are numerous with varying rates of success. Consequently, each strategy must be evaluated in light of our current understanding of physical and biological processes in the river or stream. It is difficult to precisely predict costs during the planning of a specific project. Costs for yet-to-be-funded projects are even more difficult to approximate.

The required cost estimate (Table 8-5) for the implementation of this TMDL is based upon a period of 10 years of work, estimated sediment reductions achieved by previous projects, and the rate at which projects can realistically be completed by local staff. Initial estimates are based upon the goals of the implementation plan and a review of previously completed projects. The estimates will be refined as implementation plans and projects are developed. The actual number of years needed to accomplish the ultimate goal of restoring these three waterways will vary based upon the amount of funding that is successfully acquired for projects, the amount of available staff time, and the amount of cooperation among agencies and stakeholders.

Table 8-1. Cost estimation table

Potential Project	Estimated Cost
Total =	**$ 10,636,300.00**
Initial Buffer Initiative Implementation	$ 125,000.00
Ditch Stabilization Projects	$ 400,000.00
Pennington SWCD erosion control projects	$ 375,000.00
Marshall SWCD Erosion Control Projects	$ 300,000.00
RLWD Erosion Control Projects	$ 250,000.00
River Watch - Thief River and Grygla:	$ 88,200.00
Mud River Meander and Riffle Restoration	$ 5,000,000.00
Moose River Meander and Riffle Restoration	$ 4,000,000.00
Thief River Meander Restoration	$ 700,000.00
Buffer enhancemet (plantings)	$ 109,350.00
Agassiz Refuge Alternate Strategy for Agassiz Pool: Use Strategy 1, Discontinue Strategy 6 (USGS 2014-1180)	$ (2,000,000.00)
Moose River flow enhancement	$ 1,500.00
Moose River Stage Monitoring	$ 9,000.00
Mud River flow enhancement	$ 1,500.00
Windbreaks	$ 255,200.00
Planning proects using desktop tools	$ 30,000.00
Thief River stabilization project planning	$ 15,000.00
Thief River stabilization project(s)	$ 300,000.00
Ditch maintenance review and policy adjustments	$ 5,400.00
Ditch buffer incentive payments	$ 200,000.00
Annual open house events (10 Years)	$ 29,000.00
Education and outreach (10 Years)	$ 30,000.00
Regular Flow Measurements at 9 sites	$ 27,000.00
Long-term RLWD water quality monitoring (10 years)	$ 42,000.00
Long-term Pennignton SWCD monitoring (10 years)	$ 21,600.00
Mud, Moose, Lower Thief Continuous DO monitoring + Data (4 sites)	$ 11,550.00
Septic system inspection and upgrades	$ 100,000.00
Rotational and Prescribed Grazing	$ 100,000.00
ID New Feedlots and Ag Waste Systems	$ 10,000.00
Accelerated Buffer and SWI Implementation	$ 100,000.00

8.4 Adaptive Management



There are water management activities within the Thief River Watershed that have been shown to have a negative impact upon water quality and habitat quality.

Although there are no official aquatic life impairments within the Thief River Watershed, it is highly likely that some reaches will be considered impaired following the successful adoption of TALU standards. Altered hydrology within the Thief River Watershed includes extensive human-made drainage systems.

Continued monitoring and "course corrections" responding to monitoring results are the most appropriate strategy for attaining the water quality goals established in this TMDL. Management activities will be changed or refined to efficiently meet the TMDL and lay the groundwork for de-listing the impaired water bodies.

9. Public Participation

This section describes civic engagement and public participation efforts undertaken in the Thief River Watershed during the course of the development of this TMDL report.

A key prerequisite for successful strategy development and on-the-ground implementation is meaningful civic engagement. This is distinguished from the broader term 'public participation' in that civic engagement encompasses a higher, more interactive level of involvement. The University of Minnesota Extension's definition of civic engagement is "Making 'resourceFULL' decisions and taking collective action on public issues through processes that involve public discussion, reflection, and collaboration." A resourceFULL decision is one based on diverse sources of information and supported with buy-in, resources (including human), and competence. (Further information on civic engagement is available at: http://www.extension.umn.edu/community/civic-engagement/)

An opportunity for public comment on the draft TMDL report was provided via a public notice in the State Register from June 25, 2018, through July 25, 2018.

9.1 Civic Engagement Accomplishments

Multiple public and technical advisory meetings were held in conjunction with the Thief River WRAPS Project.

