Bois de Sioux River Watershed Total Maximum Daily Load Study

A quantification of the total amount of phosphorus, total suspended solids, and bacteria that can be received by the lakes and streams in the Bois de Sioux River Watershed, and maintain their ability to support swimming, fishing, and healthy biological communities.

EOR water ecology community

Bois de Sioux Watershed District

CLEAN WATER LAND & LEGACY AMENDMENT

MINNESOTA POLLUTION CONTROL AGENCY

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Acronyms

ac-ft/yr	acre feet per year
AF	Anoxic factor
AFO	Animal Feeding Operation
AUID	Assessment Unit ID
BD-P	Bicarbonate Dithionite extractable Phosphorus
BMP	Best Management Practice
BdSRW	Bois de Sioux River Watershed
CAFO	Concentrated Animal Feeding Operation
cfu	colony-forming unit
Chl-*a*	Chlorophyll-*a*
CRP	Conservation Reserve Program
DNR	Minnesota Department of Natural Resources
DO	Dissolved Oxygen
E. coli	*Escherichia coli*
EPA	United States Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
EQuIS	Environmental Quality Information System
GIS	Geographic Information Systems
HSPF	Hydrologic Simulation Program – FORTRAN
HUC	Hydrologic Unit Code
IBI	Index of Biological Integrity
ITPHS	Imminent Threat to Public Health and Safety
km^2	square kilometer
LA	Load Allocation
Lb	pound
lb/yr	pounds per year
LGU	Local Government Unit
m	meter
mg/L	milligrams per liter
mg/m^2-day	milligram per square meter per day
ml	milliliter
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency

MS4	Municipal Separate Storm Sewer Systems
NA	North American
NASS	National Agricultural Statistics Service
NLCD	National Land Cover Dataset
NPDES	National Pollutant Discharge Elimination System
org.	organisms
P	Phosphorus
RNR	River Nutrient Region
SDS	State Disposal System
SSTS	Subsurface Sewage Treatment Systems
SWCD	Soil and Water Conservation District
T	Temperature
TMDL	Total Maximum Daily Load
TP	Total phosphorus
USDA	United States Department of Agriculture
USGS	United States Geological Survey
UV	Ultra Violet
WLA	Wasteload Allocation
WRAPS	Watershed Restoration and Protection Strategies
WWTF	Wastewater Treatment Facility
WWTP	Wastewater Treatment Plant

Executive Summary

The Clean Water Act (CWA) of 1972 requires that each state identify and conduct a Total Maximum Daily Load (TMDL) study on their impaired waters. A TMDL identifies the pollutant that is causing the impairment, and how much of that pollutant can enter the waterbody and still allow it to meet water quality standards.

This TMDL study addresses total phosphorus (TP), total suspended solids (TSS), and bacteria (in the form of *Escherichia coli* [*E. coli]*) impairments in two lakes and three streams located in the Bois de Sioux River Watershed (BdSRW), Hydrologic Unit Code (HUC), 09020101, as identified in the 2014 United States Environmental Protection Agency (EPA) CWA Section 303(d) list of impaired waters. The BdSRW is a tributary to the Red River of the North, in west-central Minnesota.

Information from multiple sources was used to evaluate the ecological health of each waterbody, including:

- All available water quality data from the TMDL study 10-year time period (2002 through 2011)
- BdSRW Hydrologic Simulation Program – FORTRAN (HSPF) model
- Sediment phosphorus concentrations
- Fisheries surveys
- Aquatic plant surveys
- Stream geomorphology and field surveys
- Stressor identification (SID) investigations
- Stakeholder input

The following pollutant sources were evaluated for each lake or stream: watershed runoff, loading from upstream waterbodies, atmospheric deposition, lake internal loading, point sources, feedlots, septic systems, and in-stream alterations. This TMDL study used an inventory of pollutant sources to develop a lake response model for each impaired lake and a load duration curve (LDC) model for each impaired stream. These models were then used to determine the pollutant reductions needed for the impaired waterbodies to meet water quality standards. The BdSRW HSPF model was used to develop load allocations (LAs) for non-point sources of pollutants from the entire drainage area within Minnesota, North Dakota, and South Dakota; however, point source wasteload allocations (WLAs) were determined for Minnesota sources only. Point sources in North Dakota and South Dakota will be assigned WLAs as part of their state's TMDL and National Pollutant Discharge Elimination System (NPDES) programs.

The TMDL study's results will aid in the selection of implementation activities during the Bois de Sioux Watershed Restoration and Protection Strategy (WRAPS) process. The purpose of the WRAPS process is to support local working groups in developing scientifically supported restoration and protection strategies for subsequent implementation planning. Following completion of the WRAPS process, the Bois de Sioux River WRAPS Report will be publically available on the Minnesota Pollution Control Agency (MPCA) BdSRW website: https://www.pca.state.mn.us/water/watersheds/bois-de-sioux-river.

1 Project Overview

1.1 Purpose

The state of Minnesota has determined that some lakes and streams in the BdSRW exceed established state water quality standards and have impaired designated beneficial uses. In accordance with the Clean Water Act (CWA), the state must conduct TMDL studies on the impaired waters. The goals of this TMDL study are to provide WLA for regulated pollutant sources and LAs for unregulated pollutant sources within the BdSRW, and to quantify the pollutant reductions needed to meet Minnesota water quality standards. Point and non-point pollutant source reductions within North and South Dakota needed to meet the assumptions of this TMDL will be addressed through the North Dakota and South Dakota TMDL studies and NPDES programs. This TMDL study addresses the following impairments within the BdSRW (HUC 09020101) (Figure 1) that are included on the federal 2014 303(d) list:

- aquatic recreation use impairments due to eutrophication (TP) in two lakes,
- aquatic recreation use impairments due to *E. coli* in two stream reaches, and
- aquatic life use impairments due to turbidity (TSS), fish/macroinvertebrate bioassessments, and/or dissolved oxygen (DO) in two stream reaches.

Other BdSRW studies referenced in the development of this TMDL study include:

- Bois de Sioux River SID Study (MPCA 2016)
- Bois de Sioux River Monitoring and Assessment Report (MPCA 2013)
- Rabbit River Turbidity TMDL Study (MPCA 2010)

This TMDL study's results will aid in the selection of implementation activities during the BdSRW's WRAPS process. The purpose of the WRAPS process is to support local working groups in developing scientifically-supported restoration and protection strategies for subsequent implementation planning. Following completion of the WRAPS process, the Bois de Sioux River WRAPS Report will be publically available on the MPCA's BdSRW website: https://www.pca.state.mn.us/water/watersheds/bois-de-sioux-river

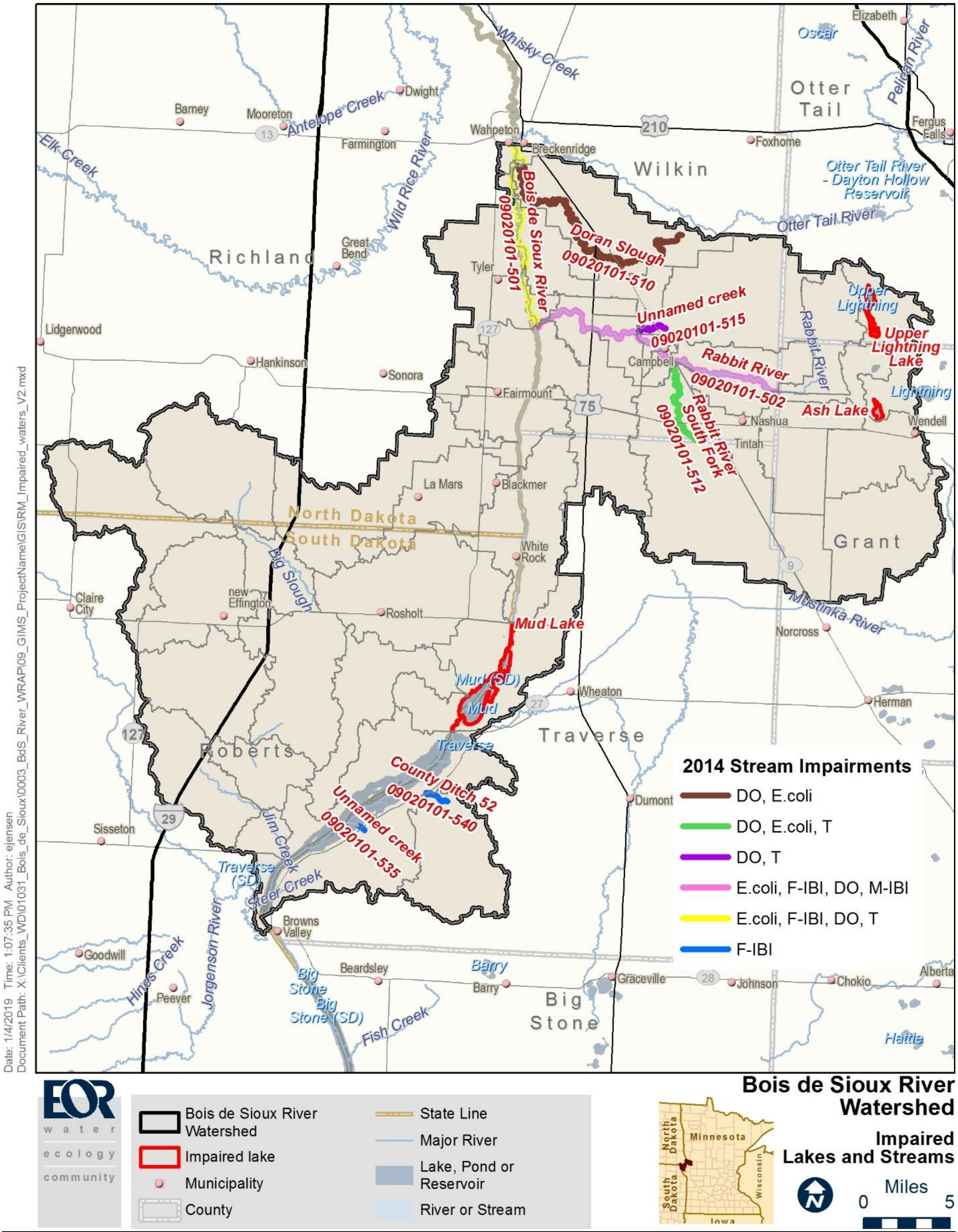

Figure 1. Impaired lakes and streams in the Bois de Sioux River Watershed

1.2 Identification of Waterbodies

Table 1. Bois de Sioux River Watershed Impaired Streams and Lakes

Affected Use: Pollutant/Stressor	AUID/ Lake ID	Name	Location/Reach Description	Designated Use Class	Listing Year	Target Start/ Completion	Impairment addressed by:
Aquatic Recreation: Nutrient/ Eutrophication Biological Indicators (Phosphorus)	26-0294-00	Ash	3 mi. NW of Wendell	2B, 3C	2014	2012/2016	TP TMDL
	78-0024-00	Mud	3 mi W of Wheaton	2B, 3C	2014	2012/2016	Deferred until next cycle*
	56-0957-00	Upper Lightning	Near Western	2B, 3C	2014	2012/2016	TP TMDL
Aquatic Recreation: *E. coli*	09020101-501	Bois de Sioux R	Rabbit R to Otter Tail R	2C	2014	2012/2016	Deferred to conduct a joint TMDL study with ND
	09020101-502	Rabbit River	Wilkin County line to Bois de Sioux R	2C	2010	2012/2016	*E. coli* TMDL
	09020101-510	Unnamed Creek (Doran Slough)	Headwaters to Bois de Sioux R	2C	2014	2012/2016	*E. coli* TMDL
Aquatic Life: Dissolved oxygen	09020101-501	Bois de Sioux River	Rabbit R to Otter Tail R	2C	1998	2014/2018	TP & TSS TMDL
	09020101-502	Rabbit River	Wilkin County line to Bois de Sioux R	2C	2004	2012/2016	TP & TSS TMDL
	09020101-510	Unnamed Creek (Doran Slough)	Headwaters to Bois de Sioux R	2C	2014	2012/2016	Non-pollutant based stressors
	09020101-512	Rabbit River, South Fork	Wilkin County line to Rabbit R	2C	2014	2012/2016	Deferred until next cycle†
	09020101-515	Unnamed Creek	Unnamed Cr to Rabbit R	2B, 2C	2014	2012/2016	Deferred until next cycle**
Aquatic Life:	09020101-502	Rabbit River	Wilkin County line to Bois de Sioux R	2C	2014	2012/2016	TP & TSS TMDL

Affected Use: Pollutant/Stressor	AUID/ Lake ID	Name	Location/Reach Description	Designated Use Class	Listing Year	Target Start/ Completion	Impairment addressed by:
Macroinvertebrate Bioassessments							
Aquatic Life: Fish Bioassessments	09020101-501	Bois de Sioux R	Rabbit R to Otter Tail R	2C	2002	2012/2016	TP & TSS TMDL
	09020101-502	Rabbit River	Wilkin County line to Bois de Sioux R	2C	2002	2012/2016	TP & TSS TMDL
	09020101-512	Rabbit River, South Fork	Wilkin County line to Rabbit R	2C	2014	2012/2016	Deferred until next cycle†
	09020101-535	Unnamed Creek	Unnamed Cr to Lk Traverse	2B, 3C	2014	2012/2016	Non-pollutant based stressors
	09020101-540	County Ditch 52	Unnamed Cr to Unnamed Cr	2B, 3C	2014	2012/2016	Non-pollutant based stressors
Aquatic Life: Turbidity	09020101-501	Bois de Sioux River	Rabbit R to Otter Tail R	2C	2008	2012/2016	TSS TMDL
	09020101-502	Rabbit River	Wilkin County line to Bois de Sioux R	2C	1996	2010***	TSS TMDL
	09020101-512	Rabbit River, South Fork	Wilkin County line to Rabbit R	2C	2014	2012/2016	Deferred until next cycle†
	09020101-515	Unnamed Creek	Unnamed Cr to Rabbit R	2B, 2C	2014	2012/2016	Deferred until next cycle**

* Additional monitoring and modeling are needed to complete a well-calibrated lake water quality response model for Mud Lake Reservoir. This lake will be reassessed in the next 10-year monitoring and assessment cycle (2020).

** Little to no monitoring data were collected from this reach during the 2002-2011 time period. Very low to stagnant flow conditions were observed during all visits by MPCA monitoring staff in 2013-2015, resulting in unsuitable conditions for monitoring. MPCA will collect more data from this reach and reassess these impairments during the next 10-year monitoring and assessment cycle (2020).

*** A Turbidity TMDL was completed for the Rabbit River in 2010. However, a TSS TMDL was completed for this impaired reach based on the new Minnesota stream TSS standard as part of this TMDL study, but consistent with the assumptions from the 2010 Turbidity TMDL.

† Insuffiencent monitoring data were collected from this reach during the 2002-2011 time period. MPCA will collect more data from this reach and reassess these impairments during the next 10-year monitoring and assessment cycle (2020).

1.3 Priority Ranking

The MPCA's projected schedule for TMDL study completions, as indicated on the federal 303(d) impaired waters list, implicitly reflects Minnesota's priority ranking of this TMDL study (see Table 1). Minnesota continues to conduct TMDL studies on the major watershed scale on a 10-year cycle to address TMDLs more efficiently and effectively. The schedule of the 10-year watershed monitoring cycle drives the sequencing of TMDL completions.

1.4 Description of the Impairments and Stressors

The following section identifies and describes the causes of lake and stream impairments in the BdSRW and the pollutant-based stressors that will be addressed by TMDLs in this study. Table 2 summarizes the TMDLs that will be completed for each impaired stream reach, listed by its Assessment Unit Identification (AUID) number.

Table 2. Pollutants addressed by TMDL for impaired streams

AUID	Impairment	Designated Use Class	*E. coli*	TP	TSS
-501	**Bacteria** **Dissolved oxygen** **Fish bioassessments** **Turbidity**	2C		●	●
-502	**Bacteria** **Dissolved oxygen** **Fish & macroinvertebrate bioassessments** **Turbidity**	2C	●	●	●
-510	**Bacteria**	2C	●		

1.4.1 Lake Eutrophication

The lake eutrophication impairments in the BdSRW were characterized by TP and the response variables of chlorophyll-a (Chl-*a*) concentrations and Secchi transparency depths that failed to meet the state water quality standards. Excessive nutrient loads, in particular TP, lead to an increase in algal blooms and reduced transparency – both of which may significantly impair or prohibit the use of lakes for aquatic recreation. This TMDL study developed TP lake response models and calculated TMDLs for all lake eutrophication impairments.

Note that Lake Traverse has high TP levels but does not have corresponding high algae levels nor low clarity and is therefore not listed as impaired due to eutrophication. White Rock/Mud Lake; however, was assessed as not supporting aquatic recreation due to eutrophication. Mud Lake is a large, shallow reservoir managed by the U.S. Army Corps of Engineers (ACOE) for flood control and for water conservation during periods of drought. The lake has a 2-meter deep channel with most of the lake between 0.3 and 0.6 meters deep; however, during high water, the depth can increase over 3 meters above normal pool elevation. Modeling was conducted to determine if the basin had sufficient residence time to be considered a lake. The results indicate that even though the mean depth is only 0.3 meters, the lake still had an estimated residence time of greater than 14 days at low flow. Flows throughout this system are highly managed by the ACOE and the contribution of flows from the Mustinka River to Lake Traverse and Mud Lake is complicated and depends on the flow regime. Mud Lake also receives discharge from three states: Minnesota, South Dakota, and North Dakota. Therefore, additional monitoring and modeling is needed to develop a well calibrated lake water quality response model for Mud Lake. Consequently, the TMDL study for Mud Lake has been deferred until the next MPCA assessment cycle.

Suggested TP goals and reductions were developed for Mud Lake and Lake Traverse (see Table 48 and Table 49) to aid in implementation of the Bois de Sioux River (-501) TP TMDL (Table 47), but these goals do not represent TMDLs. Suggested TP load targets for NPDES permitted sources within the Mustinka River Watershed (Table 44) are represented in the Mud Lake goals and reduction table (Table 48), and are based on the Bois de Sioux River (-501) achieving the river eutrophication standards (see Section 4.1.3). The suggested TP load targets for NPDES permitted sources within the Mustinka River Watershed may be modified in the future depending on the outcome of additional monitoring and modeling of Mud Lake.

1.4.2 Stream *E. coli*

The stream bacteria impairments in the BdSRW were characterized by high *E. coli* concentrations during June through September. Minnesota *E. coli* water quality standards were developed to 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 less) body contact during the warm season months, as there is very little open water swimming in Minnesota during the cold season months. This TMDL study developed *E. coli* LDCs and TMDLs for two of three stream *E. coli* impairments. The third *E. coli* impaired reach (Bois de Sioux River) is a waterbody that is shared with the state of North Dakota. The MPCA and the North Dakota Department of Health (NDDH) have agreed to perform a joint TMDL study to address the Bois de Sioux River's *E. coli* impairment.

1.4.3 Stream Turbidity

The stream aquatic life impairments due to turbidity in the BdSRW were characterized by high turbidity levels. Turbidity is a physical characteristic of water that describes the degree to which light is scattered and absorbed in the water column (therefore reducing water clarity). Turbidity is caused by suspended sediment or impurities, such as clay, silt, fine organic matter, algae, and other organic and inorganic sources. Because turbidity is a physical characteristic of water and not a pollutant, this TMDL study developed LDCs and TMDLs for TSS, a measure of suspended sediment and the primary cause of turbidity in the BdSRW.

1.4.4 Stream Fish and Macroinvertebrate Bioassessments

The fish and/or macroinvertebrate bioassessment impairments in the BdSRW were characterized by low Index of Biological Integrity (IBI) scores for fish and/or macroinvertebrates. The presence of a healthy, diverse, and reproducing aquatic community is a good indication that the aquatic life beneficial use is being supported by a lake, stream, or wetland. The aquatic community integrates the cumulative impacts of pollutants, habitat alteration, and hydrologic modification on a waterbody over time. Characterization of an aquatic community is accomplished using IBI, which incorporates multiple attributes of the aquatic community, called "metrics", to evaluate complex biological systems. For further information regarding the development of stream IBIs, refer to the MPCA *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for the Determination of Impairment: 305(b) Report and 303(d) List*.

In 2016, the MPCA completed a SID study to determine the cause of low fish and macroinvertebrate IBI scores in the BdSRW. The SID study results are summarized in Table 3. This TMDL study developed LDCs and TMDLs for the pollutant-based stressors (TP and TSS) identified as needing TMDLs through the SID process (Table 3).

The TMDL computations were completed for the mass pollutant-based stressors of TSS and TP. In the case of many stressors, a mass reduction is not the appropriate means of addressing these issues, thus no TMDL is computed (i.e., habitat stressors). Non-pollutant stressors will be addressed through the WRAPS process.

Table 3. Summary of stressors causing biological impairment in BdSRW streams by location (AUID)

Stream	AUID Last 3 digits	Biological Impairment	Stressor						
			Dissolved Oxygen	Phosphorus	Sediment/ Turbidity	Connectivity	Altered Hydrology*	Channel Alteration	Pesticides
Bois de Sioux R.	-501	Fish	•	♦,+	•		♦	◊	?
Rabbit River	-502	Fish and Macroinvertebrates	•	♦,+	•		♦	•	?
South Fork Rabbit River	-512	Fish	•	♦,+	•	o	♦		?
Unnamed Trib. to Lk. Traverse	-535	Fish				♦	♦		?
Judicial Ditch 52	-540	Fish			•	♦	♦		?

* Includes intermittency and/or geomorphology/physical channel issues
♦ A "root cause" stressor, which causes other consequences that become the direct stressors.
◊ Possible contributing root cause.
• Determined to be a direct stressor.
o A stressor, but anthropogenic contribution, if any, not quantified. Includes beaver dams as a natural stressor.
\+ Based on river nutrient concentration threshold, but not officially assessed and listed for this parameter.
? Inconclusive - not enough is known to make a conclusion either way. See reports on pesticide monitoring in Minnesota conducted by the Minnesota Department of Agriculture.

1.4.5 Stream Dissolved Oxygen

Aquatic life impairments in the Bois de Sioux River (AUID 09020101-501), Rabbit River (AUID 09020101-502), and Rabbit River - South Fork (AUID 09020101-512) were characterized by low DO levels. In 2016, the MPCA completed a SID study to determine the cause of low fish and macroinvertebrate IBI scores in the BdSRW. As part of this study, the cause of low DO levels in each impaired reach was also identified. In all cases, excess TP was identified as the primary stressor causing low DO. Excess TP in the stream increases algae and other plant growth. When algae and plant growth reach very high levels, the decomposition of and respiration from algae and aquatic plants can consume large amounts of DO resulting in stream DO levels that are too low to support fish.

2 Applicable Water Quality Standards and Numeric Water Quality Targets

All waterbodies have an MPCA-defined Designated Use Classification, which identifies the optimal purpose for that waterbody (see Table 1). The lakes and streams addressed by this TMDL study fall into one of the following two designated use classifications:

2B, 3C – a healthy warm water aquatic community; industrial cooling and materials transport without a high level of treatment

2C – a healthy indigenous fish community

Class 2 waters are protected for aquatic life and aquatic recreation, and Class 3 waters are protected for industrial consumption as defined by Minn. R. ch. 7050.0140. The most protective of these classes is 2B, for which water quality standards are provided below.

The Minnesota narrative water quality standard for all Class 2 waters (Minn. R. 7050.0150, subp. 3) states, "For all Class 2 waters, the aquatic habitat, which includes the waters of the state and stream bed, shall not be degraded in any material manner, there shall be no material increase in undesirable slime growths or aquatic plants, including algae, nor shall there be any significant increase in harmful pesticide or other residues in the waters, sediments, and aquatic flora and fauna; the normal fishery and lower aquatic biota upon which it is dependent and the use thereof shall not be seriously impaired or endangered, the species composition shall not be altered materially, and the propagation or migration of the fish and other biota normally present shall not be prevented or hindered by the discharge of any sewage, industrial waste, or other wastes to the waters".

2.1 Lakes

2.1.1 Lake Eutrophication

TP is often the limiting factor controlling primary production in freshwater lakes; as in-lake TP concentrations increase, algal growth increases resulting in higher Chl-*a* concentrations and lower water transparency. In addition to meeting TP limits, lakes must also meet Chl-*a* concentrations and Secchi transparency depth standards. In developing the lake nutrient standards for Minnesota lakes (Minn. R. ch. 7050), the MPCA evaluated data from a large cross-section of lakes within each of the state's ecoregions (Heiskary and Wilson 2005). Clear relationships were established between the causal factor (TP) and the response variables (Chl-*a* and Secchi transparency). Based on these relationships, it is expected that by meeting the TP target in each lake, the Chl-*a* and Secchi standards will, likewise, be met.

The impaired lakes within the BdSRW were assessed against the Northern Glaciated Plains Ecoregion Shallow Lakes water quality standards (Table 4). A separate water quality standard was developed for shallow lakes, which tend to have poorer water quality than deeper lakes in this ecoregion. According to the MPCA definition of shallow lakes, a lake is considered shallow if its maximum depth is less than 15 feet, or if the littoral zone (area where depth is less than 15 feet) covers at least 80% of the lake's surface area. All of the impaired lakes in the BdSRW are shallow lakes by this definition.

To be listed as impaired (Minn. R. 7050.0150, subp. 5), the summer growing season (June through September) monitoring data must show that the standards for both TP (the causal factor) and either Chl-*a* or Secchi transparency (the response variables) were exceeded. If a lake is impaired with respect to only one of these criteria, it may be placed on a review list; a weight of evidence approach is then used to determine if it will be listed as impaired. For more details regarding the listing process, see the *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 303(b) Report and 303(d) List* (MPCA 2012).

Table 4. Lake Eutrophication Standards

Ecoregion	TP (µg/L)	Chl-a (µg/L)	Secchi (m)
Northern Glaciated Plains: Shallow Lakes	< 90	< 30	> 0.7

2.2 Streams

2.2.1 Bacteria

The state of Minnesota has developed numeric water quality standards for bacteria (Minn. R. 7050.0222), specifically *E. coli*, which are protective concentrations for short- and long-term exposure to pathogens in water. The past fecal coliform and current *E. coli* numeric water quality standards for Class 2 waters are shown in Table 5. The *E. coli* and fecal coliform are fecal bacteria used as indicators for waterborne pathogens that have the potential to cause human illness. Although most are harmless themselves, fecal indicator bacteria are used as an easy-to-measure surrogate to evaluate the suitability of recreational and drinking waters, specifically, the presence of pathogens and probability of illness. Pathogenic bacteria, viruses, and protozoa pose a health risk to humans, potentially causing illnesses with gastrointestinal symptoms (nausea, vomiting, fever, headache, and diarrhea), skin irritations, or other symptoms. Pathogen types and quantities vary among fecal sources; therefore, human health risk varies based on the source of fecal contamination.

This TMDL study will use the Minnesota standard for *E. coli*. The change in the water quality standard from fecal coliform to *E. coli* is supported by an EPA guidance document on bacteriological criteria (EPA 1986). As of March 17, 2008, Minn. R. ch. 7050 water quality standards for *E. coli* are:

> *Escherichia (E.) coli - Not to exceed 126 organisms per 100 milliliters as a geometric mean of not less than five samples representative of conditions within any calendar month, nor shall more than ten percent of all samples taken during any calendar month individually exceed 1,260 organisms per 100 milliliters. The standard applies only between April 1 and October 31.*

Although surface water quality standards are now based on *E. coli*, wastewater treatment facilities (WWTFs) are permitted based on fecal coliform (not *E. coli*) concentrations.

Geometric mean is used in place of arithmetic mean in order to measure the central tendency of the data, dampening the effect that very high or very low values have on arithmetic means. The MPCA's *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List* provides details regarding how waters are assessed for conformance to the *E. coli* standard (MPCA 2012).

Table 5. Past and current numeric water quality standards of bacteria (fecal coliform and *E. coli*) for the beneficial use of aquatic recreation (primary and secondary body contact)

Past Standard	Units	Current Standard	Units	Notes
Fecal coliform	200 organisms per 100 ml	*E. coli*	126 organisms per 100 ml	Geometric mean of ≥5 samples per month (April - October)
Fecal coliform	2,000 organisms per 100 ml	*E. coli*	1,260 organisms per 100 ml	>10% of all samples per month (April - October) that individually exceed

2.2.2 Turbidity

Turbidity is a measure of reduced transparency due to suspended particles such as sediment, algae, and organic matter. The Minnesota turbidity standard was 10 Nephelometric Turbidity Units (NTU) for class 2A waters and 25 NTU for class 2B waters. The state of Minnesota has amended state water quality standards and replaced stream water quality standards for turbidity with standards for TSS. One component of the rationale for this change is that the turbidity unit (NTUs) is not concentration-based and therefore not well-suited to load-based studies (Markus 2011; http://www.pca.state.mn.us/index.php/view-document.html?gid=14922)

The new TSS criteria are stratified by geographic region and stream class due to differences in natural background conditions resulting from the varied geology of the state and biological sensitivity. The assessment window for these samples is April through September, so any TSS data collected outside of this period will not be considered for assessment purposes. The TSS standard for streams in the South River Nutrient Region (RNR) is 65 milligrams per liter (mg/L) (Table 6). For assessment, this concentration is not to be exceeded in more than 10% of samples within a 10-year data window. The TSS results are available for the watershed from state-certified laboratories, and the existing data covers a much larger spatial and temporal scale in the watershed. The TSS LDCs and TMDLs were developed for all stream turbidity impairments.

Table 6. Total suspended solids standard by stream class

River Nutrient Region	Total Suspended Solids (mg/L)
South	65

For more information, refer to the Aquatic Life Water Quality Standards Draft Technical Support Document for TSS (Turbidity), http://www.pca.state.mn.us/index.php/view-document.html?gid=14922, and the Minnesota Nutrient Criteria Development for Rivers Report, http://www.pca.state.mn.us/index.php/view-document.html?gid=14947.

2.2.3 Stream Eutrophication

Stream eutrophication standards, and in particular TP standards, were developed based on data evaluated from a large cross-section of rivers from across the state (Heiskary et al. 2013, http://www.pca.state.mn.us/index.php/view-document.html?gid=14947). Clear relationships were established between TP as the causal factor and the biological response variables (stressors) of sestonic Chl-*a*, DO flux, and the 5-day biochemical oxygen demand (BOD_5). Based on these relationships, it is expected that by meeting the TP target, the Chl-*a*, DO flux, and BOD_5 standards will likewise be met. DO flux is the magnitude of change in DO over the course of one day (daily maximum DO minus the daily minimum DO), and measures the amount of algal production in a stream, with large DO fluxes indicative of excess algal production and due to excess TP. The BOD_5 is the 5-day biochemical oxygen demand and is another measure of excess algal production in a stream. Consistent with EPA guidance, stream eutrophication criteria were developed for Minnesota's three RNR.

The river eutrophication TP standard for the Southern Nutrient Region streams is 150 micrograms per liter (µg/L) as a growing season (June through September) average, and will be used as the water quality target for stream TP (Table 7).

Table 7. Stream Eutrophication Standards

River Nutrient Region	Nutrient	Stressor		
	TP (µg/L)	Chl-a (µg/L)	DO flux (mg/L)	BOD5 (mg/L)
South	≤ 150	≤ 35	≤ 4.5	≤ 3.0

For more information, refer to the draft Minnesota Nutrient Criteria Development for Rivers Report, http://www.pca.state.mn.us/index.php/view-document.html?gid=14947, and the Minnesota Nutrient Criteria Development for Rivers Report, http://www.pca.state.mn.us/index.php/view-document.html?gid=14947.

2.2.4 Dissolved Oxygen

DO is essential to life for all aquatic organisms. When DO drops below acceptable levels, desirable aquatic organisms, such as fish, can be killed or harmed. A stream is considered impaired if there are at least three total violations and more than 10% of the "suitable" (taken before 9:00 am) May through September measurements, more than 10% of the total May through September measurements, or more than 10% of the October through April measurements violate the standard. A total of 20 independent observations are required for a DO assessment. All streams in the BdSRW are class 2B, warmwater or coolwater, streams (Table 8).

Table 8. Stream dissolved oxygen standards (Minn. R. 7050.0220)

Stream Dissolved Oxygen Standards	
Stream Class	Daily Minimum Dissolved Oxygen (mg/L)
2B – Coolwater or warmwater	5

3 Watershed and Water body Characterization

The BdSRW (HUC-8 09020101) is located in central western Minnesota and includes the drainage areas of Lake Traverse and the Bois de Sioux River. The Bois de Sioux and Otter Tail Rivers converge to form the headwaters of the Red River of the North. The BdSRW covers 2,908 square kilometers (km^2) (718,685 acres) in areas of Otter Tail, Grant, Wilkin, Big Stone, and Traverse Counties in Minnesota, Roberts County in South Dakota, and Richland County in North Dakota. Land use in the BdSRW is largely agriculture with an extensive drainage network and has low urban development pressure.

The MPCA 2013 Bois de Sioux River Watershed Monitoring and Assessment Report provides a brief history of agricultural development in the BdSRW: "Historically much of the BdSRW was covered in tall grass prairie and featured large areas of permanent and temporary wetlands (Krenz 1993).Throughout the mid- to late-1800s steamboats and railroads fostered settlement within the area (Krenz 1993). Settlers could purchase cheap land from the railroads or acquire it through government programs such as the Homestead Act (Krenz 1993). Most early residents settled along waterways in well drained areas due to the availability of natural resources and fertile river bottom soil (Krenz 1993). Eventually a shortage of well drained land occurred and attention was directed towards the flat saturated lands within the Red River Valley (Krenz 1993). Agricultural land drainage began as early as the mid-1800s to make more land within the Red River Basin available for agricultural production. Today approximately 86% of the BdSRW acreage is used for agricultural purposes. Most of the original wetlands have been lost to agricultural drainage."

3.1 Lakes

The physical characteristics of the impaired lakes and upstream lakes of the Bois de Sioux River (-501) are listed in Table 9. Lake surface areas, lake volumes, mean depths, and littoral areas (less than 15 feet) were calculated using Minnesota Department of Natural Resources (DNR) bathymetry data; maximum depths were reported from the DNR Lake Finder website; and watershed areas and watershed-to-surface-area ratios were calculated using BdSRW HSPF model subbasins (EOR 2014).

Recent fish, aquatic vegetation, and growing season annual average water quality data (TP, chl-a, and Secchi depth transparency) are summarized by lake below.

Table 9. Impaired lake physical characteristics
Note that the watershed area includes the surface area of the lake

Impaired Lake or Upstream Lake	Surface area (ac)	Littoral area (% total area)	Volume (acre-feet)	Mean depth (feet)	Maximum depth (feet)	Watershed area* (incl. lake area) (ac)	Watershed area : Surface area
Ash	171	100%	207	1.2	2.5	6,464	38: 1
Upper Lightning	695	100%	2,596	3.7	8	7,866	11: 1
Mud**	2,462	100%	3,596	1.5	3.5	837,759	340: 1
Traverse***	11,039	100%	85,283	7.7	12	235,340	21: 1

* Includes the entire drainage area located within the Mustinka River Watershed, North Dakota, and South Dakota.

** Mud Lake is a major tributary to the Bois de Sioux River (-501).

*** Lake Traverse is not impaired, but is a major tributary to Mud Lake and the Bois de Sioux River. These data were used to construct a separate BATHTUB model for Lake Traverse.

3.1.1 Ash Lake

Ash Lake (DNR Lake ID 26-0294) is located in Grant County with portions of its watershed located in Grant County (92%) and Otter Tail County (8%). Recent fish, aquatic vegetation, and growing season annual average water quality data (TP, chl-a, and Secchi depth transparency) are summarized for Ash Lake below.

As part of the DNR Shallow Lakes Program, several recent Wildlife Lake Habitat Survey Reports were completed for Ash Lake in 2006, 2009, and 2010 that summarize the aquatic plant and fish community. Ash Lake has an outlet structure with 3 four-foot wide stoplog bays (12 feet of weir) normally at elevation 1072 (1929 datum). A permanent pump station was constructed in spring of 2010 to facilitate drawdowns and enhance water level management on Ash Lake. Vegetation species and their percent occurrence at plots are summarized for 2005, 2008, and 2011 in (Table 10). Growing season mean values of TP, Chl-*a*, and Secchi depth transparency by year are summarized for Ash Lake in Figure 2, Figure 3, and Figure 4.

2006 Survey Field Notes:

"Plants distributed across the basin, density low due to poor water clarity. Coontail and sago were the dominant species. A narrow band of cattail surrounded most of the shoreline. Minnow traps present along west side of lake – no marking on the one checked. Small number of fathead minnows in trap. Bait dealer leaves boat/motor on west side of lake. A few Hyalella observed. Chironomid larvae present in much of the lake – they were brought up on tines of plant hook. The far north area was clear, plants more abundant. Very distinct demarcation between clear and turbid parts of the lake. Differences likely due to wind and fetch. The north bay is small and shallow."

2009 Survey Field Notes:

"Several species of submerged plants were observed throughout the basin; however, densities were generally low due to poor water clarity. Coontail and sago pondweed were the dominate species. Northern milfoil was more common in the southern end of the lake. The northern bay of the lake had greater water clarity, higher density of plants, and surface mats of filamentous algae. Emergent vegetation was limited to a narrow fringe of narrowleaf cattail around much of the shoreline. Approximately 15 to 20 minnow traps were set in the middle of the lake at the time of the survey. Fathead minnows and a few sticklebacks were the only fish captured with trap nets during an assessment of the fish community. Chironomids were present on the plant rake at many sample points."

2010 Survey Field Notes:

"Ash Lake is surrounded by grassland on the south and east sides of the lake, and agricultural land on the north and west sides. The perimeter of the basin is dominated by narrowleaf cattails. Several patches of bulrush are present throughout the basin. There was an abundance of star duckweed observed, the majority of which was submerged. Four trap nets were set-up on May 18 and a fish survey was conducted on May 19. The four ¼" nets contained a combined total of 15,600 fathead minnows."

2014 Survey Field Notes:

"This lake was surrounded by an agricultural landscape and had a hardwood tree buffer around ~50% of the lake. There was a large population of cattail and bulrush; much more than there was during the last survey. The emergent vegetation made many points inaccessible. The water was dirty and brown, with algae throughout the entire water body. Sago pondweed was thick through most of the lake, making navigation difficult. Lenna species were thick in parts of the lake, especially both the north and south edges. One dead stickleback was seen by the survey crew. A trap-net fish survey was done on the lake at the time of the survey. Four trap-nets were set on the lake overnight. From all four nets, 113 stickleback minnows, ~430 fathead minnows, and 2 black bullheads were caught. One of the nets had no fish in it. All four nets had mud puppies in them, and some had crayfish."

Table 10. Vegetation summary for Ash Lake (DNR)

Vegetation Species	Occurrence at plots (%)			
	6/6/2006	6/11/2009	6/9/2010	2014
Ceratophyllum demersum or coontail	80%	29%	33%	9%
Stuckenia pectinata or sago pondweed	79%	62%	87%	94%
Lenna trisulca or duckweed	21%			
Potamogeton NL spp. or narrowleaf pondweed	8%	19%		
Zannichellia palustris or horned pondweed	4%			
Typha augustifolia/glauca or narrowleaf cattail	1%	4%	3%	21%
Myriophyllum sibiricum or northern water milfoil		14%	29%	
Chara spp. or muskgrass		6%	10%	16%

Vegetation Species	Occurrence at plots (%)			
	6/6/2006	6/11/2009	6/9/2010	2014
Elodea canadensis or Canada waterweed			1%	
Scirpus spp. or bulrush				6%
No vegetation found	3%	20%	1%	

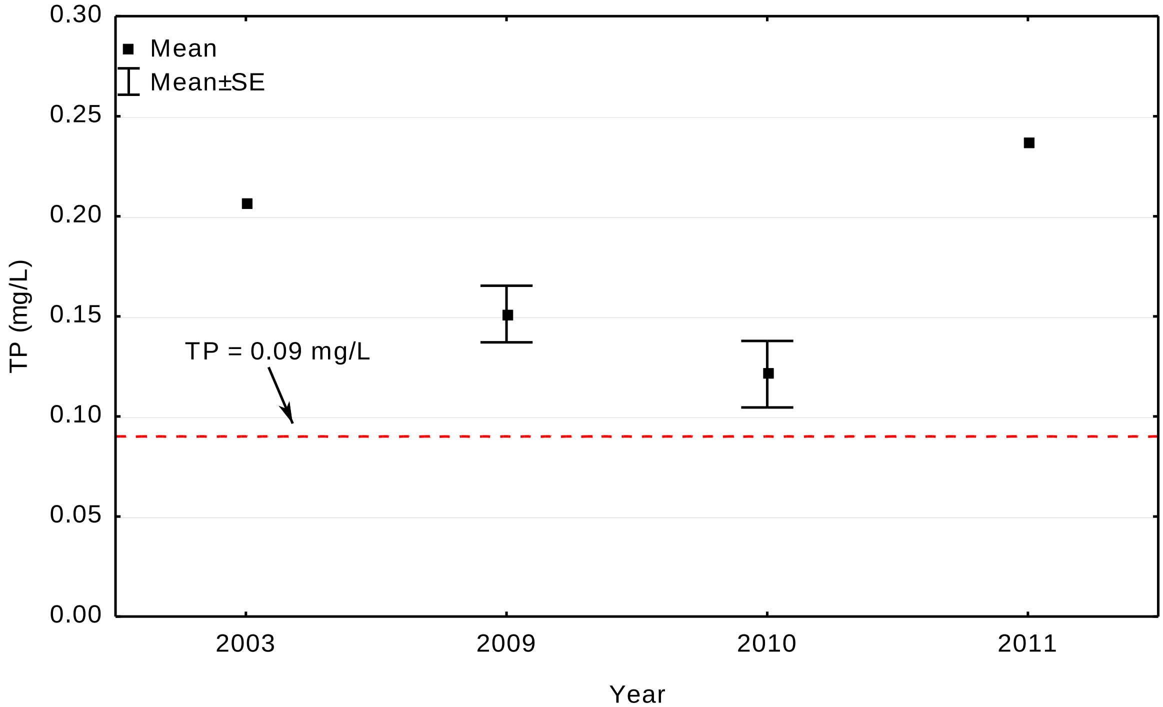

Figure 2. Growing Season Means ± SE of Total Phosphorus for Ash Lake by Year
The dashed line represents the water quality standard for TP (90 µg/L)

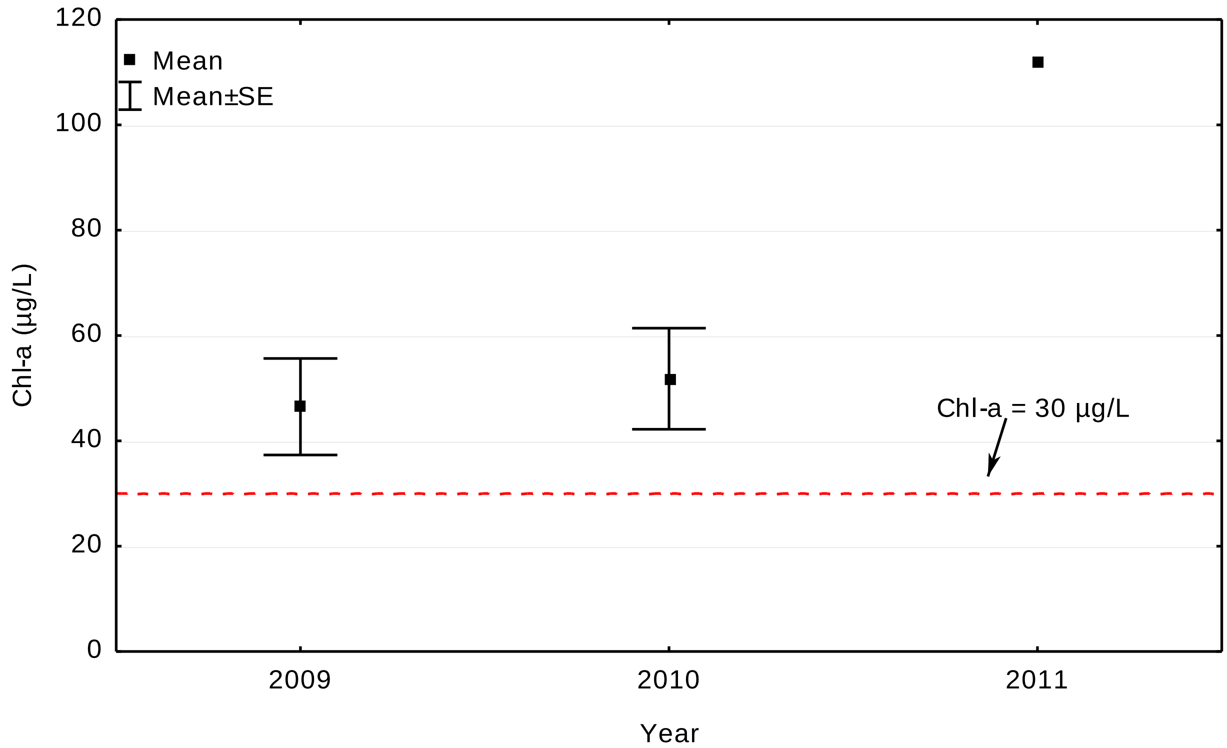

Figure 3. Growing Season Means ± SE of Chlorophyll-a for Ash Lake by Year
The dashed line represents the water quality standard for Chl-a (30 µg/L)

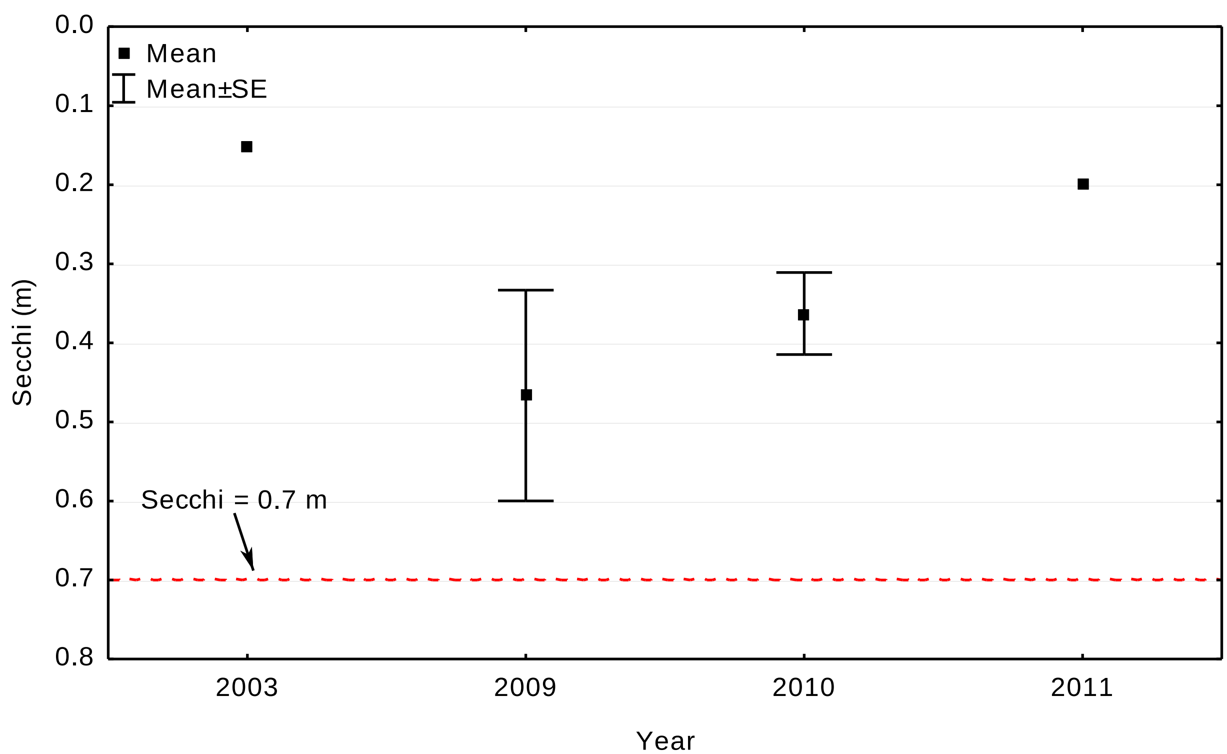

Figure 4. Growing Season Means ± SE of Secchi transparency for Ash Lake by Year
The dashed line represents the water quality standard for transparency (0.7 m)

3.1.2 Upper Lightning Lake

Upper Lightning Lake (DNR Lake ID 56-0957) is located in Otter Tail County with portions of its watershed located in Otter Tail County (8%) and Grant County (92%). Recent fish, aquatic vegetation, and growing season annual average water quality data (TP, chl-a, and Secchi depth transparency) are summarized for Upper Lightning Lake below.

