Watershed

March 2022

Minnesota River Headwaters Watershed Total Maximum Daily Load

A quantification of the total maximum daily loads of bacteria and phosphorus in the Minnesota River Headwaters Watershed's rivers and lakes allowed in order to meet and maintain their ability to support aquatic life and aquatic recreation.

MINNESOTA POLLUTION
CONTROL AGENCY

CLEAN
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AMENDMENT

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Acronyms

1W1P	One Watershed, One Plan
AFO	Animal Feeding Operations
AQR	Aquatic Recreation
ARM	Agricultural Runoff Model
AU	Animal Unit
AUID	Assessment Unit ID
AWWDF	Average wet weather design flow
BMP	Best management practice
BWSR	Board of Water and Soil Resources
CAFO	Concentrated Animal Feeding Operation
cfs	Cubic foot per second
Chl-*a*	Chlorophyll-a
CREP	Conservation Reserve Enhancement Program
CRP	Conservation Reserve Program
CWA	Clean Water Act
CWLA	Clean Water Legacy Act
DNR	Minnesota Department of Natural Resources
E. coli	*Escherichia coli*
EDA	Environmental Data Access
EPA	U.S. Environmental Protection Agency
EQuIS	Environmental Quality Information System
FWMC	Flow weighted mean concentration
HSPF	Hydrologic Simulation Program-Fortran
HUC-08	8-digit hydrologic code
IPHT	Imminent Public Health Threat
ISW	Industrial Stormwater
kg/km^2/year	Kilograms per square kilometer per year
km^2	Square kilometer
LA	Load allocation
lbs/acre	Pounds per acre

lbs/day	Pounds per day
LC	Loading capacity
LDC	Load duration curve
LGU	Local Government Unit
LIDAR	Light Detection and Ranging
LMSA	Liquid manure storage area
MAWQCP	Minnesota Agricultural Water Quality Certification Program
MDF	Maximum design flow
mgd	Million gallons per day
mg/L	Milligrams per liter
mL	Milliliter
MOS	Margin of safety
MPCA	Minnesota Pollution Control Agency
MRHW	Minnesota River Headwaters Watershed
MS4	Municipal Separate Storm Sewer Systems
N	Nitrogen
NGP	Northern Glaciated Plains
NLCD	National Land Cover Dataset
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint sources
NRS	Nutrient Reduction Strategy
NSE	Nash-Sutcliffe Efficiency
P	Phosphorus
PRP	Permanent Wetland Preserve
RIM	Reinvest in Minnesota
SDS	State Disposal System
SIETF	SSTS Implementation and Enforcement Task Force
sq mi	Square miles
SSTS	Subsurface Sewage Treatment System
TMDL	Total Maximum Daily Load
TP	Total phosphorus
TSS	Total suspended solids

WCBP	Western Corn Belt Plains
WLA	Wasteload allocation
WQBEL	Water Quality Based Effluent Limit
WRAPS	Watershed Restoration and Protection Strategy
WRP	Wetland Reserve Program
WWTP	Wastewater treatment plant

Executive summary

Section 303(d) of the Clean Water Act (CWA), and the state Clean Water Legacy Act (CWLA), provide authority for completing Total Maximum Daily Load (TMDL) studies to achieve state water quality standards and/or designated uses. The TMDL establishes the maximum amount of a pollutant a waterbody can receive on a daily basis and still meet water quality standards. The TMDL is divided into wasteload allocations (WLA) for point or permitted sources, load allocations (LA) for nonpoint sources (NPS), and natural background levels of pollutants plus a margin of safety (MOS).

This report addresses impaired stream reaches and lakes in the Minnesota River Headwaters Watershed (MRHW) listed on the 303(d) impaired waters list requiring a TMDL. The MRHW, 8-digit hydrologic code unit (HUC-08) watershed number 07020001, is located in west-central Minnesota and drains portions of South Dakota and a very small portion of North Dakota. No allocations are assigned to areas in South Dakota or North Dakota in this report. This TMDL report addresses 16 impairments in 11 stream reaches and 5 lakes in Minnesota's portion of the watershed. These 16 impairments include 11 *Escherichia coli* bacteria (*E. coli*) impairments and 5 excessive nutrients impairments. Addressing multiple impairments in one TMDL report is consistent with Minnesota's Water Quality Framework that seeks to develop watershed-wide protection and restoration strategies, rather than focus on individual reach impairments.

The MRHW lies within portions of the Western Corn Belt Plains (WCBP) and the Northern Glaciated Plains (NGP) regions. The watershed is the furthest upstream watershed in the Minnesota River Basin and covers an area of approximately 2,132 square miles (sq mi; 1,364,543 acres). Minnesota's portion of the watershed covers a total of approximately 784 sq mi (501,796 acres). Portions of six Minnesota counties are within the boundary of the watershed (percentages are of watershed areas): Big Stone (52.3%), Lac qui Parle (29.8%), Swift (7.5%), Chippewa (5.6%), Traverse (4.4%), and Stevens (0.3%). Towns within the watershed include Browns Valley, Beardsley, Barry, Clinton, Ortonville (the largest), Odessa, Nassau, Bellingham, Louisburg, Correll, and Milan.

This TMDL report used a variety of tools and methods to evaluate current loading contributions by the various pollutant sources, as well as the allowable pollutant loading capacity (LC) of the impaired waterbodies. The tools and methods include the Hydrologic Simulation Program – FORTRAN (HSPF) model, the load duration curve (LDC) approach, and a stochastic version of the BATHTUB lake eutrophication model.

Included in this report are a general strategy and cost estimate for implementation of management or structural practices to address the listed impairments. NPS contributions are the focus of implementation efforts. NPS contributions are not regulated and will need to be addressed on a voluntary basis. Permitted point sources will be addressed through the Minnesota Pollution Control Agency's (MPCA) National Pollutant Discharge Elimination System (NPDES)/State Disposal System (SDS) Permit programs.

1. Project overview

1.1. Purpose

The CWA Section 303(d) requires that states publish a list of surface waters that do not meet water quality standards, and therefore do not support their designated use(s). These waters are then classified as impaired, which dictates that a TMDL must be completed. The TMDL calculates the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and allocates pollutant loads across the sources of pollutants.

The passage of Minnesota's CWLA in 2006 provided a policy framework and resources to state and local governments to accelerate efforts to monitor, assess, and restore impaired waters and to protect unimpaired waters. The result has been a comprehensive "watershed approach" that integrates water resource management efforts, local governments, and stakeholders to develop watershed-scale TMDL reports, restoration and protection strategies, and plans for each of Minnesota's 80 major watersheds. The information gained and strategies developed in the watershed approach are presented in major watershed-scale Watershed Restoration and Protection Strategy (WRAPS) reports, which guide restoration and protection of streams, lakes, and wetlands across the watershed, including those for which TMDL calculations are not made.

This report addresses impaired stream reaches and lakes in Minnesota's portion of the MRHW that are listed on the CWA section 303(d) impaired waters list and requiring a TMDL. The MRHW in Minnesota is part of the 8-digit hydrologic unit code (HUC-08) watershed 07020001. This TMDL report addresses 11 *E. coli* bacteria impairments in 11 stream reaches and 5 excessive nutrients (phosphorus) impaired lakes. Only river reaches and lakes within the boundaries of Minnesota are included in this TMDL report. Although this report addresses many impaired streams and lakes, the biological impaired waterbodies are not addressed. These have been deferred to allow for further investigation into the impairments. An accounting of all impairments within the MRHW is found in **Appendix F**.

The MRHW is located in west-central Minnesota, northeastern South Dakota, and southeastern North Dakota. While the impaired reaches in this report have watersheds that are partially in North Dakota and South Dakota, no TMDL allocations are assigned to North Dakota or South Dakota. Of the total drainage area of 2,132 sq mi, 784 sq mi are located in Minnesota, covering portions of six Minnesota counties: Big Stone, Chippewa, Lac qui Parle, Stevens, Swift, and Traverse.

The purpose of this TMDL report is to quantify the pollutant reductions needed to meet state water quality standards for *E. coli* in stream reaches and nutrients in lakes identified in **Table 1** (streams) and **Table 2** (lakes) and shown in **Figure 1** (streams) and **Figure 2** (lakes). This TMDL report provides WLAs and LAs for the watershed as appropriate.

Two TMDL reports have included impaired reaches of the MRHW prior to this TMDL report. The *Lac qui Parle Yellow Bank Bacteria, Turbidity, and Low Dissolved Oxygen TMDL Assessment Report* (Wenck 2013) covers three fecal coliform and one turbidity impairment in three stream reaches in the Yellow Bank River (part of the HUC-08 07020001). This report was approved by the U.S. Environmental Protection Agency (EPA) in May of 2013. In addition, the Minnesota River, from Big Stone Lake to Marsh Lake Dam is included in the *Minnesota River E. coli Total Maximum Daily Load and Implementation Strategies*

(MPCA 2019b) Report due to an *E. coli* impairment. That TMDL report was approved by EPA in June of 2019.

1.2. Identification of waterbodies

This TMDL addresses 16 impairments in 11 stream reaches and 5 lakes listed on the 2018 303(d) impaired waterbodies list for the MRHW. The stream impairments include 11 *E. coli* impairments, resulting in the streams not supporting aquatic recreation (AQR) use. The lake impairments are for excessive nutrients/eutrophication indicators, and led to the lakes not supporting AQR use. **Table 1** summarizes the stream impairments and **Table 2** summarizes the lake impairments. The locations of the stream and lake impairments are shown in **Figure 1** and **Figure 2**.

Table 1. List of impaired streams covered by this TMDL in the Minnesota River Headwaters Watershed.

Assessment Unit ID	Waterbody	Impairment/ Parameter	Designated Class	Beneficial Use[1]	Listing Year
07020001-504	Unnamed creek (West Salmonsen Creek), Unnamed cr to Big Stone Lk	*Escherichia coli*	2Bg	AQR	2018
07020001-508	Little Minnesota River, MN/SD border to Big Stone Lk	*Escherichia coli*	2Bg	AQR	2018
07020001-521	Unnamed creek (Five Mile Creek), Unnamed cr to Marsh Lk	*Escherichia coli*	2Bg	AQR	2018
07020001-531	Stony Run Creek, Unnamed cr to Minnesota R	*Escherichia coli*	2Bg	AQR	2018
07020001-536	Stony Run Creek, Long Tom Lk to Unnamed cr	*Escherichia coli*	2Bg	AQR	2018
07020001-541	Unnamed creek, Unnamed cr to Big Stone Lk	*Escherichia coli*	2Bg	AQR	2018
07020001-547	Emily Creek, Unnamed cr to Lac qui Parle Lk	*Escherichia coli*	2Bg	AQR	2018
07020001-551	Unnamed creek, Headwaters to S Fk Yellow R	*Escherichia coli*	2Bg	AQR	2018
07020001-568	Unnamed creek (Meadowbrook Creek), 340th St to Big Stone Lk	*Escherichia coli*	2Bg	AQR	2018
07020001-570	Unnamed creek, CSAH 38 to Marsh Lk	*Escherichia coli*	2Bg	AQR	2018
07020001-571	Fish Creek, Headwaters to CSAH 33	*Escherichia coli*	2Bm	AQR	2018

[1] AQR = Aquatic recreation

Table 2. List of impaired lakes covered by this TMDL in the Minnesota River Headwaters Watershed.

Assessment Unit ID	Waterbody	Impairment/Parameter	Designated Class	Beneficial Use[1]	Listing Year
06-0029-00	Long Tom, Lake or Reservoir	Nutrient/eutrophication biological indicators	2B	AQR	2018
06-0060-00	Unnamed, Lake or Reservoir	Nutrient/eutrophication biological indicators	2B	AQR	2018
06-0152-00	Big Stone, Lake or Reservoir	Nutrient/eutrophication biological indicators	2B	AQR	2018
37-0046-01	Lac qui Parle (SE Bay), Lake or Reservoir	Nutrient/eutrophication biological indicators	2B	AQR	2018
37-0046-02	Lac qui Parle (NW Bay), Lake or Reservoir	Nutrient/eutrophication biological indicators	2B	AQR	2018

[1] AQR = Aquatic recreation

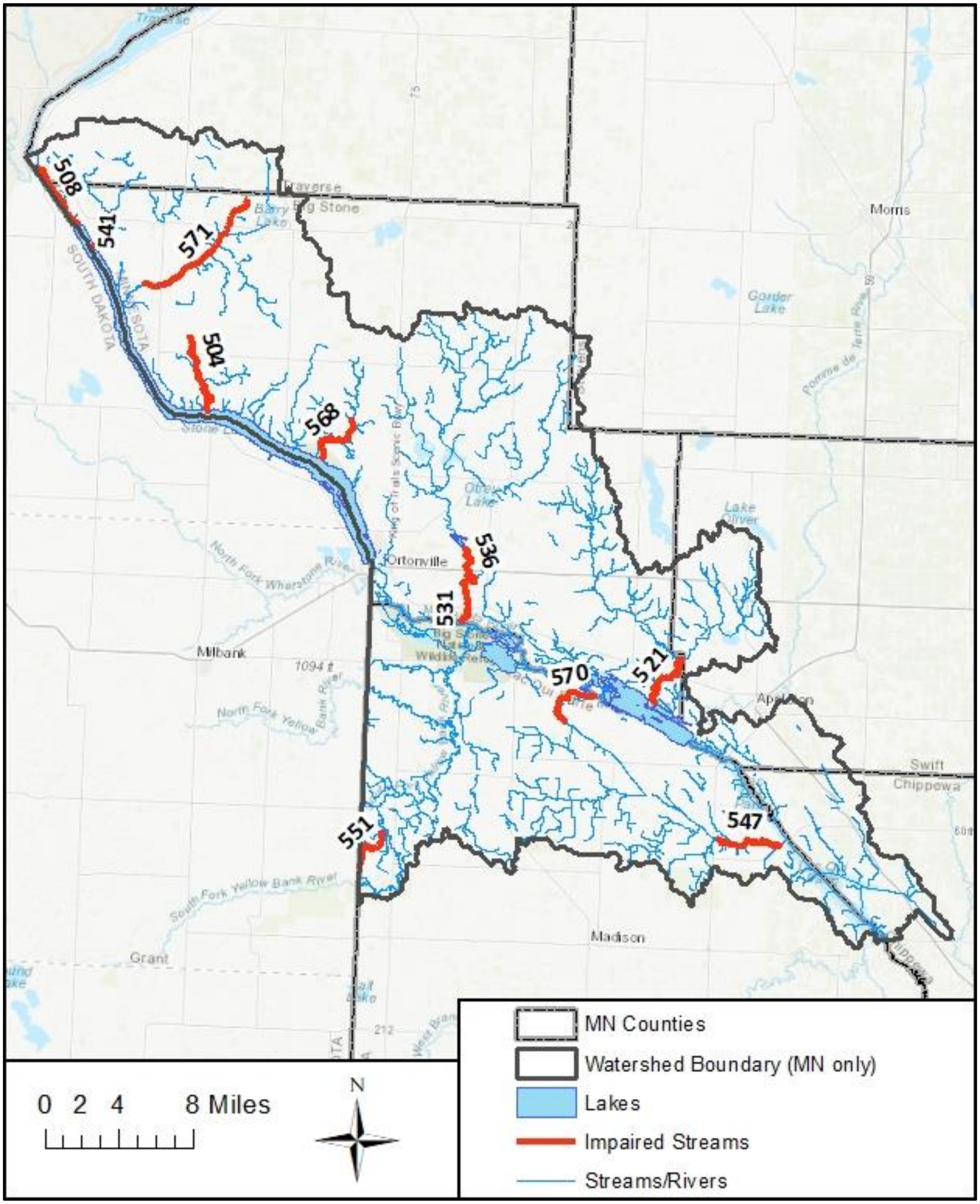

Figure 1. Impaired stream reaches in the Minnesota River Headwaters Watershed addressed in this TMDL report.

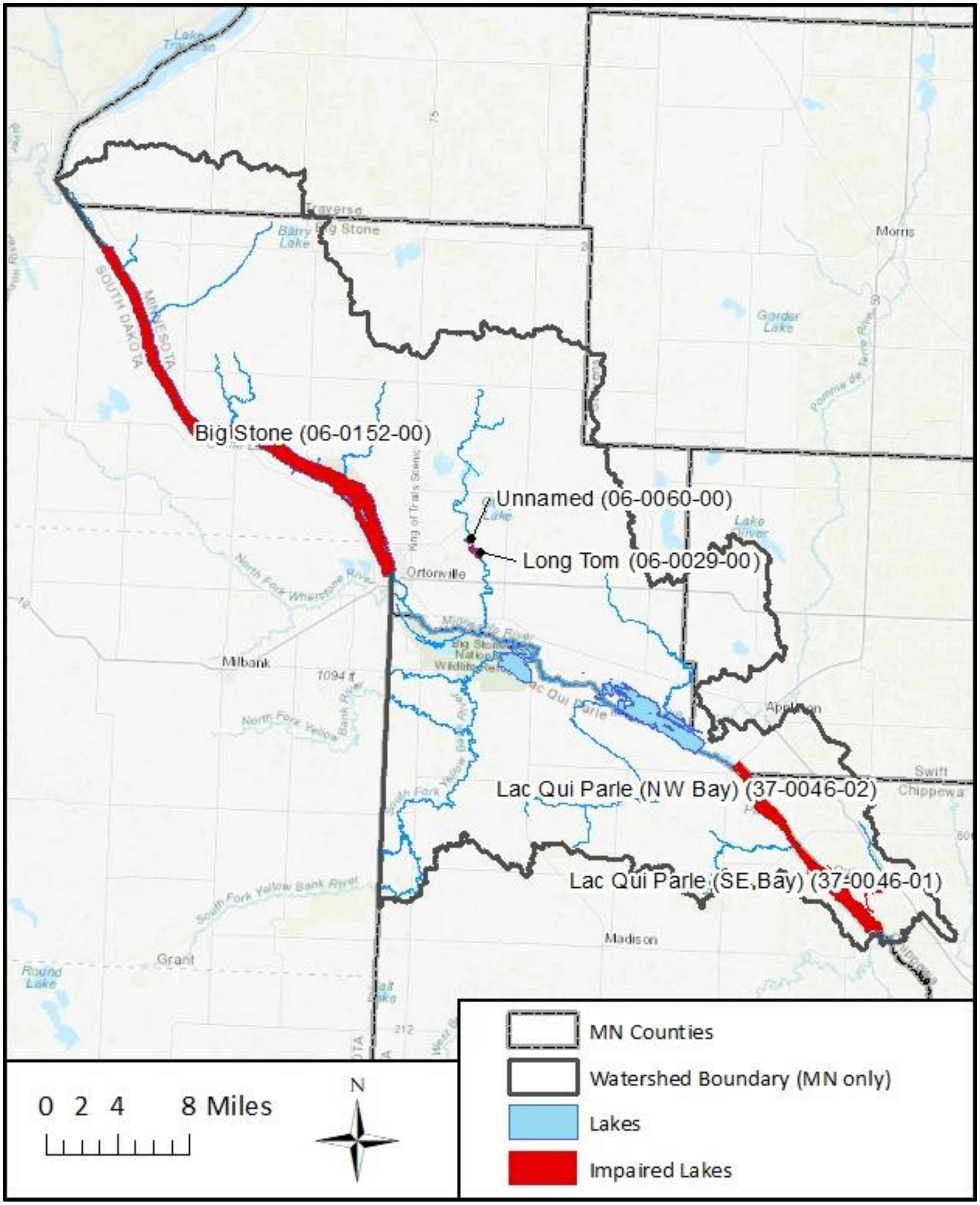

Figure 2. Impaired lakes in the Minnesota River Headwaters Watershed addressed in this TMDL report.