- A town hall meeting was held at the Whiteford Town Hall on April 6, 2011, to encourage the installation of buffer strips in the Thief River Watershed, particularly in the area between Thief Lake and Agassiz NWR where the SWAT model identified high sediment loading.
- RMB Environmental Laboratories, Inc. (RMB) and the MPCA staff gave a presentation at the Marshall County Water Resources Advisory Committee meeting in Newfolden on November 2, 2011. RMB staff also presented at the January 10, 2012 Pennington County WRAC meeting.
- A public Stakeholders' Project Kick-Off meeting was held on January 13, 2012. More information and notes from the meeting are available in the January 2012, RLWD Water Quality Report: (http://www.redlakewatershed.org/waterquality/MonthlyWQReport/2012%201%20January%20Water%20Quality%20Report.pdf)

- Online informational resources were developed to distribute information about the RLWD's projects and water quality/quantity related news specific to certain watersheds.
    - A Facebook page was created for the RLWD that serves as a means for quickly and easily sharing photos, links to reports, and other news.
    - A blog was created specifically for the Thief River Watershed at https://thiefriver.wordpress.com/.
    - Watershed-specific websites were created for the watersheds within the RLWD. Watershed-specific websites include links to existing documents and reports that relate to the watershed, photo galleries, descriptions of the watersheds, maps, meeting minutes, contacts, and more. At http://www.rlwdwatersheds.org/, users can click on the Thief River (or other watershed of their choice) to view general information about the watershed (http://www.rlwdwatersheds.org/tr-watershed-info) or learn more about the WRAPS process (http://www.rlwdwatersheds.org/wraps-info).
- Social networks within the watershed were mapped by RMB staff.
- RMB staff also attended a RLWD Board meeting to talk about upcoming civic engagement events and get feedback from the Board.
- A "World Café" event was held for the Thief River Watershed at the Black Cat Bar and Grill in Thief River Falls in January of 2013.
- A second Thief River WRAPS Project Stakeholders' Update meeting was held on February 20, 2013, at the Ralph Engelstad Arena Imperial Room in Thief River Falls. In conjunction with this meeting, 2300 brochures were mailed to residents of the watershed that provided information about the project and let people know how they could get involved.
- The RLWD set up a booth at the Thief River Falls Community Expo at the Ralph Engelstad Arena on April 25, 2013, in Thief River Falls. Technical Advisory Group meetings were held on June 12, 2013, at the Detroit Lakes MPCA office and August 27, 2014, at the RLWD Office.
- An open house event was held at the Grygla Community Center on June 17, 2014, as part of the ongoing Thief River WRAPS Project civic engagement efforts.
- The RLWD provided the Thief River Falls Parks and Recreation program with "River of Dreams" small cedar canoes that kids can decorate, launch, and track online.

Another effort to provide more modern means of informing the public about water quality issues was the creation of informational videos that explain the importance of the water quality parameters upon which the impairments in the Thief River Watershed are based. The RLWD and MPCA worked with an independent contractor to create professional videos about DO, turbidity, and *E. coli* bacteria. The video creation process involved script development, collection of video clips, and professional voiceover work. The videos were posted to YouTube and have over 8,200 views, combined as of June 4, 2018.

- DO in Lakes and River: https://youtu.be/ryIadGeJ7O8
- Turbidity: https://youtu.be/EkH3jZvADTk
- Bacteria in Lakes and Rivers: https://youtu.be/vkYUiJXyqLI

9.2 Future Plans

The RLWD and other LGUs need to continue conducting the public outreach efforts that were initiated during the WRAP process. Monthly water quality reports will be made available to the public on the RLWD website and their availability will be announced through Facebook posts, blog posts, and direct email. LGUs may continue to host open house style events that will facilitate one-on-one discussions with residents and other stakeholders. Booths at county fairs and community events (Thief River Falls Expo) are another way to connect with the public.

The RLWD Water Quality Coordinator writes monthly water quality reports that originated as reports to the RLWD Board of Managers, and represent a means of documenting project progress throughout the year (making annual report writing easier). All reports are available on the RLWD website (www.redlakewatershed.org) and are shared on social media and/or emails to a large list of email contacts.

Additional information about the Thief River Watershed can be found on webpages dedicated to the Thief River on the http://www.rlwdwatersheds.org website. This website contains links to a multitude of reports related to the Thief River and water quality.