As part of the DNR Shallow Lakes Program, several recent Wildlife Lake Habitat Survey Reports were completed for Upper Lightning Lake in 2002, 2005, 2008, and 2011 that summarize the aquatic plant and fish community. Submerged aquatic plants occurred at 11% of sample sites in 2002, 17% in 2005, 45% in 2008, and 17% in 2011. Submerged aquatic plant diversity ranged from three to seven species in those four surveys. The highest percent occurrence and species richness was found in 2008, following a suspected partial winterkill of the fish community. Upper Lightning Lake vegetation species and their percent occurrence at plots are summarized for 2005, 2008, and 2011 in Table 11. Upper Lightning Lake outlets through a 24-inch culvert under County Road 26; the runout control is the channel bottom upstream of the culvert at 1083.5 (1929 datum). Growing season means of TP, Chl-*a*, and Secchi depth transparency by year are summarized for Upper Lightning Lake in Figure 5, Figure 6, and Figure 7.

2005 Survey Field Notes:

"Most of the sample points on the lake had no vegetation. Only five species of submergent vegetation were found. No emergent species were found at any of the points, but some cattail was observed along shore, and a narrow band of bulrush was present on the lake. Water quality was poor to fair, with a Secchi reading of two feet across most of the lake. One chironomid was observed. There is extensive vertical erosion occurring at various locations along the shoreline, due to the water level being much higher than in the past."

2008 Survey Field Notes:

"Habitat conditions were much improved since the last survey in 2005. Secchi disk was visible to the bottom (up to 9.0 feet) in most locations. Submerged plants were found at 45% of sample points, compared to only 17% in 2005. Coontail, chara, and sago pondweed were the predominate species found. There was also a fringe of cattail and hardstem bulrush along parts of the shoreline. The improvement in water clarity suggests a winterkill event; however, the survey crew observed live sunfish and bullheads. The survey crew also noted severe erosion along the shoreline that was causing trees to fall into the water."

2011 Survey Field Notes:

"Secchi disk readings ranged from 1.0 to1.25 feet throughout the basin. Hardstem bulrush and cattail fringed the shoreline. Very little vegetation was observed at sample locations, except for small traces of coontail, narrowleaf pondweed species, and sago pondweed."

Table 11. Vegetation summary for Upper Lightning Lake (DNR)

Vegetation Species	Occurrence at plots (%)		
	8/29/2005	7/9/2008	8/10/2011
Ceratophyllum demersum or coontail	1%	30%	11%
Stuckenia pectinata or sago pondweed	12%	10%	4%
Lenna trisulca or duckweed	3%		
Potamogeton NL spp. or narrowleaf pondweed		2%	8%
Potamogeton zosteriformes or flat-stem pondweed		3%	
Myriophyllum sibiricum or northern water milfoil	2%		
Chara spp. or muskgrass	1%	15%	
Utricularia vulgaris or greater bladderwort		4%	
Najas marina or spiny naiad		1%	
No vegetation found	83%	55%	82%

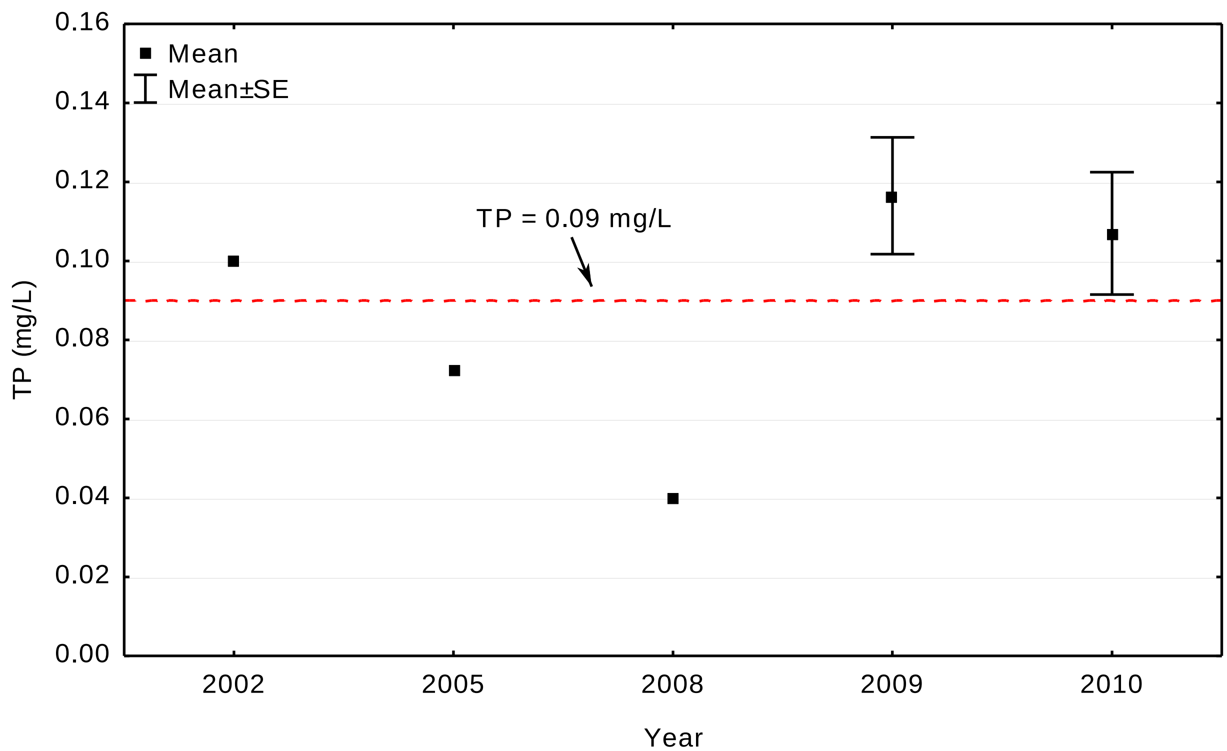

Figure 5. Growing Season Means ± SE of Total Phosphorus for Upper Lightning Lake by Year
The dashed line represents the water quality standard for TP (90 µg/L)

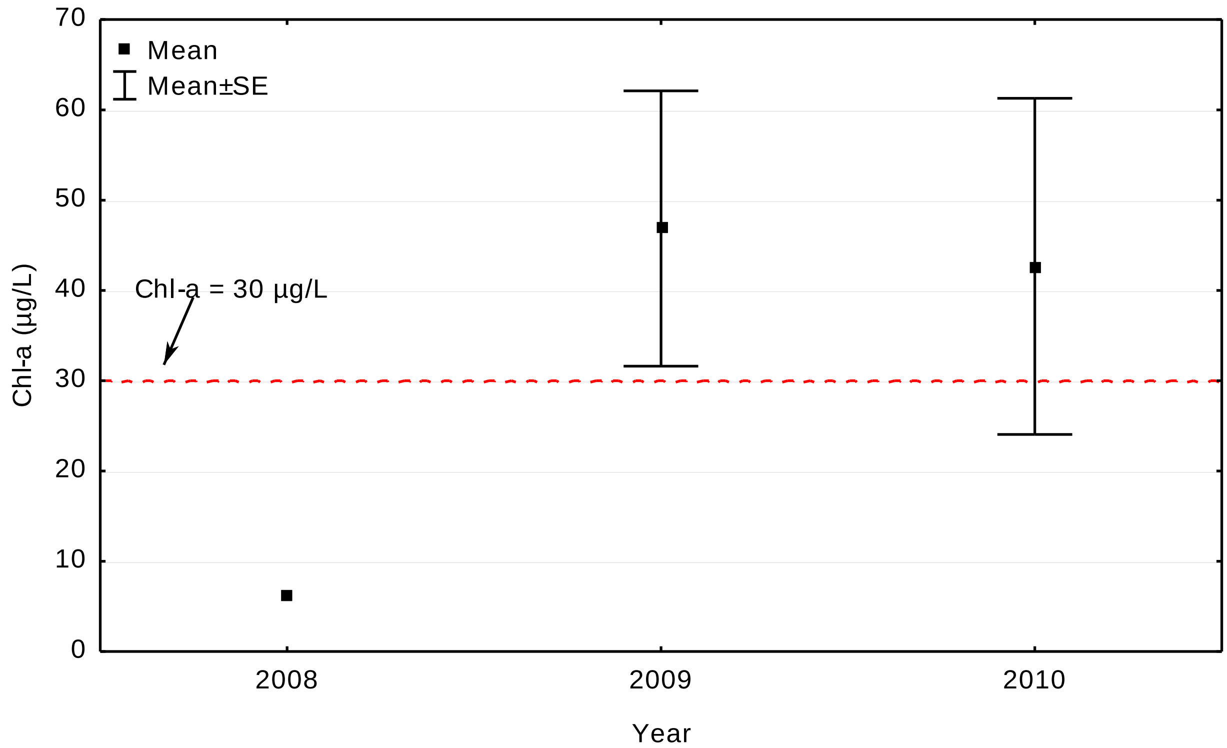

Figure 6. Growing Season Means ± SE of Chlorophyll-a for Upper Lightning Lake by Year
The dashed line represents the water quality standard for Chl-a (30 µg/L)

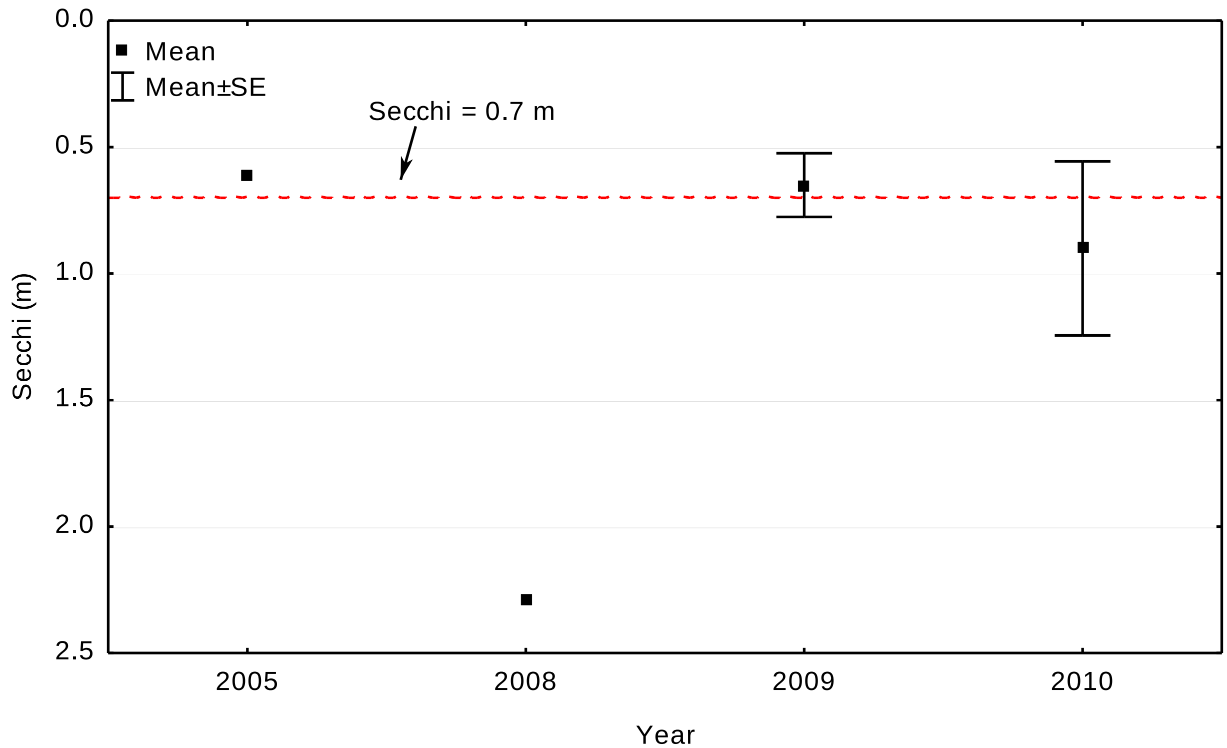

Figure 7. Growing Season Means ± SE of Secchi transparency for Upper Lightning Lake by Year
The dashed line represents the water quality standard for transparency (0.7 m)

3.1.3 Mud Lake

The Mustinka River discharges to Lake Traverse and White Rock/Mud Lakes before entering the Bois de Sioux River system. The most recent DNR fisheries survey was conducted on July 19, 2010, in Mud Lake, with excerpts from the DNR Status of the Fishery below. Mud Lake outlets through White Rock Dam at the north end of the lake. Growing season means of TP, Chl-*a*, and Secchi depth transparency by year are summarized for Mud Lake in Figure 8, Figure 9, and Figure 10.

DNR Status of the Fishery (as of 7/19/2010):

"Mud Lake is on the Minnesota-South Dakota border and is subject to border water fishing regulations. Mud Lake has a high potential for winterkill and is opened annually from December through February to restricted liberalized fishing. The DNR and South Dakota Department of Game, Fish, and Parks cooperatively manage the fishery. Little angling is known to occur on Mud Lake during the summer due to difficult access and numerous submerged boulders. Anglers are advised to carefully study a map of the lake before boating, and to drive slowly. Most fishing occurs from shore just upstream from Mud Lake below the Reservation Dam at the outlet of Lake Traverse, or during the winter through the ice. Northern pike have been abundant in all four fish assessments (1994, 1999, 2005, and 2010). In 2010, they were present from 5 different year classes and most measured 13 to 30 inches, however a couple fish over 30 inches were also sampled. Northern pike frequently experience good reproduction in Mud Lake. Walleye were abundant in 2010 with most fish measuring 9 to 12 inches, but fish up to 21 inches were also present. The majority of walleye sampled were from a strong 2009 year class that was the result of natural reproduction. Other game fish species present in moderate numbers included black bullhead, black crappie, white bass, and yellow perch."

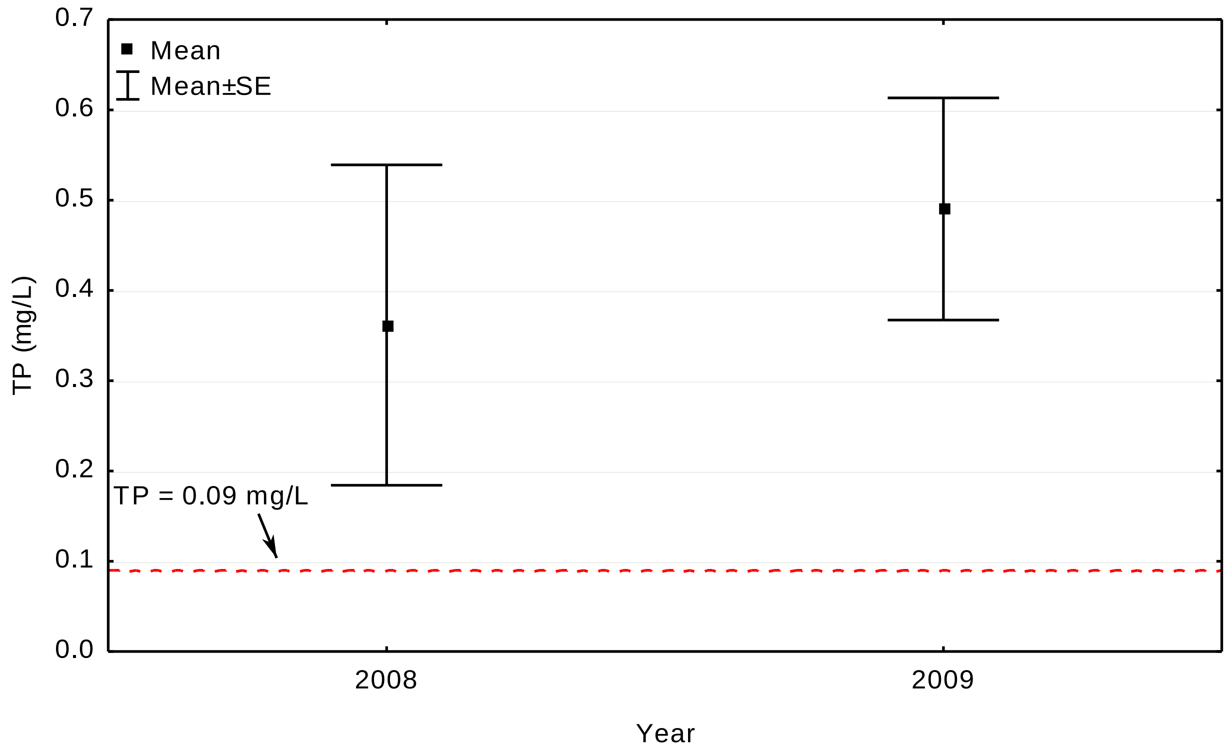

Figure 8. Growing Season Means ± SE of Total Phosphorus for Mud Lake by Year
The dashed line represents the water quality standard for TP (90 µg/L)

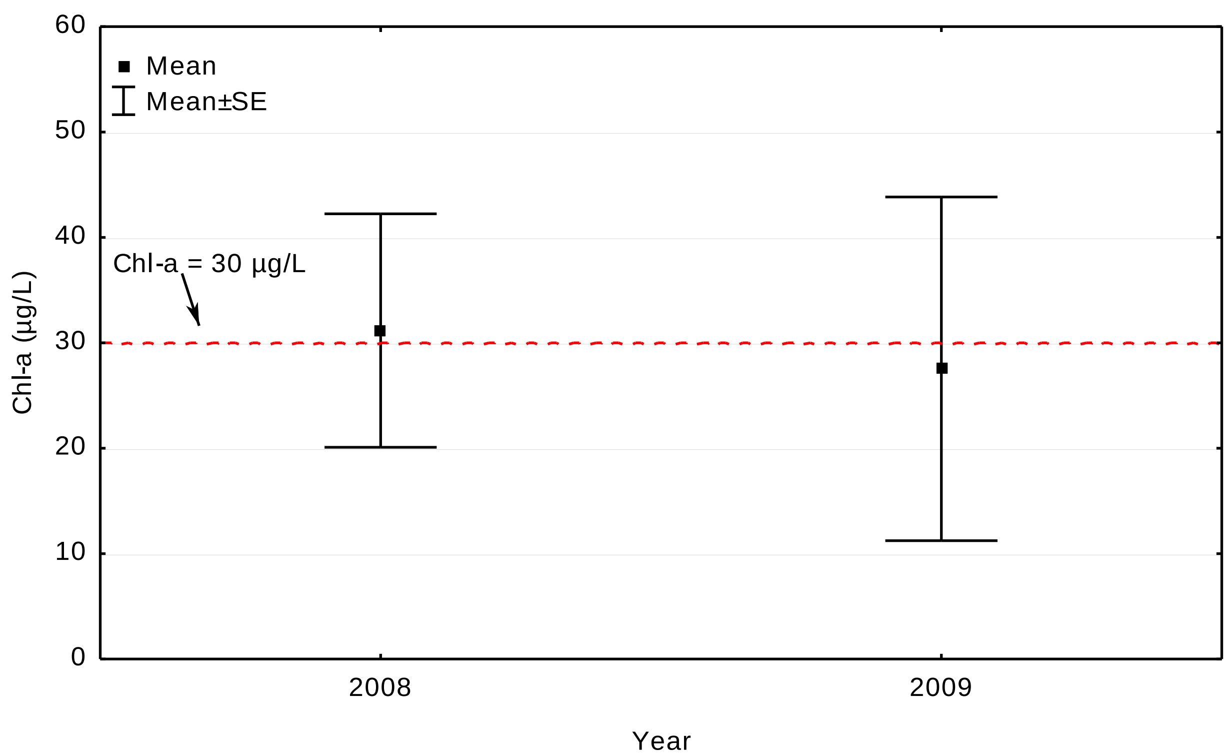

Figure 9. Growing Season Means ± SE of Chlorophyll-a for Mud Lake by Year
The dashed line represents the water quality standard for Chl-a (30 µg/L)

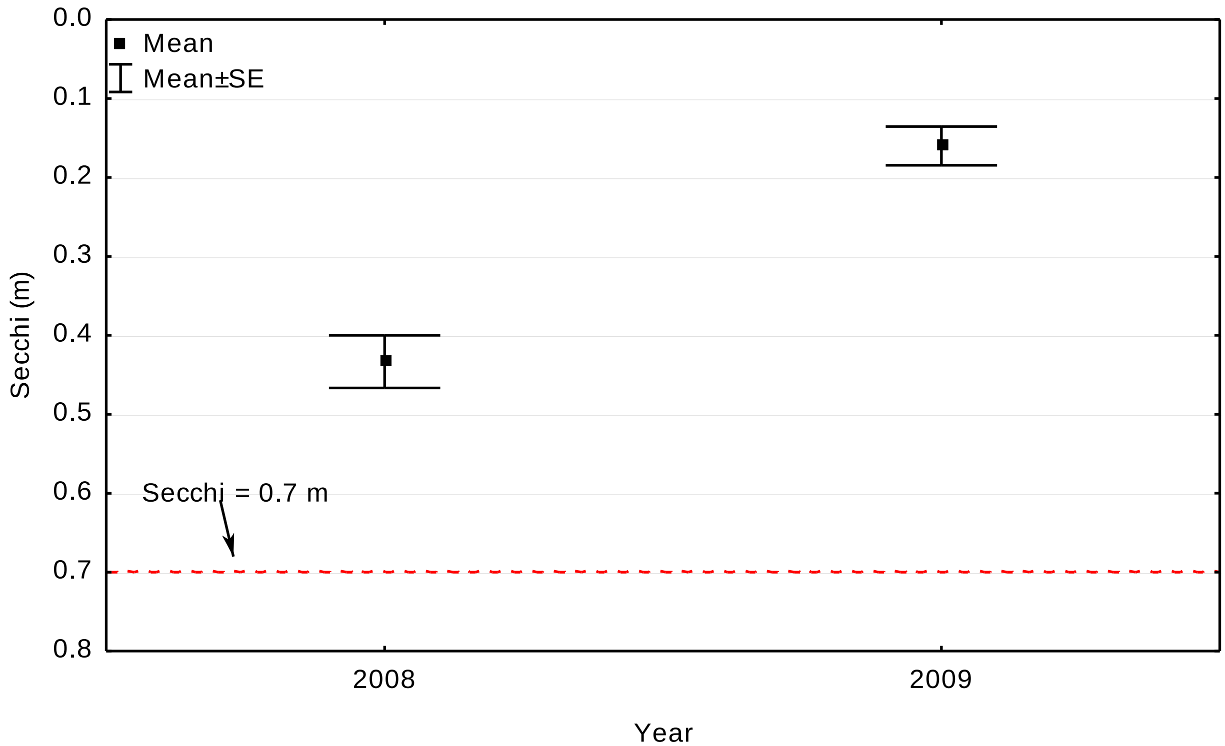

Figure 10. Growing Season Means ± SE of Secchi transparency for Mud Lake by Year
The dashed line represents the water quality standard for transparency (0.7 m)

3.1.4 Lake Traverse

The Mustinka River discharges to Lake Traverse and White Rock/Mud Lakes before entering the Bois de Sioux River system. Lake Traverse has high phosphorus levels but does not have corresponding high algae levels nor low water clarity and is therefore not listed as impaired for eutrophication. A summary of the fish and growing season annual average water quality are provided in this TMDL study due to the influence of Lake Traverse TP levels on Mud Lake TP levels, which is impaired.

The most recent DNR fisheries survey was conducted on May 21, 2014, in Lake Traverse, with excerpts from the DNR Status of the Fishery below. Lake Traverse outlets through the Reservation Highway Dam at the north end of the lake. Growing season means of TP, Chl-*a*, and Secchi depth transparency by year are summarized for Lake Traverse in Figure 11, Figure 12, and Figure 13.

DNR Status of the Fishery (as of 5/21/2014):

"Lake Traverse is located in western Minnesota just north of Browns Valley. It is a narrow lake that measures 16 miles long and up to 2 miles wide. Lake Traverse has a surface area of 11,528 acres and a maximum depth of 12 feet. It is a highly productive lake and a popular recreational destination in west-central Minnesota. Anglers should study the lake's contour map before boating as shallow reef areas exist, especially near the islands and in the northwest portion of the lake. Lake Traverse is a Minnesota-South Dakota border water and is subject to border water fishing regulations. The DNR and South Dakota Department of Game, Fish, and Parks cooperatively manage the fishery."

"Lake Traverse has typically provided a high-quality walleye fishery. Walleye from a wide range of sizes were abundant during 2014, especially from 1 to 18 inches. Good numbers of trophy-sized walleye have frequently been reported by anglers for many years. The walleye population has been maintained by natural reproduction and supplemental fry stocking. Walleye fry are normally stocked during alternate years, but the schedule is adjusted as needed based on walleye abundance, condition, and available forage. Fry stocking maintained the walleye population from 2003 to 2005, whereas natural reproduction has produced the vast majority of the walleye since 2006."

"Pike were moderately abundant in 2014. The majority of them were 18 to 22 inches, but fish up to 35 inches were present. Pike growth has been fast, but they die young and fish older than age four have rarely been sampled. Pike naturally reproduce in Lake Traverse and its tributaries. They can also migrate into Lake Traverse from Mud Lake during high flows."

"A moderate bluegill population was present. Anglers have reported catching bluegills in excess of 10 inches during recent years."

"Yellow bullheads can commonly be caught at the Bois de Sioux Bridge near the northeast corner of Lake Traverse. Yellow bullheads have a round tail and white barbells on their lower jaw. Bullheads measuring up to 14 inches were present. Channel catfish have been abundant during recent years, including fish up to 30 inches."

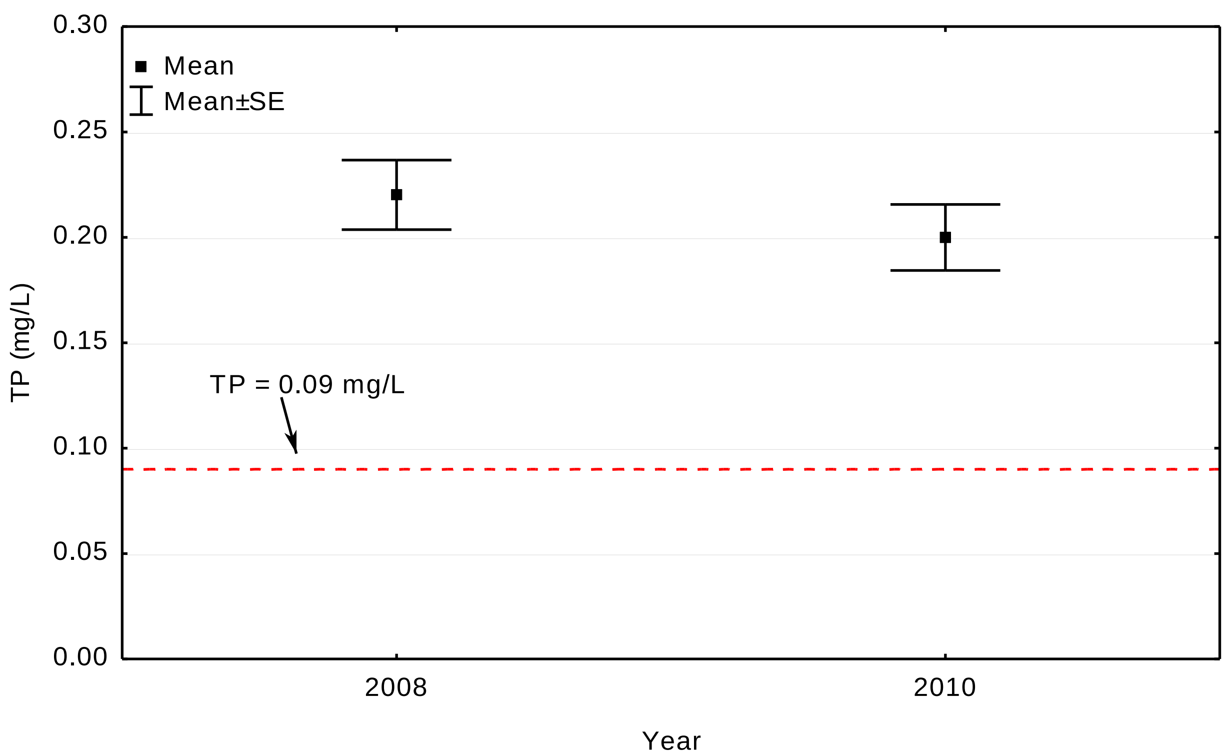

Figure 11. Growing Season Means ± SE of Total Phosphorus for Lake Traverse by Year
The dashed line represents the water quality standard for TP (90 µg/L)

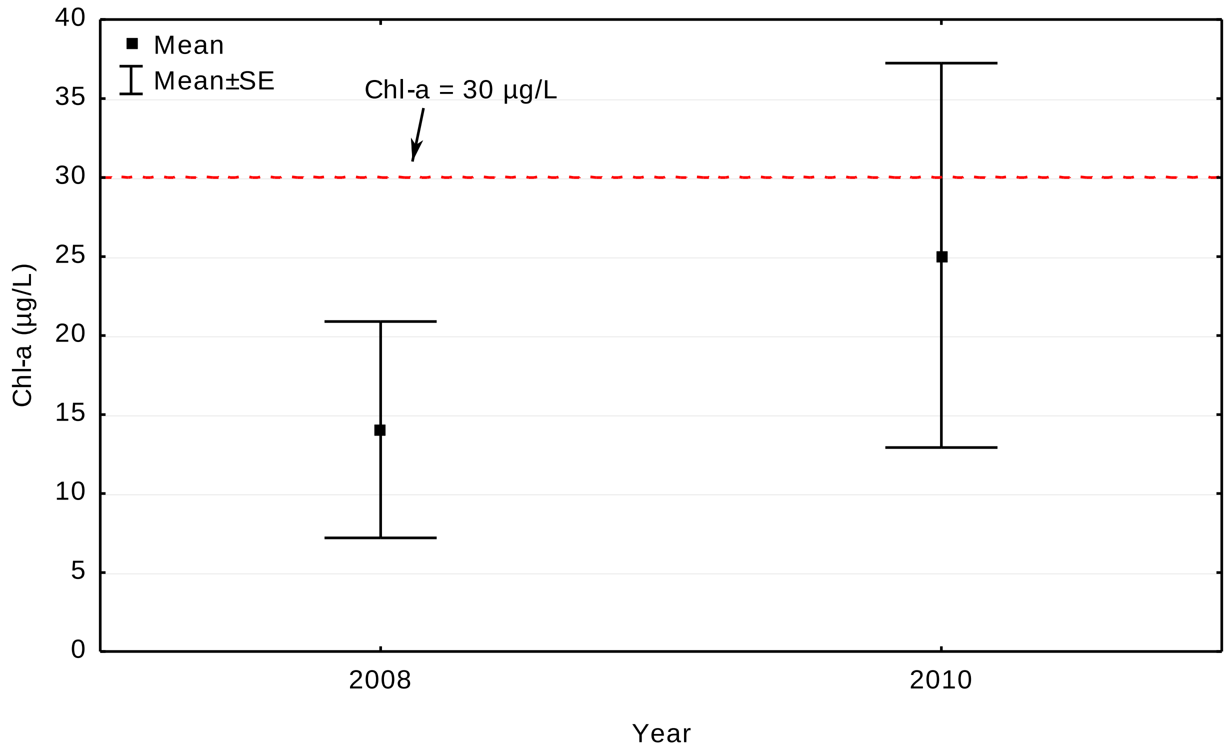

Figure 12. Growing Season Means ± SE of Chlorophyll-a for Lake Traverse by Year
The dashed line represents the water quality standard for Chl-a (30 µg/L)

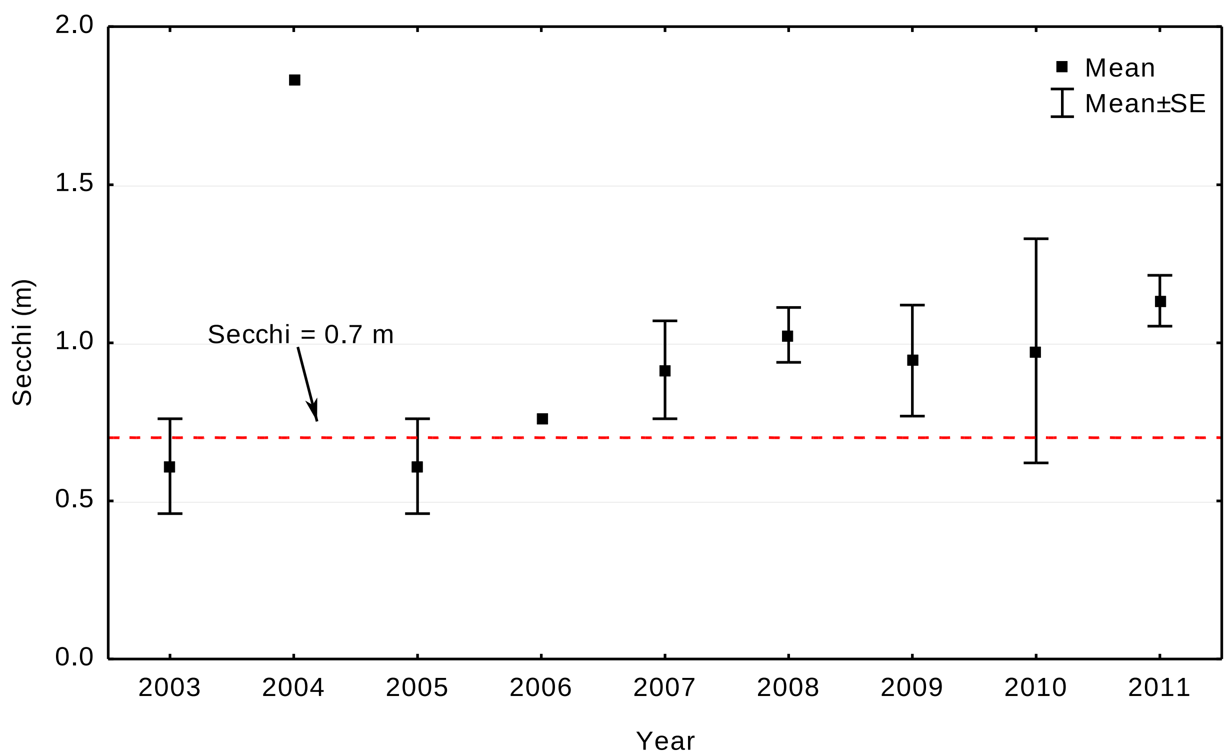

Figure 13. Growing Season Means ± SE of Secchi transparency for Lake Traverse by Year
The dashed line represents the water quality standard for transparency (0.7 m)

3.2 Streams

Table 12 lists the direct drainage and total watershed areas of the impaired stream reaches in the BdSRW. Total watershed and direct drainage areas were delineated from BdSRW HSPF model subbasins (EOR 2014). The direct drainage areas include only the area downstream of any impaired upstream reach impaired for the same pollutant.

Table 12. Impaired stream direct drainage and total watershed areas

Impaired Reach (09020101-XXX)	Reach Name	Reach Description	Upstream Impairments		Direct Drainage Area (ac)	Total Drainage Area (ac)
			Reaches	Drainage Area (ac)		
501	Bois de Sioux River	Rabbit R to Otter Tail R	502	198,006	505,357	**703,363**
502	Rabbit River	Wilkin County line to Bois de Sioux R	512	39,437	158,569	**198,006**
510	Unnamed Creek (Doran Slough)	Headwaters to Bois de Sioux R	--	--	22,672	**22,672**
Watershed						**703,363**

3.3 Subwatersheds

The impaired lake and stream subwatersheds are illustrated in Figure 14 below.

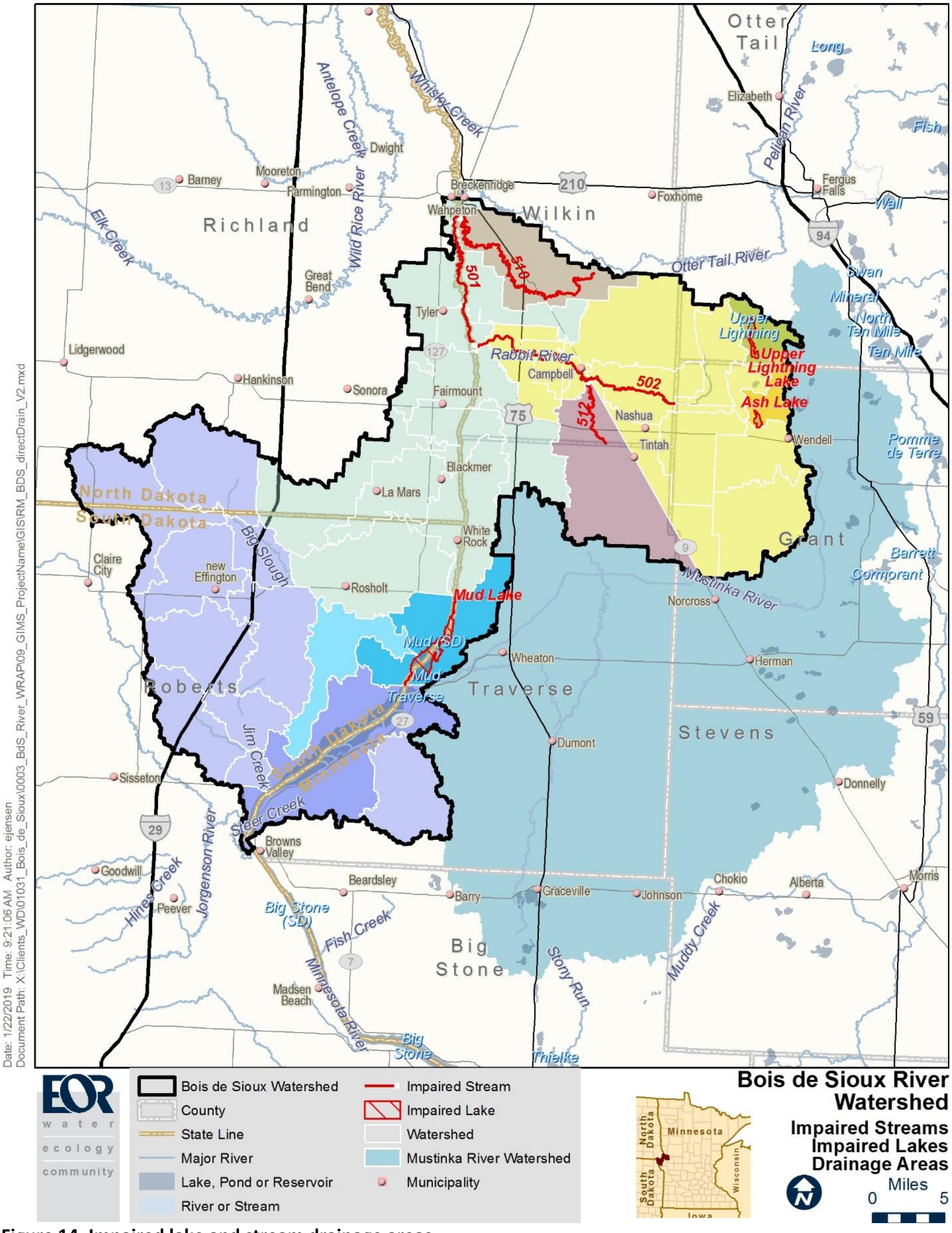

Figure 14. Impaired lake and stream drainage areas

3.4 Land Use

Land cover in the BdSRW was assessed using the Multi-Resolution Land Characteristics Consortium 2011 National Land Cover Dataset (NLCD) (https://www.mrlc.gov/data/nlcd-2011-land-cover-conus-0). This information is necessary to draw conclusions about pollutant sources and best management practices (BMPs) that may be applicable within each subwatershed. The land cover distribution within impaired lake and stream watersheds is summarized in Table 13 and Figure 15. These data were simplified to reduce the overall number of categories. Forest includes: evergreen forests, deciduous forests, mixed forests, and shrub/scrub. Developed includes: developed open space, and low, medium, and high-density developed areas. Grassland includes: native grass stands, alfalfa, clover, long term hay, and pasture. Cropland includes: all annually planted row crops (corn, soybeans, wheat, oats, barley, etc.), and fallow crop fields. Wetland includes: wetlands and marshes. Open water includes: all lakes and rivers.

The primary land cover within BdSRW is cropland (78%; Table 13).

Table 13. Bois de Sioux River Watershed and impaired lake and stream subwatershed land cover (NLCD 2011)

AUID	Waterbody Name	Developed	Cropland	Grassland/ Pasture	Woodland	Wetlands	Open Water
26-0294-00	**Ash**	5%	75%	0%	2%	12%	7%
56-0957-00	**Upper Lightning**	4%	75%	0.6%	0.7%	4%	15%
09020101-501	**Bois de Sioux River**	6%	85%	3%	0.7%	5%	1%
09020101-502	**Rabbit River**	5%	88%	2%	0.4%	3%	2%
09020101-510	**Doran Slough**	6%	91%	0.7%	0.5%	1%	0.1%
Bois de Sioux River Watershed		**5%**	**78%**	**5%**	**1%**	**6%**	**5%**

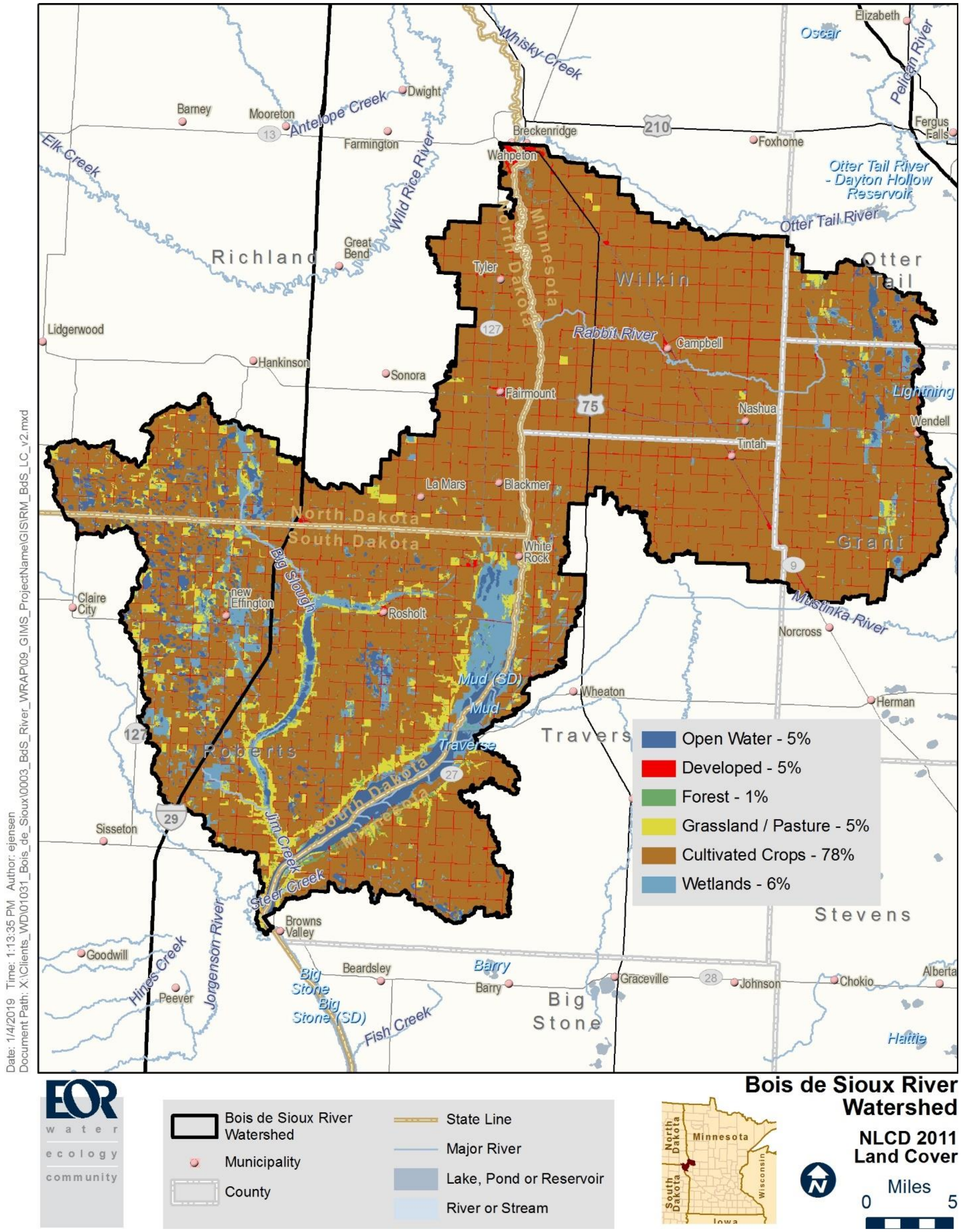

Figure 15. Bois de Sioux River Watershed Land Cover (NLCD 2011)

3.5 Current/Historical Water Quality

In instances where this TMDL study references "Natural Background Conditions", natural background conditions are considered the landscape condition that occurs outside of human influence. Minn. R. 7050.0150, subp. 4, defines the term "Natural causes" as 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.

3.5.1 Lake Eutrophication (Total Phosphorus)

The existing in-lake water quality conditions were quantified using data downloaded from the MPCA Environmental Quality Information System (EQuIS) database and available for the most recent 10-year time period (2002 through 2011). Growing season means of TP, Chl-*a*, and Secchi transparency depth were calculated using monitoring data from the growing season (June through September). Information on the species and abundance of macrophyte and fish present, within the lakes, was compiled from DNR fisheries surveys. Year-to-year water quality trends and descriptions of the aquatic plant and fish communities for each impaired lake are included in Appendix B. The 10-year growing season mean TP, Chl-*a*, and Secchi data used to calibrate the lake water quality response models for each impaired lake are listed in Table 14 below.

Table 14. Ten-year growing season mean TP, Chl-*a*, and Secchi (2002-2011)

	Ten-year (2002-2011) Growing Season Mean (June – September)					
	TP		Chl-*a*		Secchi	
Lake Name	(µg/L)	CV	(µg/L)	CV	(m)	CV
Northern Glaciated Plains Ecoregion – Shallow Lakes	**< 90**	**--**	**< 30**	**--**	**> 0.7**	**--**
Ash	146	9%	55	15%	0.4	14%
Upper Lightning	101	10%	41	27%	0.9	23%

CV = coefficient of variation, defined in BATHTUB as the standard error divided by the mean

3.5.1.1 Shallow Lakes

The relationship between TP concentration and the response variables (Chl-*a* and transparency) is often different in shallow lakes as compared to deeper lakes. In deeper lakes, algae abundance is often controlled by physical and chemical factors such as light availability, temperature, and nutrient concentrations. The biological components of the lake (such as microbes, algae, aquatic plants, zooplankton and other invertebrates, and fish) are distributed throughout the lake, along the shoreline, and on the bottom sediments. In shallow lakes, the biological components are more concentrated into less volume and exert a stronger influence on the ecological interactions within the lake. There is a more dense biological community at the bottom of shallow lakes than in deeper lakes, because of the fact that oxygen is replenished in the bottom waters and light can often penetrate to the bottom. These biological components can control the relationship between TP and the response variables.

The result of this impact, of biological components on the ecological interactions, is that shallow lakes normally exhibit one of two ecologically alternative stable states (Figure 16): the turbid water, algae-dominated state, and the clear water, aquatic plant-dominated state (Scheffer *et al.* 1993). The clear state is the most preferred, since algae communities are held in check by diverse and healthy zooplankton and fish communities. Fewer nutrients are released from the sediments in this state. The roots of the aquatic plants stabilize the sediments, lessening the amount of sediment stirred up by wind-driven mixing.

Nutrient reduction or addition in a shallow lake does not lead to linear improvement or degradation in water quality (indicated by algal biomass in Figure 16). As external nutrient loads are decreased in a lake in the turbid, algae-dominated state, slight improvements in water quality may occur at first. At some point, a further decrease in nutrient loads will cause the lake to abruptly shift from the turbid, algae-dominated state to the clear, aquatic plant-dominated state. Conversely, as external nutrient loads are increased in a lake in the clear, aquatic plant-dominated state, slight degradations in water quality may occur at first. At some point, further increase in nutrient loads will cause the lake to abruptly shift from the clear, aquatic-plant dominated state to the turbid, algae-dominated state. The general pattern in Figure 16 is often referred to as "hysteresis," meaning that when forces are applied to a system, it does not return completely to its original state nor does it follow the same trajectory on the way back.