1.3. Priority ranking

The MPCA's schedule for TMDL completions, as indicated on Minnesota's Section 303(d) impaired waters list, reflects Minnesota's priority ranking of this TMDL report. The MPCA developed a state plan Minnesota's TMDL Priority Framework Report (MPCA 2015b) to meet the needs of EPA's national measure (WQ-27) under EPA's Long-Term Vision (EPA 2013) for Assessment, Restoration and Protection under the CWA Section 303(d) Program. As part of these efforts, the MPCA identified water quality impaired stream segments that will be addressed by TMDLs by 2022. The MRHW streams and lakes addressed by this TMDL report are part of that MPCA prioritization plan to meet EPA's national measure.

2. Applicable water quality standards and numeric water quality targets

The criteria used to determine stream and lake impairments are outlined in the MPCA's document *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for the Determination of Impairment: 305(b) Report and 303(d) List* (MPCA 2019a). Minn. R. ch. 7050.0470 lists waterbody classifications and Minn. R. ch. 7050.0222 lists applicable water quality standards. These standards can be numeric or narrative in nature and define the concentrations or conditions of surface waters that allow them to meet their designated beneficial uses, such as for fishing (aquatic life), swimming (AQR) or human consumption (aquatic consumption). All impaired waters addressed in the watershed-wide TMDL report are classified as Class 2B:

> ***Class 2B waters*** *- The quality of class 2B surface waters shall be such as to permit the propagation and maintenance of a healthy community of cool or warm water aquatic biota, and their habitats according to the definitions in subpart 4c. These waters shall be suitable for aquatic recreation of all kinds, including bathing, for which the waters may be usable. This class of surface water is not protected as a source of drinking water. (Minn. R. 7050.0222, Subp. 4).*

The water quality standards shown in **Table 3** and **Table 4** are the numeric water quality target for each parameter shown. For more detailed information refer to the *MPCA TMDL Policy and Guidance* (MPCA 2014b).

2.1 Streams

Applicable water quality standards for impaired streams in this TMDL report are shown in **Table 3**, while **Table 1** shows the specific waterbodies.

Table 3. Surface water quality standards for Minnesota River Headwaters Watershed stream reaches addressed in this TMDL report.

Parameter	Water Quality Standard	Units	Criteria	Period of Time Standard Applies
Escherichia coli (*E. coli*)	Not to exceed 126	org/100 mL	Monthly geometric mean	April 1-October 31
	Not to exceed 1,260	org/100 mL	Upper 10th percentile	

Escherichia coli

Minnesota changed from a fecal coliform standard to an *E. coli* standard for bacteria impairments in 2008. The bacteria standard change is supported by an EPA guidance document on bacteriological criteria (EPA 1986). Minn. R. 7050.0222 Class 2B water quality standards for *E. coli* states:

> *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 based on *E. coli*, wastewater treatment plants (WWTPs) are permitted based on fecal coliform concentrations. A conversion factor of 126 *E. coli* organisms per 100 milliliters (mL) for every 200 fecal coliforms per 100 mL is assumed (MPCA 2009). The *E. coli* standard is based on the geometric mean of water quality observations. Geometric mean is used in place of arithmetic mean in order to describe the central tendency of the data, dampening the effect that very high or very low values have on arithmetic means. The *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for the Determination of Impairment: 305(b) Report and 303(d) List* (MPCA 2019a) provides details regarding how waters are assessed for conformance to the *E. coli* standard.

2.2 Lakes

Lake eutrophication standards are written to protect lakes as a function of their designated beneficial use. The lakes in the MRHW are considered Class 2B waters, which are protected for aquatic life and recreation. Minnesota categorizes its lake water quality standards by ecoregion and depth classification. Lakes in the MRHW are in the NGP ecoregion and are all considered shallow. **Table 4** displays the standards for the NGP ecoregion, while **Table 2** shows the specific waterbodies.

Table 4. Minnesota's lake water quality standards.

Ecoregion	TP[2] [µg/L]	Chl-*a* [µg/L]	Secchi Disk Depth [m]
Northern Glaciated Plains - Shallow Lakes[1]	<90	<30	>0.7

[1] Shallow lakes have an average depth less than 15 feet

[2] Total phosphorus

The MPCA considers a lake impaired when total phosphorus (TP) and a least one of the response variables, chlorophyll-*a* (Chl-*a*) or Secchi depth, fail to demonstrate compliance with the standards (MPCA 2018). 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 (MPCA 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 phosphorus (P) target in each lake the Chl-*a* and Secchi standards will likewise be met.

3. Watershed and waterbody characterization

The MRHW is primarily located within west-central Minnesota and northeast South Dakota, with a very small northern portion contained within North Dakota (**Figure 3**). The total drainage area is 2,132 sq mi (1,364,543 acres), of which Minnesota's portion contains approximately 36% of the total watershed area at 784 sq mi (501,796 acres). The watershed overlaps with six Minnesota counties including mainly Big Stone and Lac qui Parle Counties (52% and 30% of the Minnesota portion of the watershed, respectively), but also Swift, Chippewa, Traverse, and Stevens counties. Minnesota towns within the watershed include Browns Valley, Beardsley, Ortonville (the largest), Odessa, Nassau, Bellingham, and Milan. No part of the MRHW in Minnesota is located within the boundary of a Native American Reservation, therefore, no allocation provided in this TMDL report applies to a Native American Reservation.

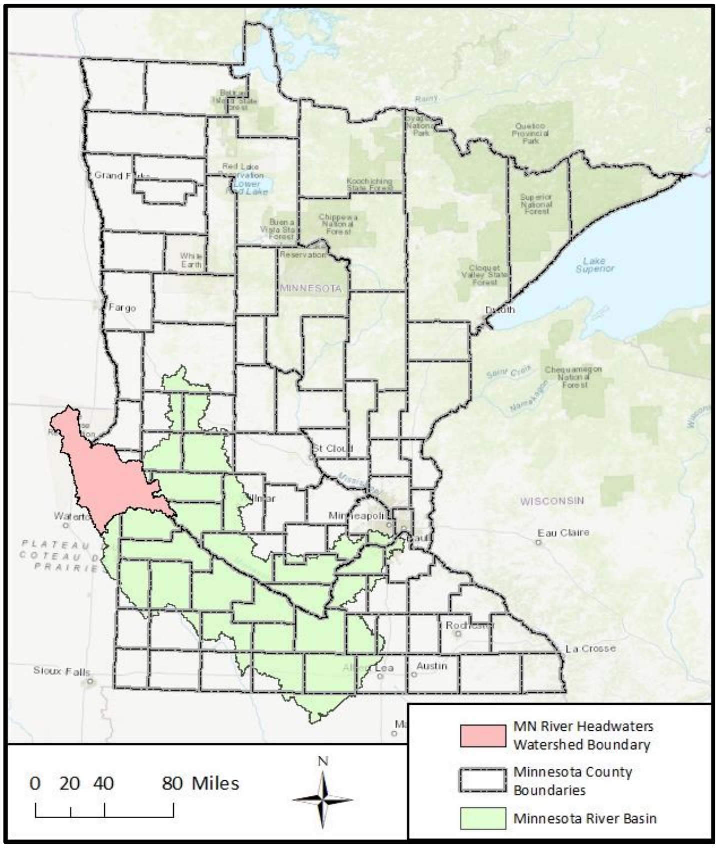

Figure 3. Location of the Minnesota River Headwaters Watershed.

The watershed originates at its highest elevations in North and South Dakota as the Little Minnesota River. The watershed continues into Minnesota and follows along the South Dakota – Minnesota border into Big Stone Lake. Once the river begins its downstream flow from Big Stone Lake near Ortonville, Minnesota, the waterway officially becomes the Minnesota River. The river passes through several large lakes within its valley including Big Stone, Marsh, and Lac qui Parle lakes. It continues its flow into the next downstream HUC-08 watershed near Montevideo, Minnesota. Approximately three-fourths of the watershed lies within the NGP ecoregion, while the southeastern quarter lies within the WCBP ecoregion.

Pre-European settlement vegetation in the watershed was dominated by tallgrass prairie as shown in **Figure 4**. Lands within the MRHW were subject to non-indigenous settlement in the mid-19th century. Over the following century and a half, the landscape underwent a near wholesale conversion from native tall grass prairie vegetation to agricultural uses. To increase arable land surface, many wetlands and free flowing streams were converted to networks of agricultural drainage ditches.

Today, cropland accounts for 54% of the watershed area (**Figure 8**), and a higher percentage of 65% in the Minnesota portion of the watershed. Of the cropland, approximately 90% is under two-year corn/soybean rotation (NLCD 2016). Animal production is an important industry in the watershed as well. Rangeland accounts for 27% of land use and is often used as pastureland. Prairie potholes are frequently found in the northern portion of watershed as well as along the Minnesota River floodplain. Open water accounts for 5% of the watershed area and wetlands another 8%.

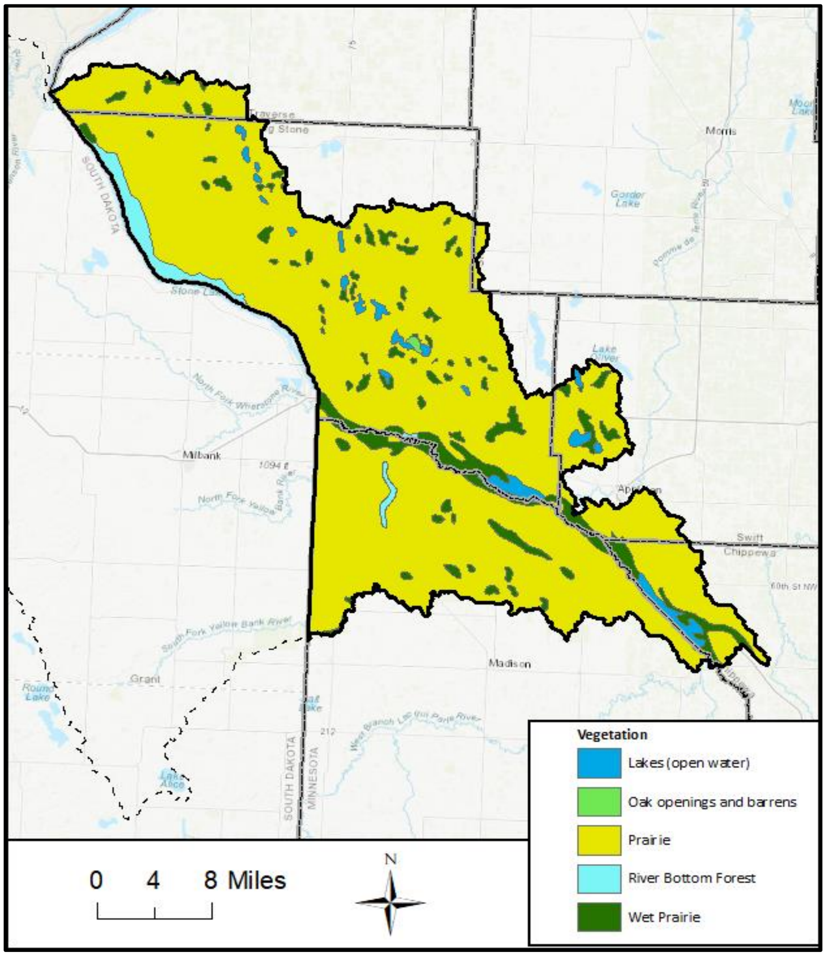

Figure 4. Marschner's pre-European settlement vegetation for the Minnesota River Headwaters Watershed (DNR 1994).

More information on the watershed characteristics of the MRHW can be found in the *Minnesota River Headwaters Watershed Characterization Report* (DNR 2019) and/or the *Minnesota River Headwaters Watershed Monitoring and Assessment Report* (MPCA 2018).

3.1 Streams

The 11 impaired stream reaches in the MRHW addressed in this TMDL report cover approximately 58 river-miles and the impaired reaches' drainage areas cover the majority of the watershed area of approximately 947 sq mi, with 591 sq mi in Minnesota. This TMDL report does not address South Dakota impaired reaches that contribute to Minnesota impaired waters. Reach information for each impaired stream in the watershed covered by this TMDL report is presented in **Table 5.**

Table 5. Approximate drainage areas and stream lengths of impaired stream reaches addressed in this TMDL report.

WID	Stream/Reach Name	Reach Length [miles]	Total Drainage Area [1] [sq mi]	Drainage Area in Minnesota [sq mi]
07020001-504	Unnamed creek (West Salmonsen Creek), Unnamed cr to Big Stone Lk	6.11	26.7	26.7
07020001-508	Little Minnesota River, MN/SD border to Big Stone Lk	4.75	317	7.3
07020001-521	Unnamed creek (Five Mile Creek), Unnamed cr to Marsh Lk	6.19	89.3	89.3
07020001-531	Stony Run Creek, Unnamed cr to Minnesota R	5.2	128.9	128.9
07020001-536	Stony Run Creek, Long Tom Lk to Unnamed cr	2.85	120	120
07020001-541	Unnamed creek, Unnamed cr to Big Stone Lk	3.48	33.2	33.2
07020001-547	Emily Creek, Unnamed cr to Lac qui Parle Lk	6.18	36.4	36.4
07020001-551	Unnamed creek, Headwaters to S Fk Yellow R	4.87	49.2	2.4
07020001-568	Unnamed creek (Meadowbrook Creek), 340th St to Big Stone Lk	5.43	18.3	18.3
07020001-570	Unnamed creek, CSAH 38 to Marsh Lk	4.81	48.9	48.9
07020001-571	Fish Creek, Headwaters to CSAH 33	8.36	79.8	79.8

[1] Square miles

3.2 Lakes

The drainage areas of the five lakes in the MRHW addressed in this TMDL report cover the entire 1,364,542 acres of the watershed, plus approximately 2.57 million additional acres from outside the watershed, for a total drainage area of approximately 3.9 million acres. Lac qui Parle Lake (37-0046-01 and 37-0046-02) drains areas encompassing four HUC-08 watersheds - MRHW (07020001), Pomme de Terre River (07020002), portions of Chippewa River (07020005), and Lac qui Parle River (07020003) watersheds (**Figure 7**). This TMDL report does not address South Dakota impaired lakes that contribute to Minnesota impaired waters. Lake information for each impaired lake in the watershed covered by this TMDL report are presented in **Table 6.**

Table 6. Approximate drainage areas of impaired lakes in this TMDL report.

WID	Lake Name	Surface Area [acres]	Average Depth [feet]	Lakeshed Area - Direct Drainage [acres]	Lakeshed Area - Total Drainage [acres]	Lakeshed Area: Surface Area Ratio	Drainage Area in Minnesota [sq mi]
06-0029-00	Long Tom, Lake or Reservoir	135	15	1,181	75,226	557	118
06-0060-00	Unnamed, Lake or Reservoir	55	13	5,997	74,046	1,346	116
06-0152-00	Big Stone, Lake or Reservoir	18,889	15	69,191	487,959	26	217
37-0046-01	Lac qui Parle (SE Bay), Lake or Reservoir	3,573	10	16,164	3,934,809	1,101	4,464
37-0046-02	Lac qui Parle (NW Bay), Lake or Reservoir	2,095	10	10,946	1,844,775	881	1,534

3.3 Subwatersheds

The drainage areas (subwatersheds) for each impaired stream reach are shown in **Figure 5.** The drainage areas for select impaired lakes (Big Stone, Unnamed, and Long Tom Lakes) are shown in **Figure 6**. The drainage areas for Lac qui Parle Lake (NW and SE Bays) are shown in **Figure 7**.

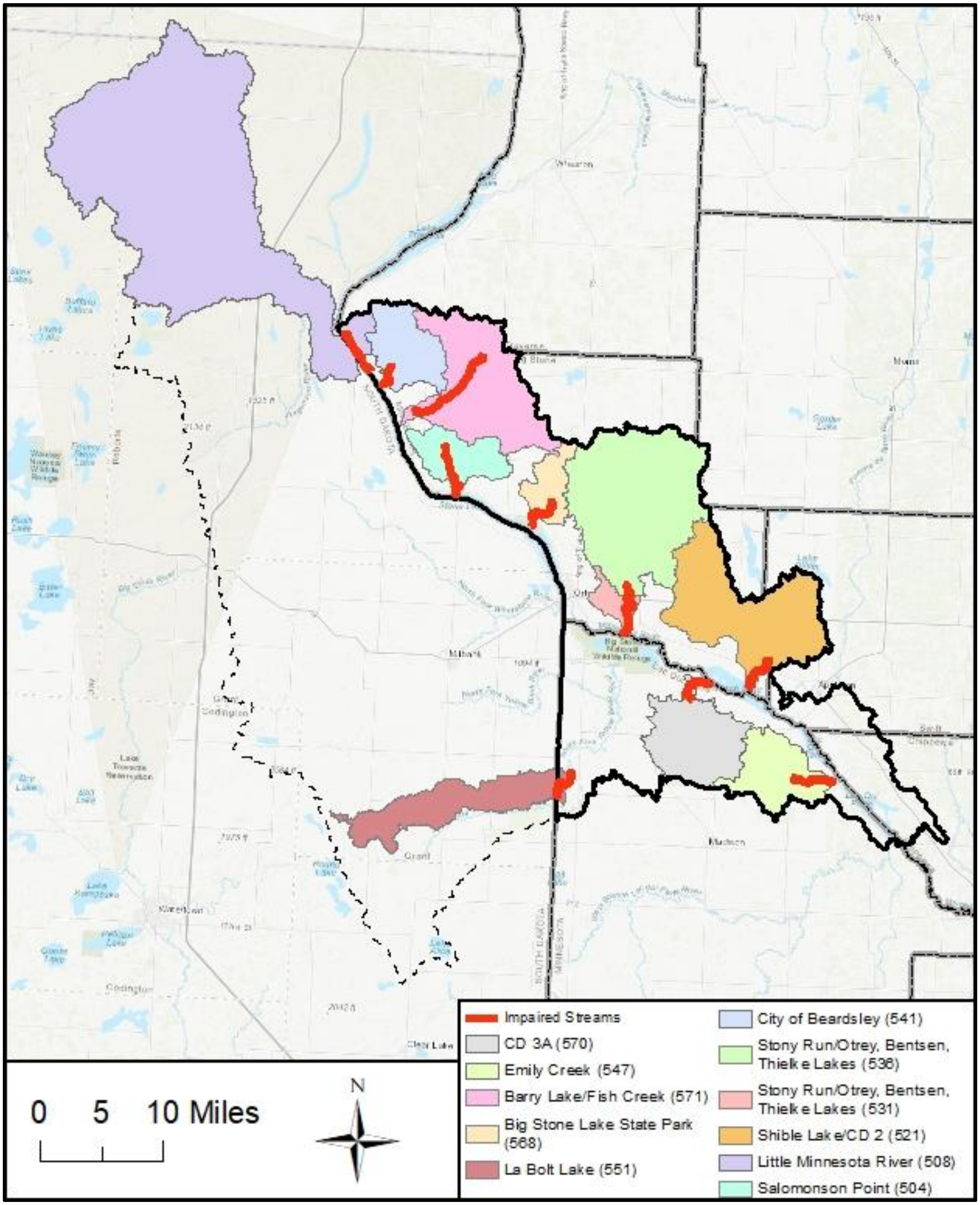

Figure 5. Drainage areas of impaired stream reaches addressed in this TMDL report.