A Thief River Watershed Public Participation Strategy document was completed by RMB staff in February 2013. This document presented the following civic engagement goals for the Thief River Watershed:

1. Increase volunteer participation in natural resource monitoring.
2. Increase the number of watershed residents participating in water quality discussions.
3. Find effective ways to engage citizens in a meaningful way.
4. Increase the resources utilized to communicate water quality activities within the watershed.
5. Create a document with contact information for local resources, specific to certain water quality concerns or funding sources.

The public can be kept informed of water related news, water quality problems, solutions to water issues, and opportunities for involvement in water-related programs through several different means.

- Websites of LGUs

  - RLWD
    - www.redlakewatershed.org
    - www.rlwdwatersheds.org
  - Pennington SWCD
    - http://www.penningtonswcd.org/
  - Marshall SWCD
    - http://marshallcounty-swcd.org/
  - MPCA
    - http://www.pca.state.mn.us/
    - http://www.pca.state.mn.us/index.php/water/water-types-and-programs/watersheds/thief-river.htmL
- Mailings to individual landowners
- Radio interviews
- Informational brochures and displays
- Press releases and advertisements with local media contacts
- SWCD newsletters
- Organization of events to bring attention to the resource
- Presentations for local civic groups

Local government can gain insights on water issues by consulting the public. The public can provide useful feedback on analysis, alternatives, and/or decisions. Working directly with the public throughout the process helps ensure that public concerns and aspirations are consistently understood and considered.

- Public meetings
- Thief River blog: www.thiefriver.wordpress.com
- Social Media (RLWD and Marshall SWCD Facebook pages)
- Public comment period on final draft reports
- Open houses
- World Café discussions

If the solutions in the WRAPS report are developed with input from local land managers, the likelihood of implementation may increase. In addition, implementation activities will be streamlined due to the collaboration between landowners, local agencies, and funding sources.

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Appendices

Appendix A – Flow summaries

Thief River at County Road 77 (S002-079)		Month						
Average Monthly Flow Summary		April	May	June	July	August	September	October
Individual Monthly	1909				443.97	395.71	299.73	362.68
	1910	1151.27	438.45	160.27	108.48	44.16	8.12	0.00
	1911	46.20	6.88	10.09	1.34	0.24	0.48	1.13
	1912	8.70	4.85	2.53	2.23	1.42	24.27	41.45
	1913	656.90	112.10	26.88	12.81	8.47	9.53	21.32
	1914	146.33	131.74	175.53	69.32	29.32	50.63	91.55
	1915	293.03	246.58	550.33	544.87	88.03	32.40	46.39
	1916	2059.73	1017.19	244.77	103.58	245.77	372.30	160.39
	1917	831.07	122.39	32.77	19.00	2.03	3.55	
	1920	944.83	147.13	365.77	36.39	5.15	0.87	6.76
	1921	441.73	48.77	121.20	21.97	8.35	15.00	
	1922							8.39
	1923	346.70	221.13	15.47	9.84	1.68	1.09	1.71
	1924	49.30	25.00	19.03	15.06	2.62	0.11	
	1928							42.48
	1929	370.80	96.45	24.70	2.27	0.09	0.00	0.00
	1930	149.30	164.81	25.80	3.32	0.05	0.00	0.00
	1931	16.54	5.40	4.17	0.83	0.10	0.00	0.00
	1932	342.50	25.34	0.53	0.00	0.00	0.25	0.51
	1933	138.03	19.68	26.08	0.71	0.00	0.00	0.00
	1934	47.58	4.63	0.46	1.53	0.00	0.00	0.00
	1935	112.17	16.79	2.74	8.98	1.77	0.43	0.00
	1936	278.83	58.29	2.55	0.00	0.00	0.00	0.00
	1937	65.93	106.77	76.10	190.85	635.23	384.23	61.13
	1938	129.60	926.13	624.33	131.69	0.22	0.00	0.00
	1939	12.13	2.43	0.60	0.19	0.00	0.00	0.00
	1940	129.03	21.01	0.98	0.01	0.00	0.00	0.00
	1941	288.90	131.14	490.53	183.51	2.41	18.63	165.06
	1942	944.33	904.94	208.27	21.13	55.58	70.07	4.94
	1943	502.93	324.48	763.57	380.00	32.55	28.87	4.80
	1944	72.27	32.77	414.80	256.79	129.44	196.63	37.42
	1945	1156.20	570.00	95.00	39.00	13.08	22.85	8.79
	1946	804.17	226.45	16.20	9.67	0.00	0.87	0.22
	1947	161.19	217.10	1048.90	561.32	49.59	3.57	8.78
	1948	993.00	978.16	35.67	62.74	94.13	108.00	0.10
	1949	356.03	210.90	326.17	75.40	523.94	283.40	43.78
	1950	740.40	4273.87	1279.03	616.48	35.19	24.47	141.62
	1951	955.70	941.61	110.03	11.48	5.92	48.75	6.14
	1952	559.97	111.39	24.91	75.43	25.01	0.05	0.00
	1953	75.93	157.42	208.67	48.69	0.45	2.51	2.53
	1954	160.07	367.03	213.67	18.23	1.69	1.39	0.19
	1955	255.95	91.13	373.77	42.58	5.24	0.00	0.00
	1956	618.77	896.16	275.37	583.81	49.58	665.97	60.23
	1957	605.20	606.58	498.37	639.55	149.98	647.17	535.87
	1960	651.10	355.77	149.00	89.64	5.58	1.52	0.62
	1961	59.30	73.19	2.60	0.11	0.10	14.77	8.31
	1962	597.78	1017.48	1774.33	721.39	368.87	181.40	16.23
	1963	974.47	575.42	423.47	100.19	15.97	1.18	0.17
	1964	200.49	337.13	1206.63	706.19	523.52	179.57	512.68
	1965	1818.22	1405.03	1054.87	430.87	37.05	96.83	510.90
	1966	2827.00	1874.42	638.10	271.16	326.48	161.92	14.79
	1967	1779.30	1751.13	509.77	212.26	20.73	1.75	28.32
	1968	36.27	22.90	762.93	1016.06	708.97	441.57	213.97
	1969	1678.43	1141.26	158.20	9.33	1.80	0.74	156.75
	1970	655.37	784.45	1374.93	404.55	2.72	3.93	98.85