The biological response of the lake to phosphorus inputs will depend on the state that the lake is in. For example, if the lake is in the clear state, the aquatic plants may be able to take up phosphorus instead of the algae. However, if enough stressors are present in the lake, increased phosphorus inputs may lead to a shift to the turbid state with an increase in algal density and decreased transparency. The two main categories of stressors that can shift the lake to the turbid state are:

- Disturbance to the aquatic plant community, for example from wind-driven mixing, benthivorous (bottom feeding) fish, boat motors, water skiing, or light availability (influenced by algal density or water depth); and
- A decrease in the number of zooplankton can result in an increase in algae. A decrease in the number of zooplankton is usually caused by an increase in the number of fish that feed directly on zooplankton due to a decrease in or absence of game fish.

This complexity in the relationships among the biological communities in shallow lakes leads to less certainty in predicting the in-lake water quality of a shallow lake based on the TP load to the lake. The relationships between external TP load and in-lake TP concentration, Chl-*a* concentration, and transparency are less predictable than in deeper lakes, and therefore lake response models are less accurate.

Another implication of the alternative stable states in shallow lakes is that different management approaches are used for shallow lake restoration than those used for restoration of deeper lakes. Shallow lake restoration often focuses on restoring the macrophyte, zooplankton, and fish communities to the lake.

The main stressor to Ash and Upper Lightning appears to be disturbance to the aquatic plant community due to light availability influenced by algal density.

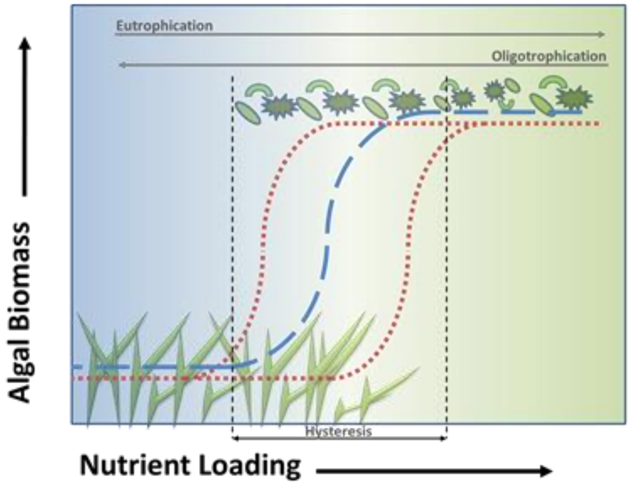

Figure 16. Alternative Stable States in Shallow Lakes

3.5.2 Stream Monitoring Stations

Figure 17 displays the stream monitoring stations where water quality data, summarized in the following sections, were collected and assessed within the 10-year timeframe of the TMDL study (2002 through 2011) to identify impairments and determine existing water quality conditions. These data were collected as part of four programs: the MPCA Intensive Watershed Monitoring program, the MPCA Watershed Pollutant Load Monitoring Network program, the MPCA Citizen Surface Water Monitoring Program, and the International Water Institute River Watch program All stream water quality data was downloaded from the MPCA EQuIS database for the most recent 10-year time period (2002 through 2011). In addition, flow data was available from three United States Geological Survey (USGS) flow gages, as part of the DNR-MPCA Cooperative Stream Monitoring program.

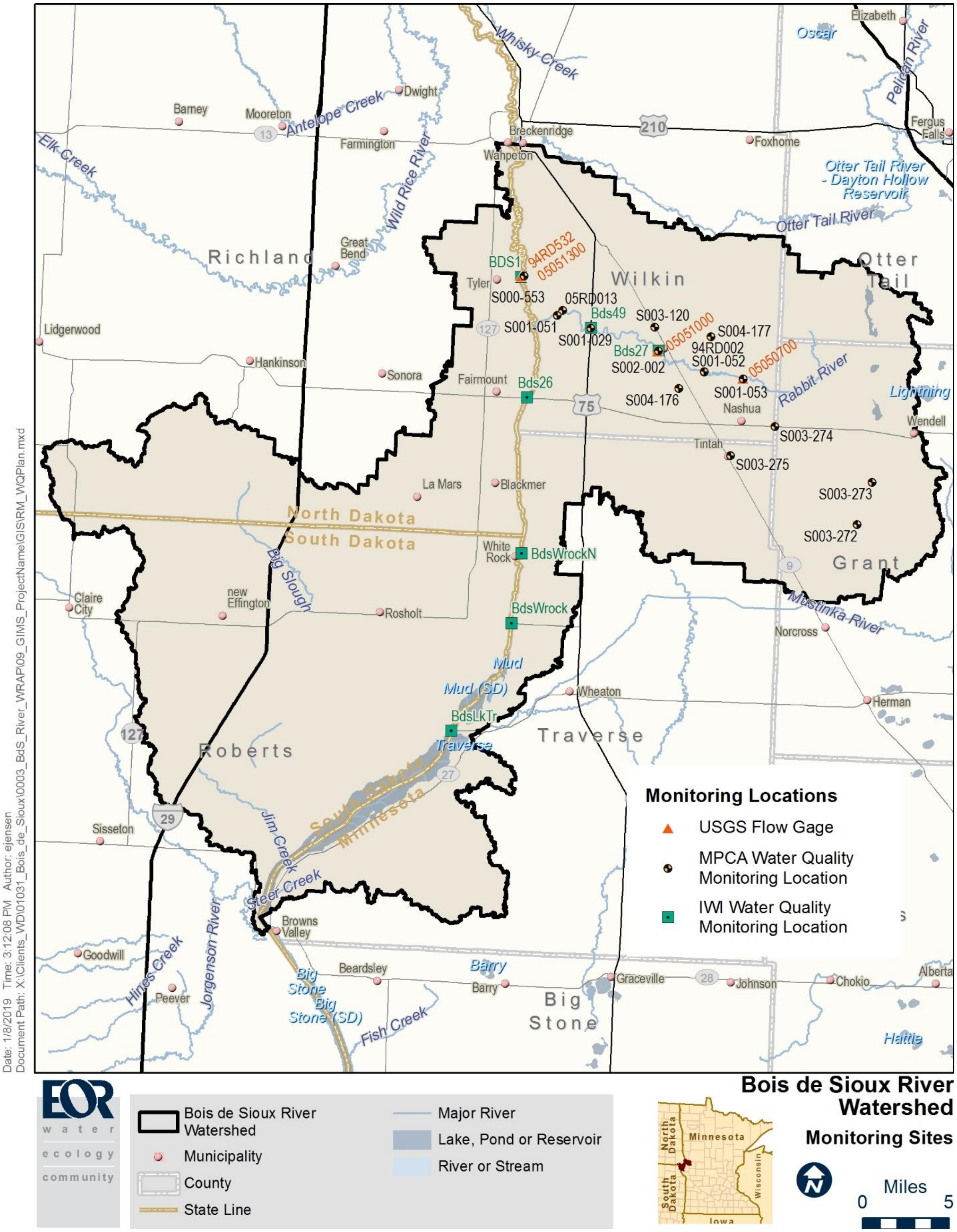

Figure 17. Monitoring stations on impaired reaches in the Bois de Sioux River Watershed

3.5.3 River Eutrophication (Total Phosphorus)

TP was identified as a stressor to aquatic life in three streams impaired by low DO or having unhealthy fish/macroinvertebrate communities. Ten-year (2002 through 2011) individual and growing season average (June through September) TP concentrations are summarized by station for the following three stream reaches: Bois de Sioux River (09020101-501) and Rabbit River (09020101-502).

3.5.3.1 Bois de Sioux River (09020101-501)

The 10-year (2002 through 2011) growing season average TP concentration for the Bois de Sioux River (09020101-501) was greater than 0.3 mg/L at both monitoring stations, compared to the ecoregion goal of less than 0.15 mg/L (Table 15 and Figure 18). To illustrate the seasonal variability in TP concentration at each station, TP data are shown by month in Figure 19 (S000-553) and Figure 20 (S000-089). For stations with a large amount of data, the average (mean) is represented as a dot with standard error bars; otherwise, each individual sample is represented by a single dot.

Table 15. Ten-year growing season average total phosphorus (mg/l) by monitoring station in Bois de Sioux River (09020101-501), 2002-2011

Monitoring Station (upstream to downstream)	Ten-year growing season average TP (mg/L)	Number of Samples
S000-553 (BOIS DE SIOUX R ON CSAH-6 5.1 MI SW OF DORAN)	0.328	98
S000-089 (BOIS DE SIOUX R. AT BRECKENRIDGE)	0.392	8
All Stations	0.387	106

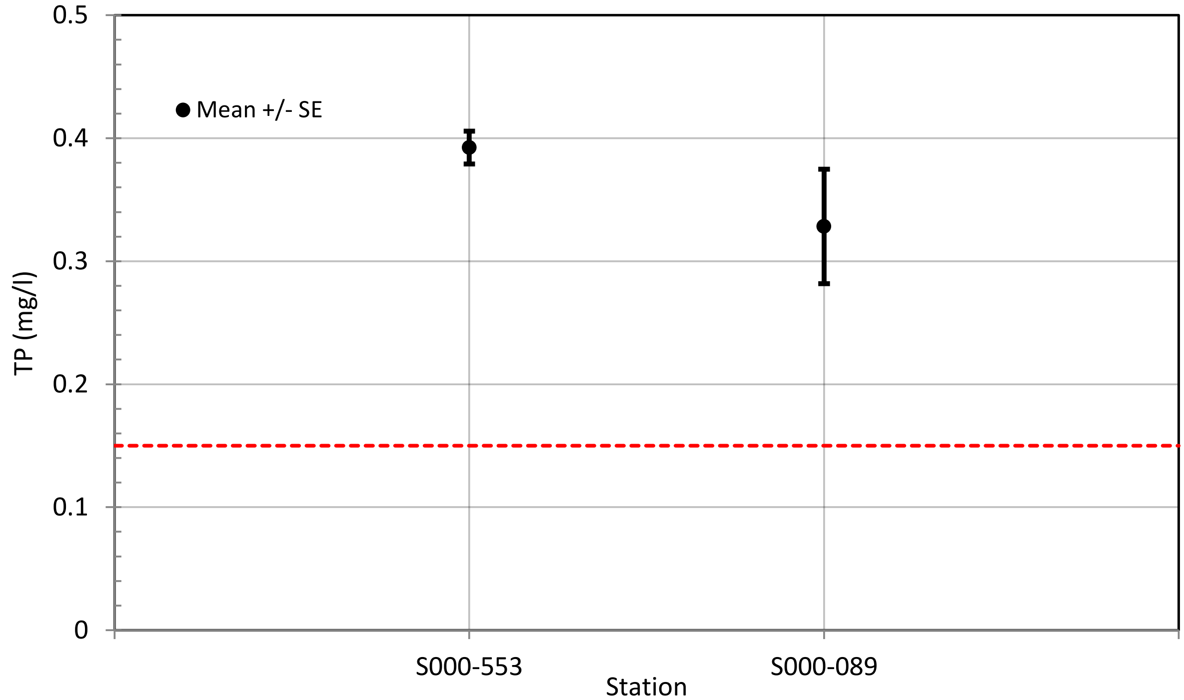

Figure 18. Ten-year growing season average total phosphorus (mg/l) by monitoring station in Bois de Sioux River (09020101-501), 2002-2011. Monitoring stations are shown in order from upstream to downstream. The dashed line represents the TP eutrophication standard for Southern Region Streams (0.15 mg/L). Ten-year growing seasons averages are shown as a block dot with standard error bars.

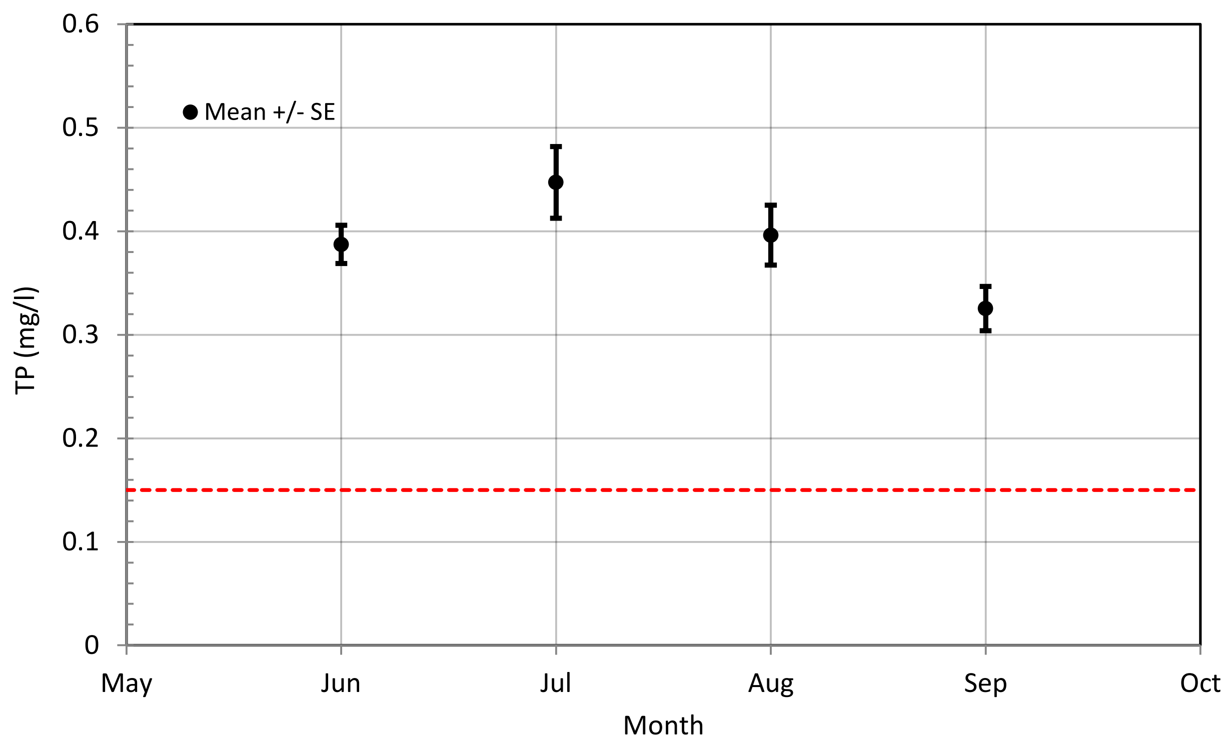

Figure 19. Total phosphorus (mg/l) by month in Bois de Sioux River (09020101-501) at monitoring station S000-553, 2002-2011. The dashed line represents the TP eutrophication standard for Southern Region Streams (0.15 mg/L). Samples are shown as the monthly average (black dot) with standard error bars.

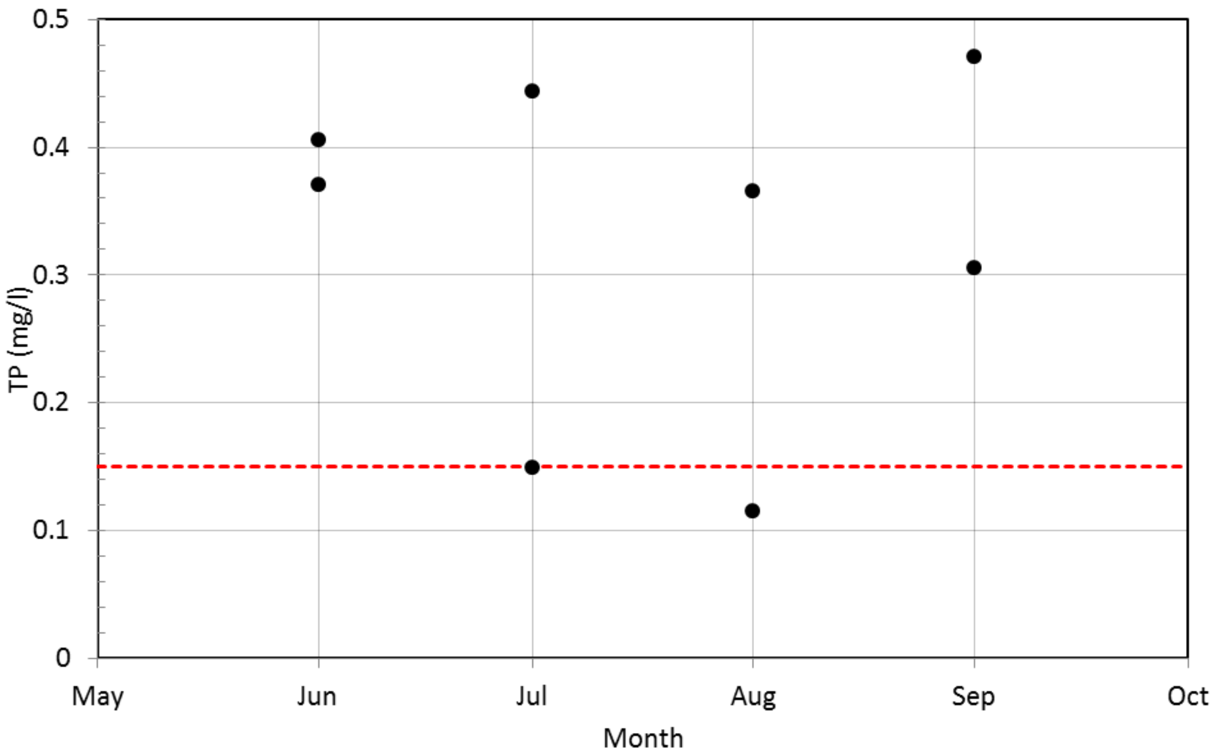

Figure 20. Total phosphorus (mg/l) by month in Bois de Sioux River (09020101-501) at monitoring station S000-089, 2002-2011. The dashed line represents the TP eutrophication standard for Southern Region Streams (0.15 mg/L). Individual samples are shown as a single black dot.

3.5.3.2 Rabbit River (09020101-502)

The 10-year (2002 through 2011) growing season average TP concentration for the Rabbit River (09020101-502) was greater than 0.3 mg/L at all monitoring stations, compared to the ecoregion goal of less than 0.15 mg/L (Table 16 and Figure 21). To illustrate the seasonal variability in TP concentration at each station, TP data are shown by month in Figure 22 (S001-053) Figure 23 (S002-002) and Figure 24 (S001-029). For stations with a large amount of data, the average (mean) is represented as a dot with standard error bars; otherwise, each individual sample is represented by a single dot.

Table 16. Ten-year growing season average total phosphorus (mg/l) by monitoring station in Rabbit River (09020101-502), 2002-2011

Monitoring Station (upstream to downstream)	Ten-year growing season average TP (mg/L)	Number of Samples
S001-053 (RABBIT R AT CSAH-19 2.5 MI N OF NASHUA)	0.361	8
S002-002 (RABBIT R, AT CSAH-4 RT BANK OF BRG, 0.1 MI SW OF CAMPBELL)	0.343	9
S001-029 (RABBIT RIVER AT US-75, 5 MILES NW OF CAMPBELL)	0.435	56
All Stations	0.414	73

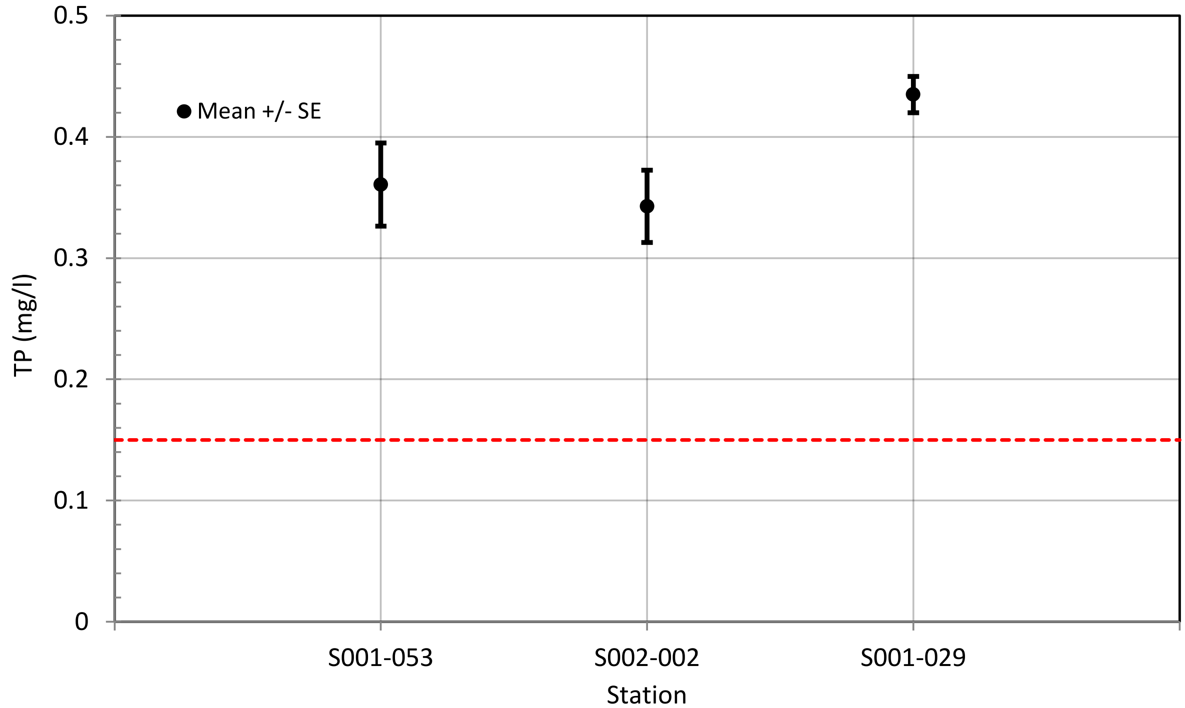

Figure 21. Ten-year growing season average total phosphorus (mg/l) by monitoring station in Rabbit River (09020101-502), 2002-2011. Monitoring stations are shown in order from upstream to downstream. The dashed line represents the TP eutrophication standard for Southern Region Streams (0.15 mg/L). Ten-year growing seasons averages are shown as a block dot with standard error bars.

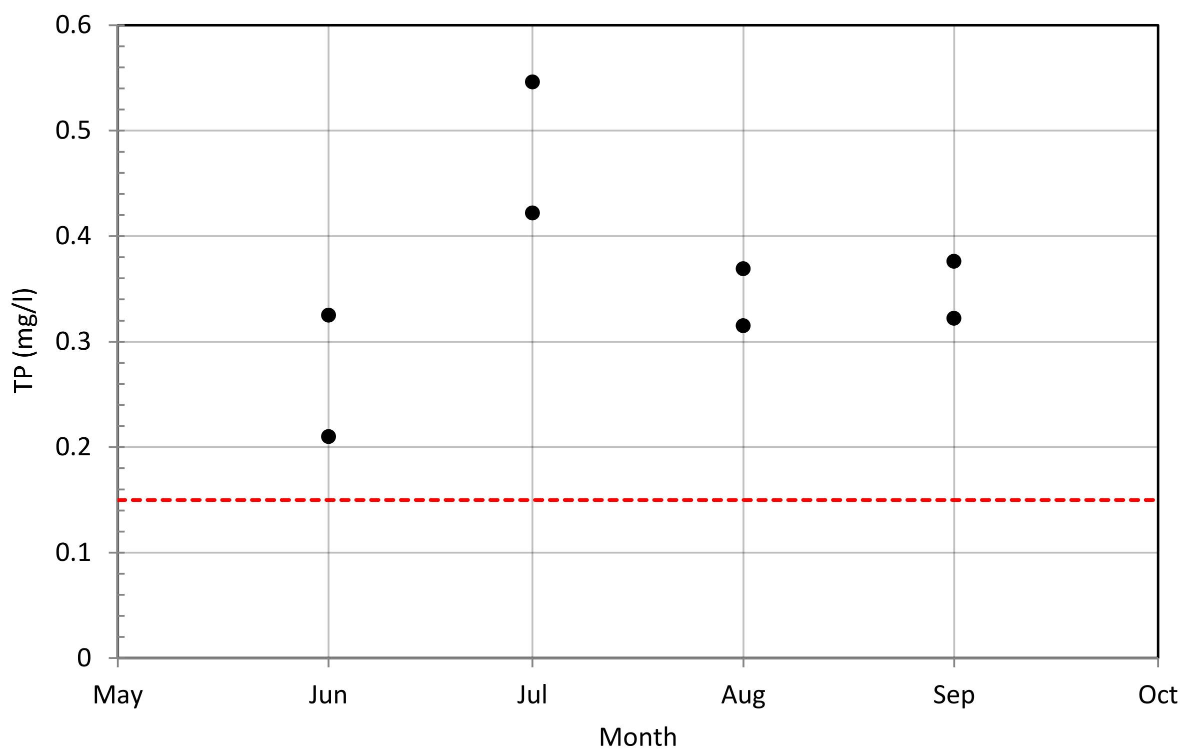

Figure 22. Total phosphorus (mg/l) by month in Rabbit River (09020101-502) at monitoring station S001-053, 2002-2011. The dashed line represents the TP eutrophication standard for Southern Region Streams (0.15 mg/L). Individual samples are shown as a single black dot.

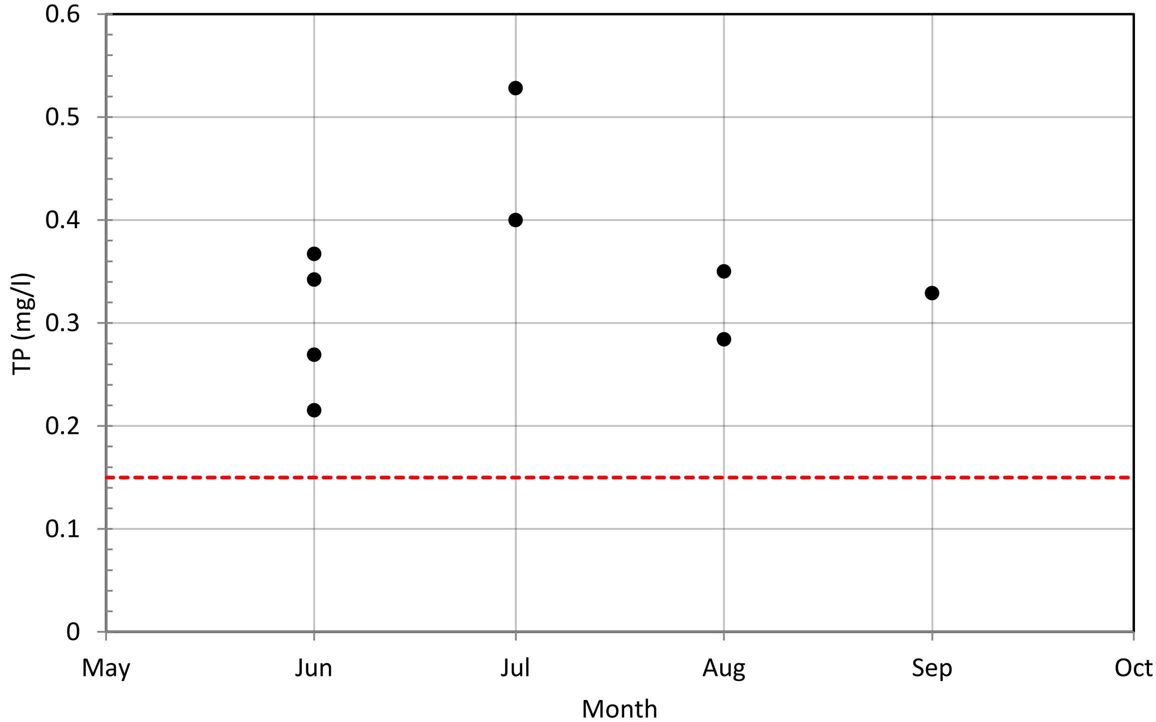

Figure 23. Total phosphorus (mg/l) by month in Rabbit River (09020101-502) at monitoring station S002-002, 2002-2011. The dashed line represents the TP eutrophication standard for Southern Region Streams (0.15 mg/L). Individual samples are shown as a single black dot.

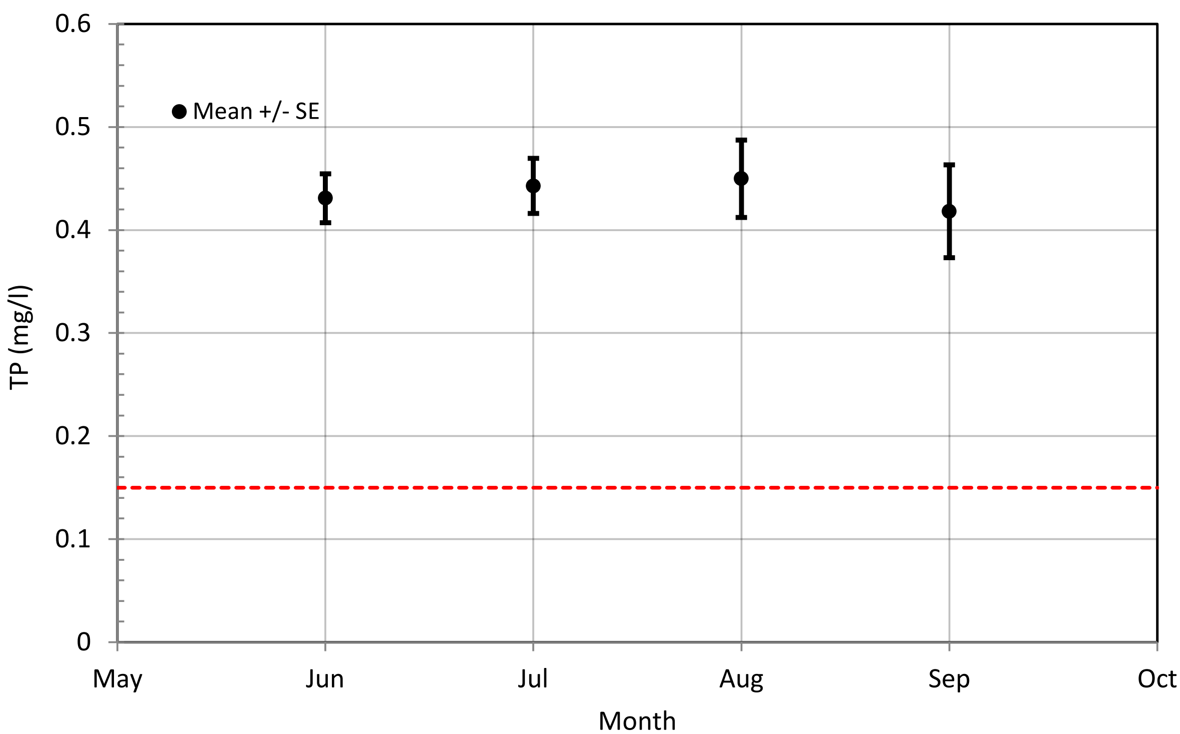

Figure 24. Total phosphorus (mg/l) by month in Rabbit River (09020101-502) at monitoring station S001-029, 2002-2011. The dashed line represents the TP eutrophication standard for Southern Region Streams (0.15 mg/L). Samples are shown as the monthly average (black dot) with standard error bars.

3.5.4 Stream Dissolved Oxygen

Ten-year (2002 through 2011) assessment statistics and instantaneous DO concentrations were summarized for the following three stream reaches impaired by low DO concentrations addressed in this TMDL study: Bois de Sioux River (09020101-501) and Rabbit River (09020101-502).

3.5.4.1 Bois de Sioux River (09020101-501)

The 10-year (2002 through 2011) DO water quality standard exceedances for the Bois de Sioux River (09020101-501) are summarized by station and all stations on the AUID in Table 17. The DO impairment for this reach was due to 8% of all samples measuring less than 5 mg/L collected between May and September at station S000-089 on the Bois de Sioux River at Breckenridge. These recent data confirmed an existing DO impairment for this reach, originally listed in 1998. Instantaneous DO measurements are shown by month for each monitoring station in Figure 25 (S00-553) and Figure 26 (S000-089).

Table 17. Ten-year DO water quality standard exceedances in Bois de Sioux River (09020101-501), 2002-2011.

Monitoring Station (upstream to downstream)	Criteria	No. of Samples (N)	No. of Samples < 5 mg/L	% Samples < 5 mg/L (If N>19)
S000-553 (BOIS DE SIOUX R ON CSAH-6 5.1 MI SW OF DORAN)	Before 9AM May – Sept.	2	0	
	All May – Sept.	18	2	
	Oct. – April	1	0	
S000-089 (BOIS DE SIOUX R. AT BRECKENRIDGE)	Before 9AM May – Sept.	3	0	
	All May – Sept.	147	12	8%
	Oct. – April	89	0	0%
All Stations	Before 9AM May – Sept.	5	0	
	All May – Sept.	165	14	8%
	Oct. – April	90	0	0%

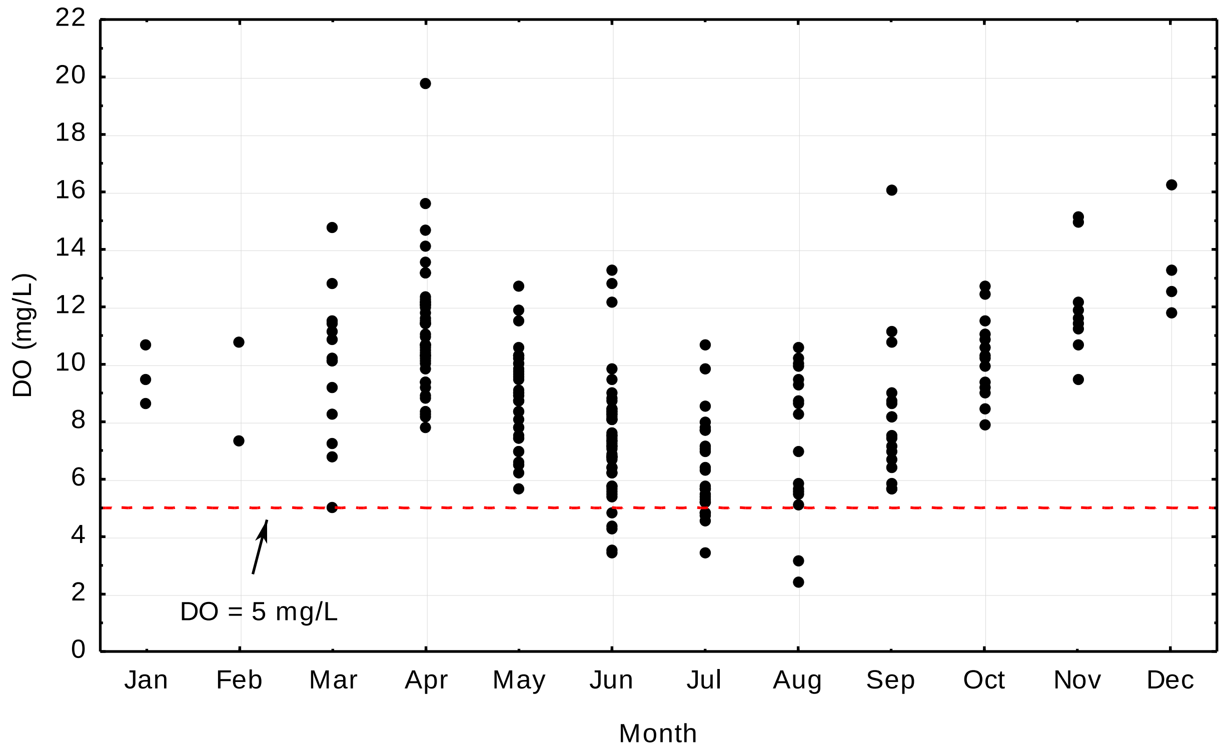

Figure 25. Dissolved oxygen (mg/L) by month in Bois de Sioux River (09020101-501) at monitoring station S000-553, 2002-2011. The dashed line represents the DO standard for warm-water streams.

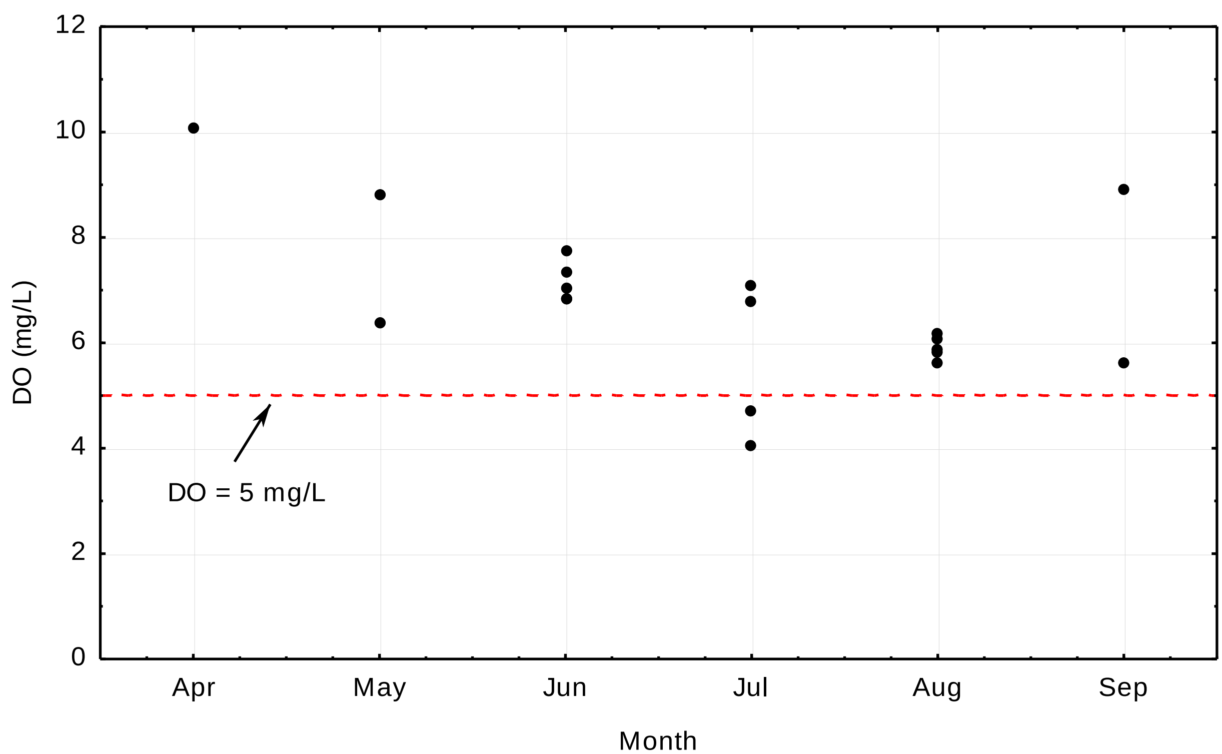

Figure 26. Dissolved oxygen (mg/L) by month in Bois de Sioux River (09020101-501) at monitoring station S000-089, 2002-2011. The dashed line represents the DO standard for warm-water streams.

3.5.4.2 Rabbit River (09020101-502)

The 10-year (2002 through 2011) DO water quality standard exceedances for the Rabbit River (09020101-502) are summarized by station and all stations on the AUID in Table 18. The DO impairment for this reach was due to 16% of all samples measuring less than 5 mg/L collected between May and September across multiple stations. There was excellent coverage of DO data for this reach. Exceedances vary by date - some at the headwaters, some at mid-reach, and some at the mouth. Exceedances do not appear to occur prior to June, based on existing data. Instantaneous DO measurements are shown by month for each monitoring station in Figure 27 (S001-053), Figure 28 (S002-002), Figure 29 (S001-029), and Figure 30 (S001-051).

Table 18. Ten-year DO water quality standard exceedances in Rabbit River (09020101-502), 2002-2011.

Monitoring Station (upstream to downstream)	Criteria	No. of Samples (N)	No. of Samples < 5 mg/L	% Samples < 5 mg/L (If N>19)
S001-053 (RABBIT R AT CSAH-19 2.5 MI N OF NASHUA)	Before 9AM May – Sept.	2	0	
	All May – Sept.	32	1	3%
	Oct. – April	21	1	5%
S002-002 (RABBIT R, AT CSAH-4 RT BANK OF BRG, 0.1 MI SW OF CAMPBELL)	Before 9AM May – Sept.	9	1	
	All May – Sept.	37	6	16%
	Oct. – April	20	0	0%
S001-029 (RABBIT RIVER AT US-75, 5 MILES NW OF CAMPBELL)	Before 9AM May – Sept.	2	0	
	All May – Sept.	102	18	18%
	Oct. – April	20	0	0%
S001-051 (RABBIT R AT CSAH-9 8 MI NW OF CAMPBELL)	Before 9AM May – Sept.	0	0	
	All May – Sept.	15	4	
	Oct. – April	7	0	
All Stations	Before 9AM May – Sept.	13	1	
	All May – Sept.	186	29	16%
	Oct. – April	68	1	0%

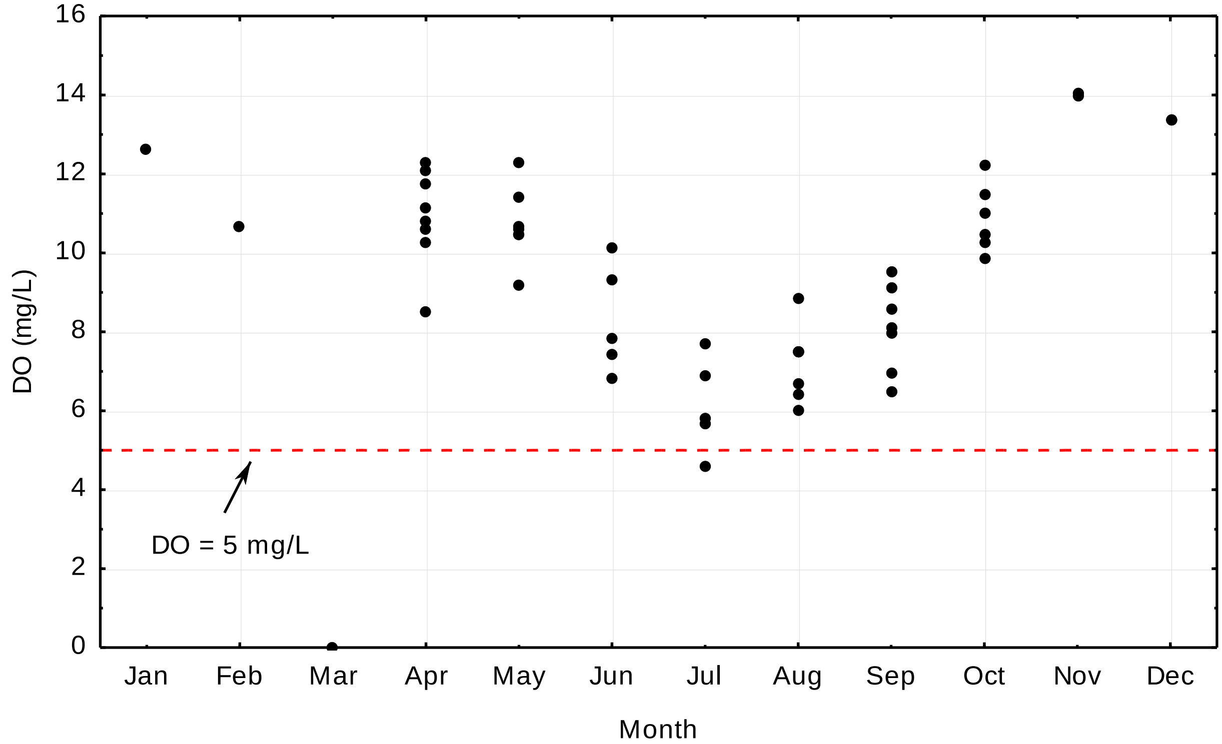

Figure 27. Dissolved oxygen (mg/L) by month in Rabbit River (09020101-502) at monitoring station S001-053, 2002-2011. The dashed line represents the DO standard for warm-water streams.

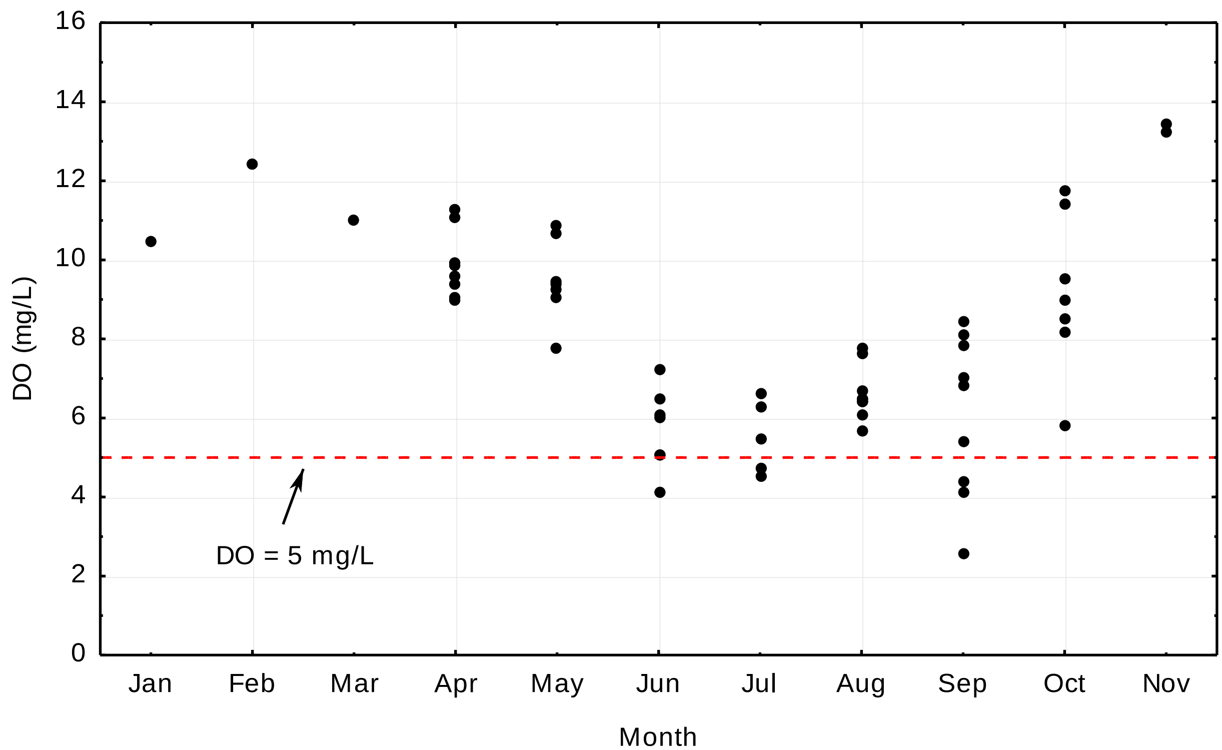

Figure 28. Dissolved oxygen (mg/L) by month in Rabbit River (09020101-502) at monitoring station S002-002, 2002-2011. The dashed line represents the DO standard for warm-water streams.

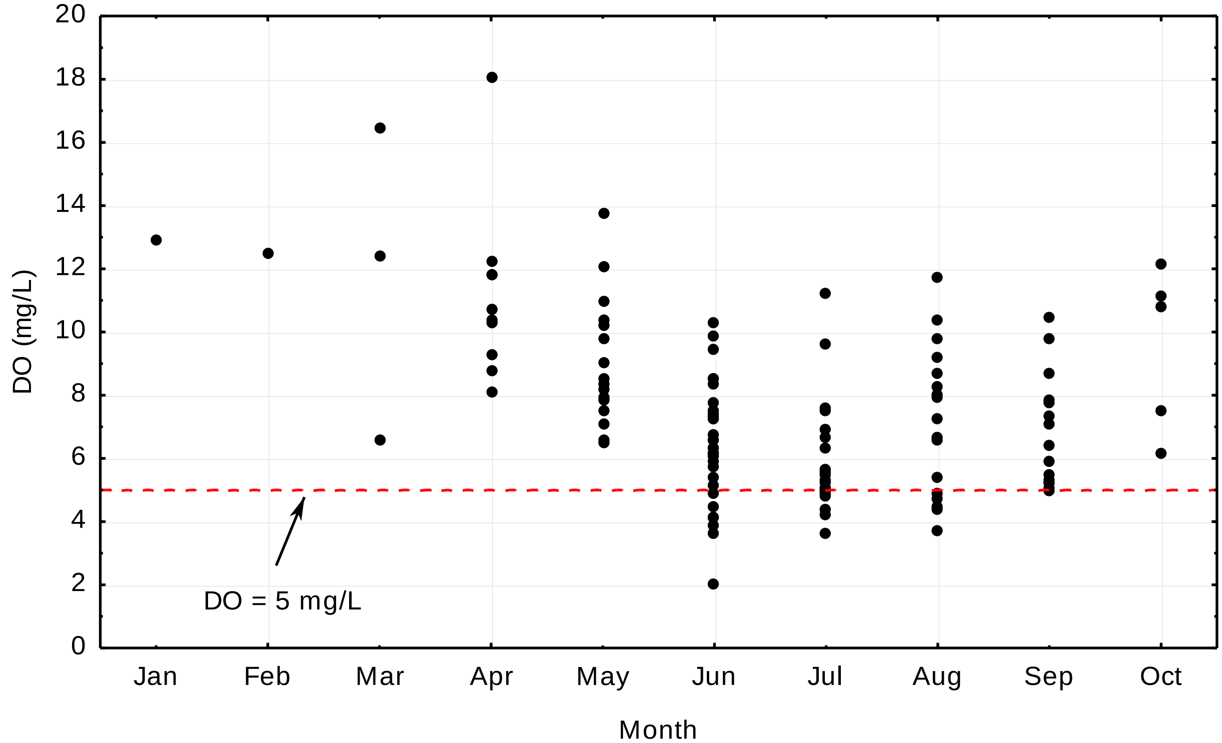

Figure 29. Dissolved oxygen (mg/L) by month in Rabbit River (09020101-502) at monitoring station S001-029, 2002-2011. The dashed line represents the DO standard for warm-water streams.