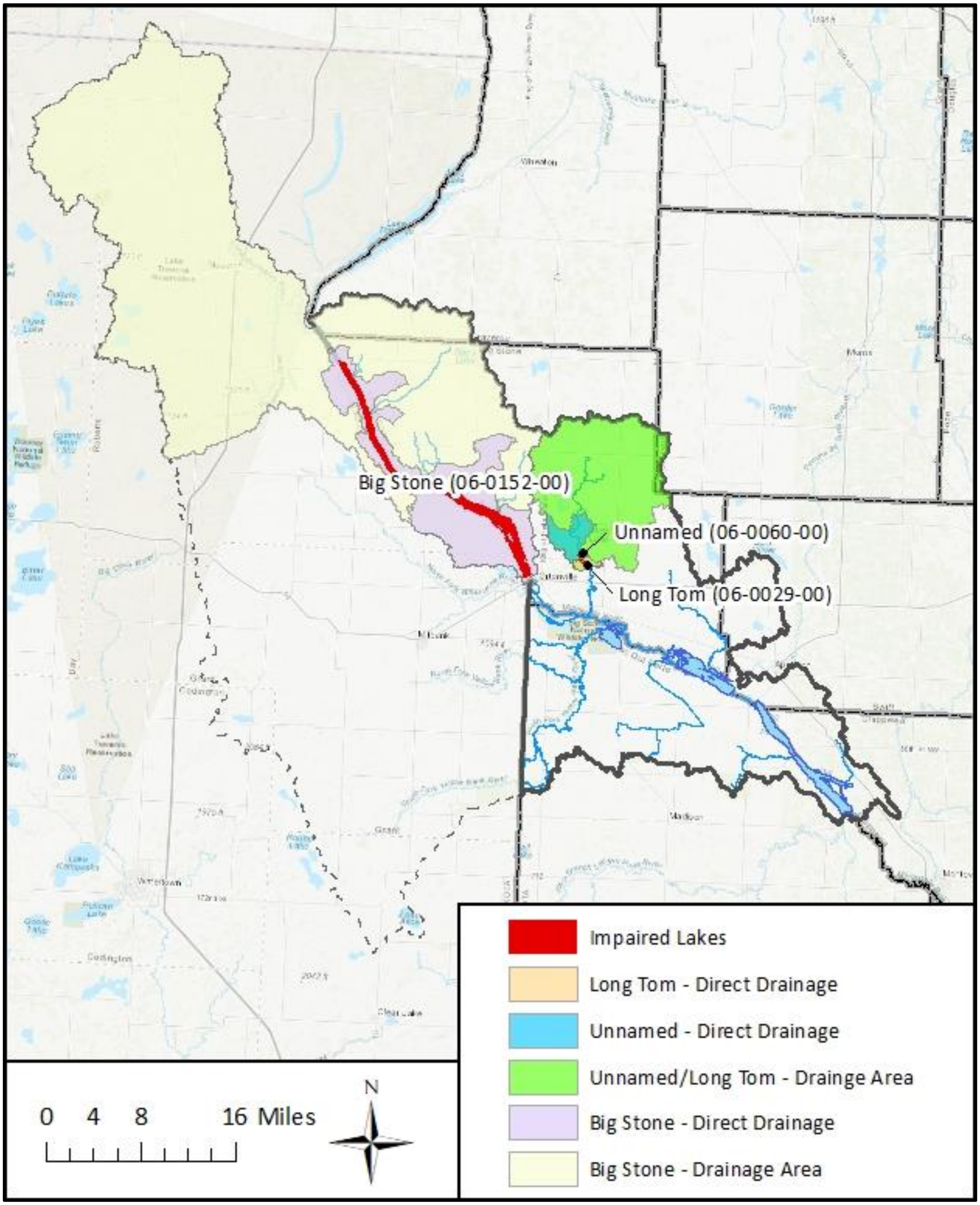

Figure 6. Drainage areas of impaired lakes (Big Stone, Unnamed, and Long Tom) addressed in this TMDL report.

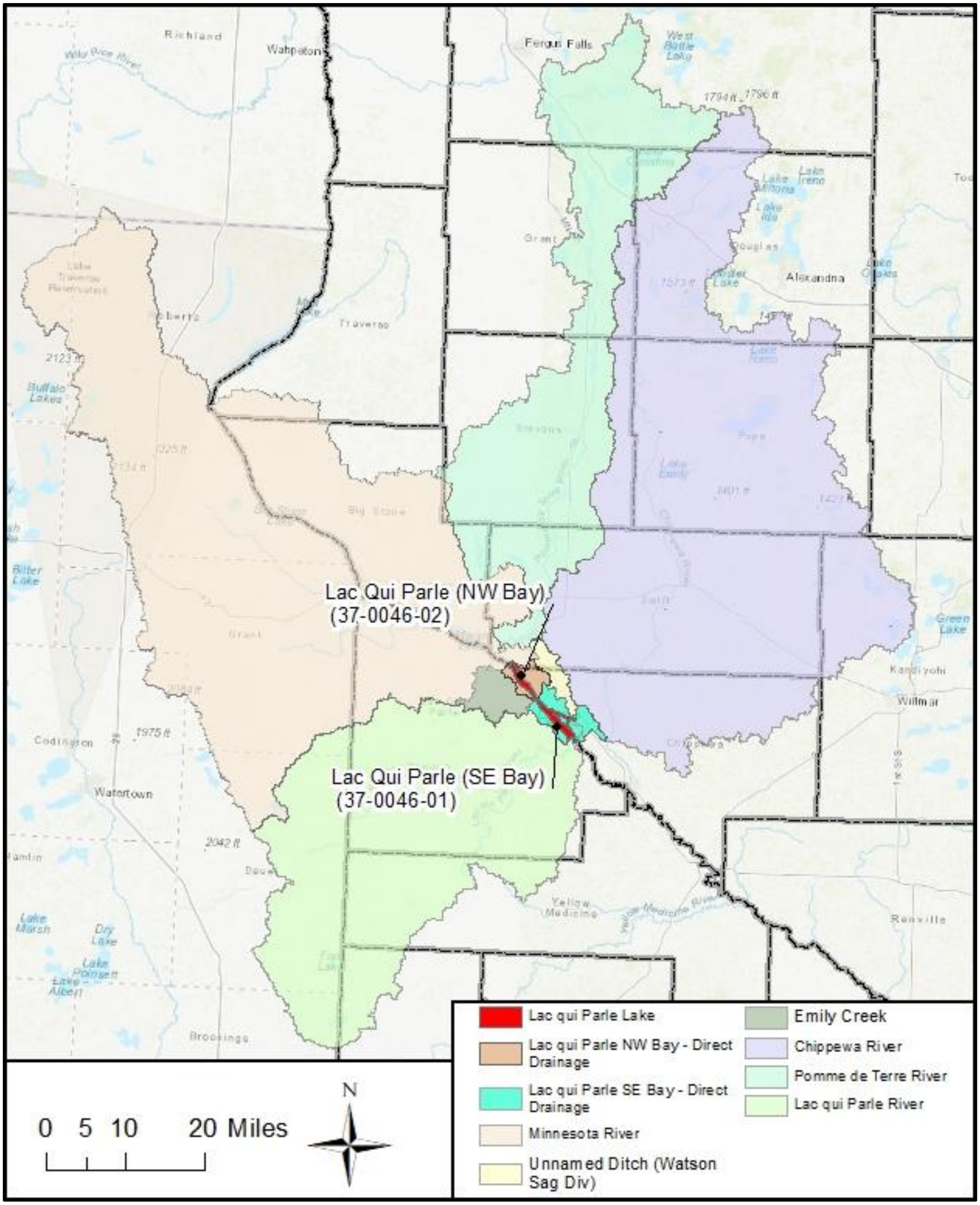

Figure 7. Drainage area for Lac qui Parle Lake.

3.4 Land use

Land cover in the MRHW was assessed using the Multi-Resolution Land Characteristics Consortium National Land Cover Dataset (NLCD) from 2016 (MRLC 2016). This information is necessary to draw conclusions about pollutant sources that may be applicable in each impaired stream reach. The land use distribution for the watershed and impaired stream reaches is provided in **Table 7** and shown in **Figure 8**. The percentages in **Table 7** are for total drainage area of the impaired waterbody and for Minnesota's portion of each drainage area, where applicable. The MRHW is dominated by cropland, accounting for 65% of total watershed area in Minnesota. Wetlands make up the second most prevalent land use type at 13% of total watershed area in Minnesota. The remaining land use types are split amongst rangeland (8%), open water (7%), developed (5%), forests and shrubs (1%), and barren (<1%).

When comparing land use in just the Minnesota portion to the entire watershed (including South and North Dakota), the area in Minnesota contains a larger percentage of cropland (65% versus 54%) and a smaller percentage of rangeland (8% versus 27%). Additionally, Minnesota contains slightly more wetland and open water coverage (3% to 4% more). The other land use types cover a similar percentage of land area as compared to the total watershed.

Table 7. Land cover percentages in the Minnesota River Headwaters Watershed (MRLC 2016).

WID	Drainage Area Portion	Drainage Area [sq mi]	Land Use/Land Cover Percentage of Drainage Area [%]						
			Cropland	Rangeland	Developed	Wetland	Water	Forest/Shrub	Barren/Mining
Total Watershed	Total	2,132	53.6%	26.8%	4.7%	8.3%	4.7%	1.7%	0.13%
	MN only	784	65.4%	8.2%	4.9%	12.9%	7.4%	0.93%	0.16%
07020001-504	Total*	27	89.4%	3.9%	4.4%	1.7%	0.05%	0.58%	0.01%
07020001-508	Total	317	46.8%	34.9%	4.5%	7.3%	2.47%	3.95%	0.17%
	MN only	7.3	54.8%	19.5%	12.2%	11.7%	0.03%	1.7%	0.08%
07020001-521	Total*	89	74.9%	4.7%	5.1%	10.9%	3.5%	0.90%	0.09%
07020001-531	Total*	129	66.1%	7.3%	4.4%	11.1%	10.3%	0.81%	0.06%
07020001-536	Total*	120	66.4%	7.0%	4.3%	11.0%	10.5%	0.85%	0.02%
07020001-541	Total*	33	83.2%	3.6%	5.3%	5.3%	1.9%	0.59%	0.12%
07020001-547	Total*	36.4	78.5%	7.5%	3.6%	8.3%	1.1%	0.8%	0.1%
07020001-551	Total	49	60.8%	30.5%	4.3%	3.3%	0.40%	0.63%	0.00%
	MN only	2.4	88.5%	0.95%	6.1%	3.0%	1.0%	0.44%	0.06%
07020001-568	Total*	18	81.8%	4.7%	4.2%	3.3%	5.1%	0.84%	0.06%
07020001-570	Total*	48.9	86.4%	1.5%	3.9%	7.3%	0.2%	0.6%	0.00%
07020001-571	Total*	80	75.6%	5.1%	4.3%	5.2%	9.3%	0.31%	0.12%
06-0029-00	Total*	118	67.1%	3.3%	4.2%	10.9%	10.5%	4.0%	0.02%
06-0060-00	Total*	116	67.9%	3.2%	4.3%	10.7%	10.4%	3.58%	0.02%
06-0152-00	Total	762	51.5%	28.5%	4.6%	6.5%	5.8%	3.0%	0.13%
	MN only	217	73.7%	6.6%	5.2%	4.9%	8.7%	0.8%	0.10%
37-0046-01	Total[1]	2,132	53.6%	26.8%	4.7%	8.3%	4.7%	1.7%	0.13%
	MN only	784	65.4%	8.2%	4.9%	12.9%	7.4%	0.93%	0.16%
37-0046-02	Total[1]	2,008	52.7%	27.9%	4.7%	8.2%	4.6%	1.8%	0.13%
	MN only	659	64.8%	8.1%	4.9%	13.4%	7.8%	0.95%	0.16%

*Watershed entirely contained in Minnesota

[1] Minnesota River Headwaters Watershed only.

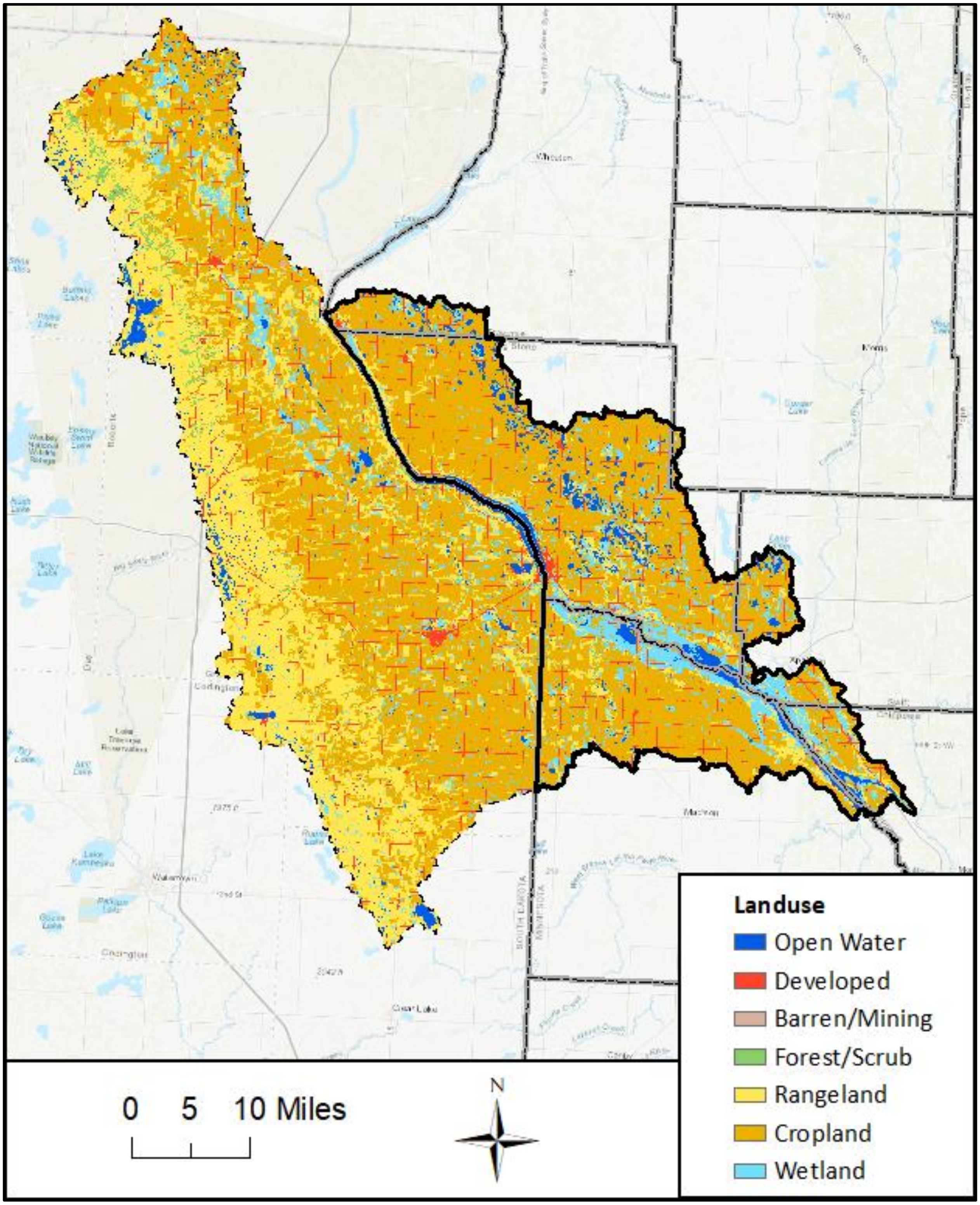

Figure 8. Land use classification in the Minnesota River Headwaters Watershed.

3.5 Current/historical water quality

Existing water quality conditions are described using data downloaded from the MPCA's Environmental Quality Information System (EQuIS) database[1]. EQuIS stores data collected by the MPCA, partner agencies, grantees, and citizen volunteers. All water quality sampling data utilized for assessments, modeling, and data analysis for this report and reference reports, are stored in this database and are accessible through the MPCA's Environmental Data Access (EDA) website[1].

Data from the current 10-year MRHW assessment period (2008 through 2017), consistent with the time period for the application of the water quality numeric standards, were used for development of this TMDL report. For *E. coli*, only data collected during the months of April through October for Class 2B streams were used. For Class 2B lakes, eutrophication data for June through September were used. Although data prior to 2008 exists, the more recent data represents the current conditions in the waterbody.

Monitoring locations used for this TMDL report are shown in **Figure 9** and they and their data are summarized in **Table 8** (streams) and **Table 9** (lakes).