Thief River at County Road 77 (S002-079) Average Monthly Flow Summary		Month						
		April	May	June	July	August	September	October
	1971	408.80	125.58	34.70	12.05	1.06	8.73	469.10
	1972	1141.33	473.48	86.26	10.47	5.07	2.38	61.84
	1973	26.40	32.58	11.21	0.82	4.93	177.76	407.29
	1974	1339.57	1642.26	623.63	45.56	132.45	61.57	36.68
	1975	1130.77	1290.90	331.37	2102.90	71.77	103.03	110.74
	1976	556.43	37.77	50.14	2.31	4.64	1.38	1.18
	1977	28.16	34.02	8.87	1.69	0.02	8.91	18.34
	1978	1645.87	624.13	151.80	92.81	43.71	69.53	160.52
	1979	1231.15	1788.39	655.70	129.74	12.70	11.32	91.45
	1980	617.18	63.41	0.03	0.00	0.00	13.99	4.16
	1981	7.75	6.13	83.20	105.40	3.38	14.59	
	1982	930.80	829.84	165.80	185.61	149.32	8.90	369.19
	1983	655.57	358.16	443.90	576.61	195.61	187.83	296.26
	1984	537.13	211.23	468.83	243.10	46.86	8.66	75.68
	1985	750.40	748.90	1002.57	1136.48	841.71	942.97	636.58
	1986	1366.77	1248.35	248.47	28.42	9.66	122.27	3.52
	1987	112.87	325.67	69.77	109.34	52.29	5.45	2.78
	1988	244.93	18.85	31.65	0.44	0.11	12.97	1.26
	1989	726.87	227.87	161.03	85.03	10.45	0.12	0.00
	1990	14.55	1.83	11.89	2.79	0.01	0.00	0.00
	1991	10.18	21.65	3.95	21.18	0.98	6.06	3.98
	1992	636.60	412.03	57.83	61.03	33.72	389.63	161.10
	1993	639.70	89.81	171.03	710.74	1011.58	1012.27	232.77
	1994	90.43	93.97	77.87	913.84	136.81	239.93	151.39
	1995	656.23	372.32	66.40	148.13	102.81	82.43	104.16
	1996	1070.17	2114.19	1176.33	690.39	360.23	31.15	67.95
	1997	1924.00	1979.03	774.30	921.39	111.03	8.91	82.93
	1998	201.93	560.16	688.90	899.45	198.97	97.10	390.48
	1999	2750.00	1893.23	1234.97	487.90	376.03	1619.10	471.42
	2000	239.53	115.45	457.43	285.35	52.10	28.90	41.84
	2001	1605.17	900.42	644.20	380.16	1129.65	235.03	77.58
	2002	50.70	167.48	2237.93	1907.74	617.81	237.80	89.06
	2003	118.44	122.87	150.78	68.94	15.30	1.36	4.67
	2006	2166.33	1073.42	35.50	6.72	4.21	7.47	0.38
	2007	336.07	43.84	449.57	236.19	1.62	0.47	16.81
	2008	151.00	63.45	493.43	146.07	1.89	6.75	216.35
	2009	2254.67	1052.52	696.27	192.11	77.84	40.40	121.23
	2010	198.93	855.42	1187.13	530.81	280.35	1065.40	1208.00
	2011	2388.80	977.94	873.27	1047.13	218.00	61.40	4.10
	2012	80.10	29.55	28.67	11.80	116.16	5.79	17.90
	2013	396.68	491.16	331.97	220.99	291.13	21.95	81.00
	2014	956.35	1327.68	1455.63	972.77	624.71	130.07	183.74
Summary Statistics (cfs/sq.mi.)	Maximum	2827.00	4273.87	2237.93	2102.90	1129.65	1619.10	1208.00
	Average	656.30	523.36	371.12	263.68	126.36	121.09	106.49
	Median	472.33	223.79	168.42	89.64	15.97	13.99	21.32
	75th Percentile	952.98	885.98	540.19	392.35	130.95	105.52	121.23
	25th Percentile	131.71	63.42	29.41	10.98	1.73	1.37	1.18
	10th Percentile	46.61	20.08	4.02	1.03	0.03	0.00	0.00
	5th Percentile	15.84	5.87	1.99	0.17	0.00	0.00	0.00
	Minimum	7.75	1.83	0.03	0.00	0.00	0.00	0.00