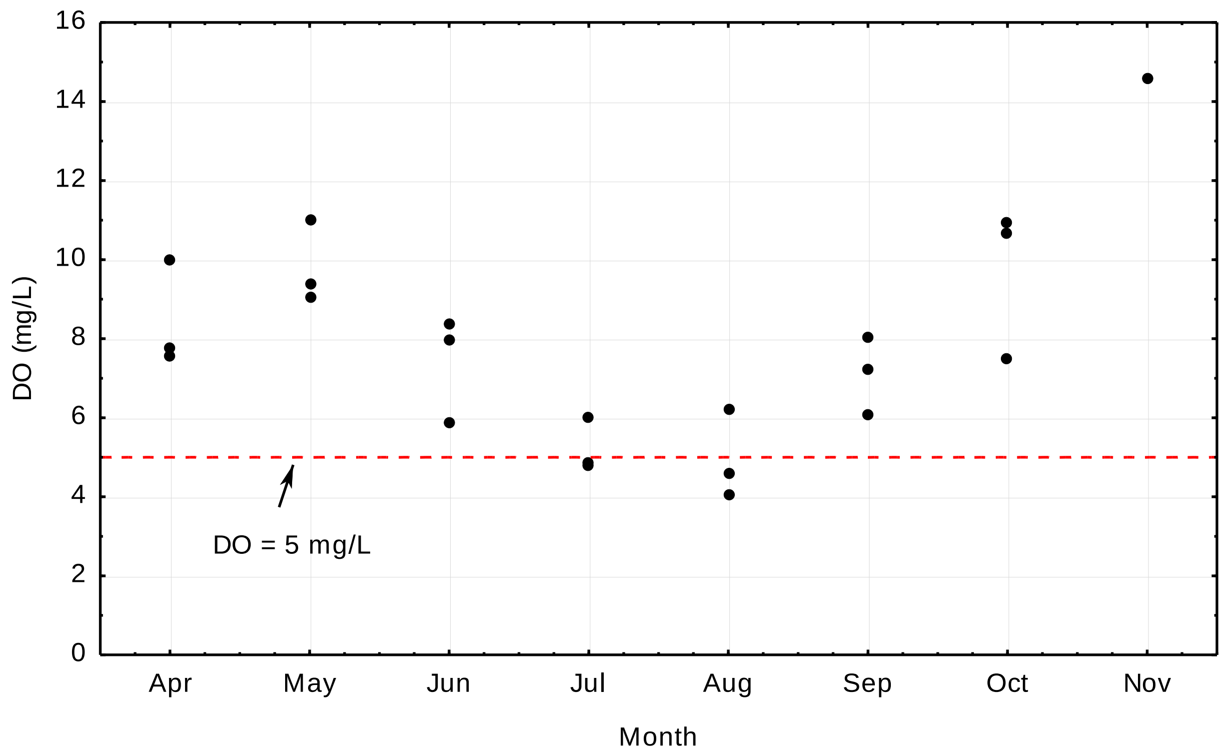

Figure 30. Dissolved oxygen (mg/L) by month in Rabbit River (09020101-502) at monitoring station S001-051, 2002-2011. The dashed line represents the DO standard for warm-water streams.

3.5.5 Stream *E. coli*

Using data from the most recent 10-year period (2002 through 2011), geometric mean *E. coli* concentrations were calculated by month for the two stream reaches impaired by *E. coli* and receiving TMDLs in this study: Rabbit River (09020101-502) and Unnamed Creek, Doran Slough (09020101-510).

3.5.5.1 Rabbit River (09020101-502)

The 10-year (2002 through 2011) April through October monthly geometric mean *E. coli* concentrations for the Rabbit River (09020101-502) are reported in Table 19. The *E. coli* impairment for this reach was due to monthly geometric means exceeding 126 org/100 mL in June and July at Station S001-029. Other monthly geometric means exceeded 126 org/100 mL, but were based on less than 5 samples. More monitoring data would be needed to confirm high *E. coli* levels during these months at these stations. There were no instantaneous exceedances of 1,260 org./100ml measured on this reach. To illustrate the seasonal variability in *E. coli* concentration at each station, *E. coli* data are shown by month in Figure 31 (S001-053), Figure 32 (S002-002), and Figure 33 (S001-029).

Table 19. Ten-year geometric mean *E. coli* (org./100ml) concentrations by month Rabbit River (09020101-502), 2002-2011. Geometric means that exceed the water quality standard of 126 org./100ml for which there are at least 5 samples are highlighted in bold.

Monitoring Station	Month	Number of Samples	Geometric Mean (org./100ml)	Minimum (org./100ml)	Maximum (org./100ml)	No. of samples > 1,260 org./100ml
S001-053 (RABBIT R AT CSAH-19 2.5 MI N OF NASHUA)	May	1	40	40	40	0
	June	1	1,110	1,110	1,110	0
	July	2	158	83	300	0
	August	1	2	2	2	0
	September	1	270	270	270	0
S002-002 (RABBIT R, AT CSAH-4 RT BANK OF BRG, 0.1 MI SW OF CAMPBELL)	April	1	10	10	10	0
	May	2	11	4	28	0
	June	2	130	120	140	0
	August	2	325	230	460	0
	September	1	150	150	150	0
S001-029 (RABBIT RIVER AT US-75, 5 MILES NW OF CAMPBELL)	April	1	5	5	5	0
	May	2	16	10	26	0
	June	9	**159**	62	460	0
	July	10	**198**	54	900	0

Monitoring Station	Month	Number of Samples	Geometric Mean (org./100ml)	Minimum (org./100ml)	Maximum (org./100ml)	No. of samples > 1,260 org./100ml
	August	11	87	2	1,203	0
	September	4	252	138	659	0

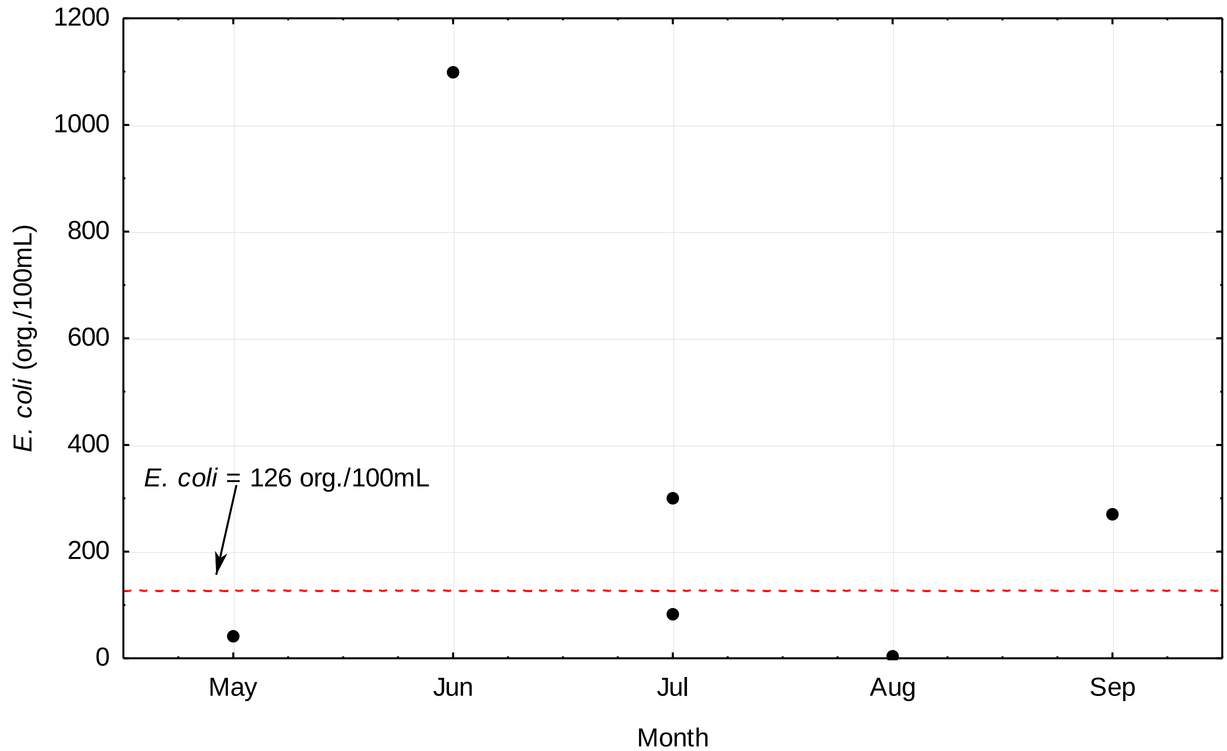

Figure 31. ***E. coli*** **(org./100mL) by month in Rabbit River (09020102-502) at monitoring station S001-053, 2002-2011. The dashed line represents the stream water quality standard (126 org./100mL)**

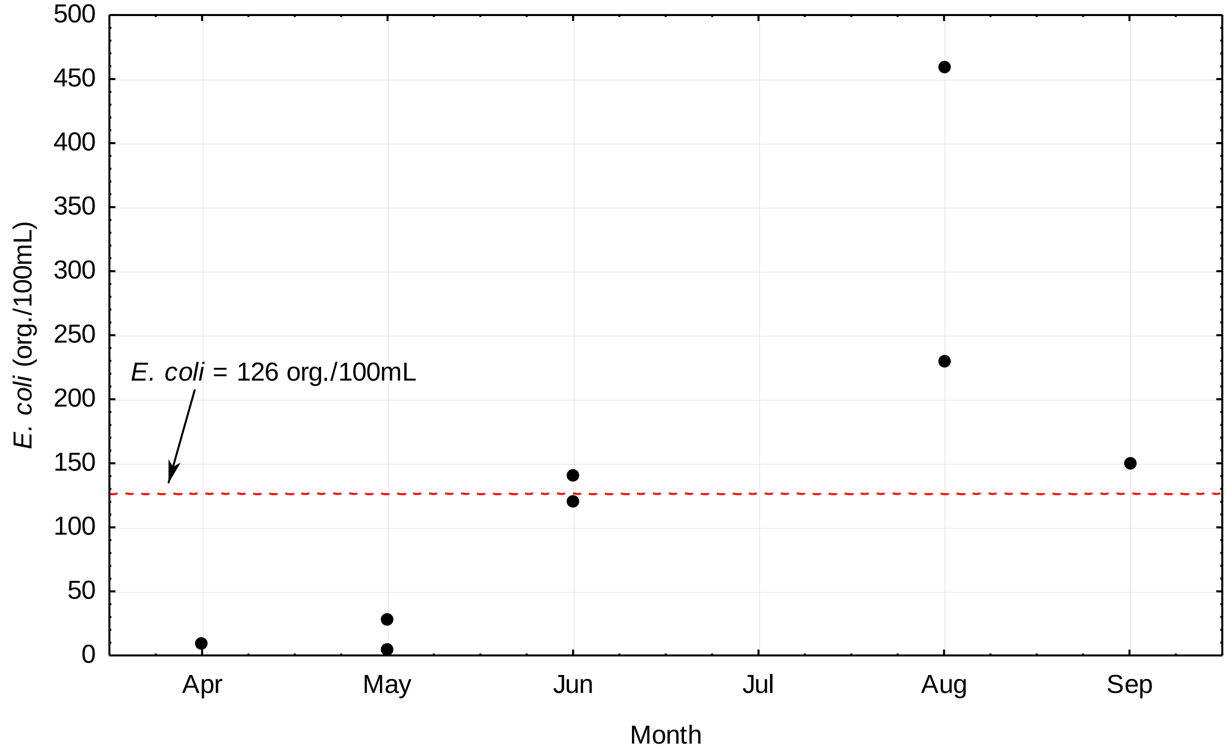

Figure 32. *E. coli* (org./100mL) by month in Rabbit River (09020102-502) at monitoring station S002-002, 2002-2011. The dashed line represents the stream water quality standard (126 org./100mL)

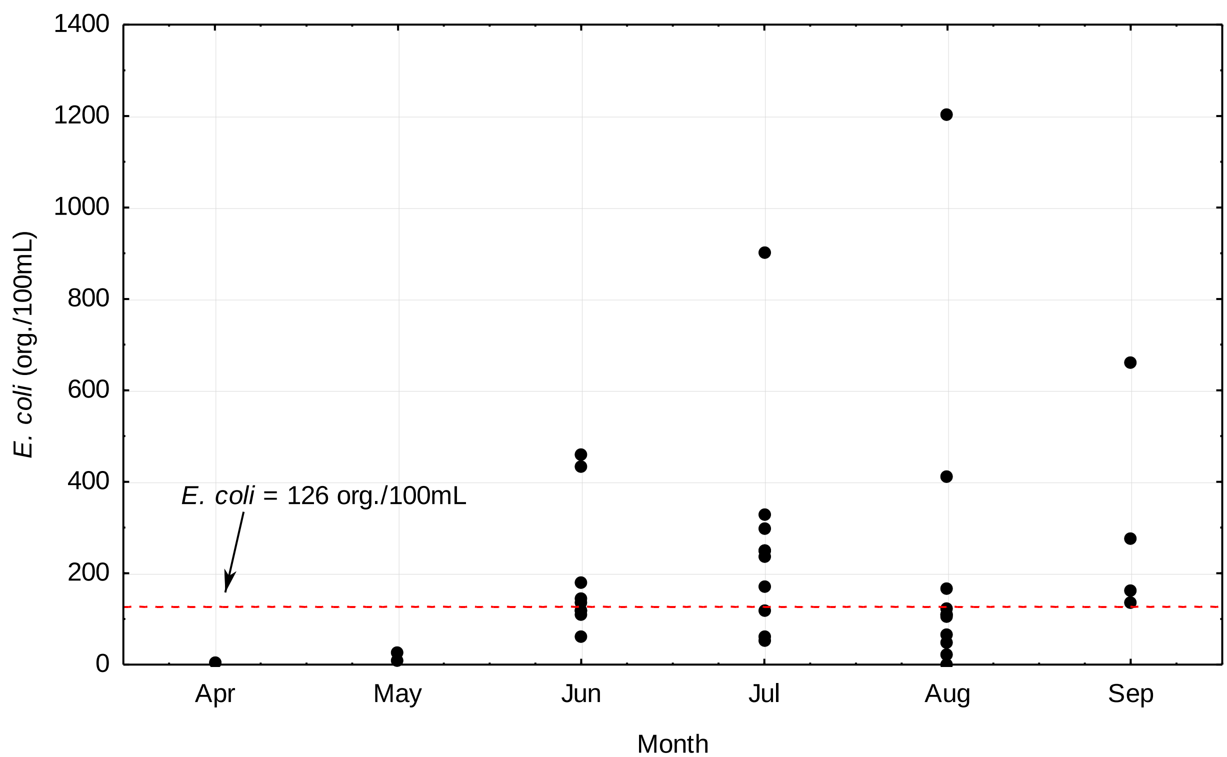

Figure 33. *E. coli* (org./100mL) by month in Rabbit River (09020102-502) at monitoring station S001-029, 2002-2011. The dashed line represents the stream water quality standard (126 org./100mL)

3.5.5.2 Unnamed Creek – Doran Slough (09020101-510)

The 10-year (2002 through 2011) April through October monthly geometric mean *E. coli* concentrations for Unnamed Creek – Doran Slough (09020101-510) are reported in Table 20. The *E. coli* impairment for this reach was due to monthly geometric means exceeding 126 org/100 mL in July and August at Station S005-145 and in August at Station S005-144. Other monthly geometric means exceeded 126 org/100 mL, but were based on less than 5 samples. More monitoring data would be needed to confirm high *E. coli* levels during these months at these stations. Four instantaneous samples exceeded 1,260 org./100mL on this reach. To illustrate the seasonal variability in *E. coli* concentration at each station, *E. coli* data are shown by month in Figure 34 (S005-145) and Figure 35 (S005-144).

Table 20. Ten-year geometric mean *E. coli* (org./100ml) concentrations by month in Unnamed Creek – Doran Slough (09020101-510), 2002-2011. Geometric means that exceed the water quality standard of 126 org./100ml for which there are at least 5 samples are highlighted in bold.

Monitoring Station	Month	Number of Samples	Geometric Mean (org./100ml)	Minimum (org./100ml)	Maximum (org./100ml)	No. of samples > 1,260 org./100ml
S005-145	April	2	13	11	15	
	June	3	169	46	921	
	July	5	**426**	131	1,553	1
	August	5	**374**	127	1,533	1
	September	1	326	326	326	
S005-144	June	5	56	10	1,553	1
	July	5	52	18	308	
	August	5	**198**	44	2,420	1
	September	3	66	47	86	

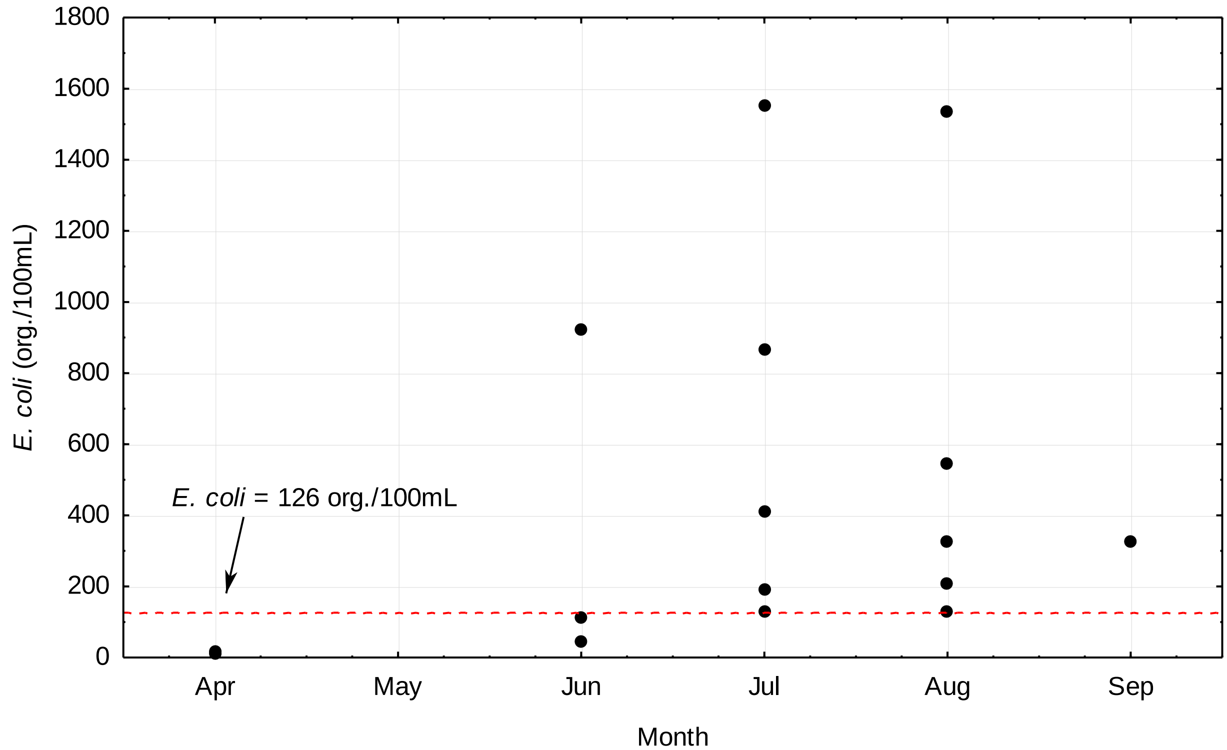

Figure 34. ***E. coli*** **(org./100mL) by month in Unnamed Creek – Doran Slough (09020102-510) at monitoring station S005-145, 2002-2011. The dashed line represents the stream water quality standard (126 org./100mL)**

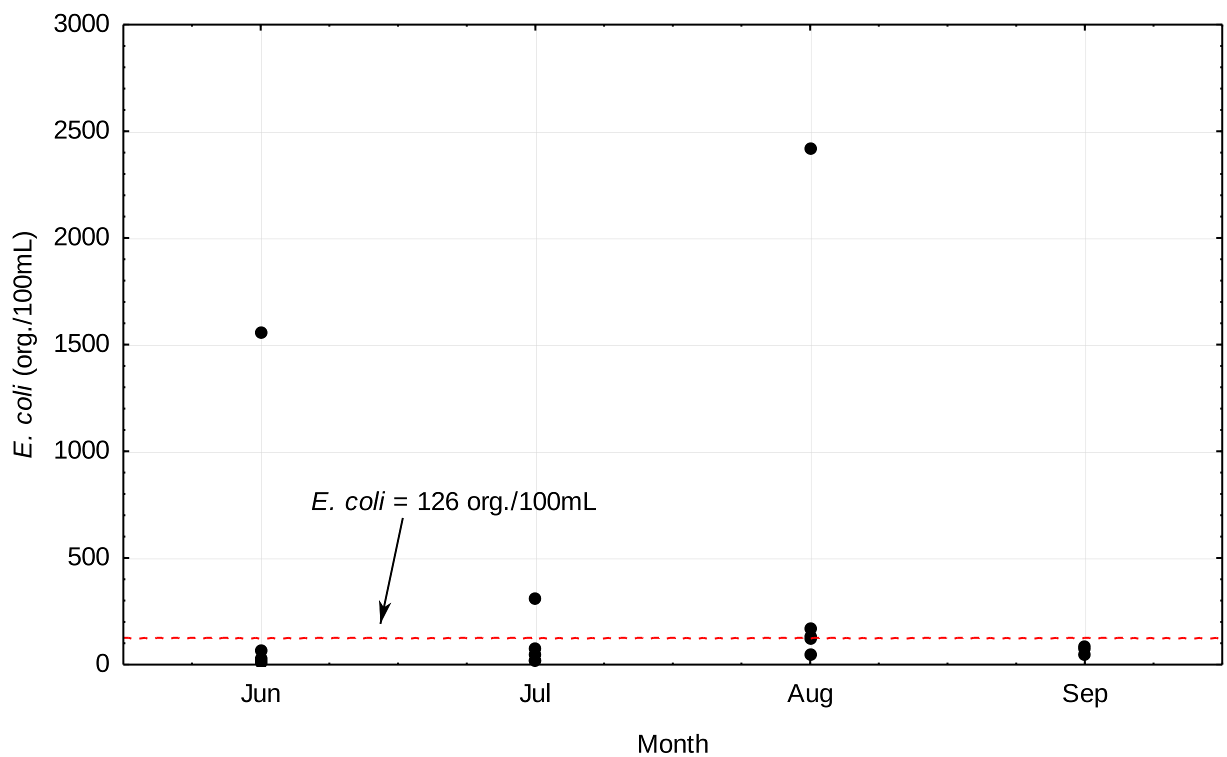

Figure 35. ***E. coli*** **(org./100mL) by month in Unnamed Creek – Doran Slough (09020102-510) at monitoring station S005-144, 2002-2011. The dashed line represents the stream water quality standard (126 org./100mL)**

3.5.6 Stream Total Suspended Solids

Using data from the most recent 10-year period (2002 through 2011), the percent of TSS samples exceeding the South RNR standard of 65 mg/L, from April through September, were calculated for the following three stream reaches: Bois de Sioux River (09020101-501) and Rabbit River (09020101-502).

3.5.6.1 Bois de Sioux River (09020101-501)

The 10-year (2002 through 2011) TSS water quality exceedances for the Bois de Sioux River (09020101-501) are reported in Table 21. The TSS impairment for this reach was due to 43% of all samples collected between April and September exceeding 65 mg/L. To illustrate the seasonal variability in TSS concentration at each station, TSS data are shown by month in Figure 36 (S000-553) and Figure 37 (S000-089). For stations with a large amount of data, the average (mean) is represented as a dot with standard error bars; otherwise, each individual sample is represented by a single dot. The TSS concentrations were highest in June and July on this reach.

Table 21. Ten-year total suspended solids water quality exceedances by station in Bois de Sioux River (09020101-501), 2002-2011 (April – September). Stations are listed in order from upstream to downstream.

Monitoring Station (upstream to downstream)	No. of Samples	No. of Samples > 65 mg/L	% of Samples > 65 mg/L
S000-553 (BOIS DE SIOUX R ON CSAH-6 5.1 MI SW OF DORAN)	231	100	43%
S000-089 (BOIS DE SIOUX R. AT BRECKENRIDGE)	10	4	40%
All Stations	241	104	43%

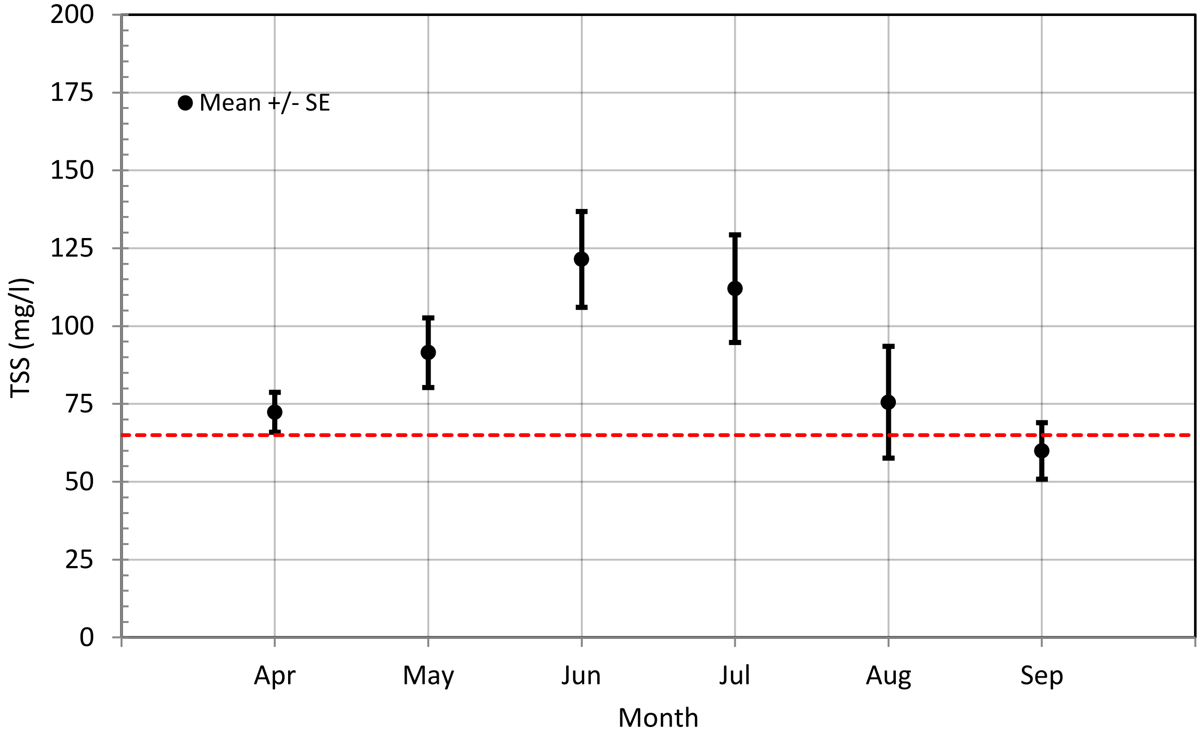

Figure 36. Total suspended solids (mg/L) by month in Bois de Sioux River (09020101-501) at monitoring station S000-553, 2002-2011. The dashed red line represents the TSS water quality standard for Southern Region Streams (65 mg/L).

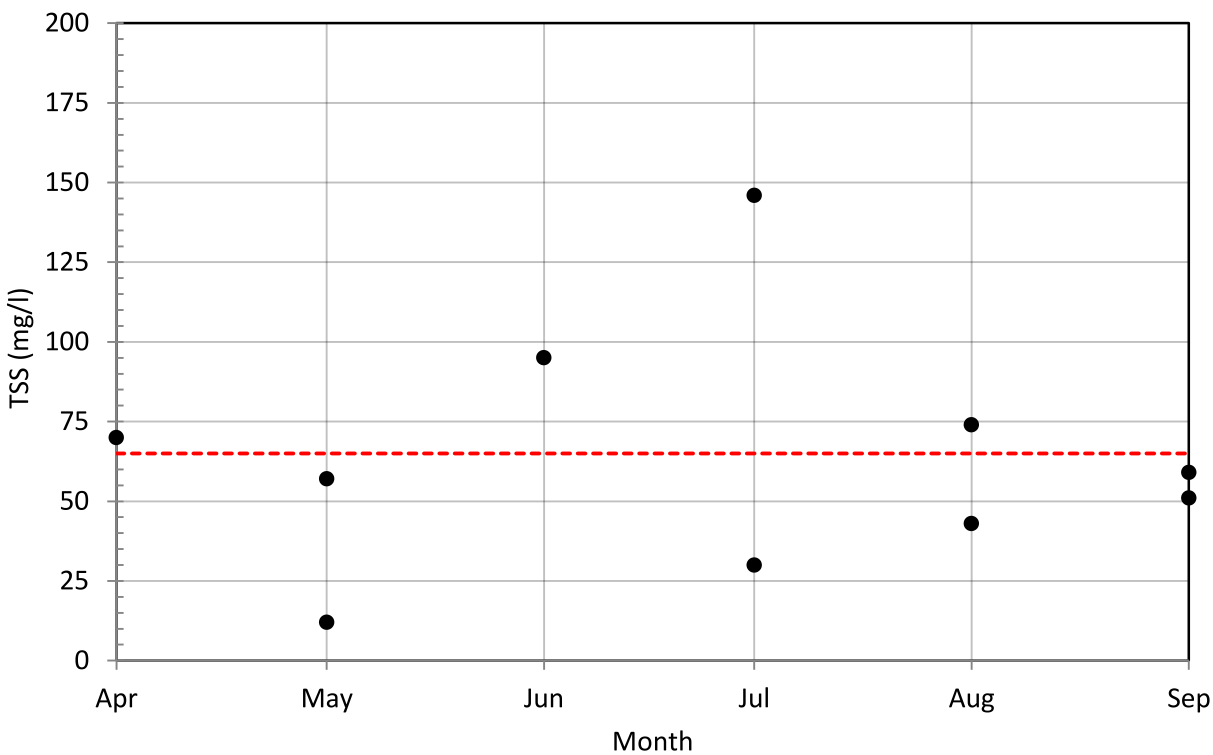

Figure 37. Total suspended solids (mg/L) by month in Bois de Sioux River (09020101-501) at monitoring station S000-089, 2002-2011. The dashed red line represents the TSS water quality standard for Southern Region Streams (65 mg/L).

3.5.6.2 Rabbit River (09020101-502)

The 10-year (2002 through 2011) TSS water quality exceedances for the Rabbit River (09020101-502) are reported in Table 22. The TSS impairment for this reach was due to 42% of all samples collected between April and September exceeding 65 mg/L. To illustrate the seasonal variability in TSS concentration at each station, TSS data are shown by month in Figure 38 (S001-053), Figure 39 (S002-002), and Figure 40 (S001-029). For stations with a large amount of data, the average (mean) is represented as a dot with standard error bars; otherwise, each individual sample is represented by a single dot. No clear patterns in TSS monthly variability were observed across all three stations.

Table 22. Ten-year total suspended solids water quality exceedances by station in Rabbit River (09020101-502), 2002-2011 (April – September). Stations are listed in order from upstream to downstream.

Monitoring Station (upstream to downstream)	No. of Samples	No. of Samples > 65 mg/L	% of Samples > 65 mg/L
S001-053 (RABBIT R AT CSAH-19 2.5 MI N OF NASHUA)	13	5	38%
S002-002 (RABBIT R, AT CSAH-4 RT BANK OF BRG, 0.1 MI SW OF CAMPBELL)	10	3	30%
S001-029 (RABBIT RIVER AT US-75, 5 MILES NW OF CAMPBELL)	70	31	44%
All Stations	93	39	42%

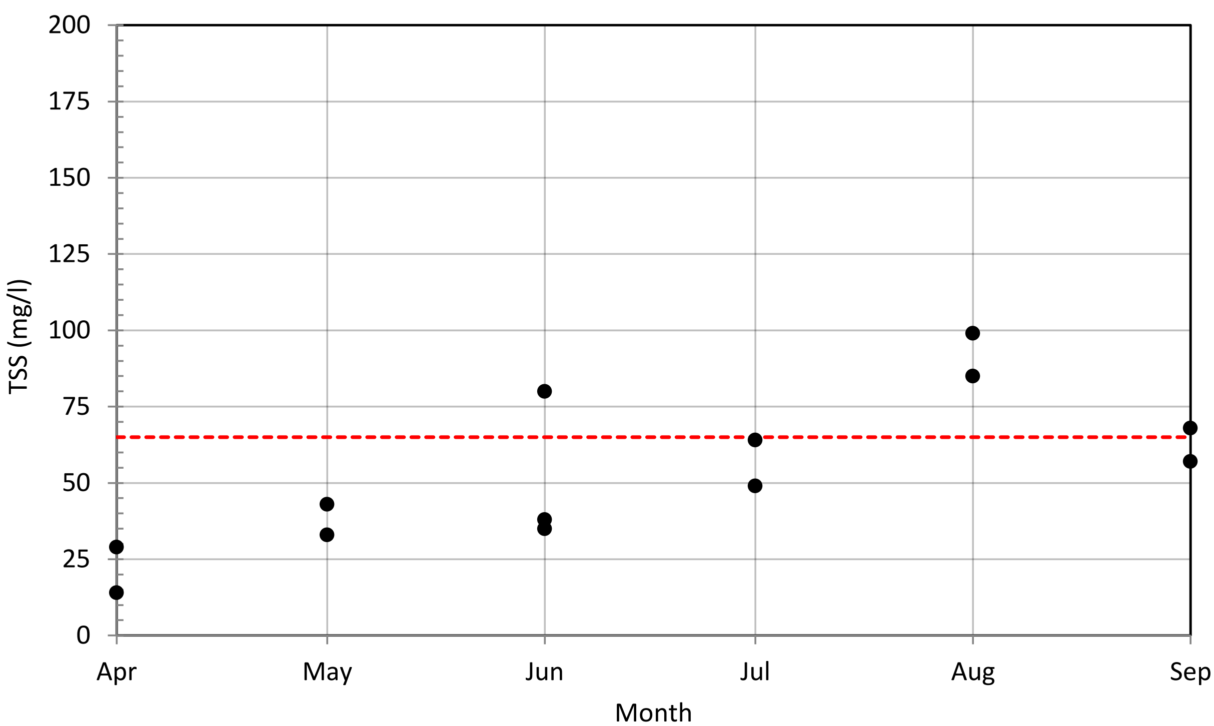

Figure 38. Total suspended solids (mg/L) by month in Rabbit River (09020101-502) at monitoring station S001-053, 2002-2011. The dashed red line represents the TSS water quality standard for Southern Region Streams (65 mg/L).

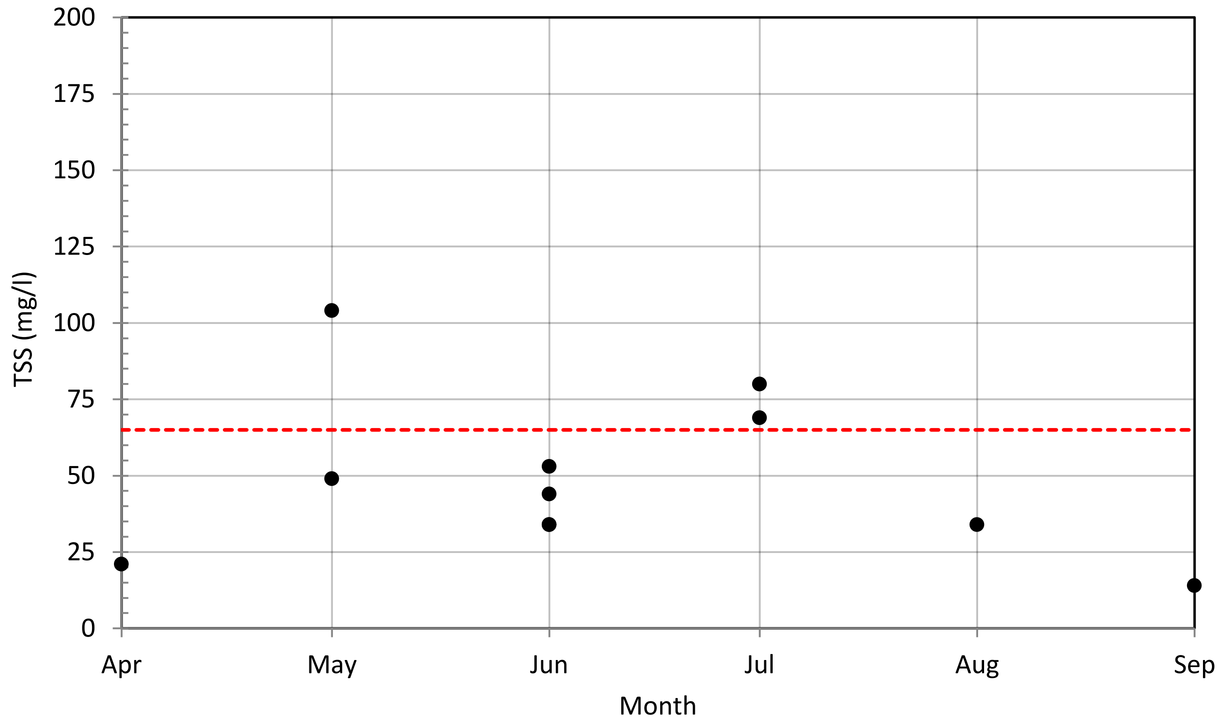

Figure 39. Total suspended solids (mg/L) by month in Rabbit River (09020101-502) at monitoring station S002-002, 2002-2011. The dashed red line represents the TSS water quality standard for Southern Region Streams (65 mg/L).

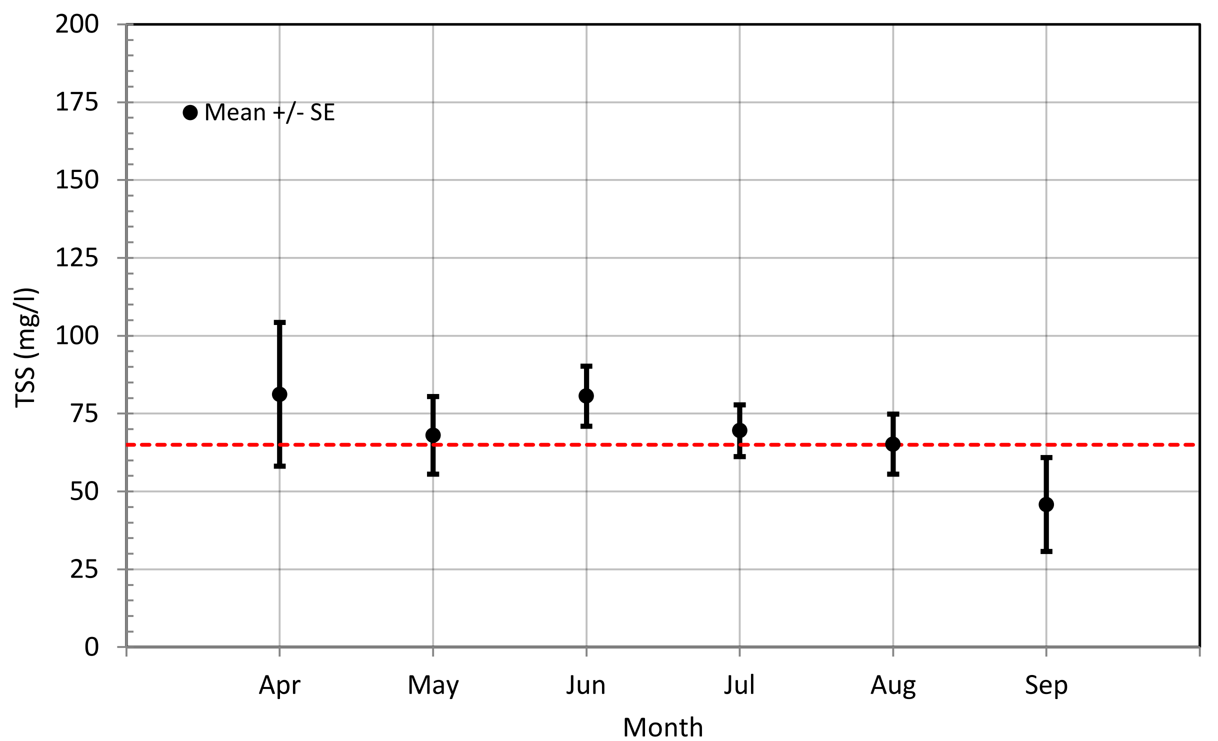

Figure 40. Total suspended solids (mg/L) by month in Rabbit River (09020101-502) at monitoring station S001-029, 2002-2011. The dashed red line represents the TSS water quality standard for Southern Region Streams (65 mg/L).

3.6 Pollutant Source Summary

Natural background conditions refer to inputs that would be expected under natural, undisturbed conditions. Natural background sources can include inputs from natural geologic processes such as soil loss from upland erosion and stream development, atmospheric deposition, and loading from forested land, wildlife, etc. For each impairment, natural background levels are implicitly incorporated in the water quality standards used by the MPCA to determine/assess impairment, and therefore natural background is accounted for and addressed through the MPCA's waterbody assessment process. Natural background conditions were also evaluated, where possible, within the modeling and source assessment portion of this TMDL study. Phosphorus and sediment loading rates by land use incorporated in the HSPF model account for natural background conditions, and wildlife sources of *E. coli* were considered for the bacteria impaired streams receiving TMDLs in this study. These source assessment exercises indicate natural background inputs are generally low compared to livestock, cropland, streambank, WWTFs, failing subsurface sewage treatment systems (SSTS), and other anthropogenic sources.

Based on the MPCA's waterbody assessment process and the TMDL source assessment exercises, there is no evidence at this time to suggest that natural background sources are a major driver of any of the impairments and/or affect the waterbodies' ability to meet state water quality standards. For all impairments addressed in this TMDL study, natural background sources are implicitly included in the LA portion of the TMDL allocation tables and TMDL reductions should focus on the major anthropogenic sources identified in the source assessment.

3.6.1 Lake Phosphorus

This section provides a brief description of the potential sources in the BdSRW that contribute to excess nutrients in the impaired lakes. The TP in lakes often originates on land. Phosphorus from sources such as phosphorus-containing fertilizer, manure, and the decay of organic matter can adsorb to soil particles. Wind and water action erode the soil, detaching particles and conveying them via stormwater runoff to nearby waterbodies where the phosphorus becomes available for algal growth. Organic material, such as leaves and grass clippings, can leach dissolved phosphorus into standing water and runoff, or be conveyed directly to waterbodies where biological action breaks down the organic matter and releases phosphorus.

3.6.1.1 Permitted Sources

The regulated sources of phosphorus, within the subwatersheds of the eutrophication impairments addressed in this TMDL study, include WWTF effluent, construction stormwater, and industrial stormwater. Phosphorus loads from NPDES permitted wastewater and stormwater sources were accounted for using the methods described in Section 4.1.3 below.

3.6.1.2 Non-permitted Sources

The following sources of phosphorus that do not require an NPDES permit were evaluated:

- Watershed runoff
- Loading from upstream waters
- Runoff from feedlots that do not require NPDES permit coverage

- Septic systems
- Atmospheric deposition
- Lake internal loading

Watershed runoff

An HSPF model (EOR 2014) was used to estimate watershed runoff volumes and TP loads from the direct drainage area of impaired lakes. The HSPF model estimates the amount of overland runoff flow on a daily basis for 30 individual subwatersheds in the BdSRW. Runoff estimates vary based on unique land cover and soil type combinations and precipitation data. The HSPF model was calibrated for the time period 2001 through 2006. The HSPF model was used to estimate the six-year (2001 through 2006) average annual flow and phosphorus load from the drainage area of each impaired lake, and daily streamflow estimates from 2001 through 2006 in the impaired streams. The HSPF TP loads for each lake in Table 23 were used to determine existing conditions in the TMDL Summary tables for each lake in Section 4.1.6.

Phosphorus loads from specific sources within the watershed (upstream waters, feedlots not requiring NPDES permit coverage, and SSTS) were also independently estimated to determine their relative contributions, described in the subsequent subsections within Section 3.6.1.2.

Table 23. HSPF six-year (2001-2006) average annual flow volumes and TP loads for lake direct drainage areas

Impaired lake or Upstream Lake	Direct drainage area (ac)	TP Conc. (µg/L)	Flow (ac-ft/yr)	TP Load (lb/yr)
Ash	6,293	303	1,547	1,261
Mud*	45,540	600	6,664	10,755
Traverse**	224,301	634	39,896	68,093
Upper Lightning	7,171	409	1,485	1,633

* Mud Lake is not addressed by a TMDL in this study but was modeled to determine the TP reductions needed to meet the assumptions of the Bois de Sioux River (-501) TP TMDL

** Lake Traverse is not impaired, but is a major tributary to Mud Lake. These data were used to construct a separate BATHTUB model for Lake Traverse.

Upstream lakes and streams

Upstream lakes and streams can contribute significant phosphorus loads to downstream impaired lakes and streams. Water quality monitoring data and flow from upstream lakes and streams, summarized in Table 24, were used to estimate the phosphorus loads to downstream impaired waters. The total upstream lake and stream loads for Mud Lake in Table 24 were used to determine existing conditions in the TMDL Summary tables in Section 4.1.6.

Table 24. Existing upstream TP loads to impaired lakes and streams

Impaired Lake or Stream	Upstream Lake or Stream (Lake ID/ AUID)	TP (µg/L)	Flow (ac-ft/yr)	TP Load (lb/yr)
Mud*	Traverse (78-0025)	214	179,842	104,826
Mud*	Mustinka River (09020102-503)	205	137,653	75,973

* Mud Lake is not addressed by a TMDL in this study but was modeled to determine the phosphorus reductions needed to meet the assumptions of the Bois de Sioux River (-501) TP TMDL

Feedlots that do not require NPDES permits

Runoff during precipitation and snow melt can carry phosphorus from uncovered feedlots to nearby surface waters. For the purpose of this TMDL study, non-permitted feedlots are defined as being all registered feedlots without an NPDES/State Disposal System (SDS) Permit that house under 1,000 animal units (AUs). While these feedlots do not fall under NPDES regulation, other regulations still apply. Phosphorus loads to impaired lakes, listed in Table 25, from non-permitted, registered feedlots were estimated based on the estimate of phosphorus generated by AU type, the fraction of feedlots contributing to waters, and the phosphorus fraction lost to surface waters from the *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds* (MPCA 2004). The number of Beef Cattle in each drainage area was based on correspondence with county officers in 2014. The total annual feedlot loads for each lake in Table 25 were used to determine existing conditions in the TMDL Summary tables for each lake in Section 4.1.6.

Table 25. Feedlot assumptions and phosphorus loads to impaired lakes

Impaired Lake or Upstream Lake	Beef Cattle		Total P generated	Fraction of feedlots contributing to waters	P fraction lost to surface waters (average flow)	Total Annual Feedlot Load
	AU	lb/ AU-yr	lb/yr	%	%	lb/yr
Ash	20	33.5	670	35	0.2	**0.5**
Mud*	0	33.5	0	35	0.2	**0**
Traverse**	147	33.5	4,925	35	0.2	**3.5**
Upper Lightning	0	33.5	0	35	0.2	**0**

* Mud Lake is not addressed by a TMDL in this study but was modeled to determine the TP reductions needed to meet the assumptions of the Bois de Sioux River (-501) TP TMDL

** Lake Traverse is not impaired, but is a major tributary to Mud Lake. These data were used to construct a separate BATHTUB model for Lake Traverse.

Subsurface sewage treatment systems

Phosphorus loads from SSTS were estimated based on assumptions described in the *Detailed Assessment of Phosphorus Sources to Minnesota Watershed* (MPCA 2004) and county specific estimates of failing septic systems rates, based on reports from Big Stone County and Grant County planning and zoning officers. The total shoreline SSTS loads due to failing systems for each lake in Table 26 were used to determine existing conditions in the TMDL Summary tables for each lake in Section 4.1.6.