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[1] https://www.pca.state.mn.us/environmental-data

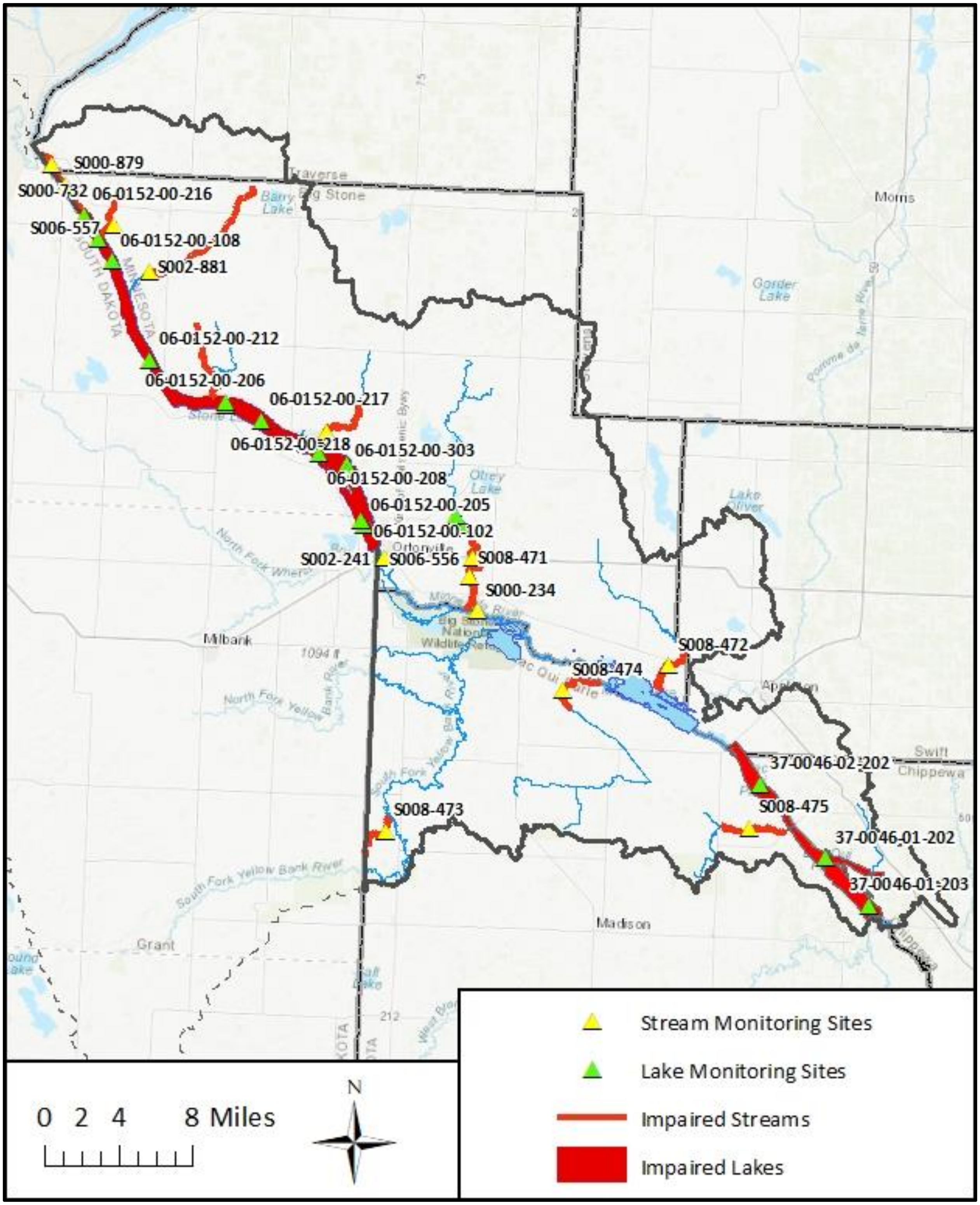

Figure 9. Monitoring locations for impaired streams and lakes used in this TMDL report.

3.5.1 Escherichia coli

E. coli is summarized using the geometric mean of all samples in a calendar month. The geometric mean better normalizes data from different flow conditions and allows a percentage change to be made equally to the geometric mean across watersheds. The geometric mean can be calculated using the following function:

$$\text{Geometric mean} = \sqrt[n]{x_1 * x_2 * \dots x_n}$$

Where $x_1, x_2, \dots, x_n$ are *E. coli* concentrations for each sampling month.

Table 8 shows the monthly *E. coli* statistics (count, geometric mean, and number of samples above 1,260 org/100 mL) for assessment unit IDs (AUIDs) needing an LDC in the MRHW. It should be noted that data is only available from June through August, as shown in **Table 8**.

Table 8. Existing *E. coli* conditions in impaired reaches requiring TMDLs in the Minnesota River Headwaters Watershed.

AUID	Station(s)	Years	June			July			August		
			n	Geo[1]	%n> 1260[2]	n	Geo[1]	%n> 1260[2]	n	Geo[1]	%n> 1260[2]
07020001-504	S002-879	2011-2012	5	519	20%	5	754	40%	6	685	0%
07020001-508	S000-732	2011-2016	10	544	20%	10	375	0%	11	195	0%
07020001-521	S008-472	2015-2016	5	293	0%	5	491	0%	5	300	0%
07020001-531	S008-471	2015-2016	5	491	20%	5	370	20%	5	180	0%
07020001-536	S006-556	2011-2012	5	108	20%	5	353	40%	6	318	33%
07020001-541	S006-557	2011-2016	10	1,731	70%	10	612	20%	11	980	45%
07020001-547	S008-475	2015-2016	5	1,467	80%	5	709	20%	5	1720	40%
07020001-551	S008-473	2015-2016	5	306	0%	5	921	60%	5	687	40%
07020001-568	S002-877	2011-2012	5	203	0%	5	366	0%	6	471	17%
	S008-470	2015-2016	5	133	0%	5	196	0%	5	319	0%
	All	2011-2016	10	164	0%	10	268	0%	11	395	0%
07020001-570	S008-474	2015-2016	5	75.8	0%	5	395	0%	5	395	20%
07020001-571	S002-881	2011-2016	10	326	10%	10	237	0%	11	283	0%

[1] Geo = geometric mean with units of org/100 mL; WQS is 126 org/100 mL.

[2] %n>1260 = percentage of samples above the 1,260 org/100 mL water quality standard.

3.5.2 Lake Nutrients

In general, historical in-lake water quality data collected from the period 1996 through 2017 were reviewed and summarized for use in this TMDL report. **Table 9** provides the number of samples and average (mean) measurements during the summer (June through September) for TP, Chl-*a*, and Secchi disk depths. The water quality standard for shallow lakes in the NGP ecoregion is 90 ug/L.

Table 9. Existing eutrophication conditions in impaired lakes covered in this TMDL report.

Lake Name	Station	Observation Period	TP (Standard: 90 μg/L)		Chl-*a* (Standard: 30 μg/L)		Secchi Disk Depth (Standard: 0.7 m)	
			n	Average [μg/L]	n	Average [μg/L]	n	Average [m]
Long Tom	06-0029-00-101	2011-2012	11	422	11	60	11	0.434
Unnamed	06-0060-00-201	2015-2016	8	597	8	97	8	1.41
Big Stone	06-0152-00-107	2011-2017	14	219.9	14	24.4	14	0.667
	06-0152-00-108	2007-2011	25	215	25	30.2	25	0.854
	06-0152-00-212	1996-2004					136	1.57
	06-0152-00-216	1996-2002					99	2.16
	06-0152-00-100	2015	1	60	1	4.28		
	06-0152-00-101	2008	1	78	1	9.62		
	06-0152-00-102	2015					10	2.18
	06-0152-00-205	2010-2015	23	103.6	22	26.8	20	1.68
	06-0152-00-206	1996					10	1.98
	06-0152-00-208	2007-2017			1	5	35	2.92
	06-0152-00-217	2005-2017					88	2.01
	06-0152-00-218	2005					4	1.94
	06-0152-00-303	2012			1	39.9	1	1.6
Lac qui Parle (NW Bay)	37-0046-02-202	2008-2015	15	161	15	69.5	15	0.47
Lac qui Parle (SE Bay)	37-0046-01-202	2015	5	124.2	5	54.8	5	0.70
	37-0046-01-203	2008-2009	10	153	10	52.9	10	0.57

3.6 Pollutant source summary

3.6.1 Escherichia coli

Bacteria in Minnesota lakes and streams mainly come from sources such as failing septic systems, WWTP releases, livestock, pets, wildlife, and urban stormwater. In addition to bacteria, human and animal waste may contain pathogens such as viruses and protozoa that could be harmful to humans and other animals.

The behavior of bacteria and pathogens in the environment is complex. Levels of bacteria and pathogens in a body of water depend not only on their source, but also weather, current, and water temperature. As these factors fluctuate, the level of bacteria and pathogens in the water may increase or decrease. Some bacteria can survive and grow in the environment while many pathogens tend to die off with time.

A literature review conducted by Emmons and Oliver Resources (EOR 2009) for the MPCA summarizes factors that have either a strong or a weak relationship to bacteria contamination in streams (**Table 10**). Bacteria sourcing can be very difficult due to the bacteria's ability to persist, reproduce, and migrate in unpredictable ways. Therefore, the factors associated with bacterial presence provide some confidence to bacterial source estimates.

Table 10. Summary of factor relationships associated with bacteria source estimates of streams (EOR 2009).

Strong relationship to fecal bacteria contamination in water	Weak relationship to fecal bacteria contamination in water
• High storm flow (the single most important factor in multiple studies) • % rural or agricultural areas greater than % forested areas in the landscape • % urban areas greater than forested riparian areas in the landscape • High water temperature • High % impervious surfaces • Livestock present • Suspended solids	• High nutrients • Loss of riparian wetlands • Shallow depth (bacteria decrease with depth) • Amount of sunlight (increased UV-A deactivates bacteria) • Sediment type (higher organic matter, clay content and moisture; finer-grained) • Soil characteristics (higher temperature, nutrients, organic matter content, humidity, moisture and biota; lower pH) • Stream ditching (present or when increased) • Epilithic periphyton present • Presence of waterfowl or other wildlife • Conductivity

Livestock and manure application, pasture area, human populations (wastewater treatment facilities and subsurface sewage treatment systems (SSTS), pet populations, and wildlife populations were all evaluated as sources of *E. coli*. As discussed below, the relative significance of each of these sources can vary depending on manure management and storage practices, climactic conditions, and stream flow. It should be noted, most of the following information is specific to Minnesota's portion of the watershed and does not include South Dakota's or North Dakota's portion of the watershed. This is due to the availability of information, and the fact this TMDL covers Minnesota's portion of the watershed only. Additional information about the methodology of bacteria source assessment in the MRHW is found in **Appendix D** and source tables by reach are in **Appendix C**.

3.6.1.1 Permitted sources

Permitted sources that are sources regulated through the NPDES were evaluated as potential sources of *E. coli* in impaired reaches. These permitted sources include wastewater effluent and permitted animal feedlot operations (AFOs).

Wastewater Treatment Plants

Human waste can be a significant source of *E. coli* during low flow periods. There are 11 NPDES wastewater permits in the MRHW - 9 domestic wastewater permits and 2 industrial permits. Of the 11 permits, 5 WWTPs discharge to impaired reaches and are sources of bacteria (see **Section 4.3.3**). All five plants have controlled discharge (pond) systems with discharge windows from March 1 to June 15 and September 15 to December 15. While *E. coli* bacterial loads discharged by WWTPs can theoretically comprise a significant portion of a receiving water's LC during low flow periods, bacterial effluent limits in WWTP permits are intended to ensure that wastewater is effectively disinfected prior to discharge. Rarely, during extreme high flow conditions, WWTPs may also be a source if they become overloaded and have an emergency discharge of partially or untreated sewage, known as a release.

Municipal Stormwater Runoff

Urban areas may contribute bacteria to surface waters from pet waste and wildlife. There are no permitted Municipal Separate Storm Sewer System (MS4) areas within the MRHW. Therefore, bacteria from permitted MS4 areas is not a source of *E. coli* in the watershed.

Feedlot Facilities

In Minnesota, AFOs are required to register with their respective county or the state if they are 1) an animal feedlot capable of holding 50 or more animal units (AUs), or a manure storage area capable of holding the manure produced by 50 or more AUs outside of shoreland; or 2) an animal feedlot capable of holding 10 or more AUs, or a manure storage area capable of holding the manure produced by 10 or more AUs, that is located within shoreland. Further explanation of registration requirements can be found in Minn. R. 7020.0350. Feedlots within delegated counties are registered through a County Feedlot Officer. Feedlots in nondelegated counties, all feedlots that are at or above 1,000 AU, and all feedlots that meet the EPA definition of a Large Concentrated Animal Feeding Operation (CAFO) are registered directly with the MPCA.

CAFOs are defined by the EPA based on the number and type of animals. The MPCA currently uses the federal CWA definition of a CAFO in permit requirements of animal feedlots along with the definition of AUs. In Minnesota, the following types of livestock facilities are issued, and must operate under, a NPDES Permit or a state issued SDS Permit: a) all federally defined CAFOs, which have had a discharge, some of which are under 1,000 AUs in size; and b) all CAFOs and non CAFOs that have 1,000 or more AUs.

CAFOs and AFOs with 1,000 or more AUs must be designed to contain all manure and manure contaminated runoff from precipitation events of less than a 25-year - 24-hour storm event. Having and complying with an NPDES permit allows some enforcement protection if a facility discharges due to a 25-year - 24-hour precipitation event (approximately 4.47” in 24 hours) and the discharge does not contribute to a water quality impairment. Large CAFOs permitted with an SDS permit or those not covered by a permit must contain all runoff, regardless of the precipitation event. Therefore, many Large CAFOs in Minnesota have chosen to have an NPDES permit, even if discharges have not occurred in the past at the facility. A current manure management plan, which complies with Minn. R. 7020.2225, and the respective permit is required for all CAFOs and AFOs with 1,000 or more AUs.

Permitted CAFOs are inspected by the MPCA in accordance with the MPCA NPDES Compliance Monitoring Strategy approved by the EPA. All large CAFOs (NPDES permitted, SDS permitted, and not required to be permitted) are inspected by the MPCA on a routine basis with an appropriate mix of field inspections, offsite monitoring and compliance assistance. The number of AUs by animal type registered with the MPCA feedlot database are used in this TMDL report.

The locations of registered feedlot operations and CAFOs are provided in **Figure 10** which shows the level of AUs at each location. In the watershed, there are 115 registered feedlot operations, in which 7 are CAFOs, with approximately 33,522 AUs. The primary animal type in the watershed is cattle (49%) and swine (46%). A complete list of CAFOs by TMDL WID is located in **Appendix E**.

All NPDES and SDS permitted feedlots are designed to have zero discharge, and as such they are not considered a significant source of *E. coli* for the MRHW TMDL. All other feedlots are accounted for as nonpermitted sources. The land application of all manure, regardless of whether the source of the manure originated from permitted (e.g., CAFOs) or nonpermitted AFOs, is also accounted for as a nonpermitted source.

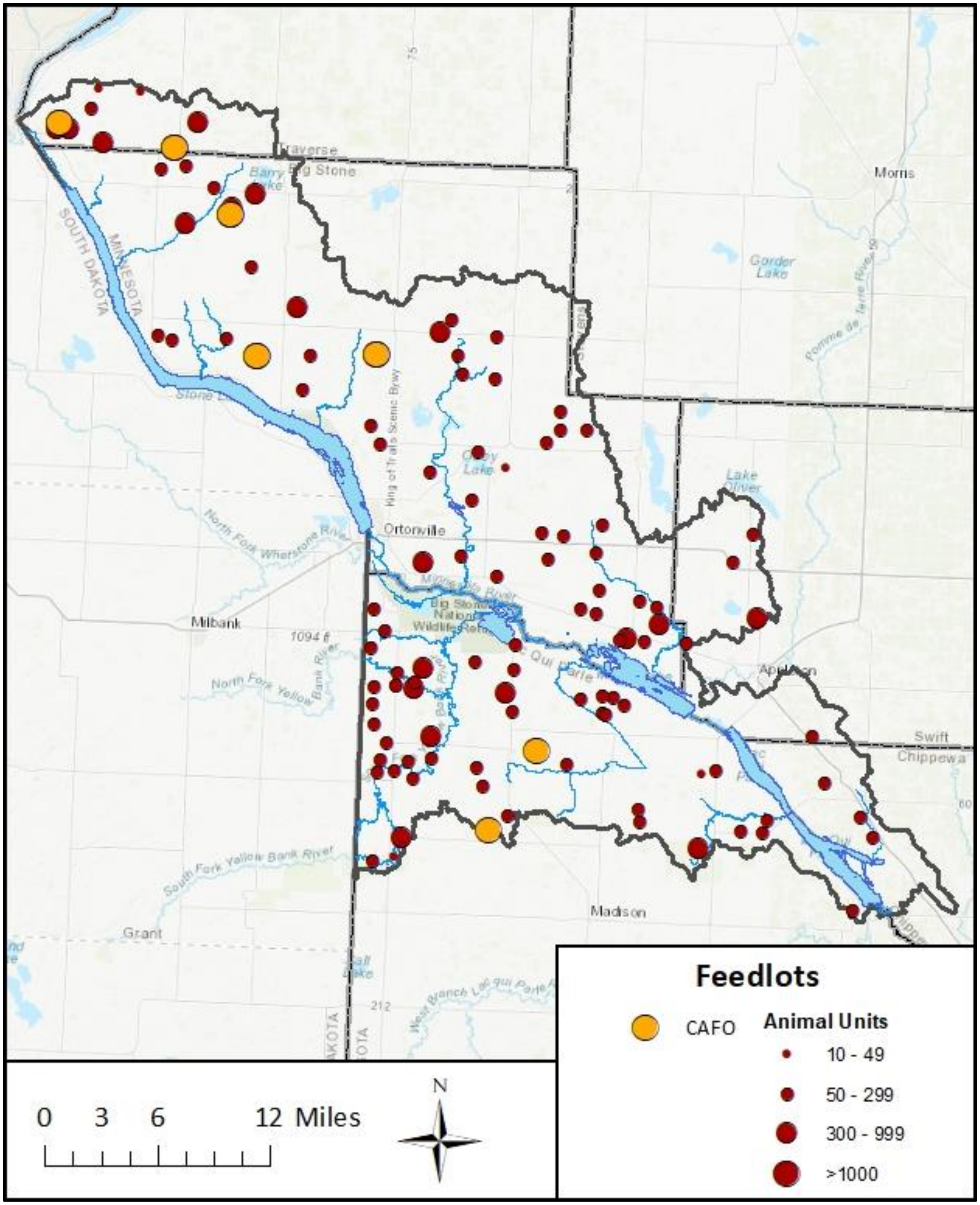

Figure 10. Feedlots in Minnesota's portion of the Minnesota River Headwaters Watershed.

3.6.1.2 Nonpermitted sources

Subsurface sewage treatment systems

Failing SSTS near waterways can be a significant source of bacteria to streams and lakes, especially during low flow periods when these sources continue to discharge, and runoff driven sources are not active. The MPCA differentiates between systems that are generally failing and those that are an imminent public health threat (IPHTs). Generally, failing systems are those that do not provide adequate treatment and may contaminate groundwater. For example, a system deemed failing to protect groundwater may have a functioning, intact tank and soil absorption system, but fail to protect ground water by providing a less than sufficient amount of unsaturated soil between where the sewage is discharged and the ground water or bedrock. Systems that have been identified as an IPHT may include systems that back up inside the house, discharge to the surface, have unsecured or damaged maintenance hole covers, and “straight pipes” which may transport raw or partially treated sewage directly to a lake, a stream, a drainage system, or ground surface (Minn. Stat. 115.55, subd. 1).

Counties are required to submit annual reports to the MPCA regarding SSTS within their respective boundaries. Data reported is aggregate information by each county so the location of SSTSs are not known to the State of Minnesota. SSTS data from 2016 in each county is shown in **Figure 11** and annual reports by counties in the watershed indicate that failing SSTS range from 0.27 (Traverse) to 5.85 (Swift) systems per 1,000 acres. These counties continue to invest in the education of landowners on the maintenance and impact failing systems can have on humans and wildlife.