Thief River at CSAH 7 (S002-088) Avg. Monthly Flow Summary		Month						
		April	May	June	July	August	September	October
Individual Monthly Mean Flows (cfs) Combination of Measured and HSPF Modeled Flows	1937	1363.7						398.2
	1966	1559.0	1762.5					
	1970	496.1	0.0					
	1971	1260.2						
	1972	1241.8	0.0			464.3	249.1	150.3
	1973				1202.8			
	1976	1318.2	1376.1		0.0			
	1979					181.6		
	1980	327.5		0.0			0.0	
	1984	710.3	0.0		203.4			0.0
	1985	181.6			0.0			
	1986	465.7		266.9	237.4			
	1989	819.3		294.9	1096.4	1197.4	1262.4	
	1991				828.2	385.0		
	1992	1156.2		111.1			428.1	
	1993	1448.2	1556.7	1300.5	974.7	656.3		
	1994	1700.2	1655.7	1069.9	1272.7		28.9	
	1995					171.0		931.9
	1996	1634.6	1418.0	1164.3	614.1	330.2	1063.9	318.6
	1997	250.2	101.8	582.7	236.6			36.3
	1998	1277.5	924.3	535.0	430.4	1053.4	428.1	145.4
	1999	75.1	863.1	1577.6	1595.0	871.9	225.9	400.9
	2000	561.3		66.6		409.0		60.0
	2001	611.0	1307.5	1313.6		124.5	818.8	686.0
	2002	1001.6	533.1	1246.1	1205.9	53.5	53.5	
	2003	1434.8	1209.3	47.6		16.8		0.0
	2004	348.2	6.9	436.0	278.6	2.5	0.0	27.6
	2007	71.8	60.5	391.3	96.4	7.7	8.2	73.8
	2008	1502.8	951.7	657.9	131.7	44.6	67.9	154.3
	2009	141.2	479.6	861.5	410.3	241.8	632.9	863.4
	2010	1760.1	732.8	634.5	735.4	204.3	54.0	11.5
	2011	0.2	0.0	3.2	7.5	131.4	1.1	8.1
	2012	70.3	228.6	249.8	197.6	328.4	24.8	71.0
	2013	446.8	1007.3	921.5	648.7	469.5	119.5	160.6
	2014	9.5	171.0	520.4	378.5	312.4	28.1	16.1
	2015	206.7	244.1	619.2	203.4	196.1	550.7	121.4
Summary Statistics (cfs/sq.mi.)	Maximum	2144.3	1878.3	1914.2	1811.5	1406.1	1503.5	1472.4
	Average	877.5	824.4	827.5	577.6	333.4	247.9	184.6
	Median	515.0	452.8	643.2	339.0	162.7	55.1	64.0
	25th Percentile	1357.8	1336.0	1036.8	609.2	386.5	169.0	181.9
	10th Percentile	1661.6	1586.4	1417.7	1219.9	674.9	761.9	559.6
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Mud River at State Highway 89 (S002-078) Avg. Monthly Flow Summary		Month						
		April	May	June	July	August	September	October
Individual Monthly Mean Flows (cfs) Combination of Measured and HSPF Modeled Flows	1937				6.1	5.2		
	1966	866.0			967.0			
	1970					17.2		
	1971						0.2	
	1972						0.3	
	1973				17.4			
	1976		17.0				0.0	
	1979			0.2		0.6	0.5	
	1980	20.0	10.0	0.0	0.0			
	1984	155.0	35.0			88.0	5.0	15.0
	1985				92.0			
	1986			16.2	4.0	1.5		
	1989	563.0						
	1991							
	1992	136.0						
	1993					139.0		
	1994				164.0			
	1995							
	1996	318.5	285.1	96.7	91.7	26.0	20.1	46.8
	1997	449.3	227.9	188.1	224.5	33.3	17.9	104.2
	1998	74.9	161.7	226.4	243.1	54.0	44.5	125.6
	1999	305.7	209.2	206.4	76.0	61.4	265.0	178.4
	2000	32.3	39.8	117.6	65.7	27.5	19.0	28.7
	2001	267.7	128.5	117.1	143.2	339.3	121.7	60.2
	2002	44.7	72.5	480.8	151.8	30.8	67.3	22.0
	2003	33.7	24.3	109.2	59.2	12.2	27.0	26.6
	2004	260.3	257.0	154.7	167.2	76.3	83.7	85.8
	2005	148.0	81.8	228.6	158.9	56.3	52.9	37.2
	2006	362.2	80.8	14.5	6.5	21.4	10.3	9.2
	2007	138.9	30.7	110.9	53.6	13.3	2.4	43.0
	2008	45.9	17.1	110.6	32.6	6.1	9.9	77.4
	2009	132.1	116.9	27.0	6.8	19.3	10.2	15.0
	2010	12.5	167.0	13.5		1710.0	244.0	114.1
	2011	1077.6	90.9	214.9	92.1	17.9	10.7	9.8
	2012	16.0	11.1	8.0	4.2	0.8	0.0	0.3
	2013	65.5	85.0	124.0	133.3	23.4	3.3	47.5
	2014	306.4	271.9	248.9	218.9	65.4	6.7	67.8
	2015	9.8	47.3	128.3	103.5	22.3	6.9	6.0
Summary Statistics (cfs/sq.mi.)	Maximum	1077.6	285.1	480.8	967.0	1710.0	265.0	178.4
	Average	233.7	107.3	127.9	126.3	110.3	41.2	53.4
	Median	138.9	81.8	117.1	91.9	24.7	10.3	43.0
	25th Percentile	44.7	32.8	21.6	21.2	14.3	3.3	15.0
	10th Percentile	17.6	17.0	9.1	5.1	3.3	0.2	9.2
	Minimum	9.8	10.0	0.0	0.0	0.6	0.0	0.3