Table 26. SSTS assumptions and phosphorus loads to impaired lakes

Impaired Lake or Upstream Lake	Shoreline ISTS[a]	Seasonal residence (4 mo/yr)	Permanent Residence	Conforming Systems	Failing Systems[b]	Capita per Residence[c]	P Production per Capita	Conforming ISTS %P "passing"	Failing ISTS %P "passing"	Conforming Systems	Failing Systems	P Load Conforming ISTS	P Load Failing ISTS	Total Shoreline ISTS P Load	Total Shoreline ISTS P Load due to Failing
	#	%	%	%	%	#	lb/yr	%	%	#	#	lb/yr	lb/yr	lb/yr	lb/yr
Ash	0	n/a	n/a	n/a	n/a	n/a	1.95	20	43	0	0	0	0	0	**0**
Mud*	6	33	67	81	19	2.46	1.95	20	43	5	1	3.7	1.6	5.3	**0.9**
Traverse**	241	88	12	81	19	2.41	1.95	20	43	195	46	75.9	38.5	114.4	**20.6**
Upper Lightning	2	100	0	100	0	2.29	1.95	20	43	2	0	0.6	0	0.6	**0**

[a] Based on counts of shoreline residences from current aerial imagery.

[b] Based on the estimate of percent of failing septic systems by County in the MPCA 2012 SSTS Annual Report Appendix C. https://www.pca.state.mn.us/sites/default/files/wq-wwists1-51.pdf.

[c] Based on the estimated number of people per household by County from the 2010 Census.

* Mud Lake is not addressed by a TMDL in this study but was modeled to determine the TP reductions needed to meet the assumptions of the Bois de Sioux River (-501) TP TMDL

** Lake Traverse is not impaired, but is a major tributary to Mud Lake. These data were used to construct a separate BATHTUB model for Lake Traverse.

Atmospheric Deposition

Atmospheric deposition represents the phosphorus that is bound to particulates in the atmosphere and is deposited directly onto surface waters. Average phosphorus atmospheric deposition loading rates were approximately 0.23 pounds per acre (lb/ac) of TP per year for an average rainfall year for the Red River Basin (Barr 2007 addendum to MPCA 2004). This rate was applied to the lake surface area to determine the total atmospheric deposition load per year to the impaired lakes and streams. The total annual atmospheric deposition load for each lake in Table 27 were used to determine existing conditions in the TMDL Summary tables for each lake in Section 4.1.6.

Table 27. Atmospheric deposition phosphorus loads to impaired lakes (MPCA 2004)

Impaired Lake or Upstream Lake	Atmospheric Deposition Phosphorus Load (lb/yr)
Ash	**40**
Mud*	**573**
Traverse**	**2,571**
Upper Lightning	**162**

* Mud Lake is not addressed by a TMDL in this study but was modeled to determine the TP reductions needed to meet the assumptions of the Bois de Sioux River (-501) TP TMDL

** Lake Traverse is not impaired, but is a major tributary to Mud Lake. These data were used to construct a separate BATHTUB model for Lake Traverse.

Internal Loading

Internal loading in lakes refers to the phosphorus load that originates in the bottom sediments or macrophytes and is released back into the water column. Internal loading can occur via:

1. *Chemical release from the sediments:* Caused by anoxic (lack of oxygen) conditions in the overlying waters or high pH (greater than nine). If a lake's hypolimnion (bottom area) remains anoxic for a portion of the growing season, the phosphorus released due to anoxia will be mixed throughout the water column when the lake loses its stratification at the time of fall mixing. In shallow lakes, the periods of anoxia can last for short periods of time and occur frequently.
2. *Physical disturbance of the sediments*: Caused by bottom-feeding fish behaviors (such as carp and bullhead), motorized boat activity, and wind-driven mixing. This is more common in shallow lakes than in deeper lakes.

Internal loading due to the anoxic release from the sediments of each lake was estimated based on the expected release rate of phosphorus from the lakebed sediment, the lake anoxic factor (AF), and the lake area. Lake sediment samples were collected and tested for concentration of TP and bicarbonate dithionite extractable phosphorus (BD-P), which analyzes iron-bound phosphorus. Phosphorus release rates were calculated using statistical regression equations, developed using measured release rates and sediment phosphorus concentrations from a large set of North American lakes (Nürnberg 1988; Nürnberg 1996). Internal loading due to physical disturbance is difficult to reliably estimate and was therefore not included in the lake TP analyses. In lakes where internal loading is believed to be substantial, the internal load estimates derived from lake sediment data shown in Table 28 are likely an underestimate of the actual internal load. For example, the Nurnberg dataset tends to under-predict internal loading in shallow lakes due to the lack of shallow lakes included in the North American dataset used to develop the regression equations.

Some amount of internal loading is implicit in the BATHTUB lake water quality model; therefore, internal loading rates added to the BATHTUB model during calibration represents the excess sediment release rate beyond the average background release rate, accounted for by the model development lake dataset. The implicit amount of internal loading in the BATHTUB model is typically smaller than the calibrated BATHTUB model rates for shallow lakes because the BATHTUB model development lake dataset is less representative of this lake type, and therefore accounts for less implicit internal loading in shallow lakes. Shallow lake sediments can easily be disturbed by wind-driven mixing of the water column or physical disturbance from boats and carp.

Most of the internal loading in Ash and Upper Lightning Lakes is likely driven by chemical release from the sediments. These lakes do not have carp or motorized boat activity issues. During large storm events, wind-driven mixing may also contribute to internal loading, as evidenced by the more turbid water in Ash Lake deeper bay compared to the shallow bay. Mud lake and Lake Traverse internal loading is likely driven by carp and wind-driven mixing due to their long fetches (unimpeded surface distance along the longest length of the lake) and the presence of carp.

The Nurnberg internal loading estimates and the excess internal load estimates used to calibrate the BATHTUB models (see Section 4.1.1.1 Model Calibration) for the four lakes are shown in Table 28. The Nurnberg internal load estimates were similar to the BATHTUB model's excess internal load estimates for Ash and Upper Lightning Lake. However, the Nurnberg estimates were much less than the BATHTUB model's excess internal load estimates for Mud Lake and Lake Traverse. The internal loading in Mud Lake and Lake Traverse is likely driven by physical disturbance, which is not accounted for in the Nurnberg estimates; therefore, the BATHTUB model's excess internal load estimates were used to estimate the existing internal load in Mud Lake and Lake Traverse.

For consistency in the TMDL, the BATHTUB model's excess internal load estimates were also used to estimate the existing internal load in Ash and Upper Lightning Lakes. Ash Lake had poor density of vegetation within the TMDL time period (2002-2011), but more abundant aquatic vegetation than Upper Lightning Lake (see Section 3.1). In 2014, Ash Lake had dense sago pondweed and heavy algae growth, indicating strong watershed loads. Therefore, the BATHTUB model's excess internal load estimate of zero was considered reasonable for Ash Lake as the watershed load estimates were likely not underestimated. Upper Lightning Lake did not have submerged vegetation over 80% of the lake bottom; therefore, the larger BATHTUB model's excess internal load estimate compared to Ash Lake was reasonable.

The BATHTUB model's calibrated excess internal loads for each lake in Table 28 were used to determine existing conditions in the TMDL Summary tables for each lake in Section 4.1.6.

Table 28. Internal phosphorus load assumptions and summary

Impaired Lake or Upstream Lake	Lake Type	Monitored Sediment P Concentration (mg/kg dry)		Nurnberg Predicted Anoxic Factor	Nurnberg Estimated Total Sediment P Release Rate NA Lakes Dataset (mg/m^2-anoxic day)			Nurnberg Average Estimated Total Sediment P Release Rate NA Lakes Dataset	BATHTUB Calibrated Excess Release Rate	BATHTUB Calibrated Excess Internal Load	
		Iron P (BD-P)	Total P (TP)	(days)	BD-P	TP	Average	(mg/m^2-calendar day)	(mg/m^2-calendar day)	(kg/yr)	(lb/yr)
Ash	Shallow	140	1,400	73	1.34	1.10	1.22	0.24	0	**0**	**0**
Mud*	Shallow	40	1,200	96	n/a	0.34	0.34	0.09	23.84	**86,752**	**191,253**
Traverse**	Shallow	84	1,300	81	0.57	0.72	0.65	0.14	3.751	**61,206**	**134,934**
Upper Lightning	Shallow	33	1,600	65	n/a	1.85	1.85	0.33	0.126	**129**	**284**

* Mud Lake is not addressed by a TMDL in this study but was modeled to determine the TP reductions needed to meet the assumptions of the Bois de Sioux River (-501) TP TMDL

** Lake Traverse is not impaired, but is a major tributary to Mud Lake. These data were used to construct a separate BATHTUB model for Lake Traverse.

n/a indicates that Mud and Upper Lightning Lake Sediment P Release Rates based on sediment BD-P concentrations in the lakes were outside the NA Lakes Dataset regression boundaries and produced a negative result.

3.6.2 Stream Total Phosphorus and Total Suspended Solids

3.6.2.1 Permitted

The regulated sources of TP and TSSs within the subwatersheds of the impaired streams addressed in this TMDL study include WWTF effluent; NPDES permitted feedlots, construction stormwater, and industrial stormwater. Phosphorus and TSS loads from NPDES permitted wastewater and stormwater were accounted for using the methods described in Section 4.2 and 4.3 below.

3.6.2.2 Non-permitted

The HSPF model was used to simulate non-permitted sources of total suspended sediment and TP in the BdSRW. The HSPF model has been used extensively in Minnesota and nationwide in support of TMDLs to simulate the complex nutrient cycling associated with TP, nitrogen, DO, algal growth, and biological oxygen demand. The model splits a watershed into small segments based on unique combinations of homogenous soils (Figure 43), topography (Figure 41), land cover (Figure 42), and climate. From these segments, daily landscape hydrology and water quality are simulated and routed through the channel network to the watershed outlet.

The Bois de Sioux HSPF model was set up to account for the varying landscapes of the watershed, most notably the different effect of depressional geology (ponds, wetlands, and lakes) versus glacial lake plain geology on hydrologic and water quality responses. While row-crop land covers predominate the watershed, this land cover type was further segmented based on unique combinations of depressional storage and soil infiltration capacity (i.e., soil type) categories, which result in very different hydrologic and water quality responses throughout the BdSRW for the same land cover type.

The model was calibrated and run using data from 2001 to 2006. Ideally, HSPF models would have much longer calibration and validation periods to account for greater climatic variability over time. However, at the time of model construction, continuous flow gage data were only available since 2001 and meteorological data available from 2006, which constrained the model calibration period between 2001 and 2006. The water quality constituents that were modeled and calibrated were flow, TSS, orthophosphate, TP, nitrate, total Kjeldahl nitrogen (TKN; organic nitrogen plus ammonia), ammonia, DO, temperature, and Chl-*a* (a pigment found in algae cells). More intense consideration was given to TSS and TP because of their importance to impairments in the BdSRW.

Average annual precipitation, runoff flow, TP, and total sediment yields were calculated from HSPF modeled daily outputs and are summarized graphically in Figure 44, Figure 45, Figure 46, and Figure 47.

Sediment and phosphorus loading characteristics

HSPF modeled results indicate that TSS loading is generally highest in higher slope agricultural areas with higher runoff potential (i.e., less soil infiltration capacity). The TP loading follows similar patterns but is more strongly influenced by runoff potential than slope. Both TSS and TP loading decrease with increased amounts of depressional storage (ponds, wetlands, and lakes) in the watershed, illustrating the importance of these features for reducing runoff and nutrient export.

Sediment source summary

In an effort to determine sediment sources in support of the Bois de Sioux HSPF model, EOR conducted a review of available literature (summarized below).

A geomorphic assessment was conducted at select sites along the impaired reaches in the BdSRW. However, this assessment was completed primarily to support the SID study for biological impairments (see Appendix 1 of the 2016 MPCA Bois de Sioux River Watershed SID Report). This assessment provides information on site-scale bank erosion rates at the specific survey locations in the watershed. This data provides evidence for the presence and severity of bank erosion at specific sites, but does not provide an estimate of the total amount of sediment derived from bank erosion at a watershed scale.

This can be determined by a sediment source fingerprinting study, which has not been completed in the BdSRW that quantifies the relative amount of sediment in the streams coming from bank, near-stream, and field erosion.

Two sediment source fingerprinting studies conducted elsewhere in the Red River Basin (Lauer et al. 2006 and Brigham et al. 2001) were reviewed which show that field erosion accounts for 65% to 90% of the total suspended sediment. Lauer et al. (2006) determined that field erosion was the dominant (90%) source of sediments in the South Branch Buffalo River in the Red River Valley based on AnnAGNPS modeling. Additionally, Brigham et al. (2001) suggested that surface (field) erosion contributes 65% to 80% of the suspended sediment to the Wild Rice River. Based on these studies and observations made during the geomorphology stream survey, it is expected that the sediment loading in the BdSRW is from approximately 80% field sources and 20% non-field sources. This relative contribution was incorporated into the model during sediment calibration.

Phosphorus source summary

Stream TP concentrations are high in the BdSRW across all flow regimes. Large peaks in TP loads are generally tied to peaks in sediment loading under high flow conditions, indicating that watershed runoff is the dominant source of TP under high flows. Under low flow conditions, an additional source of TP was added to calibrate the HSPF model, indicating that groundwater/subsurface water or P entrainment from stream sediments is the dominant source of P under low flows. This is supported by observations of stream eutrophication throughout the watershed and wetland-dominated headwaters (see the 2016 MPCA Bois de Sioux River Watershed SID Report).

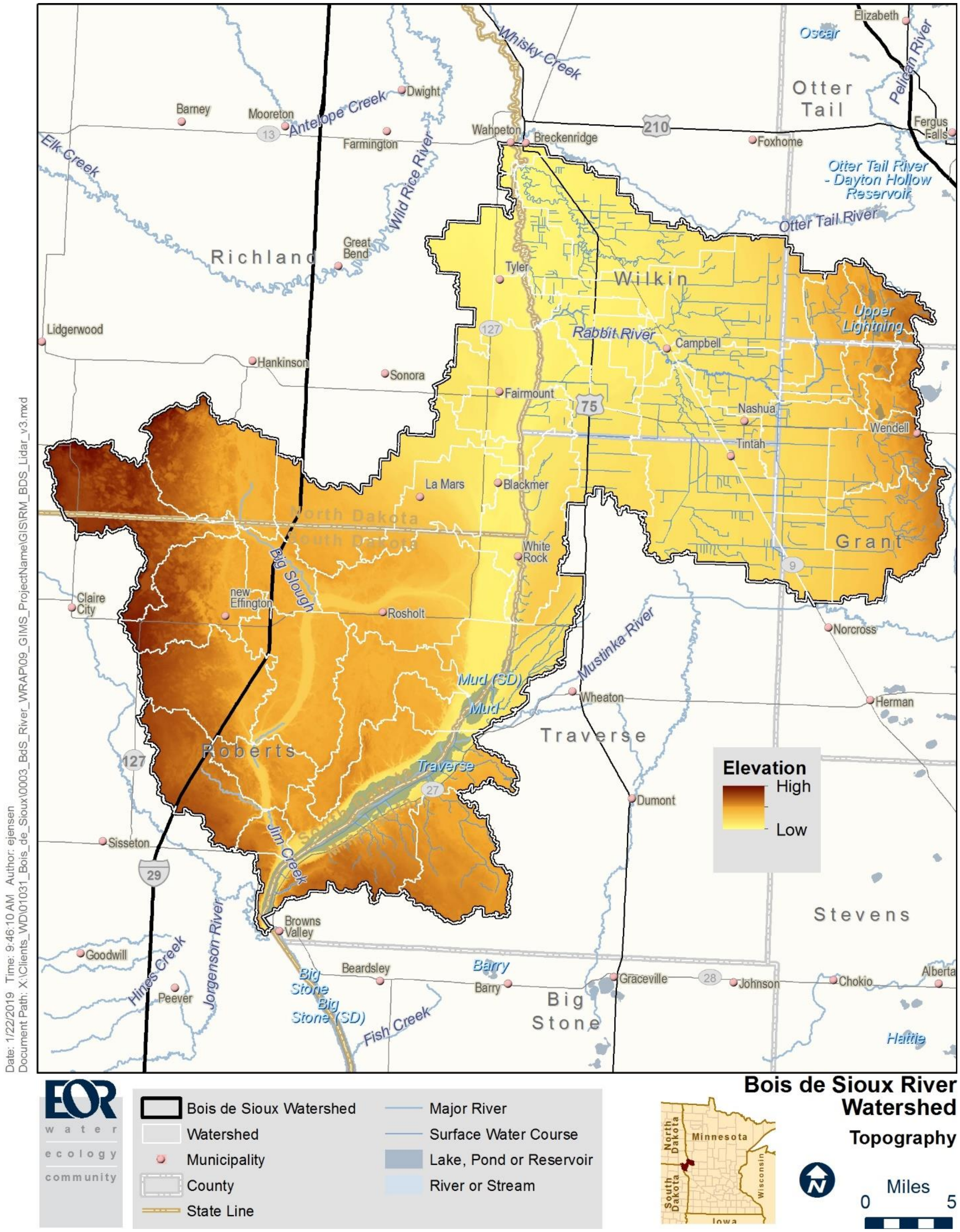

Figure 41. Topography of the Bois de Sioux River Watershed

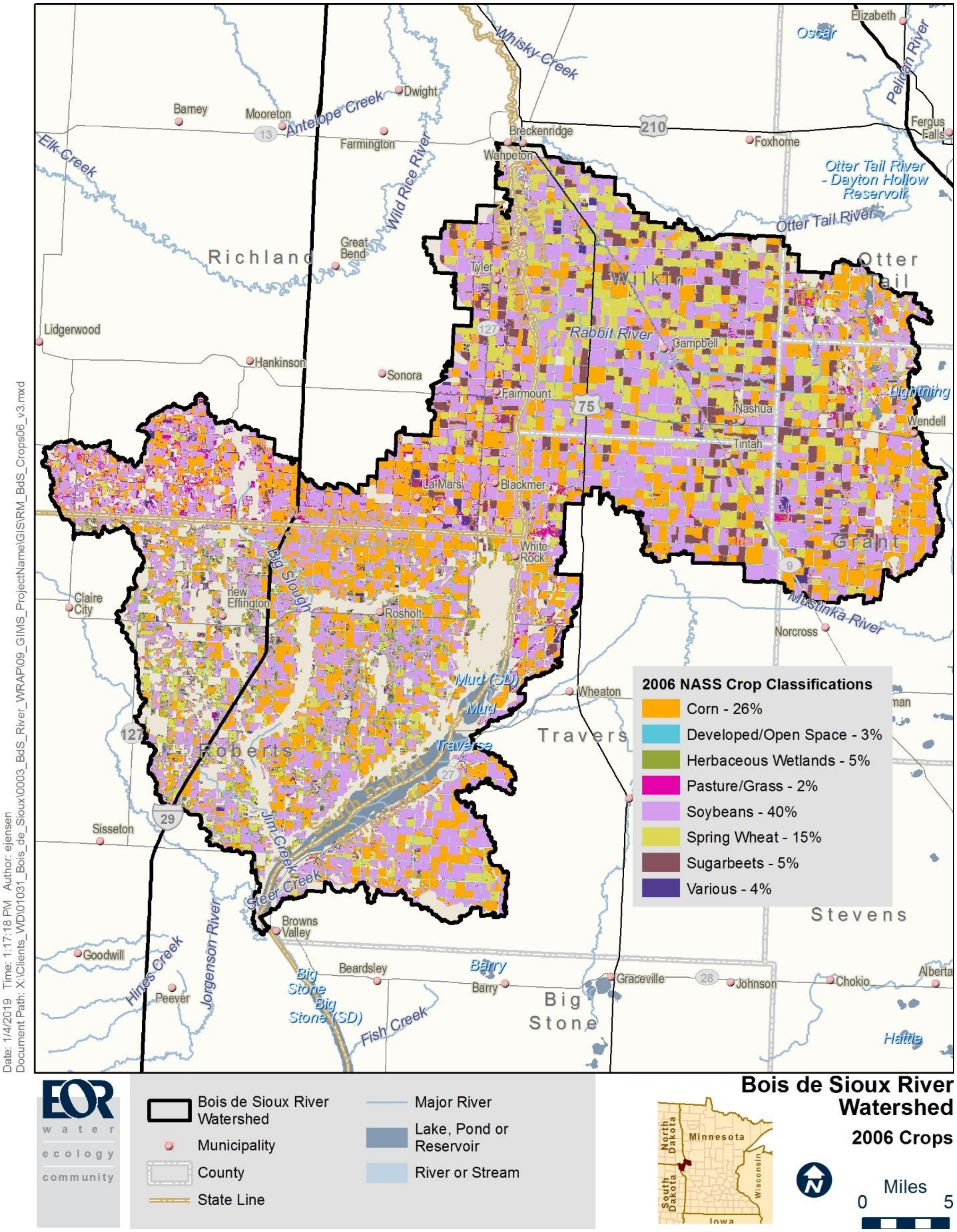

Figure 42. Crop covers in the Bois de Sioux River Watershed (2006 NASS)

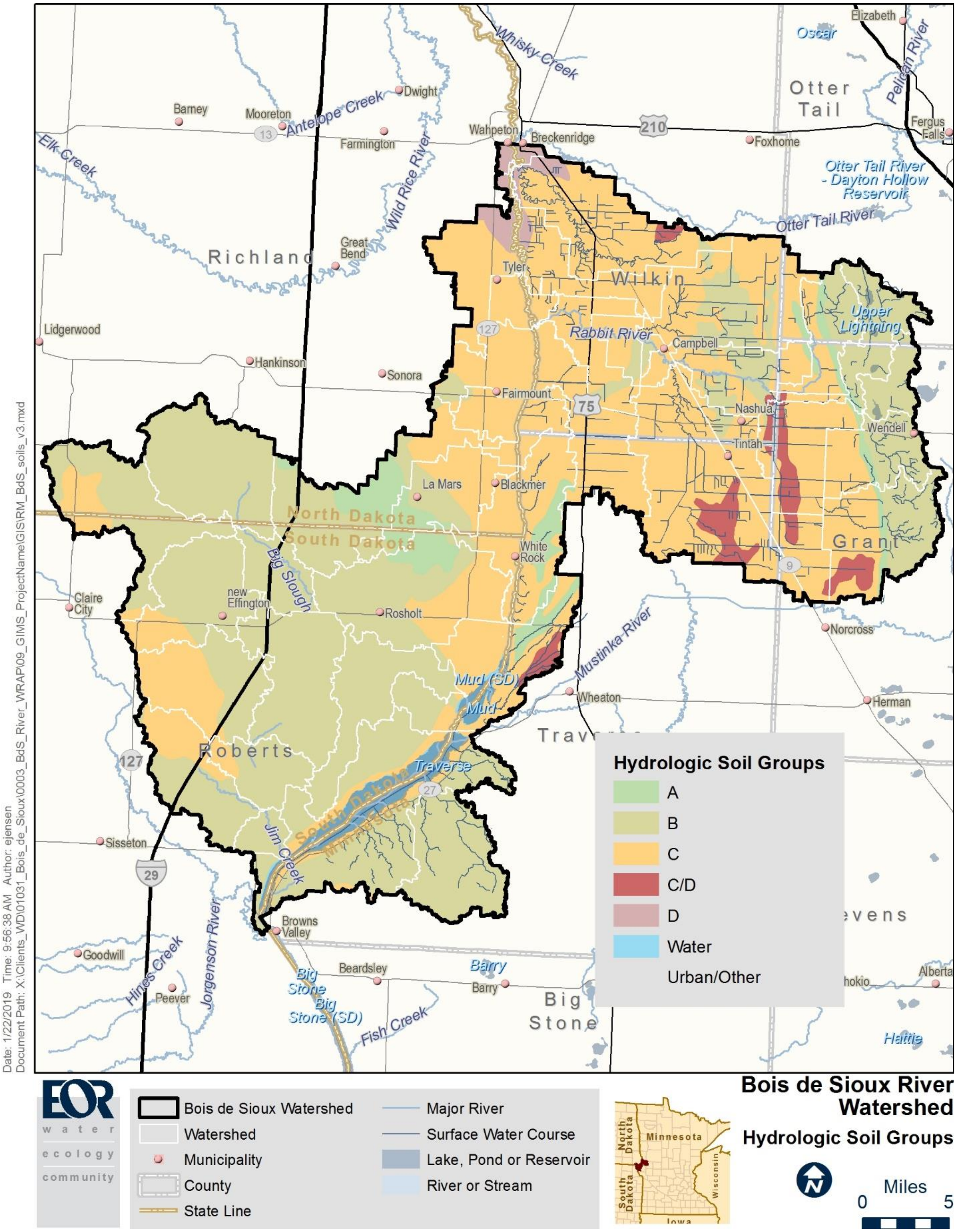

Figure 43. Hydrologic soil group distribution in the Bois de Sioux River Watershed

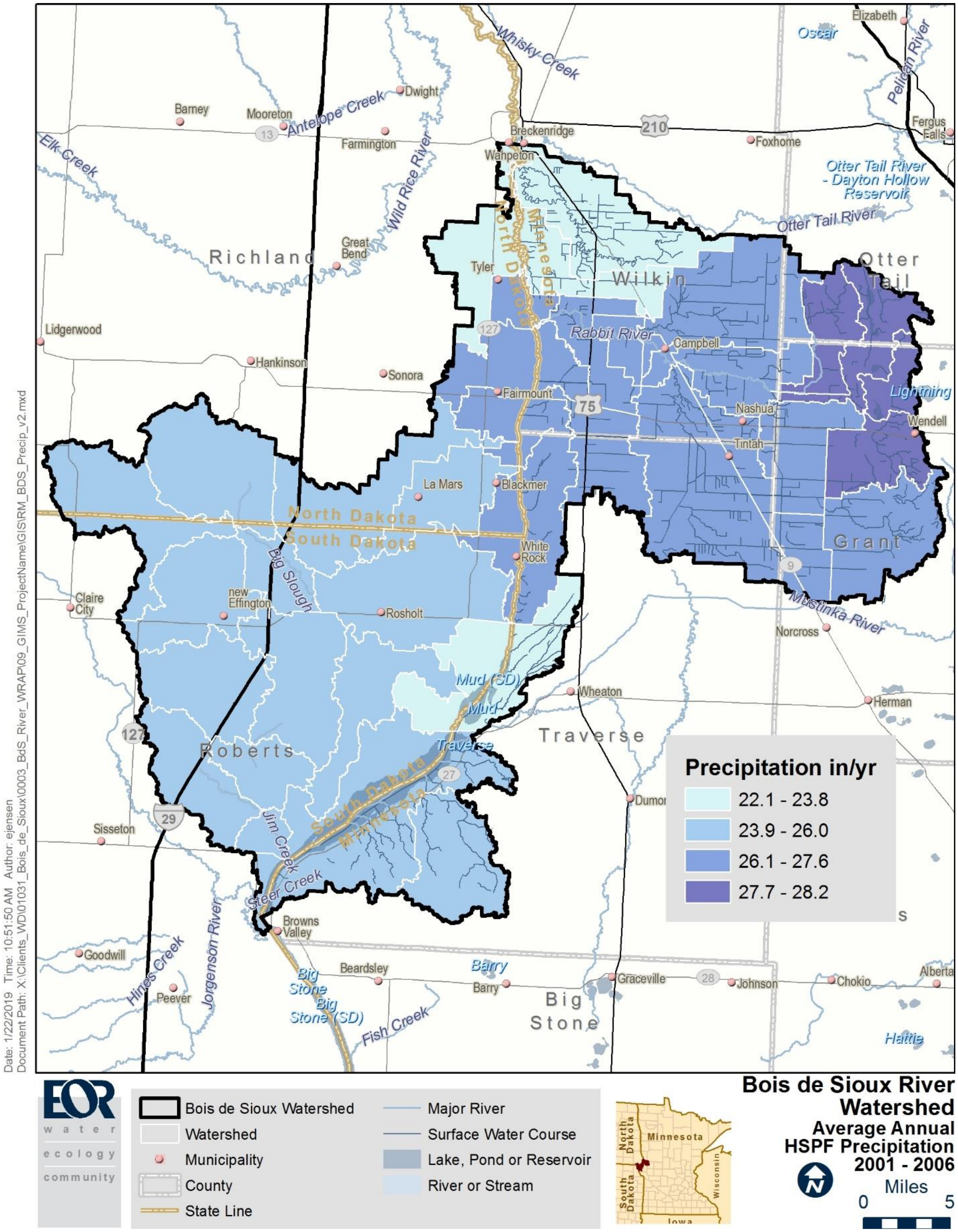

Figure 44. HSPF 2001-2006 average annual precipitation by subbasin

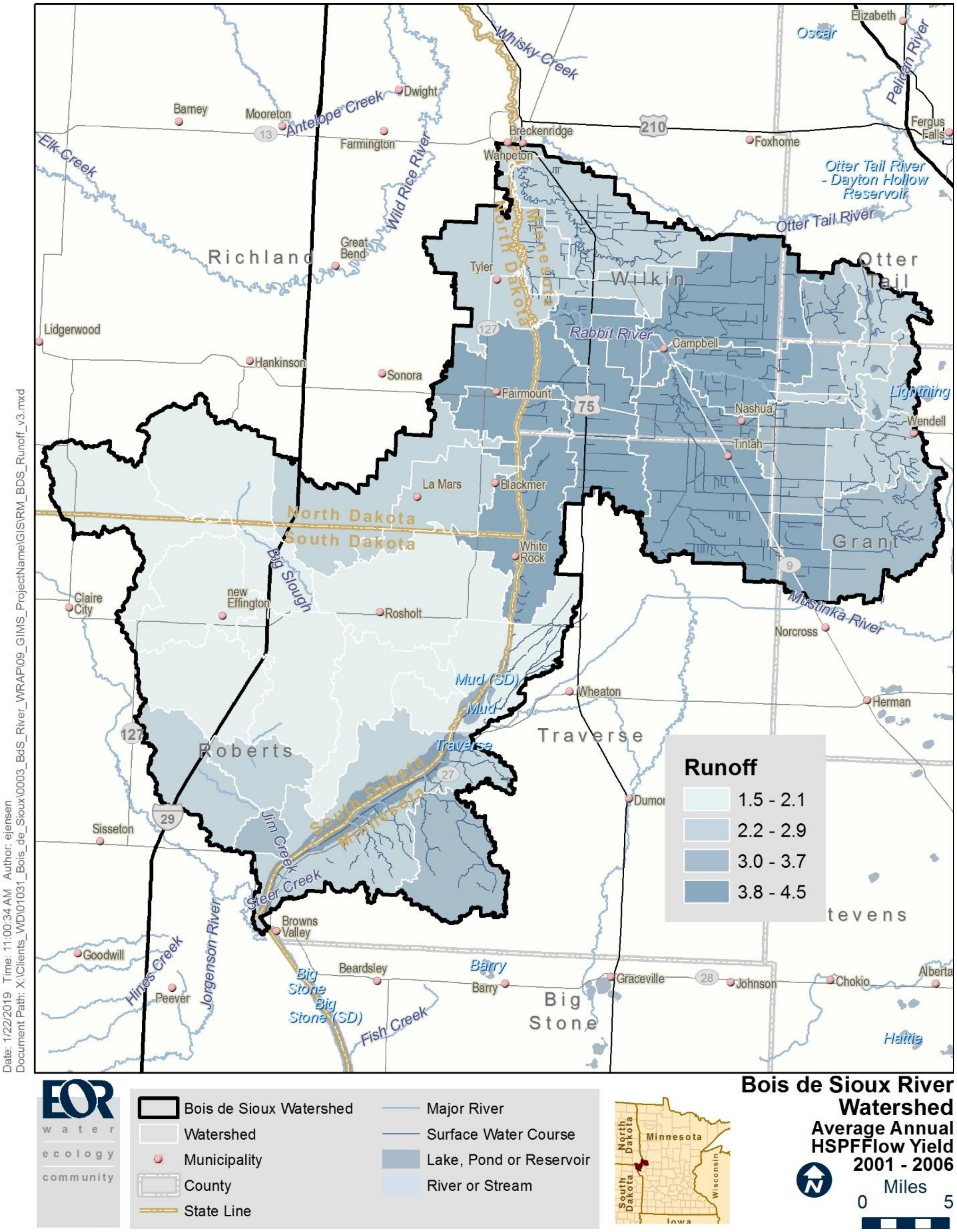

Figure 45. HSPF 2001-2006 average annual runoff flow yields by subbasin

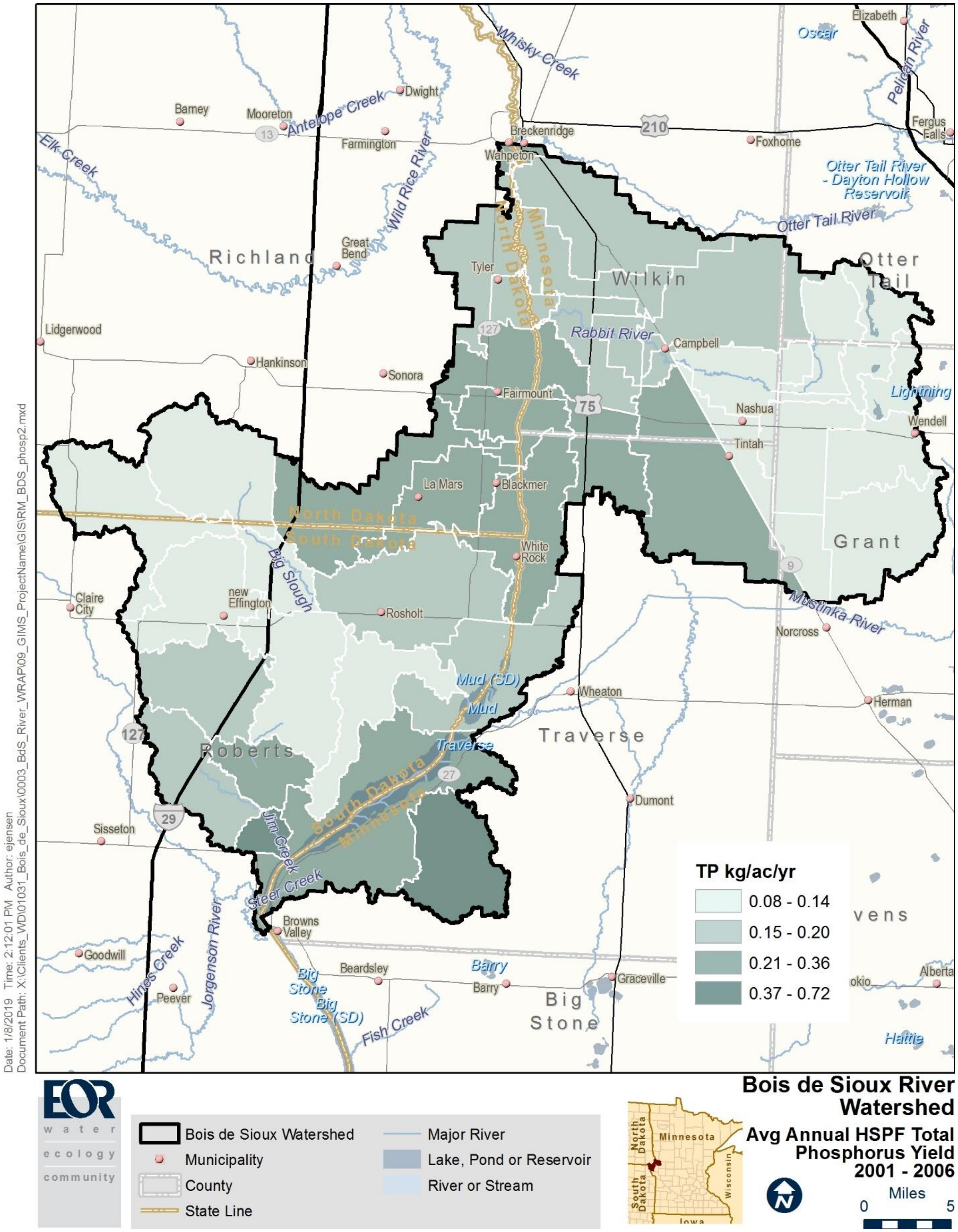

Figure 46. HSPF 2001-2006 average annual total phosphorus yields by subbasin

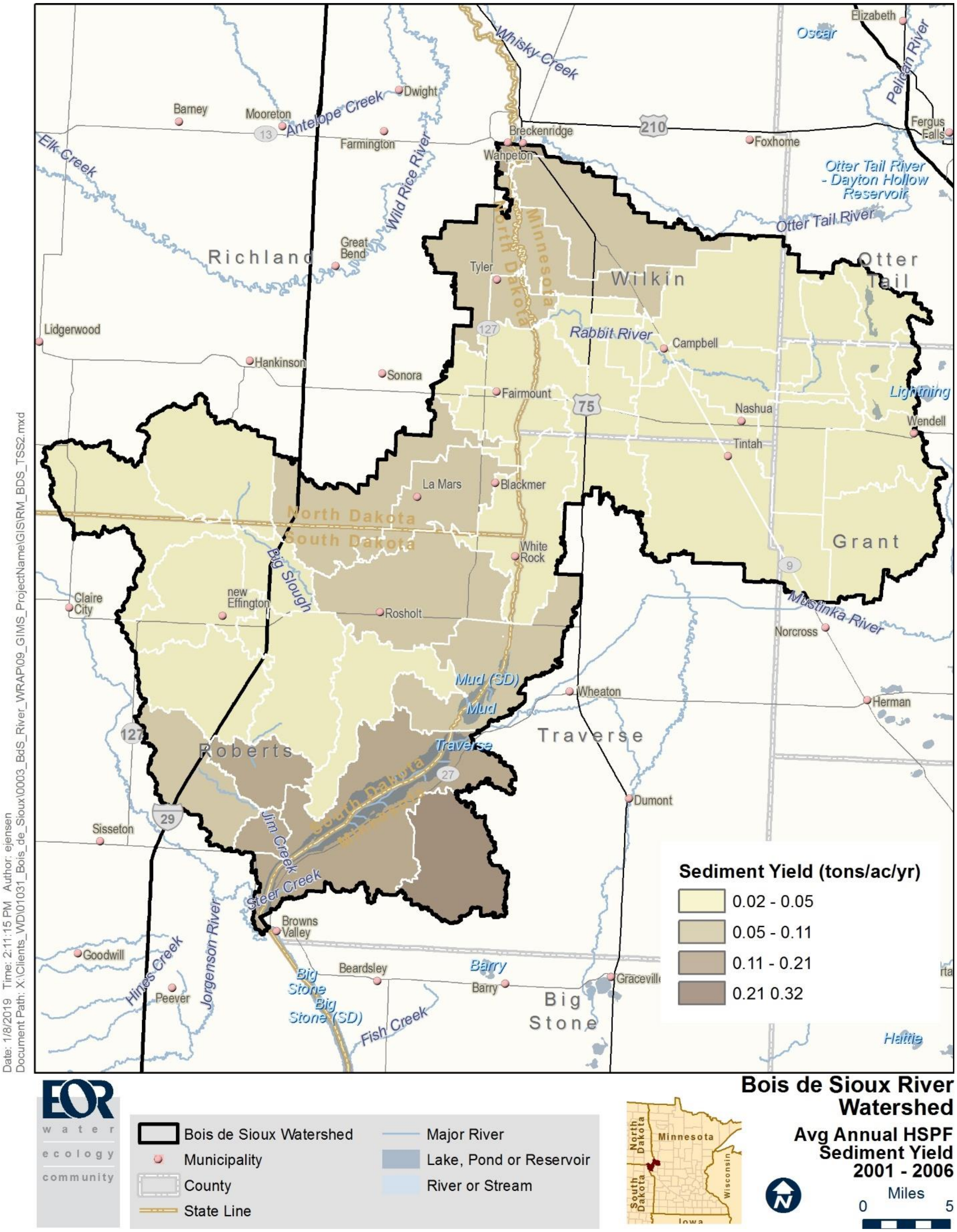

Figure 47. HSPF 2001-2006 average annual total phosphorus yields by subbasin

3.6.3 Stream *E. coli*

Humans, pets, livestock, and wildlife all contribute bacteria to the environment. These bacteria, after appearing in animal waste, are dispersed throughout the environment by an array of natural and man-made mechanisms. Bacteria fate and transport are affected by disposal and treatment mechanisms, methods of manure reuse, imperviousness of land surfaces, and natural decay and die-off due to environmental factors such as ultraviolet (UV) exposure and detention time in the landscape. The following discussion highlights sources of bacteria in the environment and mechanisms that drive the delivery of bacteria to surface waters.

To evaluate the potential sources of bacteria to surface waters a windshield survey of livestock was conducted in the BdSRW. In addition, a desktop analysis was conducted to identify other sources that are potentially contributing *E. coli* in the BdSRW. These populations may include humans, companion animals (horses, cats and dogs), and wildlife (deer, geese, ducks, and nesting birds).

Populations were calculated using published estimates for each source on an individual subwatershed basis in the TMDL study area. This is typically a Geographic Information Systems (GIS) exercise where population estimates are clipped to the individual subwatershed boundaries. In some cases, these population estimates are clipped to individual land uses (defined using the 2006 NLCD) within a subwatershed. For example, duck population estimates are assigned to open water land uses.

Bacteria production estimates are based on the bacteria content in feces and an average excretion rate (with units of colony forming units (cfu)/day-head; where *head* implies an individual animal). Bacteria content and excretion rates vary by animal type, as shown in Table 29. All production rates obtained from the literature are for fecal coliform rather than *E. coli* due to the lack of *E. coli* data. The fecal coliform production rates were converted to *E. coli* production rates based on 200 fecal coliforms to 126 *E. coli* per 100 milliliters (ml) (see discussion of *E. coli* water quality standard in Section 2.2).

However, recent research in Minnesota has shown that not all *E. coli* strains in streams originate from fecal matter and that many of these bacteria strains naturally occur in the sediments (https://www.mda.state.mn.us/sites/default/files/inline-files/ecoliditch7milecreek.pdf). Therefore, the sources described here represent potential fecal sources of *E. coli* and should be field verified through Microbial Source Tracking, as indicated as an implementation activity in the WRAPS Strategy table.

Table 29. Bacteria production by source

Source Category	Producer	*E. coli* Production Rate [cfu/day-head]	Literature Source
Humans & Pets	Humans	1.26×10^{9}	Metcalf and Eddy 1991
	Dogs	3.15×10^{9}	Horsley and Witten 1996
Livestock	Horses	2.65×10^{10}	Zeckoski et al. 2005
	Cattle	2.08×10^{10}	Zeckoski et al. 2005
	Dairy Cows	1.58×10^{10}	Zeckoski et al. 2005
	Sheep	7.56×10^{9}	Zeckoski et al. 2005

Source Category	Producer	*E. coli* Production Rate [cfu/day-head]	Literature Source
	Hogs	6.93×10^9	Zeckoski et al. 2005
Livestock	Turkeys	5.86×10^7	Zeckoski et al. 2005
	Chickens	5.61×10^7	Zeckoski et al. 2005
Wildlife	Deer	2.21×10^8	Zeckoski et al. 2005
	Geese	5.04×10^8	Zeckoski et al. 2005
	Ducks	1.51×10^9	Zeckoski et al. 2005

3.6.3.1 Permitted

Wastewater Treatment Facilities

The WWTFs are required to test fecal coliform bacteria levels in effluent twice per week during discharge. Dischargers to Class 2 waters are required to disinfect their wastewater from April through October. Wastewater disinfection is required during all months for dischargers within 25 miles of a water intake for a potable water supply system (Minn. R. 7053.0215, subp. 1). The geometric mean for all samples collected in a month must not exceed 200 cfu/ 100 ml fecal coliform bacteria. Table 30 summarizes the fecal coliform and *E. coli* data for the only WWTF located in the BdSRW, with a surface water discharge. This WWTF is a pond system. Bacteria loads from NPDES-permitted WWTF are estimated based on the design flow and permitted bacteria effluent limit of 200 org./ 100 ml.

Table 30. WWTF design flows and permitted bacteria loads

Stream Reach	Facility Name, Permit #	6" per day discharge volume (mgd)	Permitted Bacteria Load as Fecal Coliform: 200 org./ 100 ml [billion org./day]	Equivalent Bacteria Load as *E. coli*: 126 org. / 100 ml[1] [billion org./day]
-502	Campbell WWTF MN0020915	0.285	2.16	1.4

[1] WWTF permits are regulated for fecal coliform, not *E. coli*. The MPCA surface water quality standard for *E. coli* (126 org. / 100 ml) was used in place of the fecal coliform permitted limit of 200 org. / 100 ml, which was also the MPCA surface water quality standard prior to the March 2008 revisions to Minn. R. ch. 7050.

Land Application of Biosolids

The application of biosolids from WWTFs are highly regulated, monitored, and tracked (see Minn. R. ch. 7041, *Sewage Sludge Management*). Disposal methods that inject or incorporate biosolids within 24 hours of land application result in minimal possibility for mobilization of bacteria to downstream surface waters. While surface application could conceivably present a risk to surface waters, little to no runoff and bacteria transport are expected if permit restrictions are followed. Therefore, land application of biosolids was not included as a source of bacteria.

Concentrated Animal Feeding Operations

Animal waste containing fecal bacteria can be transported in watershed runoff to surface waters. The MPCA regulates concentrated animal feeding operations (CAFOs) in Minnesota, though counties may be delegated by the MPCA to administer the program for feedlots that are not under federal regulation. The primary goal of the state program for animal feeding operations (AFOs) is to ensure that surface waters are not contaminated by the runoff from feeding facilities, manure storage or stockpiles, and cropland with improperly applied manure. Livestock are also found on hobby farms, small-scale farms that are not large enough to require registration but may have small-scale feeding operations and associated manure application or stockpiles.

Livestock manure is often either surface applied or incorporated into farm fields as a fertilizer and soil amendment. This land application of manure has the potential to be a substantial source of fecal contamination, entering waterways from overland runoff and drain tile intakes. Minn. R. ch. 7020 contains manure application setback requirements based on research related to P transport, and not bacterial transport, and the effectiveness of these current setbacks on bacterial transport to surface waters is not known.

There is one active, NPDES permitted CAFO in the BdSRW located in the subwatershed of an *E. coli* impaired stream. The number of animals registered with the MPCA was verified by an Environmental Services or Feedlot officer for each county located in the BdSRW in the spring of 2014. Manure from these facilities is applied to nearby fields. The bacteria loads produced by animals at these operations were estimated based on the total number of animals (Table 31) and the bacteria production rate of each animal (Table 29).

Table 31. NPDES permitted CAFO AUs

Stream Reach	Feedlot Name	Permit #	CAFO	Beef
-502	Chad Hasbargen Farm Sec 2	MN0069744	Y	1,450

3.6.3.2 Non-permitted sources

Humans

Sewered and unsewered populations and number of households were determined using the 2010 Census data (U.S. Census Bureau 2011). Total population and the number of households were obtained for each subwatershed using block groups[1]; census block groups that overlap subwatershed boundaries were distributed between each applicable subwatershed on an area-weighted basis. Populations located in a sewered community were estimated from census block group data and boundaries of municipalities

[1] A census block in an urban area typically corresponds to individual city blocks bounded by streets; blocks in rural areas may include many square miles and may have some boundaries that are not streets. A block group is a group of census blocks. A block group is smaller than a census tract, which is a small statistical subdivision of a county (e.g., a municipality or a portion of a large city).

serviced by a WWTF (Table 30). A summary of the sewered and unsewered population and households by subwatershed are shown in Table 32.

Table 32. Sewered and unsewered population and households by subwatershed

Stream Reach	Population			Households		
	Sewered	Unsewered	Total	Sewered	Unsewered	Total
-501	0	1,105	1,105	0	541	541
-502	312	611	923	182	311	493
-510	0	261	261	0	103	103

Releases

Wastewater collection systems may occasionally be overwhelmed by the infiltration of excessive volumes of groundwater or the inflow of excessive volumes of stormwater, which may result in the need to discharge untreated wastewater, referred to as 'releases'. The occurrence of wastewater collection system releases is not known to be an issue in the BdSRW.

Illicit Discharges from Unsewered Communities

In many cases, onsite or small community cluster systems used to treat wastewater are installed and forgotten until problems arise. Residential lots in small communities throughout Minnesota cannot accommodate modern septic systems that meet the requirements of current codes due to small lot size and/or inadequate soils. In addition, many small communities are characterized by outdated, malfunctioning septic systems serving older residences. Small lots, poor soils, and inadequate septic system designs and installations may be implicated in bacterial contamination of groundwater, but the link to surface water contamination is tenuous.