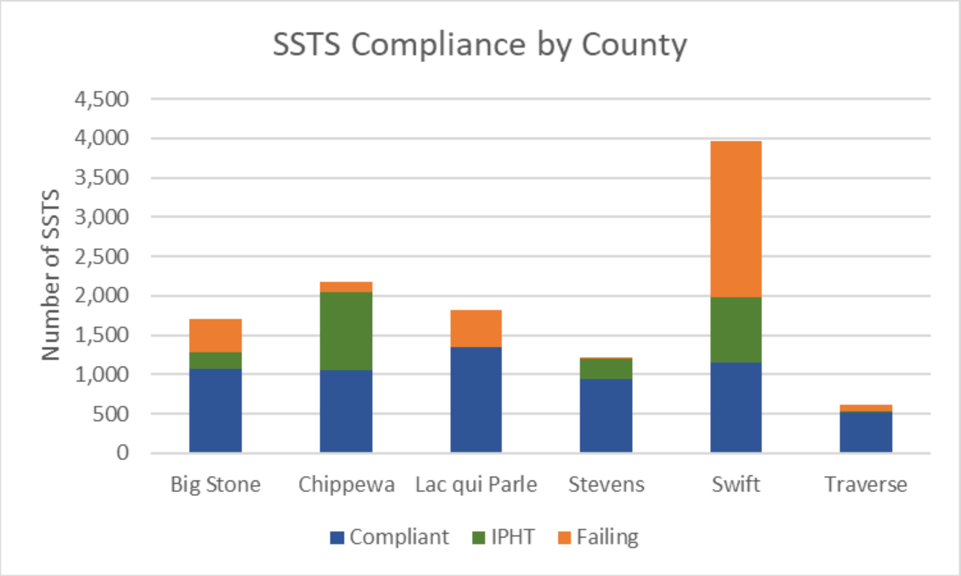

Figure 11. SSTS compliance by county for counties in the Minnesota River Headwaters Watershed.

Non NPDES Permitted Feedlots and Manure Application

AFOs under 1,000 AUs and those that are not federally defined as CAFOS do no operate with permits. These facilities must operate their facilities in accordance with Minn. R. 7020.2000 through 7020.2150 to minimize their impact on water quality. AFOs may pose an environmental concern if the facilities are located near water and manure is inadequately managed, especially in open lot feedlots. Open lots, and those located near surface water bodies present a potential pollution hazard if runoff from the lot is not treated prior to reaching a surface water. There are 95 facilities in the MRHW that have open lots. Of those with open lots, 12 are located within 1,000 feet of a lake or 300 feet of a stream and 12 have an open lot in shoreland areas.

Approximately 46% of the AUs in the watershed are swine and the majority of the manure is held in liquid manure storage areas (LMSA) and is generally injected or immediately incorporated. Another 49% of the AUs are cattle and the manure is held in either LMSAs or in stockpiles if in solid form. Solid manure is generally broadcasted and has delayed incorporation. When stored and applied properly, manure provides a natural nutrient source for crops.

Manure can be a significant source of bacteria. AFOs create a large amount of manure that is usually stored on site until field conditions and the crop rotation allow for land application of manure as a fertilizer. The timing of manure application can decrease the likelihood of bacteria loading to nearby waterbodies. Specifically, the application of manure on frozen soil in the late-winter is likely to result in surface runoff during precipitation events and snow melt. Deferring manure application until soils have thawed decreases overland runoff during snow melt and precipitation events. Injected manure is a preferred best management practice (BMP) to reduce the runoff of waste and associated bacteria, as injected manure reduces the risk of surface runoff associated with large precipitation events.

Pasture

Livestock can contribute to bacteria loading to waterbodies from poorly managed pasture lands that are overgrazed, or through the direct access of livestock to surface waters. Currently, Minnesota does not have rules regulating pasture runoff. Poorly maintained pasture can have significant overland surface flow during heavy precipitation events resulting in manure transport from the pasture. Livestock with direct access to streams and lakes can defecate directly into the waterbody resulting in direct contamination.

Wildlife and Pets

Wildlife and pet waste can contribute bacteria to streams and lakes, directly or through surface runoff. Like livestock and humans, *E. coli* is present in the digestive tracts of wildlife and pets and as such, some *E. coli* may be present in the water from these sources. Waterfowl contribute bacteria to the watershed by directly defecating into waterbodies and along the shorelines. They contribute bacteria by living in waterbodies, living near conveyances to waterbodies, or when their waste is delivered to water bodies in stormwater runoff. Areas such as state parks, national wildlife refuges, golf courses, state forest, and other conservation areas provide habitat for wildlife and are potential sources of bacteria due to the high density of animals.

Waterfowl populations were estimated by the U.S. Fish and Wildlife Service by utilizing pond level models that estimate breeding duck pairs. This model was developed from annual waterfowl populations surveys that have been conducted since the late 1980s (Reynolds et. al. 2006). The results of the model are used primarily for conservation planning and delivery, however, they are also utilized for estimating waterfowl densities. Waterfowl and wildlife population estimates for each *E. coli* impaired reach addressed in this TMDL report are provided in **Appendix C**.

Natural Reproduction

Evidence suggests that *E. coli* bacteria has the capability to reproduce naturally in water and sediment and therefore could be considered a self-propagating bacteria source. The relationship between bacterial sources and bacterial concentrations found in streams is complex, involving precipitation and flow, temperature, livestock management practices, wildlife activities, survival rates, land use practices, and other environmental factors. Two Minnesota studies describe the presence and growth of "naturalized" or "indigenous" strains of *E. coli* in watershed soils (Ishii et al. 2010), and ditch sediment and water (Sadowsky et al. 2015). Sadowsky et al. concluded that approximately 36.5% of *E. coli* strains were represented by multiple isolates, suggesting persistence of specific *E. coli* and that 36% might be used as a rough indicator of "background" levels of bacteria at this site during the study period. While these results may not be directly transferable to other locations, they do suggest the presence of background *E. coli* and a fraction of *E. coli* may be present regardless of the control measures taken by traditional implementation strategies. The *E. coli* LAs include natural background.

3.6.1.3 Source Summary

Sources of fecal bacteria are typically widespread and often intermittent. In the MRHW, the *E. coli* standard is exceeded across most flow conditions for which data were available (**Figure 17** through **Figure 27**), indicating a mix of source types. During low-flow conditions, continuous sources (failing SSTS, small communities with wastewater needs, WWTPs) can generate high concentrations of bacteria. When precipitation and stream flows are high, the influence of continuous sources is overshadowed by weather-driven sources such as manure runoff and urban stormwater.

A qualitative approach was used to identify permitted and nonpermitted sources of *E. coli* in the watershed. *E. coli* sources evaluated in the MRHW *E. coli* TMDLs include permitted sources such as wastewater, and permitted AFOs, and nonpermitted sources from humans, livestock, wildlife, and self-propagation. The relative significance of each source at any one time depends largely on climate, land management, and stream flow conditions.

3.6.2 Lake Nutrients

Phosphorus and nitrogen (N) are the primary nutrients that, in excessive amounts, pollute lakes, streams, and wetlands. The limiting nutrient controlling algal production and excessive nutrient impairments in lakes is phosphorus. Phosphorus is an essential element for plant life, but when there is too much in the water growth of algae can be accelerated resulting in nuisance algae blooms. Phosphorus is a common constituent of agricultural fertilizers, manure, and organic wastes in sewage and industrial effluent. Phosphorus has an affinity to bind to soil particles, therefore, soil erosion is also a contributor. Streambank erosion occurring during flood events can transport phosphorus to streams and lakes.

Nutrient sources are described in more detail below by permitted and nonpermitted sources, followed by a summary of phosphorus sources and loading to individual impaired lakes.

3.6.2.1 Permitted sources

Wastewater Treatment Plants

WWTPs can contribute phosphorus to lakes and streams. There are six WWTPs that discharge to impaired waters in the MRHW and are sources of phosphorus (see **Section 4.4.3**). All six plants have controlled discharge (pond) systems with discharge windows from March 1 to June 15 and September 15 to December 15. Rarely, during extreme high flow conditions, WWTPs may also be a source if they become overloaded and have an emergency discharge of partially or untreated sewage, known as a release. There are also 11 industrial permits within the watershed; however, only 1 is permitted for dewatering and therefore requires a WLA. The remaining 10 industrial permits are covered under an industrial stormwater permit and are covered by the industrial stormwater WLA.

In addition to the WWTPs in the MRHW, Lac qui Parle Lake receives water and phosphorus from the Lac qui Parle River, Pomme de Terre River, and a portion of Chippewa River watersheds. The Lac qui Parle River Watershed has 7 permitted WWTPs, the Chippewa River Watershed has 16 permitted WWTPs, and the Pomme de Terre River Watershed has 8 permitted WWTPs that drain to Lac qui Parle Lake. Based on this TMDL, 16 of the 38 facilities will have a new or potentially revised TP permit limit (**Table 11**). A meeting was held with the permitted facilities to present the TMDLs and explain the impacts to the permit limits, see **Section 9**.

Table 11. Summary of permit status changes for permitted facilities based on the Lac qui Parle Lake - SE Bay and Lac qui Parle Lake - NW Bay TMDLs.

Facility	New/Revised TP Permit Limit	Major Watershed	Facility	New/Revised TP Permit Limit	Major Watershed
Ag Processing Inc - Dawson	Yes	Lac qui Parle	Hancock WWTP	No	Chippewa
Alberta WWTP	No	Pomme de Terre	Hendricks WWTP	No	Lac qui Parle
Appleton WWTP	Yes	Pomme de Terre	Hoffman WWTP	No	Chippewa
Ashby WWTP	Yes	Pomme de Terre	ISD 2853 Lac qui Parle Valley HS	Yes	Minnesota River Headwaters
Barrett WWTP	No	Pomme de Terre	Kerkhoven WWTP	No	Chippewa
Bellingham WWTP	Yes	Minnesota River Headwaters	LG Everist Inc	Yes[1]	Minnesota River Headwaters
Benson WWTP	No	Chippewa	Lowry WWTP	No	Chippewa
Canby WWTP	No	Lac qui Parle	Madison WWTP	Yes	Lac qui Parle
Chokio WTP	Yes	Pomme de Terre	Marietta WWTP	No	Lac qui Parle
Chokio WWTP	No	Pomme de Terre	Milan WWTP	Yes	Minnesota River Headwaters
Clinton WWTP	Yes	Minnesota River Headwaters	Millerville WWTP	No	Chippewa
Clontarf WWTP	No	Chippewa	Morris WWTP	Yes	Pomme de Terre
Danvers WWTP	No	Chippewa	Murdock WWTP	Yes	Chippewa
Dawson WWTP	No	Lac qui Parle	Odessa WWTP	Yes	Minnesota River Headwaters
DeGraff WWTP	No	Chippewa	Ortonville WWTP	Yes	Minnesota River Headwaters
DENCO II LLC	Yes	Pomme de Terre	PURIS Proteins LLC	No	Lac qui Parle
Duininck Inc	Yes[1]	Chippewa	Starbuck WWTP	No	Chippewa
Evansville WWTP	No	Chippewa	Sunburg WWTP	No	Chippewa
Farwell Kensington SD WWTP	No	Chippewa	Urbank WWTP	No	Chippewa

[1]May not need a limit if the discharge does not have reasonable potential to cause or contribute to the impairment.

Construction Stormwater

Construction stormwater can be a source of phosphorus due to runoff with phosphorus bound to disturbed and easily erodible soils during construction activities. On average there are about 71 acres, or about 0.01% of the land area, under a construction stormwater permit, per year, in Minnesota's portion of the MRHW. Phosphorus from construction is considered, but not a significant contributor.

Industrial Stormwater

Industrial stormwater (ISW) can be a source of phosphorus. Phosphorus containing materials handled, used, processed, or generated that, when exposed to stormwater, may leak, leach, or decompose and be carried offsite, are a potential source to nearby waterbodies. There are 12 NPDES permitted ISW sites in the MRHW that drain to impaired lakes covered in this TMDL report. In addition, the Lac qui Parle River Watershed has 7, the Chippewa River Watershed has 17, and the Pomme de Terre River Watershed has 19. Most are MNG49 nonmetallic mining permits. More information on the ISW sites is provided in **Section 4.4.3**.

Municipal Stormwater Runoff

Phosphorus from sediment, grass clippings, leaves, fertilizers, and other phosphorus-containing materials can be conveyed through stormwater pipe networks to surface waters. The city of Morris (MS4 Permit #MS400274) in the Pomme de Terre River Watershed covers 4.9 sq mi, 0.17% of the drainage area of Lac qui Parle Lake - NW Bay and 0.08% of the drainage area of Lac qui Parle Lake SE-Bay. The remaining lakes included in this TMDL report have no MS4s in their drainage area.

Feedlot Facilities

Livestock CAFOs can be a source of phosphorus to surface and ground water. Regulations regarding manure stockpiling or LMSAs on site decrease the likelihood of a direct release of manure and associated nutrients to waterbodies. Permitted feedlot information can be found in **Section 3.6.1** and a list of CAFOs in the watershed is located in **Appendix E**.

3.6.2.2 Nonpermitted sources

Upland Erosion

Soil erosion can be a source of nutrients because phosphorus often binds to sediment particles and is transported downstream. In addition to sediment, organic materials often contain phosphorus and, much like sediment, organic materials can be transported across the landscape with runoff. Upland phosphorus pathways include overland erosion, open tile intakes, and tile lines. It frequently results from overland sheet, rill, or gully transport as water conveys phosphorus tightly bound to sediment to surface waters. Upon the formation of a gully, these areas are sensitive and highly susceptible to continued disturbance. In addition to overland flow, dissolved phosphorus can be transported through tile lines in agriculture areas. Protecting sensitive areas with deep-rooted vegetation that stabilizes soils can help mitigate phosphorus loss. Minimizing uncovered fields can also reduce the erosive power of heavy rain events.

Phosphorus loading to lakes from upland sources is estimated to be 0.3 to 0.65 pounds per acre (lbs/acre) annually for the MRHW. Overland runoff coupled with the high percentage of straightened stream channels, agricultural land use, loss of wetlands, and tiling – jointly indicating an altered hydrology – increases the conveyance of phosphorus from the landscape to waterbodies once mobilized from soils.

Stream Bank Erosion

Like overland erosion, phosphorus can be bound to sediment in streambanks and transported downstream when erosion occurs. During large precipitation events or during spring snow melt, streams can convey water at high velocity and with significant stream energy. High stream power values commonly observed in the MRHW exceed the stress streambanks can withstand. This leads to bank failure and streambank erosion, at which point sediment and bound phosphorus are transported downstream. The removal of natural vegetation can exacerbate streambank erosion along a channel. In addition, alterations to the stream reaches, e.g. channel widening and channel straightening, further increase stream energy and likelihood of streambank erosion.

Non-NPDES Permitted Feedlots and Manure Application

AFOs under 1,000 AUs and those that are not federally defined as CAFOS do not operate with permits. These facilities must operate in accordance with Minn. R. 7020.2000 through 7020.2150 to minimize their impact on water quality. AFOs may pose an environmental concern if the facilities are located near water and manure is inadequately managed, especially in open lot feedlots. Information about AFO numbers is located in **Section 3.6.1**.

Manure is a by-product of animal production and large numbers of animals create large quantities of manure. This manure is usually stockpiled or held in LMSAs, and then spread over agricultural fields. The majority of liquid manure is immediately incorporated during application while solid manure is surface applied with varying amounts of incorporation at the time of application.

Manure can have a high content of phosphorus per unit of manure. Since manure can have different ratios of nitrogen to phosphorus content, deliberate manure management measures must be employed to ensure excessive phosphorus application does not occur if manure is applied based on nitrogen rates. The solid manure that is at times applied to frozen or snow-covered soils without incorporation can lead to an increased potential for runoff into nearby lakes and streams. High intensity precipitation events during the spring can cause erosion of both the soil and the manure that is applied onto the soil, leading to high phosphorus loads making their way to streams and lakes. Land applied manure from all AFOs must comply with Minn. R. 7020.2225.

Internal Loading

Internal loading can be a significant source of phosphorus in lakes, especially if the lake has a long history of excessive external phosphorus loading. Lake bed sediments can be high phosphorus contributors as organic material and sediment fall out of the water column, settling on the bottom of a lake. Disturbance of sediment on a lake bottom from carp and other rough fish can re-suspend sediment and lead to the release of phosphorus to the water column. In addition, anoxic conditions (frequently caused by the decay of algae and plant matter) can break the bonds holding the phosphorus to the sediment and re-release it into the water column, exacerbating already high phosphorus levels.

Internal phosphorus cycles seasonally as the water in a lake turns over and phosphorus-rich water from the lake bottom mixes with surface waters. In shallow lakes that fully mix during these events, phosphorus from sediment is available to drive primary production, which in lakes is the growth of plants and algae. Internal loading and the effect of phosphorus made available varies yearly depending on environmental conditions.

Internal loading is discussed further in **Section 4.4.1**.

SSTS

Failing SSTSs with an insufficient dry zone between the leach field and bedrock or saturated zone, or improperly designed SSTSs, can result in the transport of phosphorus to groundwater and surface waters. The large number of failing SSTS in the MRHW, estimated to be between 0.27 to 5.85 per 1,000 acres (numbers by county are found in **Section 3.6.1.2**), can contribute to increased phosphorus loads of surface waters. Counties in the watershed continue to improve SSTS assessment and conduct outreach to the public regarding system maintenance.

Atmospheric Deposition

Atmospheric deposition to the surface of lakes can be a source of phosphorus, including pollen, soil (aeolian particulates), oil, coal particulate matter, and fertilizers. Atmospheric deposition is calculated from the CNET model (see **Section 4.4**) for each lake. The average precipitation was 24.8 inches and average phosphorus loading was 41 kg/km2/yr or 0.37 lbs/acre/year. In the CNET model, atmospheric deposition varies with precipitation based on departure from the average to get a distribution and account for variability.

3.6.2.3 Source Summary by Lake

Unnamed Lake

The distribution of overland phosphorus sources, based on average HSPF loads, to Unnamed Lake is shown in **Figure 12.** Cropland is the major contributor of phosphorus (93%), followed by developed land (4%). **Table 12** provides the average annual runoff, phosphorus loads, and flow weighted mean concentrations (FWMC) of phosphorus, based on the HSPF results. Stony Run Creek is the largest contributor of phosphorus to Unnamed Lake, accounting for 52% of the total load in the lake. More information on internal loading and the methods used to determine it are provided in **Section 4.4.1**.