Mud River at State Highway 54 (S002-977) Avg. Monthly Flow Summary		Month						
		April	May	June	July	August	September	October
Individual Monthly Mean Flows (cfs) Combination of Measured and HSPF Modeled Flows	1937				6.1	5.2		
	1966	866.0			967.0			
	1970					17.2		
	1971						0.2	
	1972						0.3	
	1973				17.4			
	1976		17.0				0.0	
	1979			0.2		0.6	0.5	
	1980	20.0	10.0	0.0	0.0			
	1984	155.0	35.0			88.0	5.0	15.0
	1985				92.0			
	1986			16.2	4.0	1.5		
	1989	563.0						
	1991							
	1992	136.0						
	1993					139.0		
	1994				164.0			
	1995							
	1996	210.4	137.1	71.1	45.9	14.2	10.3	31.0
	1997	274.0	104.8	156.0	149.7	22.2	10.2	65.4
	1998	22.2	104.6	141.2	155.6	28.8	23.6	72.8
	1999	171.9	115.1	146.1	50.3	36.8	164.9	163.5
	2000	21.2	30.9	75.5	41.8	18.2	10.9	14.0
	2001	145.0	90.5	85.7	99.0	275.1	111.8	51.7
	2002	18.1	39.7	335.5	104.4	18.1	46.9	13.6
	2003	19.1	13.6	64.8	37.4	7.7	16.1	15.9
	2004	118.3	139.4	95.0	95.4	43.7	43.8	45.3
	2005	61.8	44.1	147.3	102.0	35.8	34.7	21.2
	2006	231.7	52.9	9.0	2.8	12.2	5.9	4.9
	2007	66.9	31.5	84.8	30.9	10.1	1.2	22.7
	2008	11.1	11.5	80.6	30.7	7.3	14.9	55.7
	2009	150.8	138.5	94.5	32.4	32.7	15.4	11.1
	2010	12.5	167.0	13.5		1710.0	244.0	114.1
	2011	1077.6	90.9	214.9	92.1	17.9	10.7	9.8
	2012	16.0	11.1	8.0	4.2	0.8	0.0	0.3
	2013	65.5	85.0	124.0	133.3	23.4	3.3	47.5
	2014	306.4	271.9	248.9	218.9	65.4	6.7	67.8
	2015	9.8	47.3	128.3	103.5	22.3	6.9	6.0
Summary Statistics (cfs/sq.mi.)	Maximum	1900.0	729.0	2350.0	967.0	1710.0	400.3	344.9
	Average	70.8	54.5	91.5	38.0	44.6	84.0	24.8
	Median	45.5	47.6	90.9	48.7	14.5	11.6	17.9
	25th Percentile	127.7	105.2	153.2	105.7	31.6	29.6	46.2
	10th Percentile	211.6	193.4	229.5	179.4	84.0	101.2	103.1
	Minimum	0.0	2.7	0.0	0.0	0.0	0.0	0.0