'Failing' SSTS are specifically defined as systems that are failing to protect groundwater from contamination. Failing SSTS were not considered a source of fecal pollution to surface water. However, systems that discharge partially treated sewage to the ground surface, road ditches, tile lines, and directly into streams, rivers, and lakes are considered an imminent threat to public health and safety (ITPHS). The ITPHS systems also include illicit discharges from unsewered communities (sometimes called 'straight-pipes'). Straight pipes are illegal and pose an imminent threat to public health as they convey raw sewage from homes and businesses directly to surface water. Community straight pipes are more commonly found in small rural communities.

The Environmental Services officer of each county provided an estimate of the percent of systems in unsewered communities that are ITPHS in the spring of 2014 (Table 33). Bacteria load from ITPHS was estimated by subwatershed based on these percentages, the unsewered population (Table 32), and the bacteria production rate of humans (Table 29). Note that ITPHS data are derived from surveys of county staff and county level SSTS status inventories. The specific locations of ITPHS systems are not known. The table is not intended to suggest that ITPHS systems contribute excess bacteria to specific waterbodies addressed in this study; rather it suggests that, in general, ITPHS are believed to occur in the project area.

Table 33. Estimate of percent ITPHSS as reported by each county

County	%ITPHSS
Grant	0%
Otter Tail	0%
Traverse	4%
Wilkin	0%

Land Application of Septage

A state SSTS license, applicable to the type of work being performed, is required for any business that conducts work to design, install, repair, maintain, operate, or inspect all or part of an SSTS. A license is also required to land spread septage and operate a sewage collection system discharging to an SSTS. Disposal contractors are required to properly treat and disinfect septage through processing or lime stabilization. Treated septage may then be disposed of onto agricultural and forest lands. The EPA's Standards Section 503 provides general requirements, pollutant limits, management practices, and operational standards for the final use or disposal of septage generated during the treatment of domestic sewage in a treatment works.

The MPCA does not directly regulate the land application of septage, but management guidelines entail site suitability requirements with respect to soil conditions, slope, and minimum separation distances (MPCA 2002). Some cities and townships have SSTS septage ordinances (a list is available at http://www.pca.state.mn.us/index.php/view-document.html?gid=10139); these were not reviewed as a part of this TMDL study, and application of septage was not included as a source of fecal pollution in this TMDL study.

Pets

Human pets (dogs and cats) can contribute bacteria to a watershed when their waste is not properly managed. Human pets are not considered a significant source of bacteria in the BdSRW due to the low human population.

Dog waste can be a significant source of pathogen contamination of water resources (Geldreich 1996). Dog waste in the immediate vicinity of a waterway could be a significant local source with local water quality impacts. However, it is generally thought that these sources may be only minor contributors of fecal contamination on a watershed scale because the estimated magnitude of this source is very small compared to other sources. According to the American Veterinary Medical Association's (AVMA) 2006 data, 34.2% of Minnesota households own dogs with a mean number of 1.4 dogs in each of those households (AVMA 2007). In addition, it was assumed that only 38% of dog waste is not collected by owners and can contribute fecal pollution to surface waters (TBEP 2012). Bacteria load from dogs was estimated based on total households in each subwatershed (Table 32), the assumptions mentioned in this paragraph, and the bacteria production rate of dogs (Table 29).

Domestic cats, even those that spend some time outdoors, are most likely to have their waste collected indoors and were not considered a source of bacteria for this TMDL study. Feral cats may contribute significantly to bacteria levels in urban streams and rivers (Ram et al. 2007). However, feral cat populations are unknown and were not included in this TMDL study.

Livestock

Livestock have the potential to contribute bacteria to surface water through grazing activities or if their manure is not properly managed or stored. Livestock manure is typically collected and applied to nearby fields through injection, which significantly reduces the transport of bacteria contained in manure to surface waters. The population estimates provided in this TMDL study are meant to identify areas where large numbers of livestock are located. These areas should be monitored closely by each county to ensure proper management and storage of manure.

The number of feedlot animals registered with the MPCA was reviewed by an Environmental Services or Feedlot officer for the portion of each county located in the BdSRW in the spring of 2014 (Table 34). The bacteria load from grazing livestock was estimated based on the number of animals (Table 34) and the bacteria production rate of those animals (Table 29).

Table 34. MPCA registered feedlot animals by subwatershed, verified by each county

Stream Reach	Beef	Dairy	Horses	Hog	Sheep	Turkey	Chickens
-501	202	0	0	10	0	0	0
-502	110	11	0	0	0	0	0
-510	40	0	0	0	0	0	0

Wildlife

Bacteria can be contributed to surface water by wildlife (e.g., deer, geese, and ducks) dwelling in waterbodies, within conveyances to waterbodies, or when their waste is carried to stormwater inlets, creeks, and ditches during stormwater runoff events. Areas such as DNR designated wildlife management areas, state parks, national parks, national wildlife refuges, golf courses, and state forests provide wildlife habitat encouraging congregation, and could be potential sources of higher fecal coliform due to the high densities of animals. There are likely many areas within the project area where wildlife congregates, especially in the wetland-dominated northeast portion of the watershed. Due to the low number of humans, pets, and livestock in the BdSRW – wildlife is likely the dominant source of fecal contamination to the impaired streams.

Wildlife populations were estimated based on DNR population data for permit areas and zones. Because permit areas or zones do not align with subwatershed boundaries, population data for any single permit area or zone was distributed among subwatersheds on an area-weighted basis (Table 35). Populations of wildlife (deer, ducks, and geese) were estimated from the data sources and assumptions listed in Table 36. Bacteria loads from wildlife were estimated based on the population (Table 35) and bacteria production rates of wildlife (Table 29).

The presence of large numbers of wild birds on or near surface waters can act as sources of fecal contamination. In two other Red River Basin watersheds, water samples were tested for gene biomarkers for fecal coliform bacteria. Birds were found to be a major contributor to fecal pollution in the Thief River (Thief River Watershed) and a potential contributor to fecal pollution the Kripple Creek (Red Lake River Watershed).

Table 35. Wildlife population estimates by subwatershed

Stream reach	Deer	Ducks	Geese
-501	188	30	373
-502	1,102	103	1,133
-510	77	9	134

Table 36. Population Estimate Data Sources and Habitat Assumptions for Wildlife

Wildlife	Population Estimate Data Sources and Habitat Assumptions
Ducks	According to a presentation by Steve Cordts of the DNR Wetland Wildlife Population and Research Group at the 2010 DNR Roundtable, Minnesota's annual breeding duck population averaged 550,000 between the years 2005-2009. While the breeding range of the canvasback and lesser scaup is typically outside of the project area, the majority of the breeding duck population (including blue-winged teal, mallards, ring-necked ducks, and wood ducks) has a state-wide breeding range. Statewide there is approximately 90,555,611 acres of suitable open water NWI habitat, equivalent to 0.061 ducks per acre of open water. This duck population density was distributed over all suitable open water NWI land covers plus a 100 foot buffer within each subwatershed on an area-weighted basis.
Deer	The DNR report Status of Wildlife Populations, Fall 2009, includes a collection of studies that estimate wildlife populations of various species (Dexter 2009). Pre-fawn deer densities were reported by DNR deer permit area. Permit area deer population densities over all 2006 NLCD land covers except open water within each subwatershed on an area-weighted basis.
Geese	The DNR report Status of Wildlife Populations, Fall 2009, also includes a collection of studies that estimate wildlife populations of various species by Minnesota ecoregion (Dexter 2009). Geese population data were distributed over and within a 100-foot buffer of all open water areas (PWI basins, streams, ditches and rivers, and 2006 NLCD *Open Water*) on an area-weighted basis within each subwatershed.

3.6.3.3 Strengths and Limitations

The bacteria production estimates are provided at the subwatershed scale. The results inform stakeholders as to the types and relative magnitude of bacteria produced in their watershed. This information is a valuable tool for the planning and management of water bodies with respect to bacteria contamination. The potential bacteria source estimates in the project area were calculated using a GIS-based approach. However, available data sources are at different scales and have different boundaries than that of the study subwatersheds. A limitation to the estimation process is that population data at a statewide or ecoregion scale must be distributed to the subwatershed scale based on average population density. As a result, there is a probable minimum scale at which bacteria production estimates are useful.

A significant portion of bacteria producers were accounted for in the potential bacteria sources. However, several animals were not included, such as birds other than geese and ducks (e.g., song birds, and wading birds) and many wild animals (e.g., beavers, bear, and wild turkey). Data, resource limitations, and consideration for the major bacteria producers in the project area led to the selected set of bacteria producers accounted for in these estimates. The project area estimates of potential bacteria sources is also limited by the fact that bacteria delivery is not addressed (e.g., treatment of human waste at WWTFs prior to discharge to receiving waters, pet waste management, zero discharge feedlot facilities, incorporation of manure into soil, geese gathering directly on stormwater ponds). The potential bacteria source estimates also do not account for the relative risk among different types of bacteria. Instead, *E. coli* production is estimated as an indicator of the likelihood of pathogen contamination of our waterbodies.

3.6.3.4 Summary

Refer to Section 3.3 for boundaries of the contributing subwatersheds to each impaired stream reach. Bacteria production estimates by subwatershed are listed by producer in Table 37 and for all producers in Table 38.

Due to the low number of humans, pets, and livestock in the BdSRW – wildlife is likely the dominant source of fecal contamination to the impaired streams. The wildlife annual *E. coli* production estimates are likely underestimated due to the limitations noted in Section 3.6.3.3. Microbial source tracking is needed to verify wildlife bacteria sources to the impaired streams.

Table 37. Annual *E. coli* production estimates by producer

Impaired Stream Reach	Humans & Pets			Livestock							Wildlife			
	WWTF Effluent	ITPH SSTS	Dogs	Cattle	Dairy	Turkey	Chickens	Hogs	Sheep	Horses	Birds	Deer	Ducks	Geese
-502	1	3	283	2,287	170	0	0	0	0	0	unknown	243	155	571
-510	0	0	59	832	0	0	0	0	0	0	unknown	17	13	68

Table 38. Total annual *E. coli* production estimates

Impaired Stream Reach	Area	Total	Total	Humans	Livestock	Wildlife*
	(ac)	(billion org./d)	(billion org./ac/d)	(% Total)		
-502	152,886	3,713	0.02	8%	66%	26%
-510	27,441	989	0.04	6%	84%	10%

* Likely underestimates due to the unknown contribution of fecal contamination by nesting birds. Future biomarker testing is needed to confirm the presence of this source and is identified as a strategy in the Bois de Sioux River WRAPS Report.

4 TMDL Development

This section presents the overall approach to estimating the components of the TMDL study. The pollutant sources were first identified and estimated in the pollutant source assessment. The loading capacity (TMDL) of each lake or stream was then estimated using an in-lake water quality response model or stream LDC and was divided among WLAs and LAs. A TMDL for a waterbody that is impaired, as the result of excessive loading of a particular pollutant, can be described by the following equation:

$$\text{TMDL} = \text{LC} = \sum \text{WLA} + \sum \text{LA} + \text{MOS} + \text{RC}$$

Where:

Loading capacity (LC): the greatest pollutant load a waterbody can receive without violating water quality standards;

Wasteload allocation (WLA): the pollutant load that is allocated to point sources, including WWTFs, regulated construction stormwater, and regulated industrial stormwater, all covered under NPDES permits for a current or future permitted pollutant source;

Load allocation (LA): the pollutant load that is allocated to sources not requiring NPDES permit coverage, including non-regulated stormwater runoff, atmospheric deposition, and internal loading;

Margin of Safety (MOS): an accounting of uncertainty about the relationship between pollutant loads and receiving water quality;

Reserve Capacity (RC): the portion of the loading capacity attributed to the growth of existing and future load sources.

4.1 Phosphorus

4.1.1 Loading Capacity

4.1.1.1 Lake Response Model

The modeling software BATHTUB (Version 6.1) was selected to link P loads with in-lake water quality. A publicly available model, BATHTUB was developed by William W. Walker for the U.S. ACOE (Walker 1999). It has been used successfully in many lake studies in Minnesota and throughout the United States. The BATHTUB model is a steady-state annual or seasonal model that predicts a lake's summer (June through September) mean surface water quality. The BATHTUB model's time-scales are appropriate because watershed P loads are determined on an annual or seasonal basis, and the summer season is critical for lake use and ecological health. The BATHTUB model has built-in statistical calculations that account for data variability and provide a means for estimating confidence in model predictions. The heart of BATHTUB is a mass-balance P model that accounts for water and P inputs from tributaries, watershed runoff, the atmosphere, sources internal to the lake, and groundwater; and outputs through the lake outlet, water loss via evaporation, and P sedimentation and retention in the lake sediments.

System Representation in Model

In typical applications of the BATHTUB model, lake and reservoir systems are represented by a set of segments and tributaries. Segments are the basins (lakes, reservoirs, etc.) or portions of basins for which water quality parameters are being estimated, and tributaries are the defined inputs of flow and pollutant loading to a particular segment. For this study, the direct drainage area and outflow from an upstream lake or major river (e.g., Mustinka River) was defined as separate tributaries to each lake (i.e., segment).

Model Inputs

The input required to run the BATHTUB model includes lake geometry, climate data, and water quality and flow data for runoff contributing to the lake. Observed lake water quality data are also entered into the BATHTUB program in order to facilitate model verification and calibration. Lake segment inputs are listed in Table 39, and tributary inputs are listed in Table 23 and Table 24 from Section 3.6.1.2. The HSPF model estimates of average annual precipitation and evaporation rates are reported for each lake. Precipitation and evaporation rates apply only to the lake surface areas. Average P atmospheric deposition loading rates were estimated to be 0.23 pounds per acre per year (lb/ac-yr) for the Red River Basin (Barr 2007), applied over each lake's surface area. See discussion titled *Atmospheric Deposition* in *Section 3.6.1* for more details.

Table 39. BATHTUB segment input data for impaired lakes

Impaired Lake or Upstream Lake	Average Annual Precipitation (m/yr)	Average Annual Evaporation (m/yr)	Surface area (sq km)	Lake fetch (km)	Mean depth (m)	Total Phosphorus	
						(µg/L)	CV (%)
Ash	0.723	0.522	0.693	1.4021	0.37	146.2	9%
Mud*	0.609	0.531	9.9628	5.4864	0.45	442.0	22%
Traverse**	0.665	0.562	44.6738	22.86	2.35	214.4	6%
Upper Lightning	0.723	0.522	2.8121	2.7432	1.14	100.5	10%

CV = coefficient of variation, defined in BATHTUB as the standard error divided by the mean
* Mud Lake is not addressed by a TMDL in this study but was modeled to determine the TP reductions needed to meet the assumptions of the Bois de Sioux River (-501) TP TMDL
** Lake Traverse is not impaired, but is a major tributary to Mud Lake. These data were used to construct a separate BATHTUB model for Lake Traverse.

Model Equations

The BATHTUB model allows a choice among several different P sedimentation models. The Canfield-Bachmann Lake P sedimentation model (Canfield and Bachmann 1981) best represents the lake water quality response of Minnesota lakes, and is the model used in the majority of lake TMDL studies in Minnesota. In order to perform a uniform analysis, Canfield-Bachmann Lakes was selected as the standard equation for the study. However, the Canfield-Bachmann Lakes P sedimentation model tends to under-predict the amount of internal loading in shallow, frequently mixing lakes. Therefore, an explicit internal load is added to shallow lake models to improve the lake water quality response of the Canfield-Bachmann Lakes P sedimentation model (Table 40).

Model Calibration

The models were calibrated to existing water quality data, found in Table 14, and then were used to determine the TP loading capacity (TMDL) of each lake. When the predicted in-lake TP concentration was *lower* than the average observed (monitored) concentration, an explicit additional load was added to calibrate the model (Table 40). It is widely recognized that Minnesota lakes in agricultural regions have histories of high TP loading and/or very poor water quality. For this reason, it is reasonable that internal loading may be higher than that of the lakes in the data set used to derive the Canfield-Bachmann lakes formulation. When the predicted in-lake TP concentration was *higher* than the average observed (monitored) concentration, the P sedimentation factor was increased. Increased sedimentation is often found in shallow lakes that have high treatment capacity due to an aquatic plant-dominated state. In the case of Ash Lake, there is submerged aquatic vegetation providing treatment capacity for watershed runoff; however there is also excess watershed runoff causing high algal biomass. This lake is likely at the tipping point between an aquatic plant-dominated state and an algae-dominated state.

Table 40. Model calibration summary for the impaired lakes

Impaired Lake or Upstream Lake	P Sedimentation Model	Calibration Mode	Calibration Value
Ash	Canfield & Bachmann, Lakes	Phosphorus Sedimentation Factor	Increased to 1.398
Mud*	Canfield & Bachmann, Lakes	Added Internal Load	23.84 mg/m^2-day
Traverse**	Canfield & Bachmann, Lakes	Added Internal Load	3.751 mg/m^2-day
Upper Lightning	Canfield & Bachmann, Lakes	Added Internal Load	0.126 mg/m^2-day

* Mud Lake is not addressed by a TMDL in this study but was modeled to determine the TP reductions needed to meet the assumptions of the Bois de Sioux River (-501) TP TMDL

** Lake Traverse is not impaired, but is a major tributary to Mud Lake. These data were used to construct a separate BATHTUB model for Lake Traverse.

Determination of Lake Loading Capacity

Using the calibrated existing conditions model as a starting point, the TP concentrations associated with tributaries were reduced until the model indicated that the TP state standard was met, to the nearest tenth of a whole number. First, upstream lake and major river TP concentrations were assumed to meet eutrophication water quality standards. Next, the direct drainage flow-weighted mean TP concentration was reduced to no less than 150 parts per billion (µg/L) until in-lake TP concentration met the lake water quality standard. A flow-weighted mean concentration goal of 150 µg/L was chosen to represent reasonable baseline loading conditions from the highly agricultural watershed. If further reductions were needed, any added internal loads were reduced until the in-lake TP concentration met the lake water quality standard. Minnesota lake water quality standards assume that once the TP goals are met, the Chl-*a* and Secchi transparency standards will likewise be met (see *Section 2.1.1 Applicable Water Quality Standards*). With this process, a series of models were developed that included a level of TP loading consistent with lake water quality state standards, or the TMDL goal. Actual load values are calculated within the BATHTUB software, so loads from the TMDL goal models could be compared to the loads from the existing conditions models to determine the amount of load reduction required.

4.1.1.2 Stream Load Duration Curves

The loading capacities for impaired stream reaches receiving a TMDL, as a part of this study, were determined using LDCs. Flow and LDCs are used to determine the flow conditions (flow regimes) under which exceedances occur. Flow duration curves provide a visual display of the variation in flow rate for the stream. The x-axis of the plot indicates the percentage of time that a flow exceeds the corresponding flow rate as expressed by the y-axis. The LDCs take the flow distribution information, constructed for the stream, and factor in pollutant loading to the analysis. A standard curve is developed by applying a particular pollutant standard or criteria to the stream flow duration curve and is expressed as a load of pollutant per day. The standard curve represents the upper limit of the allowable in-stream pollutant load (loading capacity) at a particular flow. Monitored loads of a pollutant are plotted against this curve to display how they compare to the standard. Monitored values that fall above the curve represent an exceedance of the standard.

For the stream TMDL derivation, 2002 through 2011 USGS gaged flows (5051300 for -501, and 54017001 for -502), area-weighted to the outlet of each impaired stream reach, were used to develop flow duration curves. The loading capacities were determined by applying the TP water quality standard (0.150 mg/L) to the flow duration curve to produce a TP standard curve. Minnesota stream eutrophication standards were developed such that by meeting the TP target, the Chl-*a*, DO flux, and biological oxygen demand (BOD_5) standards will likewise be met. Loading capacities presented in the allocation tables represent the median TP load (in kg/day) along the TP standard curve within each flow regime. A TP LDC and a TMDL allocation table are provided for each stream in Section 4.1.6. Monitored TP concentrations for simulation dates within the TP assessment window (June through September) are plotted along with the TP standard curve on LDCs. Within each flow duration interval, the existing load is approximated as the median value of the monitored TP loads.

The LDC method is based on an analysis that encompasses the cumulative frequency of historical flow data over a specified period. Because this method uses a long-term record of daily flow volumes, virtually the full spectrum of allowable loading capacities is represented by the resulting curve. In the TMDL tables of this report, only five points on the entire loading capacity curve are depicted (the midpoints of the designated flow zones). However, it should be understood that the entire curve represents the TMDL and is what is ultimately approved by EPA.

4.1.2 Load Allocation Methodology

The LA represents the portion of the loading capacity designated for nonpoint sources of P. The LA includes all sources of P that do not require NPDES permit coverage, including unregulated watershed runoff, internal loading, groundwater, and atmospheric deposition, a consideration for natural background conditions, and any other identified loads described in Section 3.6.1. The LA is calculated as the remaining portion of the LC once the WLA and MOS are subtracted for each impaired lake or stream. The remainder of the LA, after subtraction of atmospheric deposition LA and internal loading LA was used to determine the watershed runoff LA for each impaired lake or stream on an areal basis. Note that the MOS was distributed proportionately among internal loading and watershed runoff based on the proportion of existing loads relative to the loading capacity. The MOS cannot be accounted for in the atmospheric deposition and upstream impaired lake or stream out-flow allocations, as no further reductions can be achieved from these sources beyond what is needed to achieve the loading capacity (i.e., atmospheric loads cannot be reduced and upstream impaired lakes are not required to improve in-lake water quality beyond the state eutrophication standards).

4.1.3 Wasteload Allocation Methodology

All regulated stormwater and wastewater were assigned a WLA based on the methods described in the following section.

4.1.3.1 MS4 Regulated Stormwater

There is no Municipal Separate Storm Sewer Systems (MS4) regulated stormwater in the BdSRW.

4.1.3.2 Regulated Construction Stormwater

Construction stormwater is regulated by NPDES/SDS permits for any construction activity disturbing: (a) one acre or more of soil, (b) less than one acre of soil if that activity is part of a "larger common plan of development or sale" that is greater than one acre, or (c) less than one acre of soil, but the MPCA determines that the activity poses a risk to water resources. The WLA for stormwater discharges, from sites where there are construction activities, reflects the number of construction sites greater than one acre in size that are expected to be active in the impaired lake or stream subwatershed at any one time.

A categorical WLA was assigned to all construction activity in each impaired stream or lake subwatershed. First, the average annual fraction of the impaired subwatershed area, under construction activity over the past five years, was calculated based on the MPCA Construction Stormwater Permit data from January 1, 2007, to October 6, 2012 (Table 41), area-weighted based on the fraction of the subwatershed located in each county. This percentage was multiplied by the watershed runoff load component to determine the construction stormwater WLA. The watershed runoff load component is equal to the total TMDL (loading capacity) minus the sum of the non-watershed runoff load components (atmospheric load, upstream lake loads, internal loads, and MOS). The average annual construction stormwater activity in the BdSRW is very low, and not a significant source of runoff to the impaired lakes and streams. A small WLA is set aside for activity under these general permits in the TMDL allocation tables, but no reductions are assigned.

Table 41. Average Annual NPDES/SDS Construction Stormwater Permit Activity by County (1/1/2007-10/6/2012)

County	Total Area (ac)	Average Annual Construction Activity (% Total Area)
Big Stone	338,286	0.014%
Grant	368,568	0.007%
Otter Tail	1,423,973	0.036%
Stevens	368,359	0.014%
Traverse	375,292	0.004%

4.1.3.3 Regulated Industrial Stormwater

Industrial stormwater is regulated by NPDES permits if the industrial activity has the potential for significant materials and activities to be exposed to stormwater discharges. The WLA for stormwater discharges from sites where there is industrial activity reflects the number of sites in an impaired lake or stream subwatershed for which NPDES Industrial Stormwater Permit coverage is required.

A categorical WLA was assigned to all industrial activity in each impaired lake or stream subwatershed. The industrial stormwater WLA was set equal to the construction stormwater WLA because industrial activities make up a very small fraction of the watershed area. The average annual industrial stormwater activity in the BdSRW is very low, and not a significant source of runoff to the impaired lakes and streams. A small WLA is set aside for activity under these general permits in the TMDL allocation tables, but no reductions are assigned.

4.1.3.4 Feedlots Requiring NPDES/SDS Permit Coverage

Animal waste, containing P, can be transported in watershed runoff to surface waters. The primary goal of the state feedlot program is to ensure that surface waters are not contaminated by runoff from feedlots, manure storage or stockpiles, and cropland with improperly applied manure. The AFOs that either: (a) have a capacity of 1,000 AUs or more, or (b) meet or exceed the EPA's CAFO threshold and discharge to Waters of the United States, are required to apply for permit coverage through the MPCA. If item (a) is triggered, the permit can be an SDS or NPDES/SDS permit; if item (b) is triggered, the permit must be an NPDES permit. These permits require that the feedlots have zero discharge to surface water. There is one active NPDES permitted feedlot operations (CAFO) within a TP impaired stream reach drainage area, in the BdSRW. The number of animals registered with the MPCA was verified by an Environmental Services or Feedlot officer for each county located in the BdSRW in the spring of 2014 (Table 42). This facility was assigned a zero WLA consistent with the conditions of the permit, which allows no discharge of pollutants from the production area of the NPDES permitted feedlot.

Table 42. NPDES permitted feedlot operation number of animals

Stream Reach	Feedlot Name	Permit #	CAFO	Beef
-502	Chad Hasbargen Farm Sec 2	MN0069744	Y	1,450

4.1.3.5 Individual National Pollutant Discharge Elimination Systems Permits

An individual WLA was provided for one NPDES-permitted WWTF whose surface discharge stations fall within a TP impaired stream subwatershed (city of Campbell in the Rabbit River system, AUID 09020101-502). This WWTF is a pond system, and past discharge monitoring records for the city of Campbell indicate that this facility does not usually discharge in June nor September due to surplus capacity ponds (designed to hold 215 days' worth of hydraulic capacity). The city of Doran is served by a community mound system, which does not discharge to surface waters.

The NPDES permits allow for two discharge windows between March 1 and June 30, and between September 1 and December 31, annually. Normally, WWTFs are only allowed to discharge six inches of volume from the secondary pond system in a 24-hour period. However, there is not sufficient stream assimilative capacity in the months of June and September for the city of Campbell to discharge.

Minn-Dak Farmers' Cooperative is a sugar beet processing company that owns and operates five remote storage facilities (piling grounds) in Minnesota. The piling grounds are used for the temporary storage of sugar beets after harvesting, but prior to processing. The beet piling grounds/sites are designed to capture all liquid discharges in on-site industrial stormwater ponds. There is one pond at each piling site. Effluent from each pond is discharged through a pump discharge station at a rate of 500 gallons per minute (gpm) which is the rated pump capacity for all of the pumping systems at each site. Two piling grounds are located in a TP impaired stream drainage area, but only one piling ground is hydrologically connected via surface water to the impaired stream.

The WLAs were calculated based on the design flow and the daily TP effluent concentration assumption, expressed in kilograms per day (kg/day) (Table 43). At the lower flow regimes, the design flows are much greater than the flow in the Rabbit River, and therefore the facilities would need to discharge at TP concentrations near the stream target.

To meet the assumptions of the TMDL, the city of Campbell will only be allowed to discharge in June and September at a TP effluent concentration assumption of 1.0 mg/L when the Rabbit River flow at USGS gage 05051000 is equal to or greater than the TMDL median low flow regime value of 12 cubic feet per second (cfs), which corresponds to the minimum flow whereby the facility can discharge at a TP effluent concentration assumption of 1.0 mg/L without causing the receiving stream to exceed the stream TP target.

The Hawes piling ground will be allowed to either discharge in the months of June through September at a TP effluent concentration assumption of 0.15 mg/L (the stream TP target) when the stream flow at the Rabbit River USGS gage 05051000 is less than 12 cfs, or at a TP effluent concentration assumption of 1.0 mg/L when the stream flow at the Rabbit River USGS gage 05051000 is equal to or greater than 12 cfs.

WLAs for the Rabbit River (-502) assume that individually permitted facilities will discharge TP concentrations of 1 mg/L or less in the months of June and September when stream flow at the Rabbit River DNR gage 05051000 is equal to or greater than 12 cfs. A stage-discharge rating curve has been developed at this gage by the DNR/MPCA and can be used to determine the equivalent stream stage at 12 cfs. The WWTF and piling ground operators will be required by their NPDES permit to verify the stream stage/flow on the day prior to discharging from their ponds. Past discharge monitoring records for the city of Campbell indicate that this facility does not usually discharge in June or September. The Hawes Piling Ground WLA for the months of June through September assumes a TP effluent concentration of 0.15 mg/L (the stream TP target) when stream flows at the Rabbit River DNR gage 05051000 is less than 12 cfs. The facility's industrial stormwater permit will ensure that discharges from the facility are consistent with the TMDL's WLAs. No restrictions on discharge are needed for the non-growing season (October through May).

To meet the Bois de Sioux River (-501) P loading capacity assumptions, daily TP effluent concentration assumptions were also determined for WWTFs that discharge to the Mustinka River, upstream of Mud Lake (Table 44). The MPCA completed an analysis to determine TP effluent concentration assumptions to protect the Bois de Sioux River (-501) outlet at low flow based on a target stream concentration of 150 µg/L because not all facilities upstream of Mud Lake have limits. New TP effluent concentration assumptions for these facilities may be determined in the future based on the target TP concentration for Mud Lake. Minnesota State Rules require that facilities that discharge to or effect a lake receive a 1.0 mg/L (or equitant) limit. Some facilities already had a 1.0 mg/L limit based on other upstream lakes (Toqua, Grant).

Table 43. WWTF design flows, daily TP WLA concentration and WLAs within the BdSRW

Impaired Reach	Facility NAME	Permit #	Secondary Pond Area (acres)	Discharge volume (mgd)	Daily TP WLA Concentration (mg/L)	Daily TP WLA Load (kg/day)
-502	city of Campbell	MN0020915	1.75	0.285	1.0	1.08
-502	Hawes Piling Ground	MN0070386	n/a	0.39	1.0*	1.48*
					0.15**	0.22**

* Applicable when stream flow at the Rabbit River USGS gage 05051000 is equal to or greater than 12 cfs
** Applicable when stream flow at the Rabbit River USGS gage 05051000 is less than 12 cfs

Table 44. WWTF design flows and annual TP WLA within the Mustinka River Watershed

Facility NAME	Permit #	Annual Wet Weather Discharge Volume (mgd)	Daily TP WLA Concentration (mg/L)	Annual TP WLA Load (kg/yr)
Big Stone Hutterite Colony	MNG580168	0.0104	1.5	21.6
city of Dumont	MN0064831	0.0149	1.5	30.9
city of Elbow Lake	MNG580082	0.2079	2.0	574.4
city of Graceville	MNG580159	0.1256	2.0	347.0
city of Herman	MNG580177	0.1015	1.0	140.2
city of Wendell	MNG580153	0.0195	1.0	26.9
city of Wheaton	MN0047287	0.2350	0.5	162.3

4.1.4 Margin of Safety

An explicit 10% MOS was accounted for in the TMDL for each impaired lake. This MOS is sufficient to account for uncertainties in predicting TP loads to lakes and predicting how lakes respond to changes in TP loading. This explicit MOS is considered to be appropriate based on:

- precedence for using an explicit 10% MOS in most other lake TMDL studies in Minnesota;
- BATHTUB model calibration using added internal load with values typical of very shallow, eutrophic lakes (see Section 3.6.1.2: Internal Loading);
- the generally good agreement between BATHTUB model predicted and observed values indicating that the models reasonably reflect the conditions in the lakes and their subwatersheds; and
- three or more years of in-lake water quality data used to calibrate the BATHTUB model.

An explicit MOS equal to 10% of the loading capacity was used for the stream TMDLs based on the following considerations:

- Most of the uncertainty in flow is the result of extrapolating flows in upstream areas of the watershed based on HSPF model calibration at stream gages near the outlet of the BdSRW. The explicit MOS, in part, accounts for this; and

- Allocations are a function of flow, which varies from high to low flows. This variability is accounted for through the development of a TMDL for each of five flow regimes.

4.1.5 Seasonal Variation

In-lake and in-stream water quality varies seasonally. Seasonal variability of phosphorus in the impaired lakes and streams addressed in this TMDL study are illustrated in Section 3.1 and Section 3.5.3. In Minnesota lakes and streams, the majority of the watershed TP load often enters the lake during the spring. During the growing season months (June through September), TP concentrations may not change drastically if major runoff events do not occur. However, Chl-*a* concentrations may still increase throughout the growing season due to warmer temperatures fostering higher algal growth rates. In shallow lakes, the TP concentration more frequently increases throughout the growing season due to the additional TP load from internal sources. This can lead to even greater increases in Chl-*a* since not only is there more TP but temperatures are also higher. This seasonal variation is taken into account in the TMDL study by using the eutrophication standards (which are based on growing season averages) as the TMDL study's goals. The eutrophication standards were set with seasonal variability in mind. The load reductions are designed so that the lakes and streams will meet the water quality standards over the course of the growing season (June through September).

Critical conditions in these lakes occur during the growing season, which is when the lakes are used for aquatic recreation. Similar to the manner in which the standards take into account seasonal variation, since the TMDL is based on growing season averages, the critical condition is covered by the TMDL.

Critical conditions and seasonal variation in stream water quality are also addressed in this TMDL study through the use of LDCs and the evaluation of load variability in five flow regimes, from high flows such as flood events, to low flows such as base flow. Through the use of LDCs, TP loading was evaluated at actual flow conditions at the time of sampling (and by month).

4.1.6 TMDL Summary

4.1.6.1 Ash Lake (26-0294-00) TP TMDL

The LC, WLA, LA, and MOS for Ash Lake TP loading are summarized in Table 45.

Table 45. Ash Lake TP TMDL and Allocations

Ash Lake Load Component		Existing (kg/yr)	Goal (kg/yr)	Goal (kg/day)	Reduction (kg/yr)	Reduction (%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.025	0.025	0.0001	0.0	0%
	Industrial stormwater (MNR50000)	0.025	0.025	0.0001	0.0	0%
	Total WLA	**0.05**	**0.05**	**0.0001**	**0.0**	
Load Allocations*	*Watershed runoff*	*573.2*	*269.4*	*0.738*	*303.8*	*53%*
	Livestock	*0.21*	*0.10*	*0.000*	*0.1*	*53%*
	Failing septics	*0.0*	*0.0*	*0.000*	*0.0*	*0%*
	Internal load	*0.0*	*0.0*	*0.000*	*0.0*	*0%*
	Total Watershed/In-lake	573.4	269.5	0.738	303.9	53%
	Atmospheric	18.1	18.1	0.050	0.0	0%
	Total LA	**591.5**	**287.6**	**0.788**	**303.9**	
MOS			**32.0**	**0.088**		
TOTAL		**591.5**	**319.6**	**0.876**	**303.9**	**51%**

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

Phosphorus Source Summary

- Approximately 80% of the subwatershed is cropland or developed.
- The lake is extremely shallow (max depth of 2.5 feet) and mixing of sediments into the water column can contribute to internal P load (see Section 3.5.1.1).
- Ash Lake is managed for wildlife habitat and water quality through the DNR Shallow Lakes Program. A lake level drawdown occurred in 2012, which has re-established aquatic vegetation and reduced algae levels to promote a clear-water state.

4.1.6.2 Upper Lightning Lake (56-0957-00) TP TMDL

The LC, WLA, LA, and MOS for Upper Lightning Lake TP loading are summarized in Table 46.

Table 46. Upper Lightning Lake TP TMDL and Allocations

Upper Lightning Lake Load Component		Existing (kg/yr)	Goal (kg/yr)	Goal (kg/day)	Reduction (kg/yr)	Reduction (%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.2	0.2	0.0005	0.0	0%
	Industrial stormwater (MNR50000)	0.2	0.2	0.0005	0.0	0%
	Total WLA	**0.4**	**0.4**	**0.0010**	**0.0**	
Load Allocations*	*Watershed runoff*	*742.0*	*517.2*	*1.417*	*224.8*	*30%*
	Livestock	*0.0*	*0.0*	*0.000*	*0.0*	*0%*
	Failing septics	*0.0*	*0.0*	*0.000*	*0.0*	*0%*
	Internal load	*129.4*	*129.4*	*0.355*	*0.0*	*0%*
	Total Watershed/In-lake	871.4	646.6	1.771	224.8	26%
	Atmospheric	73.4	73.4	0.201	0.0	0%
	Total LA	**944.8**	**720.0**	**1.972**	**224.8**	
MOS			**80.0**	**0.219**		
TOTAL		**945.2**	**800.4**	**2.192**	**224.8**	**24%**

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

Phosphorus Source Summary

- Approximately 79% of the subwatershed is cropland or developed.
- The lake is extremely shallow (max depth of eight feet) and mixing of sediments into the water column can contribute to internal P load (see Section 3.5.1.1).
- Upper Lightning Lake is managed by the DNR Shallow Lakes program for wildlife habitat and water quality. A pump and lift station are planned for installation at the lake outlet to manage lake levels with a goal of re-establishing aquatic vegetation and reducing algae levels to promote a clear-water state.

4.1.6.3 Bois de Sioux River (09020101-501) TP TMDL

Figure 48 represents the LDC for the Bois de Sioux River TP loading. The LC, WLA, LA, and MOS for the Bois de Sioux River TP loading are summarized in Table 47. Mud Lake is not being addressed by a TMDL in this study; however, Mud Lake was modeled to determine the P reductions needed to meet the assumptions of the Bois de Sioux River TP TMDL. The suggested P goals and reductions for Mud Lake are listed in Table 48. Lake Traverse is not an impaired waterbody, but is a major tributary to Mud Lake and, thus, the Bois de Sioux River. Lake Traverse was also modeled to determine the P reductions needed to meet the assumptions of the Bois de Sioux River TP TMDL. The suggested P goals and reductions for Lake Traverse are listed in Table 49.

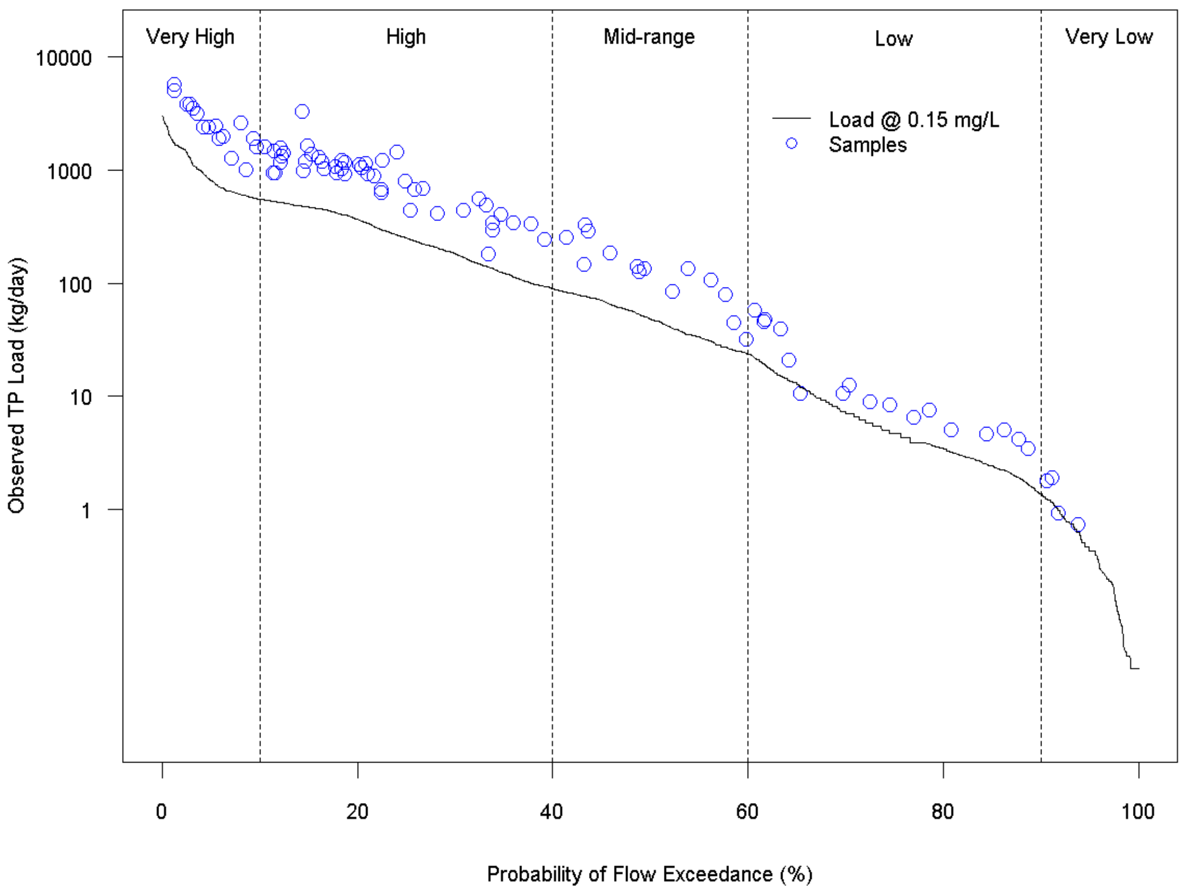

Figure 48. Bois de Sioux River (09020101-501) TP Load Duration Curve
The LDC is the TP standard load at 0.15 mg/L. Plotted sample loads are based on monitored TP concentrations from station S000-553 collected between 2001 and 2006.

Table 47. Bois de Sioux River (09020101-501) TP TMDL and Allocations

Bois de Sioux River 09020101-501 Load Component		Flow Regime				
		Very High	High	Mid	Dry	Very Dry
		Total Phosphorus (kg/day)				
Existing Load		***2,430.3***	***979.9***	***134.3***	***8.8***	***1.3***
Wasteload Allocations	*Construction Stormwater (MNR100001)*	*0.075*	*0.031*	*0.005*	*0.00003*	*0.00001*
	Industrial Stormwater (MNR500000)	*0.075*	*0.031*	*0.005*	*0.00003*	*0.00001*
	Total WLA	**0.15**	**0.06**	**0.010**	**0.00006**	**0.00002**
Load Allocations	*Rabbit River (-502)*	*261.2*	*31.9*	*10.7*	*4.0*	*0.1*
	*Watershed Runoff**	*468.4*	*193.4*	*32.4*	*0.1*	*0.3*
	Total LA	**729.6**	**225.3**	**43.1**	**4.1**	**0.4**
10% MOS		**81.1**	**25.0**	**4.8**	**0.5**	**0.04**
Total Loading Capacity		**810.8**	**250.4**	**47.9**	**4.6**	**0.4**
Estimated Load Reduction		*1,620*	*729*	*86*	*4*	*1*
		67%	*74%*	*64%*	*48%*	*68%*

* The watershed runoff goal assumes that Mud Lake discharges at a growing season (June-September) average TP concentration of 150 ug/L. See Table 48 for Mud Lake suggested phosphorus load goals and reductions by pollutant source.

Table 48. Mud Lake Suggested Phosphorus Goals and Reductions by Pollutant Source

Mud Lake Suggested Load Component		Existing (kg/yr)	Goal (kg/yr)	Goal (kg/day)	Reduction (kg/yr)	Reduction (%)
Suggested Wasteload Allocations	Big Stone Hutterite Colony WWTF (MNG580168)	21.6	21.6	0.1	0.0	0%
	Dumont WWTF (MN0064831)	30.9	30.9	0.1	0.0	0%
	Elbow Lake WWTF (MNG580082)	574.4	574.4	1.6	0.0	0%
	Graceville WWTF (MNG580159)	347.0	347.0	1.0	0.0	0%
	Herman WWTF (MNG580177)	140.2	140.2	0.4	0.0	0%
	Wendell WWTF (MNG580153)	26.9	26.9	0.1	0.0	0%
	Wheaton WWTF (MN0047287)	162.3	162.3	0.4	0.0	0%
	Construction stormwater (MNR100001)	0.02	0.02	0.00006	0.0	0%
	Industrial stormwater (MNR500000)	0.02	0.02	0.00006	0.0	0%
	Total WLA	**1,303.34**	**1,303.34**	**3.7**	**0.0**	
Suggested Load Allocations*	*Watershed runoff*	*5,054.0*	*1,265.7*	*3.5*	*3,788.4*	*75%*
	Livestock	*0.0*	*0.0*	*0.0*	*0.0*	*0%*
	Failing septics	*0.4*	*0.0*	*0.0*	*0.4*	*100%*
	*Lake Traverse***	*11,449.5*	*11,449.5*	*31.4*	*0.0*	*0%*
	*Mustinka River****	*34,181.7*	*22,727.2*	*62.3*	*11,454.5*	*34%*
	Internal load	*86,751.7*	*2,030.5*	*5.6*	*84,721.2*	*98%*
	Total Watershed/In-lake	137,437.3	37,472.9	102.7	99,964.4	73%
	Atmospheric	260.0	260.0	0.7	0.0	0%
	Total LA	**137,697.3**	**37,732.9**	**103.5**	**99,964.4**	
MOS			**2,873.1**	**7.9**		
TOTAL		**139,000.8**	**41,909.3**	**115.1**	**99,964.5**	**72%**

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

**A separate existing and goal condition BATHTUB model was constructed for Lake Traverse to aid implementation planning for load reductions to Lake Traverse. See Table 49 below.

***The Mustinka River, addressed by a separate TMDL study, flows into Lake Traverse just upstream of the outlet to Mud Lake. It was assumed for this model that negligible sedimentation of Mustinka River phosphorus loads occur in Lake Traverse prior to entering Mud Lake. The LA goal for the Mustinka River assumes that the river eutrophication standards (RES) are met (see Section 2.2.3). Note that the Mustinka River is not currently impaired for eutrophication.

Phosphorus Source Summary

- Approximately 65% of the subwatershed is cropland or developed.
- Lake Traverse and the Mustinka River discharge into Mud Lake.
- The lake is extremely shallow (max depth of 3.5 feet) with a long fetch and mixing of sediments into the water column can contribute to internal P load (see Section 3.5.1.1).
- Mud Lake has a high potential for winter fish kills.

Table 49. Lake Traverse Suggested Phosphorus Goals and Reductions by Pollutant Source

Lake Traverse Suggested Load Component		Existing	Goal		Reduction	
		(kg/yr)	(kg/yr)	(kg/day)	(kg/yr)	(%)
Suggested Wasteload Allocations	Construction stormwater (MNR100001)	0.14	0.14	0.0004	0.0	0%
	Industrial stormwater (MNR500000)	0.14	0.14	0.0004	0.0	0%
	Total WLA	**0.28**	**0.28**	**0.0008**	**0.0**	
Suggested Load Allocations*	*Watershed runoff*	*30,692.1*	*6,586.5*	*18.0*	*24,105.6*	*79%*
	Livestock	*1.6*	*0.3*	*0.0*	*1.3*	*81%*
	Failing septics	*9.3*	*0.0*	*0.0*	*9.3*	*100%*
	Internal load	*61,205.5*	*12,879.1*	*35.3*	*48,326.4*	*79%*
	Total Watershed/In-lake	91,908.5	19,465.9	53.3	72,442.6	79%
	Atmospheric	1,166.0	1,166.0	3.2	0.0	0%
	Total LA	**93,074.5**	**20,631.9**	**56.5**	**72,442.6**	
MOS			**2,162.9**	**5.9**		
TOTAL		**93,074.8**	**22,795.1**	**62.45**	**72,442.6**	**78%**

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

Phosphorus Source Summary

- Approximately 69% of the subwatershed is cropland or developed.
- The lake is extremely shallow (max depth of 12 feet) with a very long fetch and mixing of sediments into the water column can contribute to internal P load (see Section 3.5.1.1).

4.1.6.4 Rabbit River (09020101-502) TP TMDL

Figure 49 represents the LDC for the Rabbit River TP loading. The LC, WLA, LA, and MOS for the Rabbit River TP loading are summarized in Table 50.