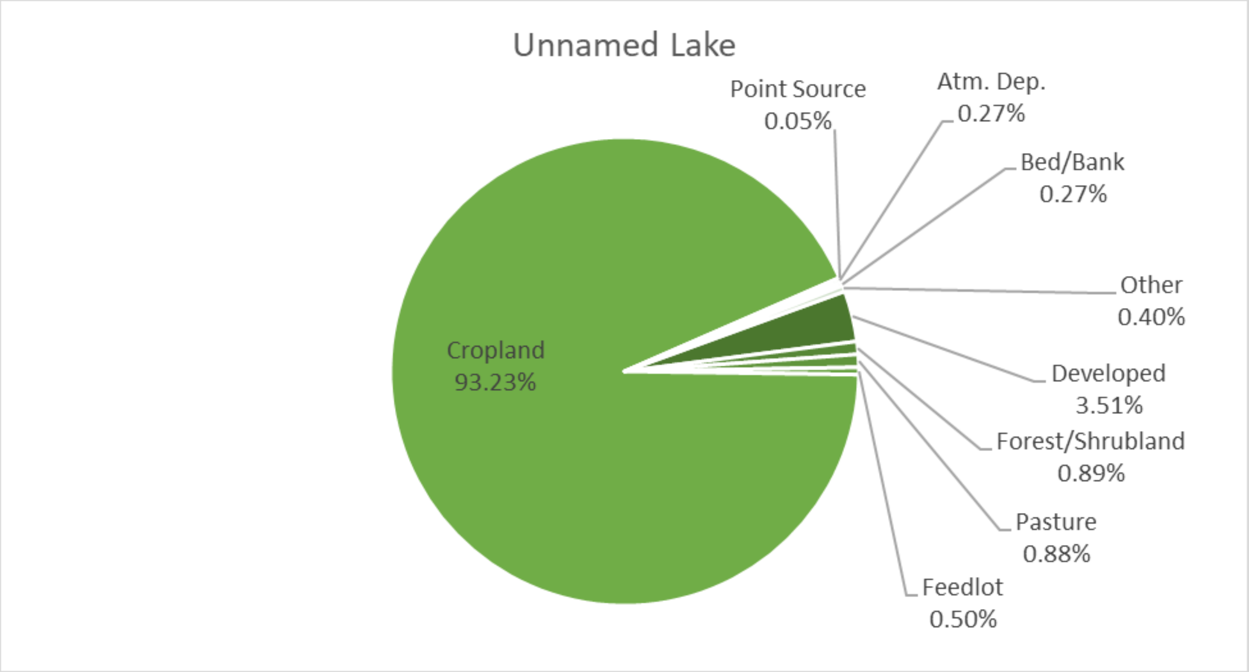

Figure 12. Average phosphorus external source summary to Unnamed Lake (06-0060-00), based on the HSPF model.

Table 12. Average phosphorus loading in Unnamed Lake by major tributary and source.

Major Tributary/Source	Average Annual Loads (1996-2017)[1]		
	Runoff [acre-ft/yr]	TP [lbs/yr]	TP FWMC[2] [mg/L]
Atmospheric Deposition[3]	134	24	
Direct Drainage	1,715	1,450	0.311
Stony Run Creek (538)	16,045	10,507	0.241
Unassessed Reach (999)	3,622	1,933	0.196
Internal Load		6,434	
Total	**21,516**	**20,348**	**0.348**

[1] Based on the HSPF and BATHTUB models.
[2] FWMC = flow weighted mean concentration, estimated as TP loading/runoff in milligrams per liter (mg/L).
[3] Direct precipitation and deposition to surface of lake.

Long Tom Lake

The distribution of overland phosphorus sources, based on average HSPF loads, to Long Tom Lake is shown in **Figure 13**. Cropland is the major contributor of phosphorus (93%), followed by developed land (4%). **Table 13** provides the average annual runoff, phosphorus loads, and FWMC of phosphorus. Outflow from Unnamed Lake is the largest contributor of phosphorus to Long Tom Lake, accounting for 99.7% of the total load in the lake. This is because most of the drainage area of Long Tom Lake flows through Unnamed Lake before reaching Long Tom Lake.

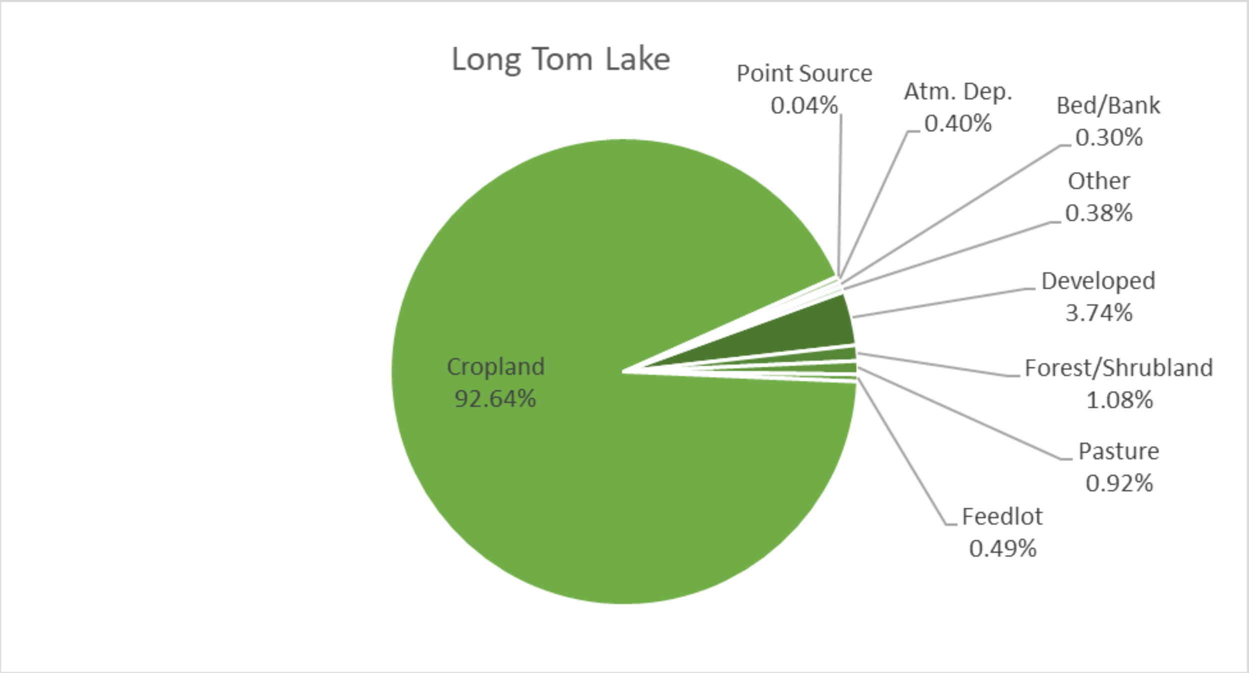

Figure 13. Phosphorus external source summary to Long Tom Lake (06-0029-00). Sources are based on HSPF model results and includes the external sources to Unnamed Lake as well as the direct drainage to Long Tom Lake.

Table 13. Phosphorus loading in Long Tom Lake (06-0029-00) by major tributary and source.

Major Tributary/Source	Average Annual Loads (1996-2017)[1]		
	Runoff [acre-ft/yr]	TP [lbs/yr]	TP FWMC[2] [mg/L]
Atmospheric Deposition[3]	310	55	
Direct Drainage, Long Tom Lake	275	143	0.191
Unnamed Lake	21,201	15,914	0.276
Total	**21,786**	**16,112**	**0.272**

[1] Based on the HSPF and BATHTUB models.
[2] FWMC = flow weighted mean concentration, estimated as TP loading/runoff in milligrams per liter (mg/L).
[3] Direct precipitation and deposition to surface of lake.

Big Stone Lake

The distribution of overland phosphorus sources, based on average HSPF loads, to Big Stone Lake is shown in **Figure 14**. Cropland is the major contributor of phosphorus (67%), followed by bed/bank erosion (18%) and developed lands (5%). **Table 14** provides the average annual runoff, phosphorus loads, and FWMC of phosphorus. In addition to runoff volume and phosphorus loads, the percentage of the phosphorus load coming from Minnesota is given, based on the HSPF results. A large portion of the total load comes from outside Minnesota (68.3%). These percentages will be used to determine LAs in the TMDL table (see **Section 4.4.6**).

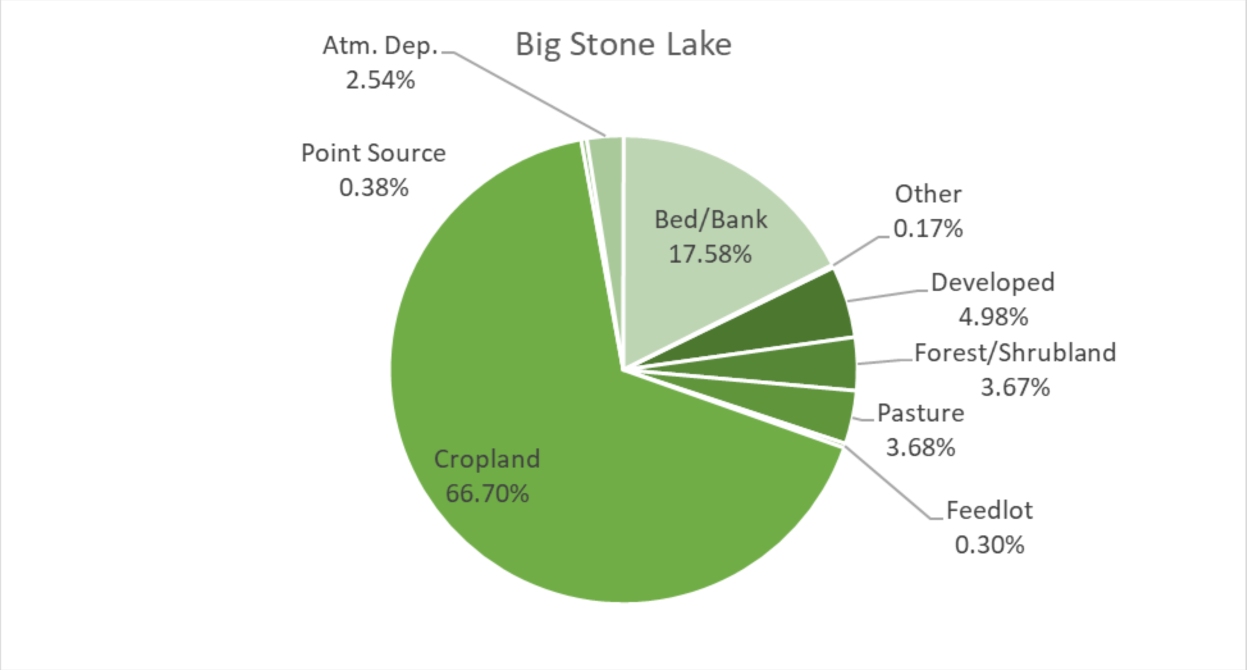

Figure 14. Phosphorus external source summary to Big Stone Lake (06-0152-00), based on the HSPF model results, watershed wide.

Table 14. Phosphorus loading in Big Stone Lake (06-0152-00) by major tributary and source.

Major Tributary/Source	Average Annual Loads (1996-2017)[1]			Percent of Load from Minnesota
	Runoff [acre-ft/yr]	TP [lbs/yr]	TP FWMC[2] [mg/L]	
Atmospheric Deposition[3]	24,818	4,428		
Direct Drainage	19,551	13,804	0.260	52.5%
Little Minnesota River (508)	82,325	46,412	0.207	0.62%
Unassessed Reach (999)	1,072	585	0.201	100%
Unnamed Creek (549)	6,909	5,134	0.273	100%
Fish Creek (572)	15,592	10,989	0.259	100%
South Dakota Tributary #1	3,246	1,904	0.216	0%
Unnamed Cr (West Salmonsen Ck)	5,646	4,776	0.311	100%
Unnamed Ck (Meadowbrook Ck)	3,688	2,822	0.281	100%
South Dakota Tributary #2	2,281	1,370	0.221	0%
Total	165,128	92,224	0.205	31.7%

[1] Based on the HSPF and BATHTUB models.
[2] FWMC = flow weighted mean concentration, estimated as TP loading/runoff in milligrams per liter (mg/L).
[3] Direct precipitation and deposition to surface of lake.

Lac qui Parle Lake NW Bay

The distribution of overland phosphorus sources, based on average HSPF loads, to Lac qui Parle Lake-NW Bay is shown in **Figure 15**. Cropland is the major contributor of phosphorus (67%), followed by bed/bank erosion (18%) and developed lands (5%). **Table 15** provides the average annual runoff, phosphorus loads, and FWMC of phosphorus. Outflow from Marsh Lake (06-0001-00) is the largest source of phosphorus loading, followed by the Pomme de Terre River. In addition to runoff volume and phosphorus loads, the percentage of the phosphorus load coming from Minnesota is given, based on the HSPF results. About 34% of the total load comes from outside Minnesota. These percentages will be used to determine LAs in the TMDL table (see **Section 4.4.7**).

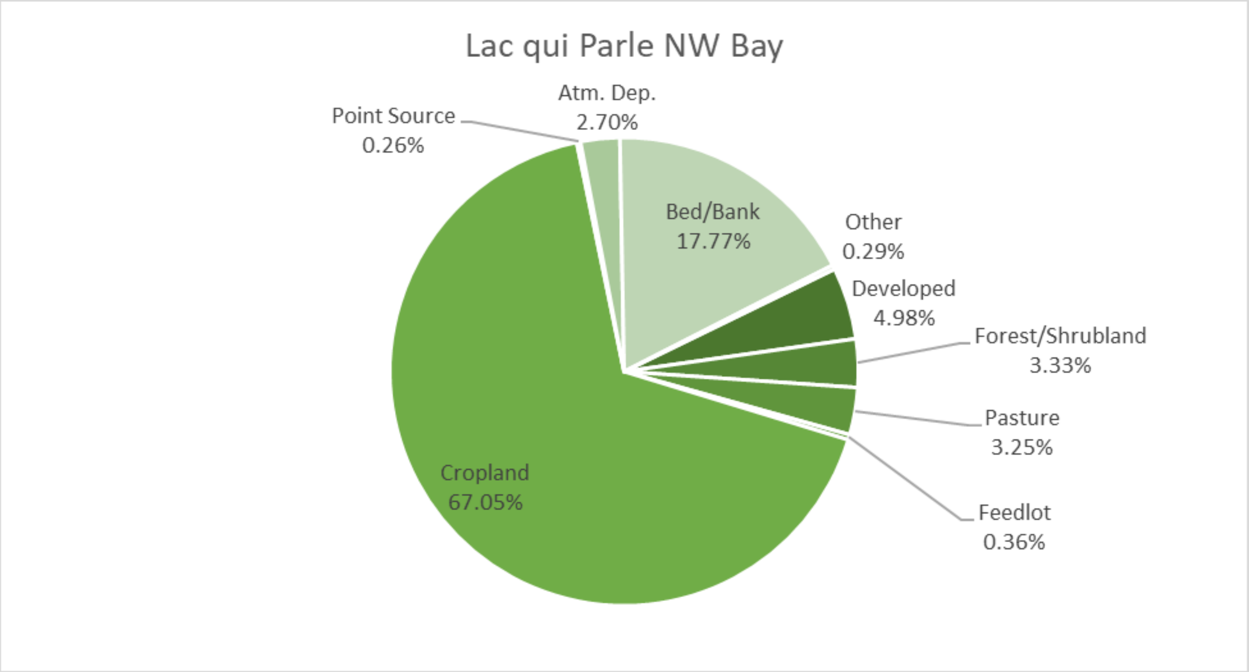

Figure 15. Phosphorus external source summary to Lac qui Parle Lake-NW Bay (37-0046-02), based on the HSPF model results, watershed wide.

Table 15. Phosphorus loading in Lac qui Parle Lake-NW Bay (37-0046-02) by major tributary and source.

Major Tributary/Source	Average Annual Loads (1996-2017)[1]			Percent of Load from Minnesota
	Runoff [acre-ft/yr]	TP [lbs/yr]	TP FWMC[2] [mg/L]	
Atmospheric Deposition[3]	4,337	780		
Direct Drainage	2,379	1,222	0.189	100%
Emily Creek (547)	7,310	9,032	0.275	100%
Minnesota River, Marsh Lake to Lac qui Parle Lake-NW Bay (Direct Drainage) (552)	1,641	877	0.197	100%
Marsh Lake (06-0001-00)	324,910	204,800	0.196	41.7%
Pomme de Terre River (07020002)	194,681	108,120	0.204	100%
Total	553,241	296,711	0.197	65.9%

[1] Based on the HSPF and BATHTUB models.
[2] FWMC = flow weighted mean concentration, estimated as TP loading/runoff in milligrams per liter (mg/L).
[3] Direct precipitation and deposition to surface of lake.

Lac qui Parle Lake SE Bay

The distribution of overland phosphorus sources, based on average HSPF loads, to Lac qui Parle Lake-SE Bay is shown in **Figure 16**. Cropland is the major contributor of phosphorus (76%), followed by bed/bank erosion (11%) and developed lands (5%). **Table 16** provides the average annual runoff, phosphorus loads, and FWMC of phosphorus. Outflow from Lac qui Parle Lake-NW Bay is the largest source of phosphorus loading, followed by the Chippewa River and Lac qui Parle River. In addition to runoff volume and phosphorus loads, the percentage of the phosphorus load coming from Minnesota is given, based on the HSPF results. About 31% of the total load comes from outside Minnesota. These percentages will be used to determine LAs in the TMDL table (see **Section 4.4.7**).

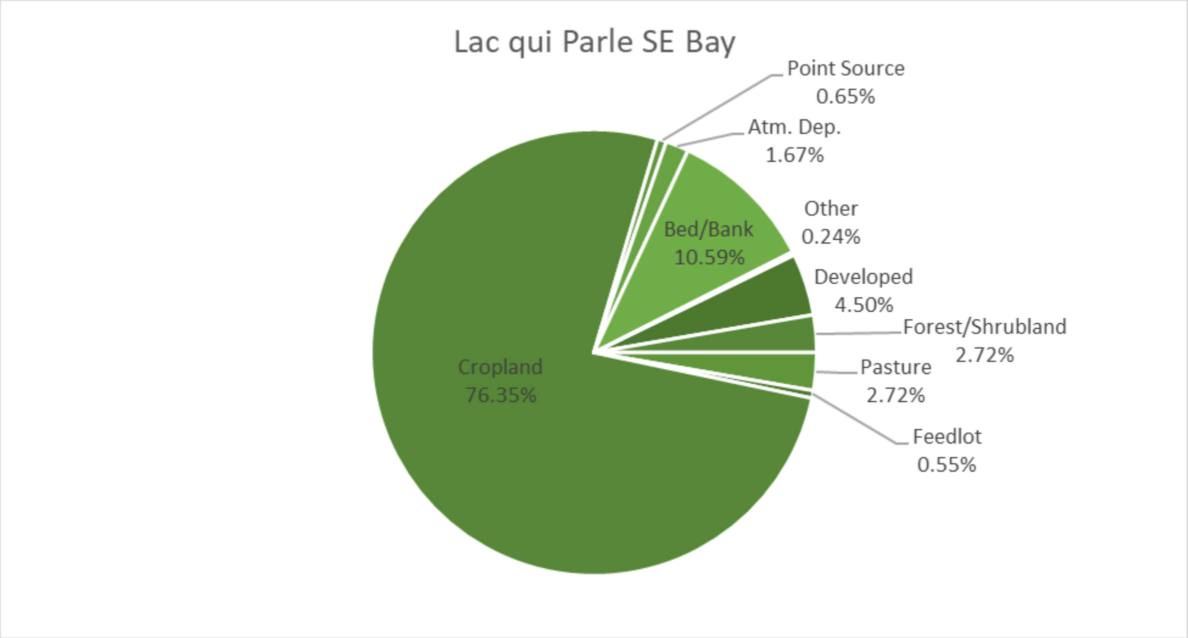

Figure 16. Phosphorus external source summary to Lac qui Parle Lake-SE Bay (37-0046-01), based on the HSPF model results, watershed wide.