Moose River at CSAH 54 (S004-211) Avg. Monthly Flow Summary		Month						
		April	May	June	July	August	September	October
Individual Monthly Mean Flows (cfs) Combination of Measured and HSPF Modeled Flows	1978	408.3						
	1979	621.9	69.7					
	1983							
	1985		394.6					
	1986	462.3	156.7					
	1988	62.0						
	1989	59.9						
	1990							
	1991							
	1992	131.7	109.3				53.0	74.1
	1993	83.4	46.1	44.3	183.6	113.6	88.9	
	1994		30.8	99.7	115.8	78.2	49.7	
	1995	55.2		23.1				
	1996	166.7	429.0	49.7				
	1997	480.2	106.7		69.7			
	1998		273.3					
	1999	578.8		206.9				
	2000							
	2001	131.8	237.2	102.7	37.9	368.1	66.3	10.2
	2002		39.7	335.0	134.3	0.0	0.0	0.0
	2003				23.7	39.7	0.0	0.0
	2007	37.0	0.0	68.9	33.1	0.3	0.1	18.9
	2008	5.4	11.1	110.4	35.0	3.5	3.1	48.7
	2009	143.1	139.9	30.0	7.2	21.5	2.8	17.1
	2010	16.4	131.9	131.2	100.3	48.0	134.0	125.2
	2011	452.4	123.5	118.4	46.2	6.3	0.0	0.0
	2012	2.5	0.0	0.0	30.4	0.0	14.8	0.1
	2013	219.6	72.4	316.7	39.1	8.7	0.0	4.9
	2014	140.1	155.0	126.1	191.5	60.1	10.2	
	2015	3.1	74.4	114.5	132.2	17.8	2.4	13.6
Summary Statistics (cfs/sq.mi.)	Maximum	621.9	429.0	335.0	191.5	368.1	134.0	125.2
	Average	202.9	130.1	117.3	78.7	54.7	28.4	26.1
	Median	131.8	108.0	106.6	46.2	19.7	3.1	11.9
	25th Percentile	55.2	44.5	48.4	34.1	4.2	0.1	0.1
	10th Percentile	5.4	10.0	26.6	26.4	0.1	0.0	0.0
	Minimum	2.5	0.0	0.0	7.2	0.0	0.0	0.0