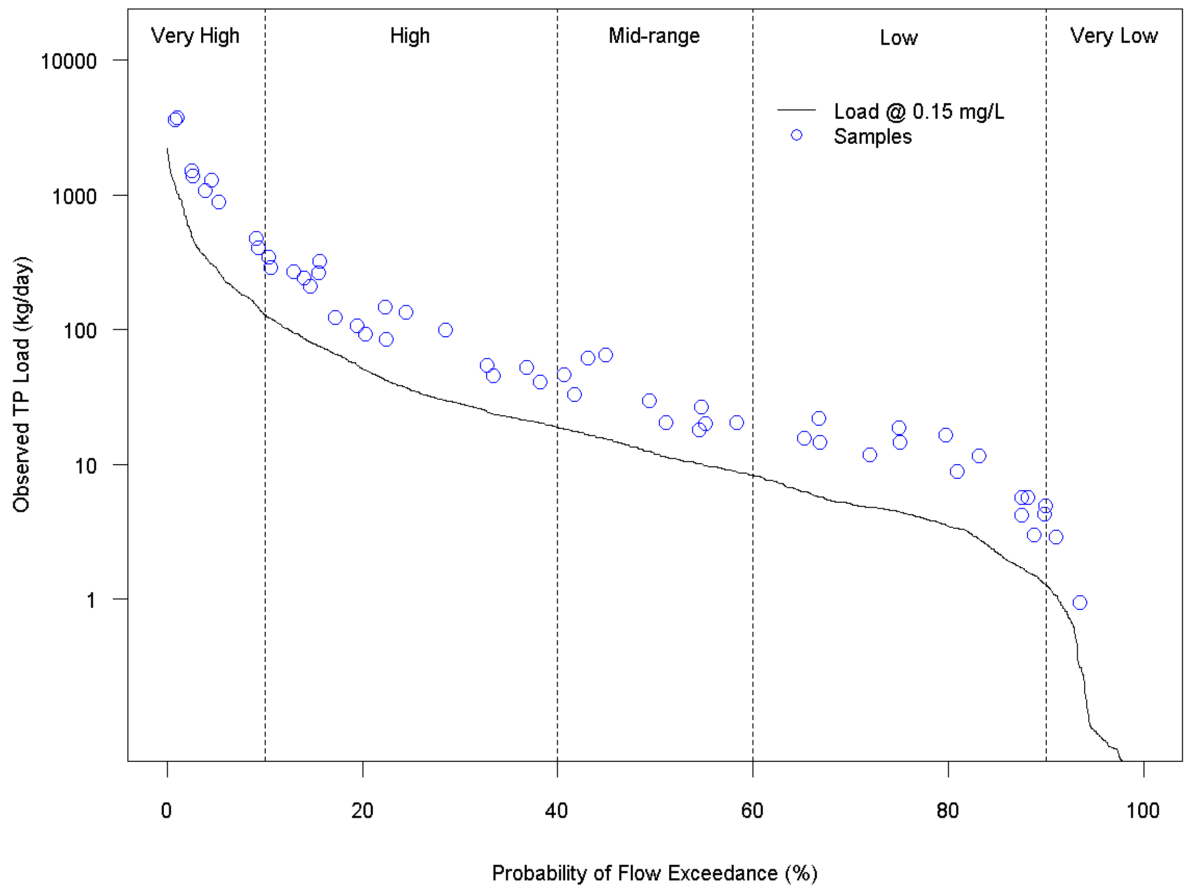

Figure 49. Rabbit River (09020101-502) TP Load Duration Curve

The LDC is the TP standard load at 0.15 mg/L. Plotted sample loads are based on monitored TP concentrations from station S001-029 collected between 2001 and 2006.

Table 50. Rabbit River (09020101-502) TP TMDL and Allocations

Rabbit River 09020101-502 Load Component		Flow Regime				
		Very High	High	Mid	Dry	Very Dry
		Total Phosphorus (kg/day)				
Existing Load		***1,280.9***	***128.2***	***27.9***	***11.5***	***1.9***
Wasteload Allocations	*Campbell WWTF (MN0020915)*	*1.08*	*1.08*	*1.08*	*1.08*	*
	Hawes Piling Grounds (MN0070386)	*1.48*	*1.48*	*1.48*	*1.48*	*0.22*
	Construction Stormwater (MNR100001)	*0.038*	*0.004*	*0.001*	*0.0001*	*0.00001*
	Industrial Stormwater (MNR500000)	*0.038*	*0.004*	*0.001*	*0.0001*	*0.00001*
	NPDES Permitted Feedlots	*0*	*0*	*0*	*0*	*0*
	Total WLA	**2.6**	**2.6**	**2.6**	**2.6**	**0.22**
Load Allocations	*Rabbit River - South Fork (-512)*	*20.7*	*3.4*	*1.3*	*0.6*	*0.02*
	Watershed Runoff	*237.9*	*25.9*	*6.8*	*0.8*	*0.07*
	Total LA	**258.6**	**29.3**	**8.1**	**1.4**	**0.09**
10% MOS		**29.0**	**3.5**	**1.2**	**0.4**	**0.03**
Total Loading Capacity		**290.2**	**35.4**	**11.9**	**4.4**	**0.34**
Estimated Load Reduction		*991*	*93*	*16*	*7*	*1.6*
		77%	*72%*	*57%*	*61%*	*82%*

* See Section 4.1.3.5 for WLA methodology in the lower flow zones

4.1.7 TMDL Baseline

The stream TP TMDLs are based on modeling results for the period 2001 through 2006 (see *HSPF modeling*). Any activities implemented during or after 2006 that lead to a reduction in loads or an improvement in an impaired stream water quality may be considered as progress towards meeting LA reductions.

4.2 Turbidity/TSS

4.2.1 Loading Capacity Methodology

The loading capacities for impaired stream reaches receiving a TMDL, as a part of this study, were determined using LDCs. Flow and LDCs are used to determine the flow conditions (flow regimes) under which exceedances occur. Flow duration curves provide a visual display of the variation in flow rate for the stream. The x-axis of the plot indicates the percentage of time that a flow exceeds the corresponding flow rate as expressed by the y-axis. The LDCs take the flow distribution information, constructed for the stream, and factor in pollutant loading to the analysis. A standard curve is developed by applying a particular pollutant standard or criteria to the stream flow duration curve and is expressed as a load of pollutant per day. The standard curve represents the upper limit of the allowable in-stream pollutant load (loading capacity) at a particular flow. Monitored loads of a pollutant are plotted against this curve to display how they compare to the standard. Monitored values that fall above the curve represent an exceedance of the standard.

For the stream TMDL derivation, 2002 through 2011 USGS gaged flows (5051300 for -501, and 54017001 for -502), area-weighted to the outlet of each impaired stream reach, were used to develop flow duration curves. The loading capacities were determined by applying the TSS water quality standard (65 mg/L) to the flow duration curve to produce a TSS standard curve. Loading capacities presented in the allocation tables represent the median TSS load (in kg/day) along the TSS standard curve within each flow regime. A TSS LDC and a TMDL allocation table are provided for each stream in Section 4.2.6. Monitored TSS concentrations for simulation dates within the TSS assessment window (April through September) are plotted along with the TSS standard curve on LDCs. Within each flow duration interval, the existing TSS load is approximated as the median value of monitored TSS loads.

The LDC method is based on an analysis that encompasses the cumulative frequency of historical flow data over a specified period. Because this method uses a long-term record of daily flow volumes, virtually the full spectrum of allowable loading capacities is represented by the resulting curve. In the TMDL tables of this report, only five points on the entire loading capacity curve are depicted (the midpoints of the designated flow zones). However, it should be understood that the entire curve represents the TMDL and is what is ultimately approved by the EPA.

4.2.2 Load Allocation Methodology

The LAs represent the portion of the loading capacity that is designated for non-regulated sources of TSS (as described in Section 3.6.3) and a consideration for natural background conditions, that are located downstream of any other impaired waters with TMDLs located in the BdSRW. The remainder of the loading capacity (TMDL) after subtraction of the MOS, atmospheric deposition, and calculation of the WLA was used to determine the LA for each impaired stream on an areal basis.

4.2.3 Wasteload Allocation Methodology

All regulated stormwater and wastewater were assigned a WLA based on the methods described in the following section.

4.2.3.1 MS4 Regulated Stormwater

There is no MS4 regulated stormwater in the BdSRW.

4.2.3.2 Regulated Construction Stormwater

Construction stormwater is regulated by NPDES permits for any construction activity disturbing: (a) one acre or more of soil, (b) less than one acre of soil if that activity is part of a "larger common plan of development or sale" that is greater than one acre, or (c) less than one acre of soil, but the MPCA determines that the activity poses a risk to water resources. The WLA for stormwater discharges from sites where there are construction activities reflects the number of construction sites greater than one acre in size and that are expected to be active in the impaired lake or stream subwatershed at any one time.

A categorical WLA was assigned to all construction activity in each impaired stream or lake subwatershed. First, the average annual fraction of the impaired subwatershed area under construction activity over the past five years was calculated based on the MPCA Construction Stormwater Permit data from January 1, 2007 to October 6, 2012 (Table 51), area-weighted based on the fraction of the subwatershed located in each county. This percentage was multiplied by the watershed runoff load component to determine the construction stormwater WLA. The watershed runoff load component is equal to the total TMDL (loading capacity) minus the sum of the nonwatershed runoff load components (atmospheric load, upstream lake loads, internal loads, and MOS).

Table 51. Average Annual NPDES/SDS Construction Stormwater Permit Activity by County (1/1/2007-10/6/2012)

County	Total Area (ac)	Average Annual Construction Activity (% Total Area)
Big Stone	338,286	0.014%
Grant	368,568	0.007%
Otter Tail	1,423,973	0.036%
Stevens	368,359	0.014%
Traverse	375,292	0.004%

4.2.3.3 Regulated Industrial Stormwater

Industrial stormwater is regulated by NPDES permits if the industrial activity has the potential for significant materials and activities to be exposed to stormwater discharges. The WLA for stormwater discharges from sites where there is industrial activity reflects the number of sites in an impaired stream subwatershed for which NPDES industrial stormwater permit coverage is required.

A categorical WLA was assigned to all industrial activity in each impaired stream subwatershed. The industrial stormwater WLA was set equal to the construction stormwater WLA because industrial activities make up a very small fraction of the watershed area.

4.2.3.4 Feedlots Requiring NPDES/SDS Permit Coverage

Animal waste, containing solids, can be transported in watershed runoff to surface waters. The primary goal of the state feedlot program is to ensure that surface waters are not contaminated by runoff from feedlots, manure storage or stockpiles, and cropland with improperly applied manure. The AFOs that either: (a) have a capacity of 1,000 AUs or more, or (b) meet or exceed the EPA's CAFO threshold and discharge to Waters of the United States, are required to apply for permit coverage through the MPCA. If item (a) is triggered, the permit can be an SDS or NPDES/SDS permit; if item (b) is triggered, the permit must be an NPDES permit. These permits require that the feedlots have zero discharge to surface water.

There is one active NPDES permitted feedlot operation (CAFO) within a TSS impaired stream reach drainage area in the BdSRW (Table 52). The number of animals registered with the MPCA was verified by an Environmental Services or Feedlot officer for each county located in the BdSRW in the spring of 2014. This facility was assigned a zero WLA consistent with the conditions of the permit, which allows no discharge of pollutants from the production area of the NPDES permitted feedlot.

Table 52. NPDES permitted feedlot operations in a TSS impaired stream reach subwatershed

Stream Reach	Feedlot Name	Permit #	CAFO	Beef
-502	Chad Hasbargen Farm Sec 2	MN0069744	Y	1,450

4.2.3.5 Individual National Pollutant Discharge Elimination Systems Permits

Minnesota's TSS water quality standard is intended to protect aquatic life from the damaging effects of inorganic non-volatile suspended solids (NVSS) to the gills and filter feeding organs of fish and aquatic invertebrates. The TSS associated with municipal wastewater discharges are predominantly organic volatile suspended solids (VSS) which do not tend to persist in the environment. The WLAs developed for these TMDLs will be expressed in terms of TSS. The NPDES permits for WWTFs may contain water quality-based effluent limits that account for the NVSS characteristics of the discharge. Such limits would be consistent with the assumptions and requirements of the TMDL study's WLAs.

An individual WLA was provided for one NPDES-permitted WWTF, whose surface discharge stations fall within a turbidity impaired stream subwatershed (city of Campbell in the AUID 09020101-502 subwatershed). This WWTF is a pond system. The city of Doran is served by a community mound system, which does not discharge to surface waters. The NPDES permits allow for two discharge windows between March 1 and June 30, and between September 1 and December 31, annually. The WWTFs are only allowed to discharge six inches of volume from the secondary pond system in a 24-hour period. The WLA was calculated based on the design flow and the NPDES/SDS discharge limit of 45 mg/L, expressed in kilograms per day (Table 53).

Minn-Dak Farmers' Cooperative is a sugar beet processing company that owns and operates five remote storage facilities (piling grounds) in Minnesota. The piling grounds are used for the temporary storage of sugar beets after harvesting, but prior to processing. The beet piling grounds/sites are designed to capture all liquid discharges in on-site industrial stormwater ponds. There is one pond at each piling site. Effluent from each pond is discharged through a pump discharge station at a rate of 500 gpm, which is the rated pump capacity for all of the pumping systems at each site. Two piling grounds are located in a TSS impaired stream drainage area, but only one piling ground is hydrologically connected via surface water to the impaired stream. The WLA was calculated based on the design flow and the NPDES/SDS discharge limit of 30 mg/L, expressed in kilograms per day (Table 53).

Table 53. WWTF design flows and permitted TSS loads

Impaired Reach	Facility NAME	Permit #	Secondary Pond Area (acres)	Discharge volume (mgd)	Daily TSS Effluent Limit (mg/L)	Daily TSS WLA (kg/day)
-502	Campbell WWTF	MN0020915	1.75	0.285	45	48.6
-502	Hawes Piling Ground	MN0070386	n/a	0.39	30	44.3

4.2.4 Margin of Safety

An explicit MOS equal to 10% of the loading capacity was used for the stream TMDLs based on the following considerations:

- Most of the uncertainty in flow is the result of extrapolating flows in upstream areas of the subwatershed based on HSPF model calibration at stream gages near the outlet of the BdSRW. The explicit MOS, in part, accounts for this; and
- Allocations are a function of flow, which varies from high to low flows. This variability is accounted for through the development of a TMDL for each of five flow regimes.

4.2.5 Seasonal Variation

The TSS water quality standard applies for the period April through September, which corresponds to the open water season when aquatic organisms are most active and when high stream TSS concentrations generally occur. The TSS loading varies with the flow regime and season. Spring is associated with large flows from snowmelt, the summer is associated with the growing season as well as periodic storm events and receding stream flows, and the fall brings increasing precipitation and rapidly changing agricultural landscapes. Seasonal variability of TSS in the impaired streams addressed in this TMDL study are illustrated in Section 3.5.6.

Critical conditions and seasonal variation are addressed in this TMDL through several mechanisms. The TSS standard applies during the open water months. Data was collected throughout this period. The water quality analysis conducted on these data evaluated variability in flow using five flow regimes: from high flows, such as flood events, to low flows, such as base flow. With LDCs and monthly summary figures, TSS loading was evaluated at actual flow conditions at the time of sampling (and by month).

4.2.6 TMDL Summary

4.2.6.1 Bois de Sioux River (09020101-501) TSS TMDL

Figure 50 represents the LDC for the Bois de Sioux River TSS loading. The LC, WLA, LA, and MOS for the Bois de Sioux River TSS loading are summarized in Table 54.

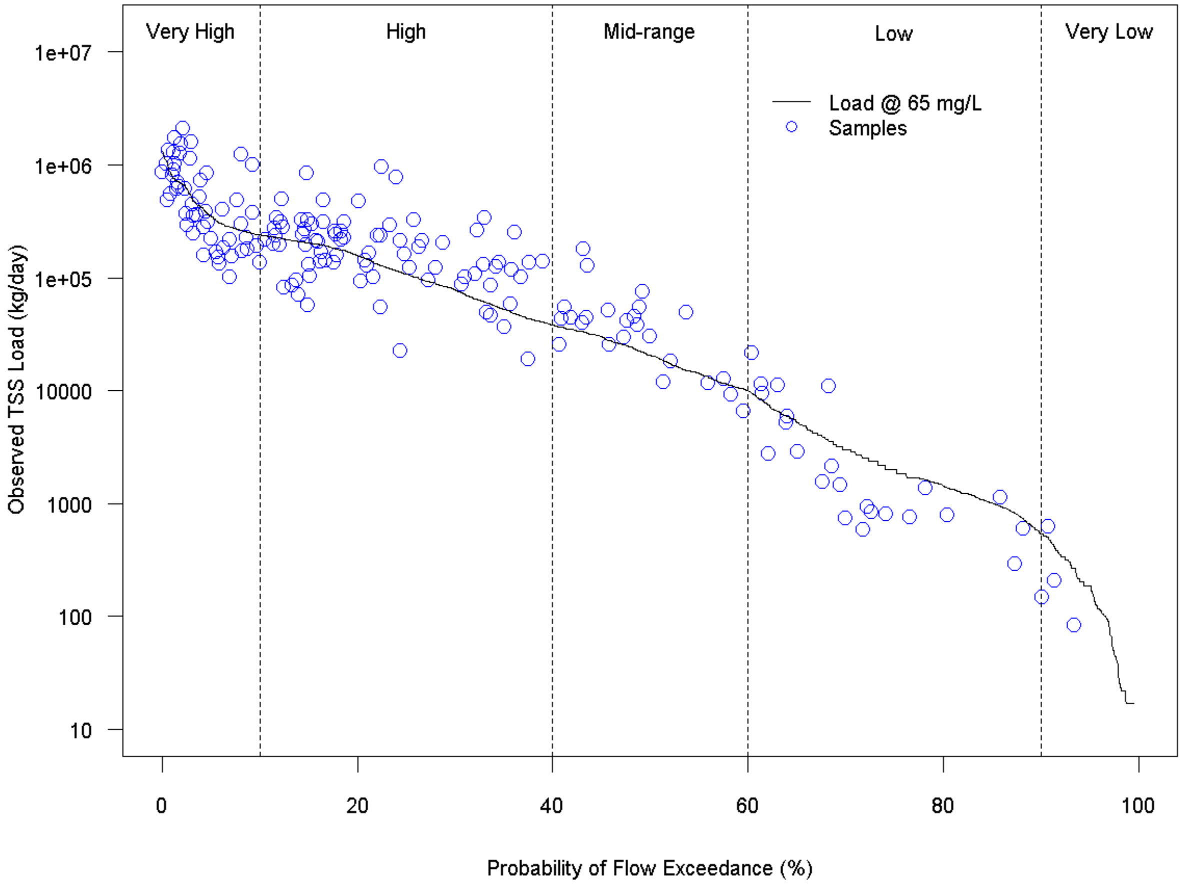

Figure 50. Bois de Sioux River (09020101-501) TSS Load Duration Curve

The LDC is the TSS standard load at 0.65 mg/L. Plotted sample loads are based on monitored TSS concentrations from station S000-553 collected between 2001 and 2006.

Table 54. Bois de Sioux River (09020101-501) TSS TMDL and Allocations

Bois de Sioux River 09020101-501 Load Component		Flow Regime				
		Very High	High	Mid	Dry	Very Dry
		Total Suspended Solids (kg/day)				
Existing Load		***466,992***	***167,209***	***40,673***	***1,467***	***177***
Wasteload Allocations	*Construction Stormwater (MNR100001)*	*32.77*	*13.41*	*2.20*	*0.02*	*0.02*
	Industrial Stormwater (MNR500000)	*32.77*	*13.41*	*2.20*	*0.02*	*0.02*
	Total WLA	**65.5**	**26.8**	**4.4**	**0.04**	**0.04**
Load Allocations	*Rabbit River (-502)**	*112,165*	*13,635*	*4,645*	*1,696*	*42*
	Watershed Runoff	*203,988*	*83,462*	*13,722*	*111*	*124*
	Total LA	**316,153**	**97,097**	**18,367**	**1,807**	**166**
10% MOS		**35,135**	**10,792**	**2,041**	**201**	**18**
Total Loading Capacity		**351,354**	**107,916**	**20,412**	**2,008**	**184**
Estimated Load Reduction		*115,638*	*59,293*	*20,261*	*NA*	*NA*
		25%	*35%*	*50%*	*NA*	*NA*

* The load allocation for the Rabbit River (-502) is based on the sum of the WLA and LA from the Rabbit River (-502) TSS TMDL (see Table 55)

4.2.6.2 Rabbit River (09020101-502) TSS TMDL

Figure 51 represents the LDC for the Rabbit River TSS loading. The LC, WLA, LA, and MOS for the Rabbit River TSS loading are summarized in Table 55.

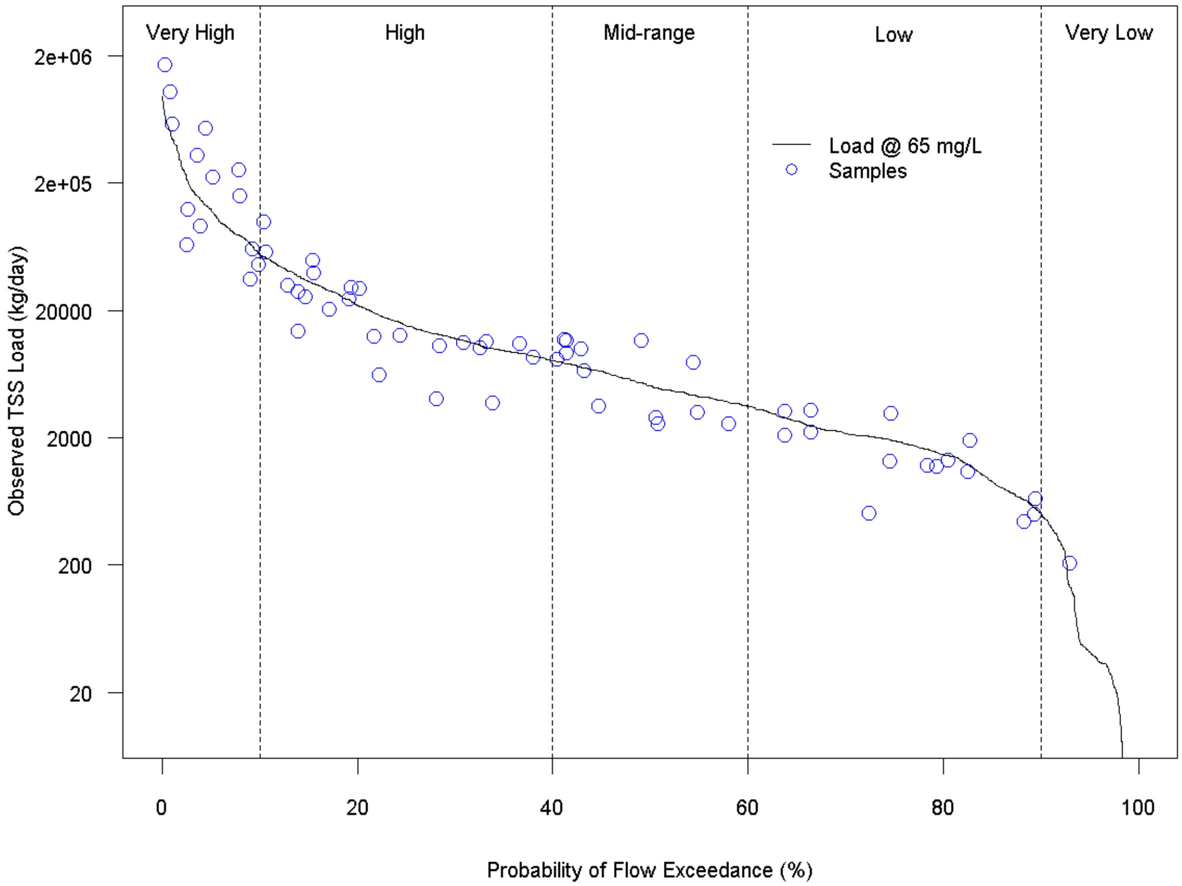

Figure 51. Rabbit River (09020101-502) TSS Load Duration Curve

The LDC is the TSS standard load at 0.65 mg/L. Plotted sample loads are based on monitored TSS concentrations from station S001-029 collected between 2001 and 2006.

Table 55. Rabbit River (09020101-502) TSS TMDL and Allocations

Rabbit River 09020101-502 Load Component		Flow Regime				
		Very High	High	Mid	Dry	Very Dry
		Total Suspended Solids (kg/day)				
Existing Load		*190,609*	*13,715*	*7,825*	*1,303*	*207*
Wasteload Allocations	*Campbell WWTF (MN0020915)*	*48.6*	*48.6*	*48.6*	*48.6*	*
	Hawes Piling Grounds (MN0070386)	*44.3*	*44.3*	*44.3*	*44.3*	*
	Construction Stormwater (MNR100001)	*16.6*	*1.9*	*0.6*	*0.2*	*0.01*
	Industrial Stormwater (MNR500000)	*16.6*	*1.9*	*0.6*	*0.2*	*0.01*
	NPDES Permitted Feedlots	*0*	*0*	*0*	*0*	*0*
	Total WLA	**126.1**	**96.7**	**94.1**	**93.3**	*
Load Allocations	*Rabbit River - South Fork (-512)***	*8,969*	*1,495*	*558*	*250*	*6*
	Watershed Runoff	*103,070*	*12,043*	*3,992*	*1,353*	*
	Total LA	**112,039**	**13,538**	**4,550**	**1,603**	*
10% MOS		**12,463**	**1,515**	**516**	**188**	**5**
Total Loading Capacity		**124,628**	**15,150**	**5,160**	**1,884**	**47**
Estimated Load Reduction		*65,981*	*NA*	*2,665*	*NA*	*160*
		35%	*NA*	*34%*	*NA*	*77%`*

*The WLA for treatment facilities requiring NPDES permits is based on the design flow. The WLA exceeded Very Low flow regime TMDL allocation to the Rabbit River. The WLA and LA allocations are determined instead by the formula: *TSS Allocation = (flow volume contribution from a given source) x (Daily TSS effluent limit in mg/L TSS from Table 53 in Section 4.2.3.5)*
** The load allocation for the Rabbit River, South Fork (-512) is based on the sum of the estimated WLA and LA from the Rabbit River, South Fork (-512) (note: the Rabbit River – South Fork TSS TMDL has been deferred until more data is available)

4.2.7 TMDL Baseline

The stream TSS TMDLs are based on modeling results for the period 2001 through 2006 (see *HSPF modeling*). Any activities implemented during or after 2006 that lead to a reduction in loads or an improvement in an impaired stream water quality may be considered as progress towards meeting a WLA or LA.

4.3 Bacteria (*E. coli*)

4.3.1 Loading Capacity Methodology

The loading capacities for impaired stream reaches receiving a TMDL as a part of this study were determined using LDCs. Flow and LDCs are used to determine the flow conditions (flow regimes) under which exceedances occur. Flow duration curves provide a visual display of the variation in flow rate for the stream. The x-axis of the plot indicates the percentage of time that a flow exceeds the corresponding flow rate as expressed by the y-axis. The LDCs take the flow distribution information constructed for the stream and factor in pollutant loading to the analysis. A standard curve is developed by applying a particular pollutant standard or criteria to the stream flow duration curve and is expressed as a load of pollutant per day. The standard curve represents the upper limit of the allowable in-stream pollutant load (loading capacity) at a particular flow. Monitored loads of a pollutant are plotted against this curve to display how they compare to the standard. Monitored values that fall above the curve represent an exceedance of the standard.

For the -502 TMDL derivation, 2002 through 2011 USGS gaged flows (Station 54017001), area-weighted to the outlet of each impaired stream reach, were used to develop flow duration curves. For the -510 TMDL derivation, 2002 through 2011 USGS gaged flows (Station 54017001), volume weighted to the *E. coli* monitoring station using the HSPF model, were used to develop flow duration curves. The loading capacities were determined by applying the *E. coli* water quality standard (126 org./ 100 ml) to the flow duration curve to produce a bacteria standard curve. Loading capacities presented in the allocation tables represent the median *E. coli* load (in billion org./day) along the bacteria standard curve within each flow regime. A bacteria LDC and a TMDL allocation table are provided for each stream in Section 4.3.6. Monitored *E. coli* concentrations for simulation dates within the *E. coli* assessment window (April through October) are plotted along with the *E. coli* standard curve on LDCs. Within each flow duration interval, the existing *E. coli* load is approximated as the median value of monitored *E. coli* loads.

The LDC method is based on an analysis that encompasses the cumulative frequency of historical flow data over a specified period. Because this method uses a long-term record of daily flow volumes virtually the full spectrum of allowable loading capacities is represented by the resulting curve. In the TMDL tables of this report, only five points on the entire loading capacity curve are depicted (the midpoints of the designated flow zones). However, it should be understood that the entire curve represents the TMDL and is what is ultimately approved by the EPA.

4.3.2 Load Allocation Methodology

The LAs represent the portion of the loading capacity that is designated for non-regulated sources of *E. coli* (as described in Section 3.6.2) and a consideration for natural background conditions, that are located downstream of any other impaired waters with TMDLs located in the BdSRW. The remainder of the loading capacity (TMDL) after subtraction of the MOS and calculation of the WLA was used to determine the LA for each impaired stream, on an areal basis.

4.3.3 Wasteload Allocation Methodology

4.3.3.1 MS4 Regulated Stormwater

There is no MS4 regulated stormwater in the BdSRW.

4.3.3.2 Regulated Construction Stormwater

The *E. coli* WLAs for regulated construction stormwater (Permit #MNR100001) were not developed since *E. coli* is not a typical pollutant from construction sites.

4.3.3.3 Regulated Industrial Stormwater

There are no *E. coli* benchmarks associated with the Industrial Stormwater Permit because no industrial sectors regulated under the permit are known to be *E. coli* sources. Therefore, *E. coli* TMDLs will not include an industrial stormwater WLA.

4.3.3.4 Feedlots Requiring NPDES/SDS Permit Coverage

Animal waste, containing fecal contamination (*E. coli*), can be transported in watershed runoff to surface waters. The primary goal of the state feedlot program is to ensure that surface waters are not contaminated by runoff from feedlots, manure storage or stockpiles, and cropland with improperly applied manure. Any AFOs that either: (a) have a capacity of 1,000 AUs or more, or (b) meet or exceed the EPA's CAFO threshold and discharge to Waters of the United States, are required to apply for permit coverage through the MPCA. If item (a) is triggered, the permit can be an SDS or NPDES/SDS permit; if item (b) is triggered, the permit must be an NPDES permit. These permits require that the feedlots have zero discharge to surface water.

There is one active NPDES permitted feedlot operation (CAFO) within an *E. coli* impaired stream reach drainage area in the BdSRW (Table 56). The number of animals registered with the MPCA was verified by an Environmental Services or Feedlot officer for each county located in the BdSRW in the spring of 2014. These facilities are assigned a zero WLA consistent with the conditions of the permit, which allows no discharge of pollutants from the production area of the NPDES permitted feedlot.

Table 56. NPDES permitted feedlot operation number of animals

Stream Reach	Feedlot Name	Permit #	CAFO	Beef
-502	Chad Hasbargen Farm Sec 2	MN0069744	Y	1,450

4.3.3.5 Individual National Pollutant Discharge Elimination Systems Permits

An individual WLA was provided for all NPDES-permitted WWTF that have fecal coliform discharge limits (200 org./100ml, March 1 through October 31) and whose surface discharge stations fall within an impaired stream subwatershed. There is one NPDES-permitted WWTF whose surface discharge stations fall within an *E. coli* impaired stream subwatershed (city of Campbell in the AUID 09020101-502 subwatershed). This WWTF is a pond system. The city of Doran is served by a community mound system, which does not discharge to surface waters.

The NPDES permits allow for two discharge windows between March 1 and June 30, and between September 1 and December 31, annually. The WWTFs are only allowed to discharge six inches of volume from the secondary pond system in a 24-hour period. The WLA was calculated based on the design flow and a permitted fecal coliform effluent limit of 200 org./ 100 ml (Table 57).

The WLAs are based on *E. coli* loads even though the facilities' discharge limits are based on fecal coliform. If a discharger is meeting the fecal coliform limits of their permit, it is assumed that they are also meeting the *E. coli* WLA in these TMDLs.

Minn-Dak Farmers' Cooperative is a sugar beet processing company that owns and operates five remote storage facilities (piling grounds) in Minnesota. The piling grounds are used for the temporary storage of sugar beets after harvesting, prior to processing. The beet piling grounds/sites are designed to capture all liquid discharges in on-site industrial stormwater ponds. There is one pond at each piling site. Effluent from each pond is discharged through a pump discharge station at a rate of 500 gpm, which is the rated pump capacity for all of the pumping systems at each site. Two piling grounds are located in an *E. coli* impaired stream drainage area; however, the Minn-Dak effluents are not expected to contain bacteria.

Table 57. WWTF design flows and permitted bacteria loads

Impaired Reach	Facility Name	Permit #	Secondary Pond Area (acres)	6" per day discharge volume (mgd)	Permitted Bacteria Load as Fecal Coliform: 200 org./ 100 ml [billion org./day]	Equivalent Bacteria Load as *E. coli*: 126 org. / 100 ml[1] [billion org./day]
-502	Campbell WWTF	MN0020915	1.75	0.285	2.16	1.4

[1] WWTF permits are regulated for fecal coliform, not *E. coli*. The MPCA surface water quality standard for *E. coli* (126 org. / 100 ml) was used in place of the fecal coliform permitted limit of 200 org. / 100 ml, which was also the MPCA surface water quality standard prior to the March 2008 revisions to Minn. R. ch. 7050.

4.3.4 Margin of Safety

An explicit MOS equal to 10% of the loading capacity was used for the stream TMDLs based on the following considerations:

- Most of the uncertainty in flow is the result of extrapolating flows in upstream areas of the watershed based on HSPF model calibration at stream gages near the outlet of the BdSRW. The explicit MOS, in part, accounts for this;
- Allocations are a function of flow, which varies from high to low flows. This variability is accounted for through the development of a TMDL for each of five flow regimes; and
- With respect to the *E. coli* TMDLs, the load duration analysis does not address bacteria re-growth in sediments, die-off, and natural background levels. The MOS helps to account for the variability associated with these conditions.

4.3.5 Seasonal Variation

Use of these water bodies for aquatic recreation potentially occurs from April through October, which includes all or portions of the spring, summer, and fall seasons. The *E. coli* loading varies with the flow regime and season. Spring is associated with large flows from snowmelt, the summer is associated with the growing season as well as periodic storm events and receding stream flows, and the fall brings increasing precipitation and rapidly changing agricultural landscapes. Seasonal variability of *E. coli* in the impaired streams addressed in this TMDL study are illustrated in Section 3.5.5.

Critical conditions and seasonal variation are addressed in this TMDL through several mechanisms. The *E. coli* standard applies during the recreational period, and data were collected throughout this period. The water quality analysis conducted on these data evaluated variability in flow using five flow regimes: from high flows, such as flood events, to low flows, such as base flow. Through the use of LDCs and monthly summary figures, *E. coli* loading was evaluated at actual flow conditions at the time of sampling (and by month), and monthly *E. coli* concentrations were evaluated against precipitation and stream flow.

4.3.6 TMDL Summary

4.3.6.1 Rabbit River (09020101-502) *E. coli* TMDL

Figure 52 represents the LDC for the Rabbit River *E. coli* loading. The LC, WLA, LA, and MOS for the Rabbit River *E. coli* loading are summarized in Table 58.

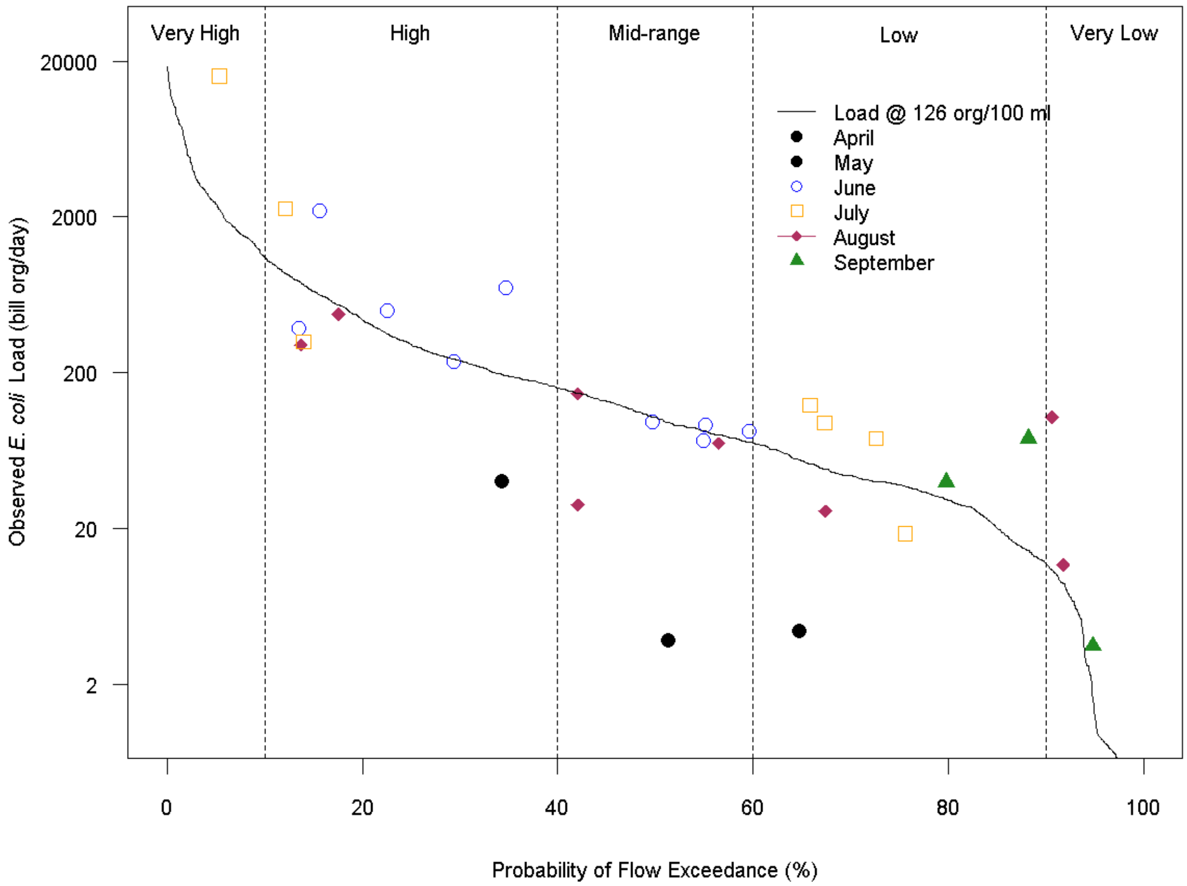

Figure 52. Rabbit River (09020101-502) *E. coli* Load Duration Curve

The LDC is the *E. coli* standard load at 126 org./100 ml. Plotted sample loads are based on monitored *E. coli* concentrations from station S001-029 collected between 2001 and 2006.

Table 58. Rabbit River (09020101-502) *E. coli* TMDL and allocations

Rabbit River 09020101-502 Load Component		Flow Regime				
		Very High	High	Mid	Low	Very Low
		E. coli (billion organisms per day)				
Existing Load		***16,013***	***428***	***78***	***40***	***12***
Wasteload Allocations	*Campbell WWTF (MN0020915)*	*1.4*	*1.4*	*1.4*	*1.4*	***
	NPDES Permitted Feedlots	*0*	*0*	*0*	*0*	*0*
	Total WLA	**1.4**	**1.4**	**1.4**	**1.4**	*****
Load Allocations	*Watershed Runoff*	*2,189.9*	*271.4*	*92.0*	*32.8*	***
	Total LA	**2,189.9**	**271.4**	**92.0**	**32.8**	*****
10% MOS		**243.5**	**30.3**	**10.4**	**3.8**	**0.1**
Total Loading Capacity		**2,434.8**	**303.1**	**103.8**	**38.0**	**1.4**
Estimated Load Reduction		*13,578*	*125*	*NA*	*2*	*11*
		85%	*29%*	*NA*	*4%*	*88%*

*The WLA for treatment facilities requiring NPDES permits is based on the design flow. The WLA exceeded Very Low flow regime TMDL allocation to the Rabbit River. The WLA and LA allocations are determined instead by the formula: *E. coli Allocation = (flow volume contribution from a given source) x (126 org./100 ml E. coli)*

4.3.6.2 Doran Slough (09020101-510) *E. coli* TMDL

Figure 53 represents the LDC for the Doran Slough *E. coli* loading. The LC, WLA, LA, and MOS for the Doran Slough *E. coli* loading are summarized in Table 59.

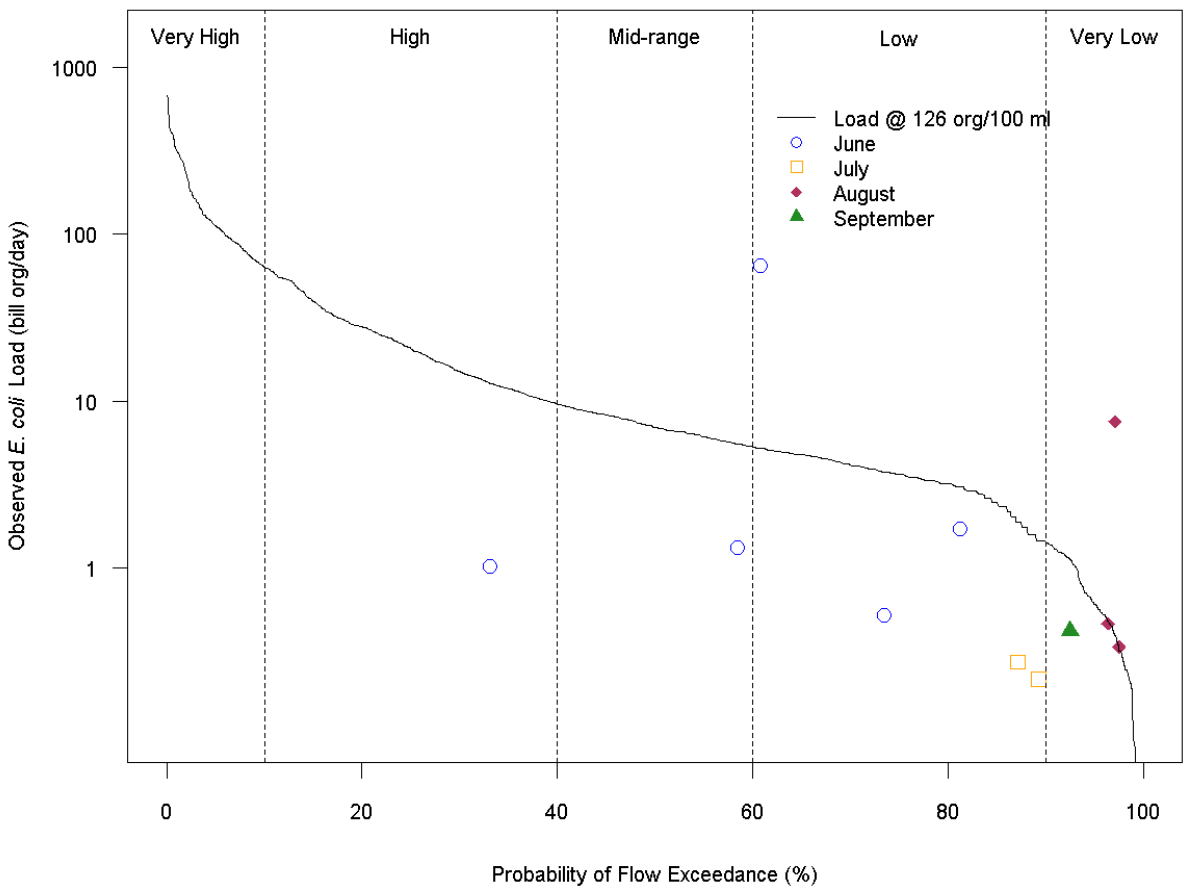

Figure 53. Doran Slough (09020101-510) *E. coli* Load Duration Curve

The LDC is the *E. coli* standard load at 126 org./100 ml. Plotted sample loads are based on monitored *E. coli* concentrations from station S005-144 collected between 2001 and 2006.

Table 59. Doran Slough (09020101-510) *E. coli* TMDL and allocations

Doran Slough 09020101-510 Load Component		Flow Regime				
		Very High	High	Mid	Low	Very Low
		Billion organisms per day				
Existing Load		***NA***	***1.0***	***1.3***	***0.5***	***0.4***
Wasteload Allocations	*NPDES Permitted Facilities*	*0*	*0*	*0*	*0*	*0*
	Total WLA	**0**	**0**	**0**	**0**	**0**
Load Allocations	*Watershed Runoff*	*100.7*	*18.5*	*6.3*	*3.2*	*0.5*
	Total LA	**100.7**	**18.5**	**6.3**	**3.2**	**0.5**
10% MOS		**11.2**	**2.1**	**0.7**	**0.4**	**0.1**
Total Loading Capacity		**111.9**	**20.6**	**7.0**	**3.6**	**0.6**
Estimated Load Reduction*		*NA*	*NA*	*NA*	*NA*	*NA*
		NA	*NA*	*NA*	*NA*	*NA*

* A limited amount of *E. coli* monitoring data was collected during the time period of the HSPF modeled flows (2001-2006). Therefore, while no load reductions were estimated based on these monitoring data, later monitoring data suggests much higher *E. coli* concentrations and reductions needed. The geometric average *E. coli* concentrations in July and August ranged from 198 to 426 org/100mL in this reach (see Table 20 in Section 3.5.5.2 – or reductions of 36% to 70% to achieve monthly geometric averages less than 126 org/100 mL.

4.3.7 TMDL Baseline

The stream *E. coli* TMDLs are based on flow modeling results for the period 2001 through 2006 (see *HSPF modeling*) and *E. coli* monitoring data for the period 2002 through 2011. Any activities implemented during or after 2006 that lead to a reduction in loads or an improvement in an impaired stream water quality may be considered as progress towards meeting a WLA or LA.

4.4 Aquatic Life Impairments not addressed by TMDLs

The low DO and macroinvertebrate/fish bioassessment impairments can sometimes be linked back to a mass pollutant, but those links were not able to be made for four impaired reaches in the BdSRW. A list of the aquatic life use impairments not addressed by TMDL calculations in this study is provided in Table 60. These impairments will be addressed through restoration strategies identified in the WRAPS report and through the One Watershed One Plan process. The Bois de Sioux River WRAPS Report will be publically available on the MPCA's BdSRW website:

https://www.pca.state.mn.us/water/watersheds/bois-de-sioux-river

Table 60. Bois de Sioux River Watershed aquatic life use impairments not addressed by TMDLs

AUID Waterbody Name Listed Pollutant or Stressor	Reason
09020101-535 Unnamed Creek (Unnamed Cr to Lk Traverse) Fish Bioassessments	Connectivity and hydrological alteration (leading to channel instability and probably low base flow volumes) are the main stressors to aquatic life. Without fixing the connectivity issue at Hwy 27, it is unlikely that addressing other stressors will be very beneficial to the stream fish community. There is probably very limited overwintering habitat in this small stream system, and so the stream would need connection to the lake and lowest reaches of the stream so that fish overwintering in those locations could repopulate the stream above Hwy 27.
09020101-540 County Ditch 52 (Unnamed Cr to Unnamed Cr) Fish Bioassessments	Altered hydrology and fish barriers are the main stressors to aquatic life. The watershed area drained by JD-52 has been enlarged to include land that is in the Mustinka River Watershed. This means that added runoff is sent into JD-52, which is causing serious channel instability problems. Excess sediment from bank erosion is damaging stream habitat. There are also three fish migration barriers (State Hwy 27, Twp. Rd. 18, and CR-66).
09020101-510 Unnamed Creek (Doran Slough) Dissolved Oxygen	Flashiness and lack of flow is the main stressor to aquatic life. Low/no flow periods are problematic in this stream. No field measurements were collected in 2010, 2013, and 2015 due to lack of flow, and an HSPF model run predicted dry periods at numerous points in 2001-2006. Small, very tolerant fish species may be able to survive these periods in pools that retain some water; however, this scenario would not support a diverse fish community and sensitive species would not persist.
09020101-515 Unnamed Creek (Headwaters to Rabbit River) Dissolved Oxygen & Turbidity	The MPCA visited this reach in July in 2013, 2014, and 2015 in an attempt to deploy sonde instrumentation for measurement of daily DO fluxes and to collect TP water quality data to link the low DO and turbidity impairments to stream eutrophication. The MPCA observed stagnant or very low flow conditions that are inadequate for sonde deployment and collection of water quality samples during each visit. Given the flow conditions at this site from 2013-2015, intermittent flow and/or altered hydrology -- and resulting high water temperatures -- are likely the most important factors for low DO. As well, decreased stream flow and water movement may result in lower levels of DO due to lower rates of diffusion from the air. Because the cause of low DO in this reach could not be linked to a mass-based pollutant (e.g., phosphorus), a TMDL was not completed for this impairment.

5 Future Growth/Reserve Capacity

The top economic activity in the BdSRW is agriculture, with 78% of the land in cultivated cropland. Land use is not expected to change much in the future, as it has not changed much in the recent past.