Table 16. Phosphorus loading in Lac qui Parle Lake-SE Bay (37-0046-01) by major tributary and source.

Major Tributary/Source	Average Annual Loads (1996-2017)[1]			Percent of Load from Minnesota
	Runoff [acre-ft/yr]	TP [lbs/yr]	TP FWMC[2] [mg/L]	
Atmospheric Deposition[3]	7,515	1,329		
Direct Drainage	4,112	2,828	0.253	100%
Direct Drainage, near outlet	183	120	0.241	100%
Unnamed Ditch (Watson Sag Div)(518)	3,700	2,542	0.253	100%
Lac qui Parle River (07020003)	219,482	101,880	0.171	87%
Chippewa R Overflow (07020005)	260,003	187,091	0.265	100%
Direct Drainage near Chippewa River overflow	1,447	958	0.243	100%
Lac qui Parle Lake-NW Bay Outflow	529,003	263,510	0.183	45.5%
Total	1,025,445	560,258	0.201	72%

[1] Based on the HSPF and BATHTUB models.

[2] FWMC = flow weighted mean concentration, estimated as TP loading/runoff in milligrams per liter (mg/L).

[3] Direct precipitation and deposition to surface of lake.

4. TMDL development

A TMDL represents the maximum mass of a pollutant that can be assimilated by a receiving waterbody without causing an impairment in that receiving waterbody. TMDLs are developed based on the following equation:

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

Where:

LC = loading capacity, the greatest amount of a pollutant a waterbody can receive and still meet water quality standards (see **Section 4.3.1**);

WLA = wasteload allocation, the portion of the LC allocated to existing or future permitted point sources (see **Section 4.3.3**);

LA = load allocation, the portion of the LC allocated for existing or future NPS (see **Section 4.3.2**);

MOS = margin of safety, accounting for any uncertainty associated with attaining the water quality standard. The MOS may be explicitly stated as an added, separate quantity in the TMDL calculation or may be implicit, as in a conservative assumption (EPA 2007) (see **Section 4.3.4**);

RC = reserve capacity, or the portion of the TMDL that accommodates for future loads (see **Section 4.4.5**).

Per Code of Federal Regulations (40 CFR 130.2(1)), TMDLs can be expressed in terms of mass per time, toxicity or other appropriate measures. For this TMDL report, the TMDLs, allocations and margins of safety are expressed in mass/day. Discussion of each TMDL component is included in greater detail below.

4.1 Natural background consideration

Natural background was given consideration in the development of LA in this TMDL. Natural background is the landscape condition that occurs outside of human influence. “Natural background” is defined in both Minnesota rule and statute. 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. The CWLA (Minn. Stat. § 114D.15, subd. 10) defines natural background as “characteristics of the water body resulting from the multiplicity of factors in nature, including climate and ecosystem dynamics, that affect the physical, chemical or biological conditions in a water body, but does not include measurable and distinguishable pollution that is attributable to human activity or influence.” Natural background conditions refer to inputs of pollution 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 study. These source assessment exercises indicate natural background inputs are generally low compared to livestock, cropland, streambank, WWTPs, failing SSTSs, 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 report, 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. Federal law instructs an agency to distinguish between natural and nonpoint source loads "[w]herever possible." 40 C.F.R. § 130.2(g). However, Minnesota law does not compel the MPCA to develop a separate LA for natural background sources, distinct from NPS[2].

4.2 Data Sources

Hydrologic Simulation Program-Fortran

The HSPF model is a comprehensive package for simulation of watershed hydrology, sediment and other pollutant transportation, and water quality for conventional and toxic organic pollutants. HSPF incorporates the watershed-scale Agricultural Runoff Model (ARM) and NPS models into a basin-scale analysis framework that includes fate and transport in one dimensional stream channels. It is a comprehensive model of watershed hydrology and water quality that allows the integrated simulation of point sources, land and soil contaminant runoff processes, and in-stream hydraulic and sediment-chemical interactions. The result of this simulation is a time history of the runoff flow rate, sediment load, and nutrient and pesticide concentrations, along with a time history of water quantity and quality at the outlet of any subwatershed.

An HSPF model was developed in 2017 for the MRHW and updated in 2019. The HSPF models predict the range of flows that have historically occurred in the modeled area and the load contributions from a variety of point and NPS in the watershed. The HSPF model for the Upper MRHW simulates hydrology and water quality for the period 1996 to 2017.

Environmental Quality Information System

The MPCA uses a system called EQuIS to store water quality data from more than 17,000 sampling locations across the state. All discrete water quality sampling data utilized for assessments and data analysis for this TMDL report are stored in this accessible database, described in **Section 3.5**. The EQuIS locations and water quality data used in this TMDL report are provided in **Figure 9** and **Table 8** (streams) and **Table 9** (lakes).

4.3 *Escherichia coli*

4.3.1 Loading capacity methodology

The LC is the greatest amount of a pollutant a waterbody can receive and still meet the water quality standard. The loading capacities for impaired stream reaches in the MRHW were determined using the LDC approach. A LDC is developed by combining the (simulated or observed) river/stream flow at the downstream end of the WID with the observed/measured *E. coli* data available within the segment. Methods detailed in the EPA document, *An Approach for Using Load Duration Curves in the Development of TMDLs* (EPA 2007), were used in creating the curves for the impaired streams within the MRHW.

A system's water quality often varies based on flow regime, with elevated pollutant loadings sometimes occurring more frequently under one regime or another. Loading dynamics during certain flow conditions can be indicative of the type of pollutant source causing an exceedance (e.g., point sources

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[2] Matter of Decision to Deny Petitions for a Contested Case Hearing, 924 N.W.2d 638 (Minn. Ct. App. 2019), review denied (Apr. 24, 2019)

may contribute more loading under low flow conditions). The LDC approach identifies these flow regimes and presents the observed and “allowable” loading within each regime, to compute necessary load reductions. To represent different types of flow events, and pollutant loading during these events, five flow regimes were identified based on percent exceedance: Very High Flow (0% to 10% of flows exceed), High Flow (10% to 40%), Mid Flow (40% to 60%), Low Flow (60% to 90%), and Very Low Flow (90% to 100%).

Benefits of LDC analysis include: (1) the loading capacities are calculated for multiple flow regimes, not just a single point; (2) use of the method helps identify specific flow regimes and hydrologic processes/patterns where loading may be a concern; and (3) ensuring that the applicable water quality standards are protective across all flow regimes. The LDC approach is limited (1) in the ability to track individual loadings or relative source contributions and (2) when a correlation between flow and water quality is lacking and flow is not the driving force behind pollutant delivery mechanics.

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 (the LC curve). In the TMDL equation tables of this report (see **Section 4.3.6**), only five points on the entire LC curve are depicted (the midpoints of the designated flow regimes). However, it should be understood that the entire curve represents the TMDL and is what the EPA ultimately approves.

The LC for *E. coli* was calculated using both MPCA standards: the geometric mean (i.e., geomean) standard of 126 organisms/100 mL and the standard, which requires fewer than 10% of samples above 1,260 organisms/100 mL. The TMDL allocations are calculated based on the 126 organisms/100 mL standard. The water quality standards for *E. coli* apply from April to October. Loads are calculated using the method in **Table 17** as organisms per day (org/day) and reported as billions of organisms/day.

Table 17. Converting flow and concentration into bacterial load.

Load (org/day) = *E. coli* Standard (organisms/100mL) * Flow (cfs) * Factor			
Multiply **Flow** (cfs) by **28.316** to convert	ft^3 per second (cfs)	→	Liters per second
Multiply by **1000** to convert	Liters per second	→	Milliliters per second
Divide by **100** to convert	Milliliters per second	→	Organisms/second
Multiply by **86,400** to convert	Organisms per second	→	Organisms/day

The LDCs were developed using the most recent 10-year period with available data from April through October. Since available flows from the HSPF model used to develop the LDCs is 1996 through 2017, the period 2008 through 2017 was used to develop the LDCs. **Table 18** provides a list of available water quality stations and HSPF model reaches used to develop the LDCs.

Table 18. WIDs with developed LDCs and the corresponding flow data source and water quality stations used.

WID	Flow Station USGS or HSPF ID	Available Water Quality Stations
07020001-504	HSPF RCHRES 425	S002-879
07020001-508	HSPF RCHRES 433+432	S000-732
07020001-521	HSPF RCHRES 410	S008-472
07020001-531	HSPF RCHRES 501	S008-471
07020001-536	HSPF RCHRES 417	S006-556
07020001-541	HSPF RCHRES 431	S006-557
07020001-547	HSPF RCHRES 405	S008-475
07020001-551	HSPF RCHRES 504	S008-473
07020001-552	HSPF RCHRES 409	S000-234, S002-241
07020001-568	HSPF RCHRES 424	S002-877, S008-470
07020001-570	HSPF RCHRES 452	S008-474
07020001-571	HSPF RCHRES 429	S002-881

4.3.2 Load allocation methodology

LA represent the portion of the LC designated for NPS of *E. coli*. The LA is the remaining load once the WLA, and MOS are determined and subtracted from the LC. The LA includes all sources of *E. coli* that do not require NPDES permit coverage, including unregulated watershed runoff, wildlife sources, and a consideration for “natural background” conditions. NPS of *E. coli* were previously discussed in **Section 3.6.1**.

4.3.3 Wasteload allocation methodology

WLAs are developed for any permitted discharge in the drainage area of an impaired reach. These are discharges requiring an NPDES permit, and typically include water treatment plants, permitted MS4s, industrial discharges, construction stormwater, and permitted CAFOs.

Wastewater Treatment Plants

WWTPs are based on the reported maximum allowable discharge and the permitted concentration limits. The conversion for WWTPs from concentrations to loads is shown in **Table 19.** The WWTPs, permit numbers, permitted flows, and WLAs are provided in **Table 20**. No WWTP permits need to be revised for fecal coliform based on this TMDL report.

Table 19. Converting discharge and concentrations into bacterial loads.

Wasteload (org/day) = *E. coli* Limit (126 organisms/100mL) * Flow (mgd)[1] * Factor			
Multiply *E. coli* limit (**126** organisms/100ml) by **10** to convert	organisms per 100 mL	→	organisms per Liter
Multiply by **3.785** to convert	organisms per Liter	→	organisms per gallon
Multiply by **1,000,000** to convert	organisms per gallon	→	organisms per million gallons

[1] Million gallons per day

Table 20. Bacteria WLAs for NPDES permits in impaired reaches of the Minnesota River Headwaters Watershed.

Name	Permit No.	SD	Permit Limit (as *E. coli*)		Max Daily Flow (mgd)	*E. coli* WLAs (billion org/day)	Flow Type
			org/100 mL	org/L			
Bellingham WWTP	MNG580152	SD001	126	1260	0.344[1]	1.639	Controlled
Clinton WWTP	MNG580193	SD001	126	1260	0.749[1]	3.574	Controlled
ISD 2853 Lac qui Parle Valley High School	MNG580091	SD001	126	1260	0.293[1]	1.399	Controlled
~~Odessa WWTP~~[2]	~~MNG580099~~	~~SD002~~	~~126~~	~~1260~~	~~0.196[1]~~	~~0.932~~	~~Controlled~~
~~Ortonville WWTP~~[2]	~~MNG580151~~	~~SD001~~	~~126~~	~~1260~~	~~3.584[1]~~	~~17.094~~	~~Controlled~~

[1] Based on 6” daily discharge of secondary pond.

[2] Removed after public notice given that they are not included in TMDL tables in Section 4.3.6.

Straight Pipe Septic Systems

Straight pipe septic systems are illegal and unpermitted, and as such, receive a WLA of zero.

Industrial and Construction Stormwater Permits

WLAs for permitted construction stormwater (permit# MNR100001) were not developed for *E. coli*, since *E. coli* is not a typical pollutant associated with construction sites. ISW receives a WLA only if bacteria or *E. coli* is part of benchmark monitoring for an industrial site in the drainage area of an impaired water body. There are no bacteria or *E. coli* benchmarks associated with any ISW Permits (permit# MNR050000) in the impaired watersheds. Therefore, no ISW *E. coli* WLAs were assigned.

Municipal Separate Storm Sewer System

There are no MS4 NPDES stormwater permits in the watershed, therefore, no MS4 area is assigned a WLA.

Livestock Facilities

NPDES permitted feedlot facilities are assigned a WLA of zero. Discharge of bacteria (*E. coli*) from fields where manure has been land-applied may occur during runoff events, but those discharges are covered under the LA portion of the TMDL and do not require an additional WLA. A list of CAFOs and the WIDs they contribute to is included in **Appendix E**.

WLA during low flows

The total daily LC of some stream reaches during low and very low flow regimes are very small due to the occurrence of very low flows in the stream/river. Consequently, for some of the impaired reaches the permitted wastewater design discharge is close to, or higher than, the streamflow during these flow regimes. This translates to these point sources appearing to use all of, or exceeding, the LC during these flow periods. In reality, this will never occur as the discharge is a part of the streamflow and can never exceed total streamflow. To account for these unique situations, the WLA (and LA) are expressed as an equation rather than an absolute number. The equation is:

$$\textit{Allocation} = \textit{Point Source Discharge} \times \textit{Water Quality Standard Concentration}$$

The units in the equation are converted so that they are consistent to the allocation and a proper load can be calculated. This assigns a concentration-based limit to the WLA for these lower flow rates.

4.3.4 Margin of safety

The purpose of the MOS is to account for uncertainty with the allocations. Uncertainty can be associated with data collection, lab analysis, data analysis, modeling error, and implementation activities. An explicit 10% of the LC was applied to each flow regime as the MOS for all LDCs developed for this TMDL. The LDC approach minimizes a great deal of uncertainty. Allocations and loading capacities are based on flow, which often varies by several orders of magnitude. This variability is accounted for by using the five flow regimes and the LDCs. The explicit 10% MOS accounts for:

- Uncertainty in the simulated flow data from the HSPF model;
- Uncertainty in the observed water quality data;
- Uncertainty that the water quality data adequately represents conditions in the reach; and
- Uncertainty with regrowth, die-off, and natural background levels of *E. coli*.

The majority of the MOS is apportioned to uncertainty related to the HSPF model. The hydrologic calibration statistics for the HSPF model at the Minnesota River at Ortonville, Minnesota (USGS station ID 05292000) were:

- -0.7% Error in total flow volume;
- -5.9% Error in bottom 50% low flows;
- 1.0% Error in the top 10% high flows;
- A Nash-Sutcliffe coefficient of model fit efficiency (NSE) of 0.947 for daily flows;
- And, an NSE of 0.935 for monthly flows.

Overall, the HSPF model accuracy was determined to be “Very Good”. More information on the calibration of the HSPF model can be found in Tetra Tech (2016).

4.3.5 Seasonal variation

Geometric means for *E. coli* within the impaired reaches are often above the state chronic standard from April through October. Exceedances of the acute standard are also common in these reaches during this time period. Fecal bacteria are most productive at temperatures similar to their origination environment in animal digestive tracts. Thus, these organisms are expected to be at their highest concentrations during warmer summer months when streamflow is low and water temperatures are high. High *E. coli* concentrations in many of the reaches continue into the fall, which may be attributed to constant sources of *E. coli* (such as failing SSTS and animal access to the stream) and less flow for dilution. However, some of the data may be skewed as more samples were collected in the summer months than in October. Seasonal and annual variations are accounted for by setting the TMDL across the entire flow record using the load duration method.

4.3.6 TMDL summary

The LDCs in **Figure** 17 through **Figure 27** shows the percent likelihood of flow exceedance on the x-axis, while the computed *E. coli* loading is shown on the y-axis. “Allowable” loadings under each flow condition, based on the water quality standards (both the geometric mean and instantaneous standards), is shown with a red and green line. Observed loads are also shown, indicated by points on the plot. The median loads for each flow regime are shown as a solid blue line for median existing loads (labeled as “Existing”) and a dashed red line for median “allowable” load (labeled as “Target”) for the geometric mean standard under each flow condition. Observed loads are broken out by station, allowing for a detailed examination of when and where loading exceedances have occurred. The “allowable” loads are the LC of the stream reach.

The following rounding conventions were used in the *E. coli* TMDL tables:

- Values ≥10 reported in mass/day have been rounded to the nearest whole value.
- Values <10 and ≥1 reported in mass/day have been rounded to the nearest tenth.
- Values <1 and ≥0.01 reported in mass/day have been rounded to the nearest hundredth.
- Values <0.01 reported in mass/day have been rounded to enough significant digits so that the value is greater than zero and a number is displayed in the table.
- While some of the numbers in the tables show multiple digits, they are not intended to imply great precision.
- Some small arithmetic errors may exist; this is due to rounding errors.
- Mass refers to billions of organisms for *E. coli*.

Each table offers a representative load reduction to provide watershed planners a single target reduction to aid in planning that is not dependent on flow conditions. A single, representative load reduction is easier for watershed planners to translate into annual load reductions when developing restoration and protection plans to improve water quality in the watershed. Since *E. coli* is assessed by month, an average of the monthly geometric means was used to determine the representative existing condition. The overall estimated percent reduction is the reduction in the average geometric mean to meet the 126 org/100 mL standard. Load reductions for each flow regime can be found in **Appendix A**. The baseline years are included as a footnote for each TMDL table and are based on the years with available observed water quality data closest to the average annual flow condition for the LDC period.

Two of the impaired stream reaches (07020001-508 and -551) drain parts of South and/or North Dakota. Therefore, a percentage of the load capacity to represent Minnesota’s portion was used to develop the TMDLs. To determine the percentage of load capacity for Minnesota, the HSPF model was utilized to calculate the portion of the load capacity at the end of the impaired reach that comes from Minnesota. Since HSPF does not model bacteria, flow was used as a surrogate. The percentage of flow coming from Minnesota in each impaired reach was used to determine Minnesota’s LC. It is assumed that the drainage areas in South and/or North Dakota will meet Minnesota standards. A table is presented for each reach with the total load capacity along with Minnesota’s portions. The TMDL tables are for the Minnesota portion of the load capacity.