Based on information obtained from the United States Census Bureau, four of the counties in the BdSRW have experienced declining populations from 1990 to 2010 (Grant, Minnesota -3.6% , Traverse, Minnesota -20.3%, Wilkin, Minnesota -12.5%, and Richland, Minnesota -10.0%) and two counties have experienced increasing populations (Ottertail, Minnesota +12.9% and Roberts, South Dakota +2.8%).

How changing sources of pollutants may or may not impact TMDL allocations are discussed below. However, it is unlikely that the cities in the BdSRW will become an MS4 in the future given the very low overall population of the BdSRW.

5.1 New or Expanding Permitted MS4 WLA Transfer Process

While there are currently no MS4s in the BdSRW, in general, future transfer of watershed runoff loads in a TMDL study may be necessary if any of the following scenarios occur within the project watershed boundaries.

1. New development occurs within a regulated MS4. Newly developed areas that are not already included in the WLA must be transferred from the LA to the WLA to account for the growth.
2. One regulated MS4 acquires land from another regulated MS4. Examples include annexation or highway expansions. In these cases, the transfer is WLA to WLA.
3. One or more non-regulated MS4s become regulated. If this has not been accounted for in the WLA, then a transfer must occur from the LA.
4. Expansion of a U.S. Census Bureau Urban Area encompasses new regulated areas for existing permittees. An example is existing state highways that were outside an Urban Area at the time the TMDL study was completed, but are now inside a newly expanded Urban Area. This will require either a WLA to WLA transfer or a LA to WLA transfer.
5. A new MS4 or other stormwater-related point source is identified and is covered under a NPDES permit. In this situation, a transfer must occur from the LA.

Load transfers will be based on methods consistent with those used in setting the allocations in this TMDL study (see Section 4.2.3). One transfer rate was defined for each impaired stream as the total WLA (in kg/day or billion org./day) divided by the watershed area downstream of any upstream impaired waterbody (acres). In the case of a load transfer, the amount transferred from LA to WLA will be based on the area (acres) of land coming under permit coverage multiplied by the transfer rate (in kg/ac-day or billion org./ac-day). The MPCA will make these allocation shifts. In cases where WLA is transferred from or to a regulated MS4, the permittees will be notified of the transfer and have an opportunity to comment.

5.2 New or Expanding Wastewater (TSS or *E. coli* TMDLs only)

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 in-stream target and will ensure that the effluent concentrations will not exceed applicable water quality standards or surrogate measures. The process for modifying any and 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.

For more information on the overall process, visit the MPCA's TMDL Policy and Guidance webpage.

6 Reasonable Assurance

6.1 Non-regulatory

Large in-lake and watershed nonpoint source load reductions were identified for all of the impaired lakes and streams addressed in this TMDL study. In-lake load reductions will be achieved through management of a clear-water state. This has been most successful in southwest Minnesota via whole lake drawdowns, which consolidate sediments, reestablish plant communities, and kill the fish community (which is usually dominated by panfish that overgraze zooplankton). The BdSRW WRAPS Report addresses how to achieve the significant watershed load reductions needed in this watershed. As part of the WRAPS report, an agricultural conservation planning framework was used to identify nutrient reduction strategies at multiple scales (nutrient management, source control, in-field controls, edge of field controls, and in-stream controls).

At the local level, the Bois de Sioux Watershed District (BdSWD) and the Grant, Otter Tail, Stevens, and Traverse County Soil and Water Conservation Districts (SWCD) currently implement programs that target improving water quality and have been actively involved in projects to improve water quality in the past. Willing landowners within this watershed have implemented many practices in the past including: conservation tillage, cover crops, buffer strips, gully stabilizations, and impoundments. It is assumed that these activities will continue. The MPCA maintains a website documenting the number of BMPs implemented by the watershed since 2004, titled “BMPs Implemented by Watershed.” Information regarding the number of specific BMPs implemented in the BdSRW can be found on this website (https://www.pca.state.mn.us/water/best-management-practices-implemented-watershed). Between 2004 and 2017, the most common BMPs implemented in the BdSRW were nutrient management, tillage/residue management, living cover to crops in fall/spring, and septic system improvements. In addition, the watershed has completed other large-scale improvements that are not captured on this inventory. Information about grants received and projects completed or in progress can be found on the BdSWD Website: http://www.bdswd.com/.

Potential state funding of restoration and protection projects include Clean Water Fund grants. At the federal level, funding can be provided through Section 319 grants that provide cost-share dollars to implement activities in the watershed. Various other funding and cost-share sources exist, which will be listed in the BdSRW WRAPS Report. The implementation strategies described in this plan have been demonstrated to be effective in reducing nutrient loading to lakes and streams. There are programs in place within the watershed to continue implementing the recommended activities. The One Watershed One Plan effort for this watershed is underway and will use the strategies from the WRAPS in developing the plan for prioritized and targeted implementation actions. Monitoring will continue and adaptive management will be in place to evaluate the progress made towards achieving water quality goals.

6.2 Regulatory

6.2.1 Regulated Construction Stormwater

State implementation of the TMDL study will be through action on NPDES permits for regulated construction stormwater. To meet the WLA for construction stormwater, construction stormwater activities are required to meet the conditions of the Construction General Permit under the NPDES program and properly select, install, and maintain all BMP required under the permit, including any applicable additional BMP required in Appendix A of the Construction General Permit for discharges to impaired waters, or meet local construction stormwater requirements if they are more restrictive than requirements of the State General Permit.

6.2.2 Regulated Industrial Stormwater

To meet the WLA for industrial stormwater, industrial stormwater activities are required to meet the conditions of the industrial stormwater general permit or Nonmetallic Mining & Associated Activities general permit (MNG49) under the NPDES program and properly select, install and maintain all BMP required under the permit.

6.2.3 Wastewater and State Disposal System Permits

The MPCA issues permits for WWTFs that discharge into waters of the state. The permits have site specific limits on bacteria that are based on water quality standards. Permits regulate discharges with the goals of: (1) protecting public health and aquatic life, and (2) assuring that every facility treats wastewater. In addition, SDS permits set limits and establish controls for land application of sewage.

6.2.4 Subsurface Sewage Treatment Systems Program

The SSTS, commonly known as septic systems, are regulated by Minn. Stat. §§ 115.55 and 115.56.

These regulations detail:

- Minimum technical standards for individual and mid-size SSTS;
- A framework for local administration of SSTS programs; and
- Statewide licensing and certification of SSTS professionals, SSTS product review and registration, and establishment of the SSTS Advisory Committee.

6.2.5 Feedlot Rules

The MPCA regulates the collection, transportation, storage, processing, and disposal of animal manure and other livestock operation wastes. The MPCA Feedlot Program implements rules governing these activities and provides assistance to counties and the livestock industry. The feedlot rules apply to most aspects of livestock waste management including the location, design, construction, operation, and management of feedlots and manure handling facilities.

There are two primary concerns about feedlots in protecting water:

- Ensuring that manure on a feedlot or manure storage area does not run into water; and
- Ensuring that manure is applied to cropland at a rate, time, and method that prevents bacteria and other possible contaminants from entering streams, lakes, and ground water.

6.2.6 Nonpoint Source

Existing nonpoint source statutes/rules:

- 50-foot buffer required for the shore impact zone of streams classified as protected waters (Minn. Stat. § 103F.201) for agricultural land uses. November 1, 2017, was the deadline for compliance.
- 16.5-foot minimum width buffer required on public drainage ditches (Minn. Stat. § 103E.021). November 1, 2018 was the deadline for compliance.
- Protecting highly erodible land within the 300-foot shoreland district (Minn. Stat. § 103F.201).
- Excessive soil loss statute (Minn. Stat. § 103F.415)
- Nuisance nonpoint source pollution (Minn. R. 7050.0210, subp. 2)

7 Monitoring Plan

7.1 Lake and Stream Monitoring

Volunteers throughout the watershed conduct stream and lake condition monitoring through the MPCA Volunteer Monitoring Program. As part of the MPCA Intensive Watershed Monitoring strategy, eight stream sites are monitored for biology (fish and macroinvertebrates) and water chemistry, and a representative set of lakes across a range of conditions and lake type (size and depth) are monitored for water chemistry. Details about the MPCA IWM strategy can be found in the BdSRW Monitoring and Assessment Report: https://www.pca.state.mn.us/sites/default/files/wq-ws3-09020101b.pdf. In addition, the River Watch Program, coordinated by the Bois de Sioux Watershed District, monitors stream temperature, conductivity, DO, and pH at 30 designated sites once a month from April through October. The IWM Cycle I water quality and flow monitoring locations within the BdSRW are presented in Figure 54.

The DNR conducts lake and stream surveys to collect information about game fish populations, which are then used to evaluate abundance, relative abundance size (length and weight), condition, age and growth, natural reproduction/recruitment, and effects of management actions (stocking and regulations). Other information collected for lake population assessments include basic water quality information (temperature, DO profile, Secchi, pH, and alkalinity), water level and for fish disease and parasites. Additional information collected for lake surveys include lab water chemistry (TP, alkalinity, TDS, Chl-*a*, Conductivity, pH), watershed characteristics, shoreline characteristics, development, substrates, and aquatic vegetation. In the last few years, the DNR has begun near-shore sampling to develop fish IBIs at lakes in watersheds that have ongoing assessments. The frequency of sampling depends on importance/use. The most important/heavily used lakes are sampled about every five years. Less important/heavily used lakes are sampled every 7, 10, 12, or 15 years. If there is a management action (regulation or stocking) that needs to be evaluated more quickly, sampling could occur every other year. Full surveys are often only done about every 20 years.

In 2020, the MPCA will begin its second 10-year cycle of IWM in the BdSRW. As part of this WRAPS/TMDL update, the MPCA provided an opportunity for local stakeholders to recommend monitoring sites based on local needs.

Based upon the requests from the BdSRW's stakeholders, the MPCA will add the County Ditch 52 and Judicial Ditch 2 (east of the town of Tintah) as locations for the 2020 IWM stream chemistry monitoring sites. The MPCA will also perform aquatic recreation use-related monitoring for TP, Chl-a, and Secchi Disk on Upper Lightning Lake and Lake Traverse, based upon local needs requests.

7.1.1 Future Monitoring Recommendations

For some of the BdSRW's streams and lakes, the TMDL study and WRAPS report are limited by the lack of data that has been collected within this watershed. Additional flow and water quality sampling data are needed from the impaired lakes and streams in the BdSRW to better understand the extent of the impairment, establish better baseline conditions, and to track performance towards achieving pollutant reduction and TMDL goals.

Stream Monitoring

Annual flow and water quality sampling are needed from the four impaired stream reaches in the BdSRW (see Table 61). At each monitoring station, continuous stage should be monitored during the ice free season with 8-12 flow measurements collected across the range of flows to develop a rating curve for the stream. In addition, 14 water quality samples should be collected each year across the range of flows for TSS, TP, orthophosphate, nitrite-nitrate, Chl-*a*, DO flux, BOD5, and *E. coli*. In addition, Microbial Source Tracking should be collected under baseflow and a storm event and analyzed for ruminants, humans, birds, and beavers to refine the bacteria source assessments for the *E. coli* impaired AUIDs.

Lake Monitoring

Continued water quality sampling is needed from the three impaired lakes in the BdSRW: Ash Lake (26-0294), Upper Lightning Lake (56-0957), and Mud Lake Reservoir (78-0024). Monthly surface water samples should be collected May through September for physical parameter profiles (DO, temperature, conductivity, pH, lake level), TP, Chl-*a*, Secchi depth, and site conditions (algae presence, etc.).

Special Investigation Lake Monitoring

Additional monitoring and modeling is needed to complete a well-calibrated lake water quality response model for the Mud Lake Reservoir and upstream Lake Traverse. Continuous flow and TP grab samples should be collected for two to three years at all inlets and outlets to the lakes, in addition to lake level monitoring and lake surface water quality monitoring (monthly May-September TP, Chl-a and Secchi) in Mud Lake and Lake Traverse. Lake inlet/outlet sites include: Mustinka River inlet to Lake Traverse, Lake Traverse outlet to Mud Lake, and the Mud Lake outlet. Reservoir level management records should also be compiled for this two to three year time period to input into a lake water quality response model.

Table 61. Stream monitoring sites in the BdSRW

AUID	Impairments	Monitoring Station(s)
Bois de Sioux River (-501)	***E. coli*, Dissolved oxygen, Fish bioassessments, and Turbidity**	S000-553 S000-089
Rabbit River (-502)	***E. coli*, Dissolved oxygen, Fish & macroinvertebrate bioassessments, and Turbidity**	S001-029
Doran Slough (-510)	***E. coli***	S005-144
Rabbit River, South Fork (-512)	**Dissolved oxygen, Fish bioassessments, and Turbidity**	S004-176

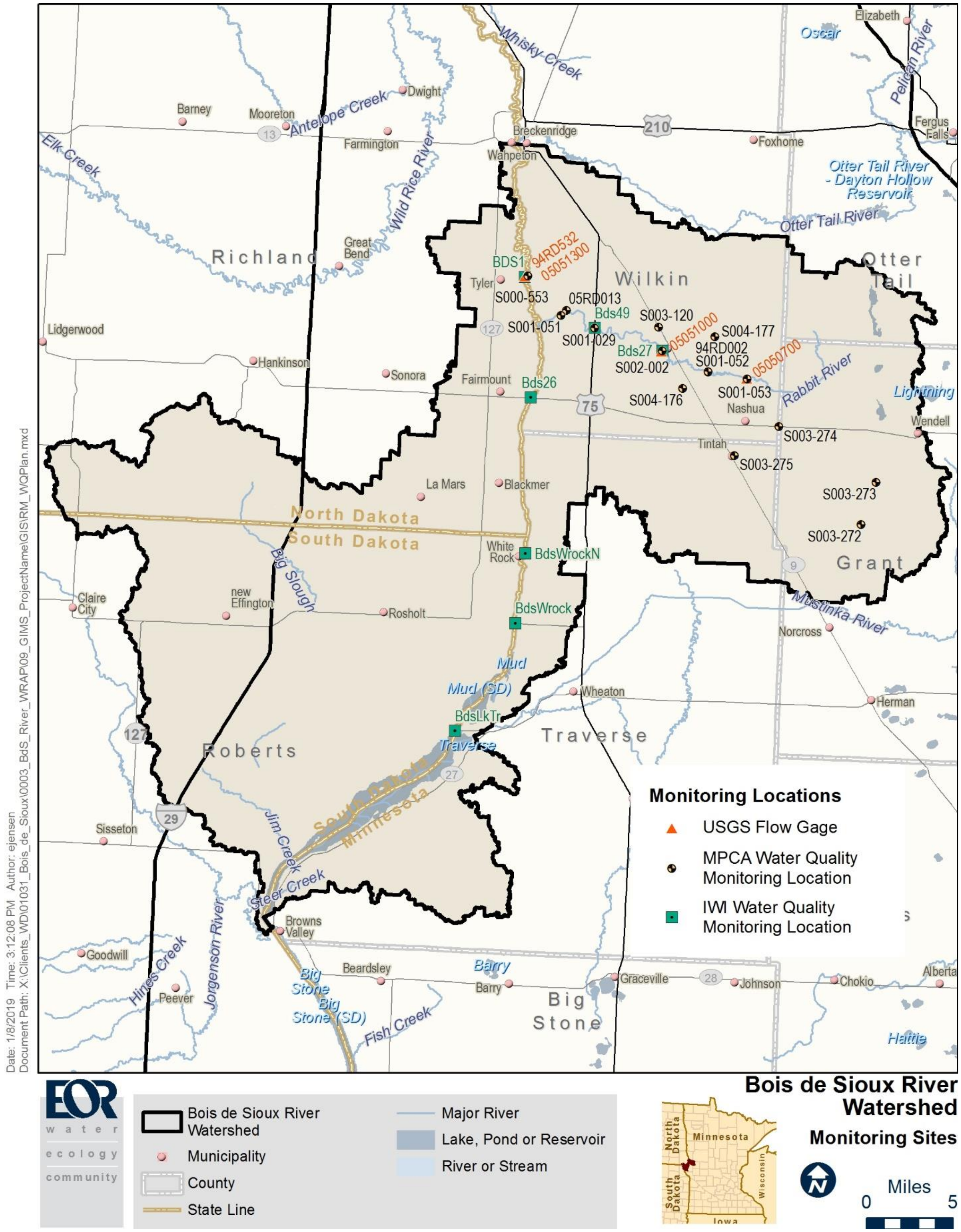

Figure 54. The IWM Cycle I water quality and flow monitoring locations within the BdSRW

7.2 BMP Monitoring

On-site monitoring of implementation practices should also take place in order to better assess BMP effectiveness. A variety of criteria such as land use, soil type, and other watershed characteristics, as well as monitoring feasibility, will be used to determine which BMPs to monitor. Under these criteria, monitoring of a specific type of implementation practice can be accomplished at one site but can be applied to similar practices under similar criteria and scenarios. Effectiveness of other BMPs can be extrapolated based on monitoring results.

8 Implementation Strategy Summary

The TMDL study's results aided in the selection of implementation strategies during the BdSRW WRAPS process. The purpose of the WRAPS process is to support local working groups in developing scientifically supported restoration and protection strategies for subsequent implementation planning. The Bois de Sioux River WRAPS Report will be publically available on the MPCA BdSRW website: https://www.pca.state.mn.us/water/watersheds/bois-de-sioux-river.

8.1 Permitted Sources

8.1.1 Construction Stormwater

The WLA for stormwater discharges from sites where there is construction activity reflects the number of construction sites greater than one acre in size, that are 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/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 study. All local construction stormwater requirements must also be met.

8.1.2 Industrial Stormwater

The WLA for stormwater discharges from sites where there is industrial activity reflects the number of sites in the watershed for which NPDES Industrial Stormwater Permit coverage is required, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The industrial stormwater control measures that are required to be implemented at the industrial sites are identified in the relevant state NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000), NPDES/SDS Individual Industrial Stormwater Permit (MN0070386), or NPDES/SDS General Permit for Construction Sand & Gravel, Rock Quarrying and Hot Mix Asphalt Production facilities (MNG490000). If a facility owner/operator obtains stormwater coverage under the 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 WLA in this TMDL study. All local stormwater management requirements must also be met.

8.1.3 Wastewater

The MPCA issues permits for WWTFs that discharge into waters of the state. The permits have site-specific limits that are based on water quality standards. Permits regulate discharges with the goals of: (1) protecting public health and aquatic life, and (2) assuring that every facility treats wastewater. In addition, SDS permits set limits and establish controls for land application of sewage.

8.1.3.1 Phosphorus

This TMDL includes new discharge requirements for the City of Campbell WWTF and Minn-Dak Farmers' Cooperative's Hawes Piling Ground. To meet the Rabbit River (-502) P loading capacity, a provision will be included in the city of Campbell WWTF NPDES Permit to only allow discharge at a TP effluent concentration assumption of 1.0 mg/L in the months of June and September when the stream flow at the Rabbit River USGS gage 05051000 is equal to or greater than 12 cfs. Past discharge monitoring records for the city of Campbell indicate that this facility does not usually discharge in June nor September due to surplus capacity ponds (designed to hold 215 days' worth of hydraulic capacity). No restrictions on discharge are needed for the non-growing season (October through May). To meet the Rabbit River P loading capacity, the Hawes Piling Ground NPDES permit will contain provisions to ensure consistency with the TMDL's WLA: June through September at a TP effluent concentration assumption of 0.15 mg/L (the stream TP target) when the stream flow at the Rabbit River USGS gage 05051000 is less than 12 cfs, and a TP effluent concentration assumption of 1.0 mg/L when the stream flow at the Rabbit River USGS gage 05051000 is equal to or greater than 12 cfs.

8.2 Non-Permitted Sources

8.2.1 Best Management Practices

A variety of potential BMPs to restore and protect the lakes and streams within the BdSRW have been outlined and prioritized in the WRAPS report. This information from the WRAPS report will inform the One Watershed One Plan process.

8.2.2 Education and Outreach

A crucial part in the success of the restoration and protection efforts that will be designed to clean up the impaired lakes and streams and protect the non-impaired water bodies will be participation from local citizens. In order to gain support from these citizens, education and civic engagement opportunities will be necessary. A variety of educational avenues will be used throughout the BdSRW. These include (but are not limited to): press releases, meetings, workshops, focus groups, trainings, websites, etc. Local staff (conservation district, watershed, county, etc.) and board members work to educate the residents of the watersheds about ways to clean up their lakes and streams on a regular basis. Education will continue throughout the BdSRW.

8.2.3 Technical Assistance

The BdSRW District, counties, and SWCDs within the watershed provide assistance to landowners for a variety of projects that benefit water quality. Assistance provided to landowners varies from agricultural and rural BMPs, to urban and lakeshore BMPs. This technical assistance includes education and one-on-one training. Many opportunities for technical assistance are a result of educational workshops or trainings. It is important that these outreach opportunities for watershed residents continue. Marketing is necessary to motivate landowners to participate in voluntary cost-share assistance programs.

Programs such as state cost share, Clean Water Legacy funding, Environmental Quality Incentives Program (EQIP), and Conservation Reserve Program (CRP) are available to help implement the best conservation practices that each parcel of land is eligible for, and to target the best conservation practices per site. Conservation practices may include, but are not limited to: stormwater bioretention, septic system upgrades, feedlot improvements, invasive species control, wastewater treatment practices, agricultural and rural BMPs, and internal loading reduction. More information about types of practices and implementation of BMPs are discussed in the BdSRW WRAPS Report.

8.2.4 Partnerships

Partnerships with counties, cities, townships, citizens, businesses, watersheds, and lake associations are one mechanism through which the BdSRWD and the Grant, Otter Tail, Traverse, and Wilkins County SWCDs will protect and improve water quality. Strong partnerships with state and local government to protect and improve water resources and to bring waters within the BdSRW into compliance with state standards will continue. A partnership with local government units (LGUs) and regulatory agencies such as cities, townships, and counties may be formed to develop and update ordinances to protect the area's water resources.

8.3 Cost

The Clean Water Legacy Act requires that a TMDL study include an overall approximation of the cost to implement the TMDL study (Minn. Stat. 2007, §114D.25).

8.3.1 Phosphorus

An analysis of the cost to implement the TP TMDLs was completed as part of the WRAPS process. The total cost to achieve a 54% reduction in TP loads watershed-wide was approximately $15.2 million (see Section 3.2, Table 14 and 15 of the Bois de Sioux River WRAPS Report).

8.3.2 TSS

The Clean Water Legacy Act requires that a TMDL study include an overall approximation of the cost to implement the TMDL study (Minn. Stat. 2007, § 114D.25). A detailed analysis of the cost to implement the TSS TMDLs was not conducted. The Group of 16 (G16), an interagency work group (Board of Water Resources, United States Department of Agriculture (USDA), MPCA, Minnesota Association of SWCDs, Minnesota Association of Watershed Districts, Natural Resources and Conservation Service) assessed restoration costs for several TMDL studies with an average cost estimate of $117,000 per square mile for a watershed-based treatment approach. Multiplied by the total area of the TSS-impaired stream watersheds (1,099 square miles) results in a total cost of $129 million.

8.3.3 Bacteria

The cost estimate for bacteria load reduction is based on identifying and verifying wildlife sources to the impaired streams through Microbial Source Tracking, as no anthropogenic sources were identified as part of the TMDL source assessment process Microbial Source Tracking is approximately $200 per sample per biomarker. Assuming collection of 8 biomarkers at 3 locations on two occasions along all three of the impaired stream reaches, the total cost would be approximately $30,000.

8.4 Adaptive Management

This list of implementation strategies in the companion WRAPS report prepared alongside this TMDL study was produced with adaptive management (Figure 55) in mind. Continued monitoring and "course corrections" responding to monitoring results are the most appropriate strategy for attaining the water quality goals established in this TMDL study, the WRAPS, and subsequent One Watershed One Plan efforts. Management activities will be changed or refined over time to efficiently meet the TMDLs and lay the groundwork for de-listing the impaired water bodies.

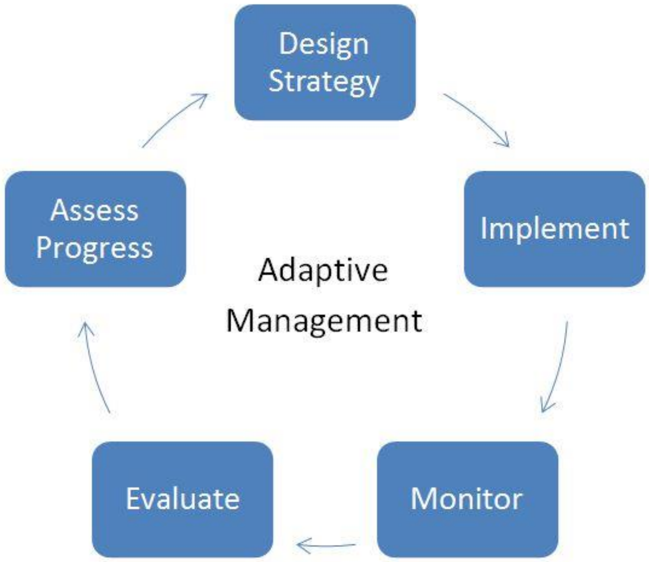

Figure 55. Adaptive Management

9 Public Participation

9.1 Technical Committee Meetings

The BdSRW is made up of numerous local partners who have been involved at various levels throughout the project. The technical committee is made up of members representing the BdSRWD, MPCA, DNR, counties, and SWCDs within the watershed. Table 62 outlines the meetings that occurred regarding the BdSRW monitoring, TMDL study development, and WRAPS report development. Additional information about technical committee members and meeting agendas can be requested from the MPCA Project Manager listed on the BdSRW webpage: https://www.pca.state.mn.us/water/watersheds/bois-de-sioux-river.

Table 62. Bois de Sioux River Watershed TMDL Technical Committee Meetings

<table>
<tr><th>Date</th><th>Location</th><th>Meeting Focus</th></tr>
<tr><td>March 7, 2013</td><td rowspan="3">Bois de Sioux Watershed District Office, Wheaton, MN</td><td>Civic Engagement Campaign Update, Stream Geomorphology Methodology, HSPF Modeling Update</td></tr>
<tr><td>January 23, 2014</td><td>Impairments, Data Summary, Stressor ID Update</td></tr>
<tr><td>March 8, 2016</td><td>TMDL Results and WRAPS Kick-off</td></tr>
</table>

9.2 Civic Engagement

The MPCA along with the local partners and agencies in the BdSRW recognize the importance of public involvement in the watershed process. Table 63 outlines the opportunities used to engage the public and targeted stakeholders in the watershed. Additional information about civic engagement can be requested from the MPCA Project Manager listed on the BdSRW webpage: https://www.pca.state.mn.us/water/watersheds/bois-de-sioux-river.

Table 63. Bois de Sioux River Watershed TMDL Civic Engagement Meetings

<table>
<tr><th>Date</th><th>Location</th><th>Focus</th></tr>
<tr><td>October 2011</td><td>Press Release and Radio Spot on KFGO AM Radio’s “Ripple Effects”</td><td>Project Kick-off and Stream Stability Assessment Field Work</td></tr>
<tr><td>April 2012</td><td>Poster Mailing</td><td>Health of the Valley Campaign</td></tr>
<tr><td>October 2012</td><td rowspan="2">Press Release and Radio Spot on KFGO AM Radio’s “Ripple Effects”</td><td>Stream Health and Channel Stability</td></tr>
<tr><td>February 2013</td><td>Watershed Restoration and Soil Health</td></tr>
<tr><td>February 27, 2014</td><td>City of Campbell Community Center</td><td>TMDL and WRAPS Open House</td></tr>
<tr><td>Ongoing</td><td>Project Website: www.healthofthevalley.com</td><td>TMDL and WRAPS Process, Events and Documentation</td></tr>
</table>

Public Notice

An opportunity for public comment on the draft TMDL report was provided via a public notice in the *State Register* from April 2, 2018 through June 4, 2018. There were three comment letters received and responded to as a result of the public comment period.

10 Literature Cited

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11 Appendix A: BATHTUB Supporting Information

The models' predicted and observed values used in the Bois de Sioux TMDL Study are presented in Tables 64 through 79.

Table 64. Ash Lake Calibrated Model Predicted & Observed Values

Ash Lake
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Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 Ash Lake

	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	146.2	0.27	89.2%	146.2	0.10	89.2%

Table 65. Ash Lake Calibrated Model Water and Phosphorus Balances

Ash Lake
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Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct Drainage	25.5	1.9	1.43E-01	0.20	0.07
PRECIPITATION				0.7	0.5	2.51E-03	0.10	0.72
TRIBUTARY INFLOW				25.5	1.9	1.43E-01	0.20	0.07
***TOTAL INFLOW				26.2	2.4	1.46E-01	0.16	0.09
ADVECTIVE OUTFLOW				26.2	2.0	1.47E-01	0.19	0.08
***TOTAL OUTFLOW				26.2	2.0	1.47E-01	0.19	0.08
***EVAPORATION					0.4	1.31E-03	0.10	

Overall Mass Balance Based Upon Predicted Outflow & Reservoir Concentrations
Component: TOTAL P

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct Drainage	573.4	96.9%	2.63E+04	99.7%	0.28	303.1	22.5
PRECIPITATION				18.1	3.1%	8.18E+01	0.3%	0.50	36.1	26.1
TRIBUTARY INFLOW				573.4	96.9%	2.63E+04	99.7%	0.28	303.1	22.5
***TOTAL INFLOW				591.5	100.0%	2.64E+04	100.0%	0.27	247.2	22.6
ADVECTIVE OUTFLOW				296.9	50.2%	1.15E+04		0.36	146.2	11.4
***TOTAL OUTFLOW				296.9	50.2%	1.15E+04		0.36	146.2	11.4
***RETENTION				294.6	49.8%	1.11E+04		0.36		

Overflow Rate (m/yr)	2.9	Nutrient Resid. Time (yrs)	0.0634
Hydraulic Resid. Time (yrs)	0.1262	Turnover Ratio	15.8
Reservoir Conc (mg/m3)	146	Retention Coef.	0.498

Table 66. Ash Lake TMDL Goal Scenario Model Predicted & Observed Values

Ash Lake

File: X:\Clients_WD\01031_Bois_de_Sioux\0003_BdS_River_WRAP\07_Modeling\BATHTUB\Ash_goal.btb

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 Ash Lake

Variable		Predicted Values---> Mean	CV	Rank	Observed Values---> Mean	CV	Rank
TOTAL P	MG/M3	90.0	0.25	75.8%	146.2	0.09	89.2%

Table 67. Ash Lake TMDL Goal Scenario Model Water and Phosphorus Balances

Ash Lake

File: X:\Clients_WD\01031_Bois_de_Sioux\0003_BdS_River_WRAP\07_Modeling\BATHTUB\Ash_goal.btb

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct Drainage	25.5	1.9	1.43E-01	0.20	0.07
PRECIPITATION				0.7	0.5	2.51E-03	0.10	0.72
TRIBUTARY INFLOW				25.5	1.9	1.43E-01	0.20	0.07
***TOTAL INFLOW				26.2	2.4	1.46E-01	0.16	0.09
ADVECTIVE OUTFLOW				26.2	2.0	1.47E-01	0.19	0.08
***TOTAL OUTFLOW				26.2	2.0	1.47E-01	0.19	0.08
***EVAPORATION					0.4	1.31E-03	0.10	

Overall Mass Balance Based Upon Predicted Component: TOTAL P — Outflow & Reservoir Concentrations

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct Drainage	301.5	94.3%	7.27E+03	98.9%	0.28	159.4	11.8
PRECIPITATION				18.1	5.7%	8.18E+01	1.1%	0.50	36.1	26.1
TRIBUTARY INFLOW				301.5	94.3%	7.27E+03	98.9%	0.28	159.4	11.8
***TOTAL INFLOW				319.6	100.0%	7.36E+03	100.0%	0.27	133.6	12.2
ADVECTIVE OUTFLOW				182.8	57.2%	3.79E+03		0.34	90.0	7.0
***TOTAL OUTFLOW				182.8	57.2%	3.79E+03		0.34	90.0	7.0
***RETENTION				136.8	42.8%	2.63E+03		0.37		

Overflow Rate (m/yr)	2.9	Nutrient Resid. Time (yrs)	0.0722
Hydraulic Resid. Time (yrs)	0.1262	Turnover Ratio	13.8
Reservoir Conc (mg/m3)	90	Retention Coef.	0.428

Table 68. Mud Lake Calibrated Model Predicted & Observed Values

Mud Lake
File: X:\Clients_WD\01031_Bois_de_Sioux\0003_BdS_River_WRAP\07_Modeling\BATHTUB\Mud_wMR_calibrated.btb

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 Mud Lake

		Predicted Values--->			Observed Values--->		
Variable		Mean	CV	Rank	Mean	CV	Rank
TOTAL P	MG/M3	442.0	0.12	99.3%	442.0	0.22	99.3%

Table 69. Mud Lake Calibrated Model Water and Phosphorus Balances

Mud Lake
File: X:\Clients_WD\01031_Bois_de_Sioux\0003_BdS_River_WRAP\07_Modeling\BATHTUB\Mud_wMR_calibrated.btb

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct Drainage	184.3	8.2	6.64E-01	0.10	0.04
2	1	1	Lake Traverse	3196.0	53.4	2.85E+01	0.10	0.02
3	1	1	Mustinka River outflow	2243.7	168.3	2.83E+02	0.10	0.08
4	3	1	Mustinka River Watershed point sources		1.0	9.75E-03	0.10	
PRECIPITATION				10.0	6.1	3.68E-01	0.10	0.61
TRIBUTARY INFLOW				5623.9	229.9	3.13E+02	0.08	0.04
POINT-SOURCE INFLOW					1.0	9.75E-03	0.10	
***TOTAL INFLOW				5633.9	236.9	3.13E+02	0.07	0.04
ADVECTIVE OUTFLOW				5633.9	231.7	3.13E+02	0.08	0.04
***TOTAL OUTFLOW				5633.9	231.7	3.13E+02	0.08	0.04
***EVAPORATION					5.3	2.80E-01	0.10	

Overall Mass Balance Based Upon Predicted Outflow & Reservoir Concentrations
Component: TOTAL P

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct Drainage	4889.1	3.5%	4.78E+05	1.8%	0.14	599.9	26.5
2	1	1	Lake Traverse	11449.5	8.2%	2.62E+06	9.9%	0.14	214.4	3.6
3	1	1	Mustinka River outflow	34181.7	24.6%	2.34E+07	88.1%	0.14	203.0	15.2
4	3	1	Mustinka River Watershed point sources	1468.8	1.1%	4.31E+04	0.2%	0.14	1487.4	
PRECIPITATION				260.0	0.2%	1.69E+04	0.1%	0.50	42.9	26.1
INTERNAL LOAD				86751.7	62.4%	0.00E+00		0.00		
TRIBUTARY INFLOW				50520.3	36.3%	2.65E+07	99.8%	0.10	219.8	9.0
POINT-SOURCE INFLOW				1468.8	1.1%	4.31E+04	0.2%	0.14	1487.4	
***TOTAL INFLOW				139000.8	100.0%	2.65E+07	100.0%	0.04	586.6	24.7
ADVECTIVE OUTFLOW				102391.3	73.7%	1.70E+08		0.13	442.0	18.2
***TOTAL OUTFLOW				102391.3	73.7%	1.70E+08		0.13	442.0	18.2
***RETENTION				36609.5	26.3%	1.47E+08		0.33		

Overflow Rate (m/yr)	23.3	Nutrient Resid. Time (yrs)	0.0143
Hydraulic Resid. Time (yrs)	0.0194	Turnover Ratio	70.1
Reservoir Conc (mg/m3)	442	Retention Coef.	0.263

Table 70. Mud Lake Suggested Goal Scenario Model Predicted & Observed Values

Mud Lake							
File:	**X:\Clients_WD\01031_Bois_de_Sioux\0003_BdS_River_WRAP\07_Modeling\BATHTUB\Mud_wMR_goal150.btb**						
Predicted & Observed Values Ranked Against CE Model Development Dataset							
Segment:	**1**	**Mud Lake**					
	Predicted Values--->			**Observed Values--->**			
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**	
TOTAL P MG/M3	150.0	0.10	89.8%	442.0	0.22	99.3%	

Table 71. Mud Lake Suggested Goal Scenario Model Water and Phosphorus Balances

Mud Lake

File: X:\Clients_WD\01031_Bois_de_Sioux\0003_BdS_River_WRAP\07_Modeling\BATHTUB\Mud_wMR_goal150.btb

Overall Water & Nutrient Balances

Overall Water Balance — **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct Drainage	184.3	8.2	6.64E-01	0.10	0.04
2	1	1	Lake Traverse	3196.0	53.4	2.85E+01	0.10	0.02
3	1	1	Mustinka River outflow	2243.7	168.3	2.83E+02	0.10	0.08
4	3	1	Mustinka River Watershed point sources		1.0	9.75E-03	0.10	
PRECIPITATION				10.0	6.1	3.68E-01	0.10	0.61
TRIBUTARY INFLOW				5623.9	229.9	3.13E+02	0.08	0.04
POINT-SOURCE INFLOW					1.0	9.75E-03	0.10	
***TOTAL INFLOW				5633.9	236.9	3.13E+02	0.07	0.04
ADVECTIVE OUTFLOW				5633.9	231.7	3.13E+02	0.08	0.04
***TOTAL OUTFLOW				5633.9	231.7	3.13E+02	0.08	0.04
***EVAPORATION					5.3	2.80E-01	0.10	

Overall Mass Balance Based Upon Predicted — **Outflow & Reservoir Concentrations**

Component: TOTAL P

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct Drainage	1222.5	2.9%	2.99E+04	0.2%	0.14	150.0	6.6
2	1	1	Lake Traverse	11449.5	27.3%	2.62E+06	17.0%	0.14	214.4	3.6
3	1	1	Mustinka River outflow	25252.5	60.3%	1.28E+07	82.5%	0.14	150.0	11.3
4	3	1	Mustinka River Watershed point sources	1468.8	3.5%	4.31E+04	0.3%	0.14	1487.4	
PRECIPITATION				260.0	0.6%	1.69E+04	0.1%	0.50	42.9	26.1
INTERNAL LOAD				2256.1	5.4%	0.00E+00		0.00		
TRIBUTARY INFLOW				37924.5	90.5%	1.54E+07	99.6%	0.10	165.0	6.7
POINT-SOURCE INFLOW				1468.8	3.5%	4.31E+04	0.3%	0.14	1487.4	
***TOTAL INFLOW				41909.4	100.0%	1.55E+07	100.0%	0.09	176.9	7.4
ADVECTIVE OUTFLOW				34737.4	82.9%	1.82E+07		0.12	150.0	6.2
***TOTAL OUTFLOW				34737.4	82.9%	1.82E+07		0.12	150.0	6.2
***RETENTION				7172.1	17.1%	7.56E+06		0.38		

Overflow Rate (m/yr)	23.3	Nutrient Resid. Time (yrs)	0.0160
Hydraulic Resid. Time (yrs)	0.0194	Turnover Ratio	62.3
Reservoir Conc (mg/m3)	150	Retention Coef.	0.171

Table 72. Lake Traverse Calibrated Model Predicted & Observed Values

Lake Traverse						
File:	**X:\Clients_WD\01031_Bois_de_Sioux\0003_BdS_River_WRAP\07_Modeling\BATHTUB\Traverse_noMR_calibrated.**					
Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	**1**	**Lake Traverse**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	214.4	0.39	95.2%	214.4	0.06	95.2%

Table 73. Lake Traverse Calibrated Model Water and Phosphorus Balances

Lake Traverse
File: X:\Clients_WD\01031_Bois_de_Sioux\0003_BdS_River_WRAP\07_Modeling\BATHTUB\Traverse_noMR_calibrated.btb

Overall Water & Nutrient Balances

Overall Water Balance — **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Direct Drainage	907.7	48.8	9.52E+01	0.20	0.05
PRECIPITATION				44.7	29.7	8.83E+00	0.10	0.67
TRIBUTARY INFLOW				907.7	48.8	9.52E+01	0.20	0.05
***TOTAL INFLOW				952.4	78.5	1.04E+02	0.13	0.08
ADVECTIVE OUTFLOW				952.4	53.4	1.10E+02	0.20	0.06
***TOTAL OUTFLOW				952.4	53.4	1.10E+02	0.20	0.06
***EVAPORATION					25.1	6.30E+00	0.10	

Overall Mass Balance Based Upon **Predicted** **Outflow & Reservoir Concentrations**
Component: **TOTAL P**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Direct Drainage	30703.3	33.0%	7.54E+07	99.6%	0.28	629.3	33.8
PRECIPITATION				1166.0	1.3%	3.40E+05	0.4%	0.50	39.2	26.1
INTERNAL LOAD				61205.5	65.8%	0.00E+00		0.00		
TRIBUTARY INFLOW				30703.3	33.0%	7.54E+07	99.6%	0.28	629.3	33.8
***TOTAL INFLOW				93074.8	100.0%	7.58E+07	100.0%	0.09	1185.6	97.7
ADVECTIVE OUTFLOW				11446.0	12.3%	2.54E+07		0.44	214.4	12.0
***TOTAL OUTFLOW				11446.0	12.3%	2.54E+07		0.44	214.4	12.0
***RETENTION				81628.7	87.7%	6.74E+07		0.10		

Overflow Rate (m/yr)	1.2	Nutrient Resid. Time (yrs)	0.2418
Hydraulic Resid. Time (yrs)	1.9662	Turnover Ratio	4.1
Reservoir Conc (mg/m3)	214	Retention Coef.	0.877

Table 74. Lake Traverse Suggested Goal Scenario Model Predicted & Observed Values

Lake Traverse
File: X:\Clients_WD\01031_Bois_de_Sioux\0003_BdS_River_WRAP\07_Modeling\BATHTUB\Traverse_noMR_goal.btb

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 Lake Traverse

		Predicted Values--->			Observed Values--->		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	90.0	0.35	75.8%	214.4	0.06	95.2%

Table 75. Lake Traverse Suggested Goal Scenario Model Water and Phosphorus Balances

Lake Traverse
File: X:\Clients_WD\01031_Bois_de_Sioux\0003_BdS_River_WRAP\07_Modeling\BATHTUB\Traverse_noMR_goal.btb

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct Drainage	907.7	48.8	9.52E+01	0.20	0.05
PRECIPITATION				44.7	29.7	8.83E+00	0.10	0.67
TRIBUTARY INFLOW				907.7	48.8	9.52E+01	0.20	0.05
***TOTAL INFLOW				952.4	78.5	1.04E+02	0.13	0.08
ADVECTIVE OUTFLOW				952.4	53.4	1.10E+02	0.20	0.06
***TOTAL OUTFLOW				952.4	53.4	1.10E+02	0.20	0.06
***EVAPORATION					25.1	6.30E+00	0.10	

Overall Mass Balance Based Upon Component: Predicted TOTAL P — Outflow & Reservoir Concentrations

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct Drainage	7319.0	32.1%	4.29E+06	92.7%	0.28	150.0	8.1
PRECIPITATION				1166.0	5.1%	3.40E+05	7.3%	0.50	39.2	26.1
INTERNAL LOAD				14310.1	62.8%	0.00E+00		0.00		
TRIBUTARY INFLOW				7319.0	32.1%	4.29E+06	92.7%	0.28	150.0	8.1
***TOTAL INFLOW				22795.1	100.0%	4.63E+06	100.0%	0.09	290.4	23.9
ADVECTIVE OUTFLOW				4804.9	21.1%	3.69E+06		0.40	90.0	5.0
***TOTAL OUTFLOW				4804.9	21.1%	3.69E+06		0.40	90.0	5.0
***RETENTION				17990.2	78.9%	5.04E+06		0.12		

Overflow Rate (m/yr)	1.2	Nutrient Resid. Time (yrs)	0.4144
Hydraulic Resid. Time (yrs)	1.9662	Turnover Ratio	2.4
Reservoir Conc (mg/m3)	90	Retention Coef.	0.789

Table 76. Upper Lightning Lake Calibrated Model Predicted & Observed Values

Upper Lightning Lake
File: X:\Clients_WD\01031_Bois_de_Sioux\0003_BdS_River_WRAP\07_Modeling\BATHTUB\Upper Lightning_calibrated.btb

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 Upper Lightning Lake

Variable		Predicted Values---> Mean	CV	Rank	Observed Values---> Mean	CV	Rank
TOTAL P	MG/M3	100.5	0.34	79.5%	100.5	0.10	79.5%

Table 77. Upper Lightning Lake Calibrated Model Water and Phosphorus Balances

Upper Lightning Lake
File: X:\Clients_WD\01031_Bois_de_Sioux\0003_BdS_River_WRAP\07_Modeling\BATHTUB\Upper Lightning_calibrated.btb

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Direct Drainage	29.0	1.8	3.30E-02	0.10	0.06
PRECIPITATION				2.8	2.0	4.13E-02	0.10	0.72
TRIBUTARY INFLOW				29.0	1.8	3.30E-02	0.10	0.06
***TOTAL INFLOW				31.8	3.8	7.43E-02	0.07	0.12
ADVECTIVE OUTFLOW				31.8	2.4	9.59E-02	0.13	0.07
***TOTAL OUTFLOW				31.8	2.4	9.59E-02	0.13	0.07
***EVAPORATION					1.5	2.15E-02	0.10	

Overall Mass Balance Based Upon Predicted Outflow & Reservoir Concentrations
Component: TOTAL P

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Direct Drainage	742.3	78.5%	1.10E+04	89.1%	0.14	408.7	25.6
PRECIPITATION				73.4	7.8%	1.35E+03	10.9%	0.50	36.1	26.1
INTERNAL LOAD				129.4	13.7%	0.00E+00		0.00		
TRIBUTARY INFLOW				742.3	78.5%	1.10E+04	89.1%	0.14	408.7	25.6
***TOTAL INFLOW				945.2	100.0%	1.24E+04	100.0%	0.12	245.5	29.7
ADVECTIVE OUTFLOW				239.3	25.3%	7.41E+03		0.36	100.5	7.5
***TOTAL OUTFLOW				239.3	25.3%	7.41E+03		0.36	100.5	7.5
***RETENTION				705.8	74.7%	1.36E+04		0.17		

Overflow Rate (m/yr)	0.8	Nutrient Resid. Time (yrs)	0.3409
Hydraulic Resid. Time (yrs)	1.3461	Turnover Ratio	2.9
Reservoir Conc (mg/m3)	101	Retention Coef.	0.747

Table 78. Upper Lightning Lake TMDL Goal Scenario Model Predicted & Observed Values

Upper Lightning Lake
File: X:\Clients_WD\01031_Bois_de_Sioux\0003_BdS_River_WRAP\07_Modeling\BATHTUB\Upper Lightning_goal.btb

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 Upper Lightning Lake

	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	90.0	0.33	75.8%	100.5	0.10	79.5%

Table 79. Upper Lightning Lake TMDL Goal Scenario Model Water and Phosphorus Balances

Upper Lightning Lake
File: X:\Clients_WD\01031_Bois_de_Sioux\0003_BdS_River_WRAP\07_Modeling\BATHTUB\Upper Lightning_goal.btb

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct Drainage	29.0	1.8	3.30E-02	0.10	0.06
PRECIPITATION				2.8	2.0	4.13E-02	0.10	0.72
TRIBUTARY INFLOW				29.0	1.8	3.30E-02	0.10	0.06
***TOTAL INFLOW				31.8	3.8	7.43E-02	0.07	0.12
ADVECTIVE OUTFLOW				31.8	2.4	9.59E-02	0.13	0.07
***TOTAL OUTFLOW				31.8	2.4	9.59E-02	0.13	0.07
***EVAPORATION					1.5	2.15E-02	0.10	

Overall Mass Balance Based Upon Predicted TOTAL P Component — Outflow & Reservoir Concentrations

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct Drainage	597.6	74.7%	7.14E+03	84.1%	0.14	329.0	20.6
PRECIPITATION				73.4	9.2%	1.35E+03	15.9%	0.50	36.1	26.1
INTERNAL LOAD				129.4	16.2%	0.00E+00		0.00		
TRIBUTARY INFLOW				597.6	74.7%	7.14E+03	84.1%	0.14	329.0	20.6
***TOTAL INFLOW				800.4	100.0%	8.49E+03	100.0%	0.12	207.9	25.1
ADVECTIVE OUTFLOW				214.4	26.8%	5.72E+03		0.35	90.0	6.7
***TOTAL OUTFLOW				214.4	26.8%	5.72E+03		0.35	90.0	6.7
***RETENTION				586.0	73.2%	9.75E+03		0.17		

Overflow Rate (m/yr)	0.8	Nutrient Resid. Time (yrs)	0.3606
Hydraulic Resid. Time (yrs)	1.3461	Turnover Ratio	2.8
Reservoir Conc (mg/m3)	90	Retention Coef.	0.732