Unnamed creek (West Salmonsen Creek), Unnamed cr to Big Stone Lk (07020001-504)

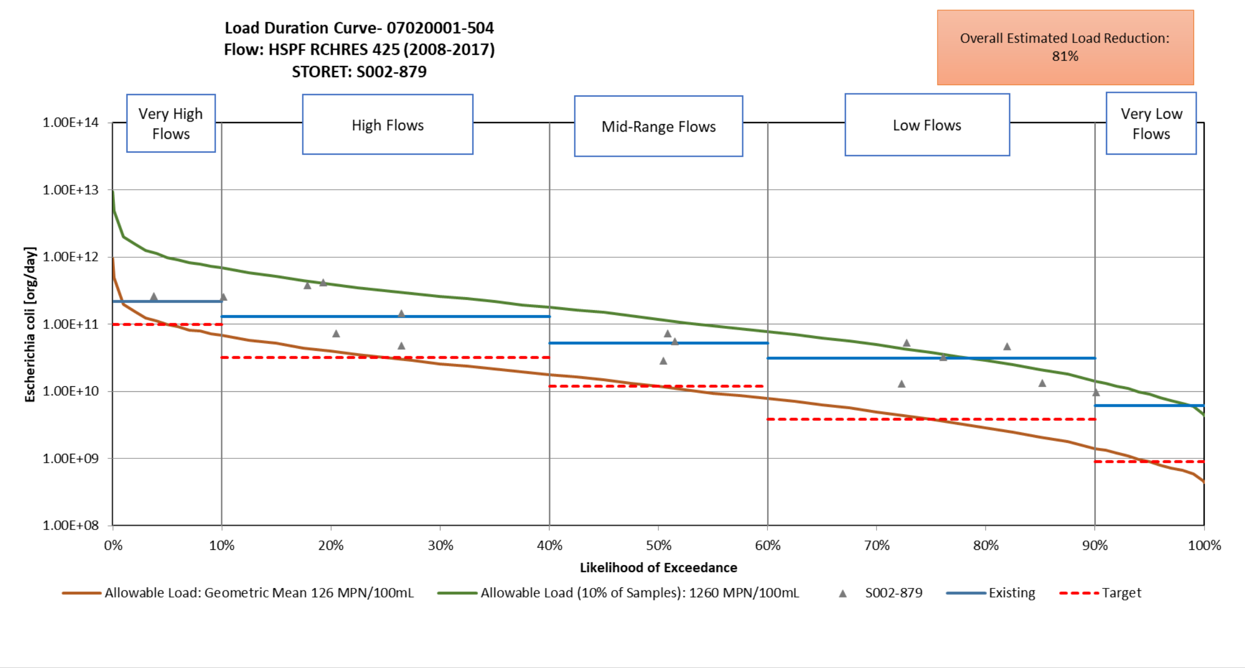


Figure 17. Unnamed creek (West Salmonsen Creek), Unnamed cr to Big Stone Lk (07020001-504) *E. coli* LDC.

Table 21: *E. coli* allocations for Unnamed creek (West Salmonsen Creek), Unnamed cr to Big Stone Lk (07020001-504), based on the 126 organisms/100 mL standard.

Escherichia coli	Flow Condition				
	Very High	High	Mid-Range	Low	Very Low
	[Billion organisms/day]				
Loading Capacity[1]	98	32	12	3.8	0.89
Wasteload Allocation	0	0	0	0	0
Load Allocation	88	29	11	3.4	0.8
Margin of Safety (MOS)	9.8	3.2	1.2	0.38	0.09
Average existing monthly geometric mean	653 org/100 mL				
Overall estimated percent reduction[2]	81%				

[1] Baseline year is 2012 for this TMDL.

[2] The overall estimated percent reduction is the reduction in the average geometric mean to meet the 126 org/100 mL standard.

Little Minnesota River, MN/SD border to Big Stone Lk (07020001-508)

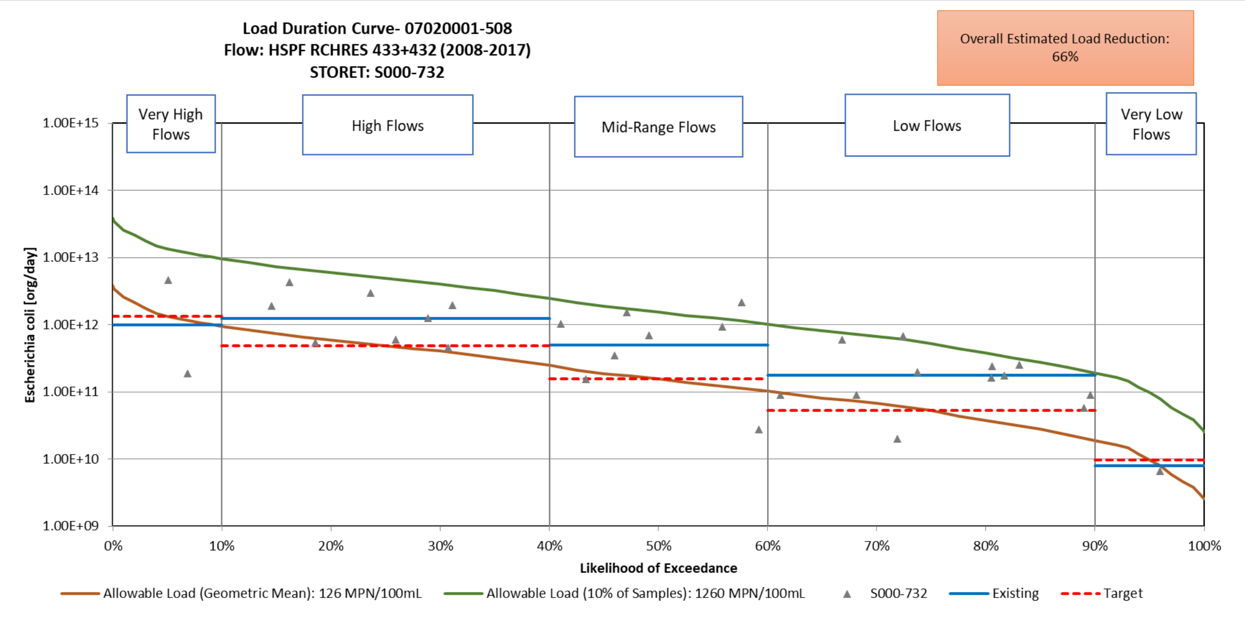


Figure 18. Little Minnesota River, MN/SD border to Big Stone Lk (07020001-508) *E. coli* LDC.

Table 22. Total and Minnesota load capacities for Little Minnesota River, MN/SD border to Big Stone Lk (07020001-508), based on the 126 organisms/100 mL standard.

Escherichia coli	Flow Condition				
	Very High	High	Mid-Range	Low	Very Low
	[Billion organisms/day]				
Total Load	1,353	489	157	53	9.7
MN Load	31	11	3.6	1.2	0.22

Table 23. *E. coli* allocations for Little Minnesota River, MN/SD border to Big Stone Lk (07020001-508). Loading capacity and allocations are for Minnesota only and are based on the 126 organisms/100 mL standard.

Escherichia coli	Flow Condition				
	Very High	High	Mid-Range	Low	Very Low
	[Billion organisms/day]				
Loading Capacity[1]	31	11	3.6	1.2	0.22
Wasteload Allocation	0	0	0	0	0
Load Allocation	28	10	3.2	1.1	0.20
Margin of Safety (MOS)	3.1	1.1	0.36	0.12	0.02
Average existing monthly geometric mean	371 org/100 mL				
Overall estimated percent reduction[2]	66%				

[1] Baseline year is 2015 for this TMDL.

[2] The overall estimated percent reduction is the reduction in the average geometric mean to meet the 126 org/100 mL standard.

Unnamed creek (Five Mile Creek), Unnamed cr to Marsh Lk (07020001-521)

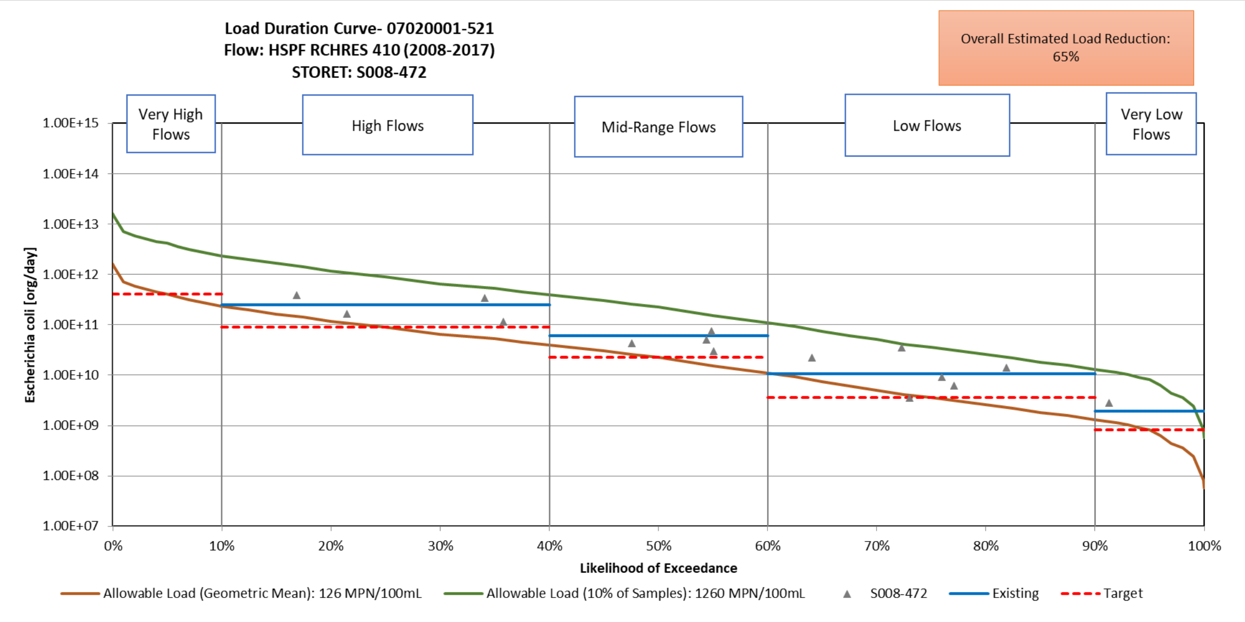


Figure 19. Unnamed creek (Five Mile Creek), Unnamed cr to Marsh Lk (07020001-521) *E. coli* LDC.

Table 24. *E. coli* allocations for Unnamed creek (Five Mile Creek), Unnamed cr to Marsh Lk (07020001-521), based on the 126 organisms/100 mL standard.

Escherichia coli	Flow Condition				
	Very High	High	Mid-Range	Low	Very Low
	[Billion organisms/day]				
Loading Capacity[1]	**413**	**90**	**22**	**3.6**	**0.8**
Wasteload Allocation	**0**	**0**	**0**	**0**	**0**
Load Allocation	**372**	**81**	**20**	**3.2**	**0.72**
Margin of Safety (MOS)	**41**	**9.0**	**2.2**	**0.36**	**0.08**
Average existing monthly geometric mean	**361 org/100 mL**				
Overall estimated percent reduction[2]	**65%**				

[1] Baseline year is 2015 for this TMDL.

[2] The overall estimated percent reduction is the reduction in the average geometric mean to meet the 126 org/100 mL standard.

Stony Run Creek, Unnamed cr to Minnesota R (07020001-531)

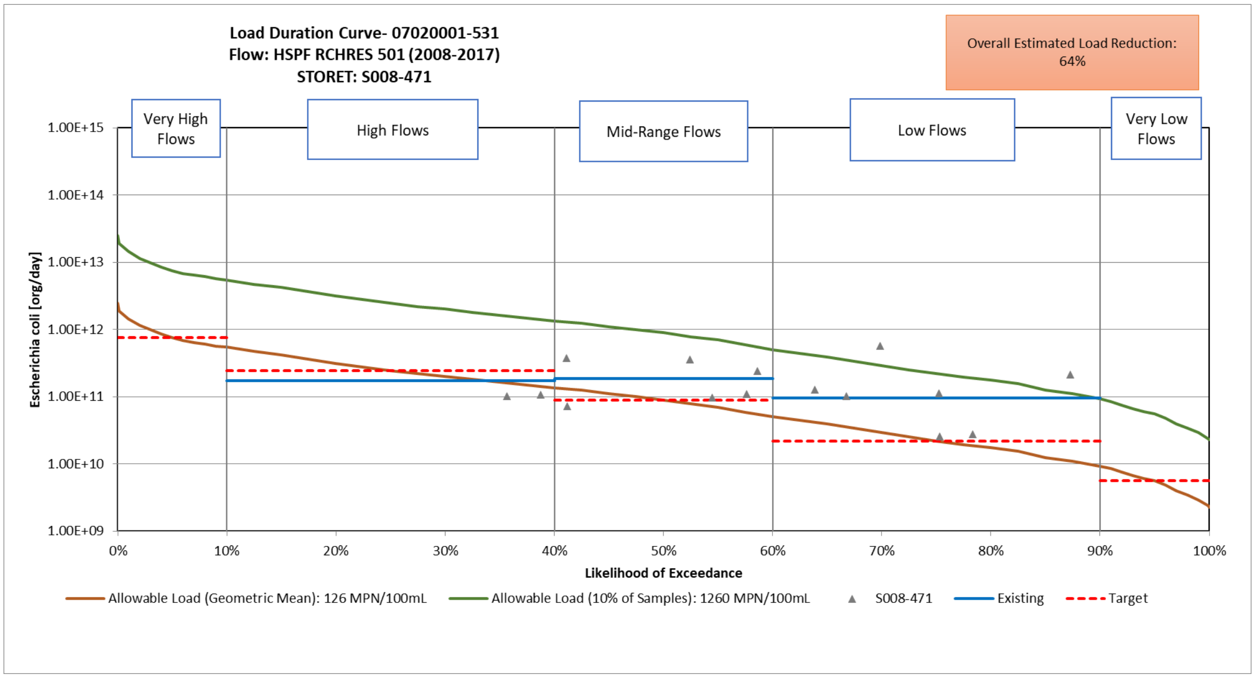


Figure 20. Stony Run Creek, Unnamed cr to Minnesota R (07020001-531) *E. coli* LDC.

Table 25. *E. coli* allocations for Stony Run Creek, Unnamed cr to Minnesota R (07020001-531), based on the 126 organisms/100 mL standard.

Escherichia coli		**Flow Condition**				
		Very High	**High**	**Mid-Range**	**Low**	**Very Low**
		[Billion organisms/day]				
Loading Capacity[1]		**750**	**247**	**90**	**22**	**5.6**
Wasteload Allocation	*Clinton WWTP*	3.6	3.6	3.6	3.6	3.6
	Total WLA	**3.6**	**3.6**	**3.6**	**3.6**	**3.6**
Load Allocation	**Total LA**	**671**	**218**	**77**	**16**	**1.4**
Margin of Safety (MOS)		**75**	**25**	**9.0**	**2.2**	**0.56**
Average existing monthly geometric mean		**347 org/100 mL**				
Overall estimated percent reduction[2]		**64%**				

[1] Baseline year is 2015 for this TMDL.

[2] The overall estimated percent reduction is the reduction in the average geometric mean to meet the 126 org/100 mL standard.

Stony Run Creek, Long Tom Lk to Unnamed cr (07020001-536)

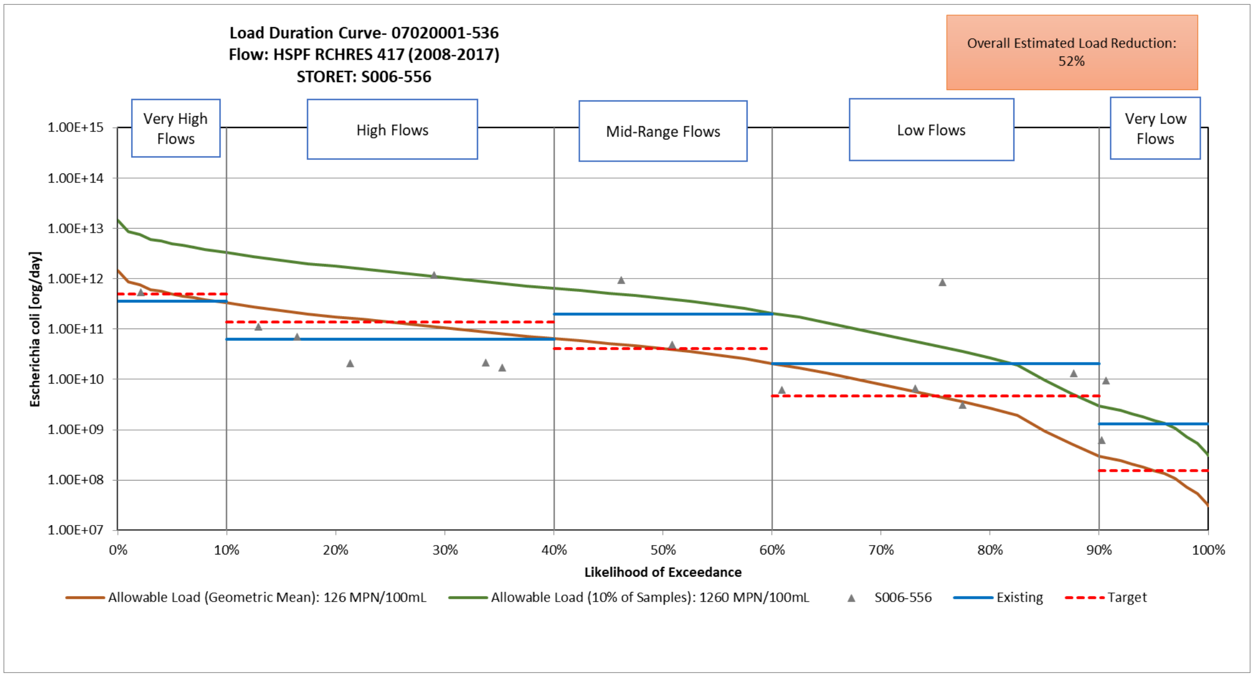


Figure 21. Stony Run Creek, Long Tom Lk to Unnamed cr (07020001-536) *E. coli* LDC.

Table 26. *E. coli* allocations Stony Run Creek, Long Tom Lk to Unnamed cr (07020001-536), based on the 126 organisms/100 mL standard.

Escherichia coli		Flow Condition				
		Very High	**High**	**Mid-Range**	**Low**	**Very Low**
		[Billion organisms/day]				
Loading Capacity[1]		**492**	**137**	**41**	**4.7**	**0.15**
Wasteload Allocation	*Clinton WWTF*	3.6	3.6	3.6	3.6	###[2]
	Total WLA	**3.6**	**3.6**	**3.6**	**3.6**	**###[2]**
Load Allocation	**Total LA**	**439**	**119**	**33**	**0.63**	**###[3]**
Margin of Safety (MOS)		**49**	**14**	**4.1**	**0.47**	**0.02**
Average existing monthly geometric mean		**260 org/100 mL**				
Overall estimated percent reduction[4]		**52%**				

[1] Baseline year is 2012 for this TMDL.

[2] ### = The permitted wastewater design flows exceed the stream flow in the indicated flow zone(s). The allocations are expressed as an equation rather than an absolute number, WLA = (flow contribution from a given source) x (126 org per 100 mL) x conversion factor (see Section 4.3.3).

[3] WLA exceeded load capacity for this zone, therefore LA is determined by the formula: Allocation = (flow from a given source) X (*E. coli* concentration standard).

[4] The overall estimated percent reduction is the reduction in the average geometric mean to meet the 126 org/100 mL standard.

Unnamed creek, Unnamed cr to Big Stone Lk (07020001-541)

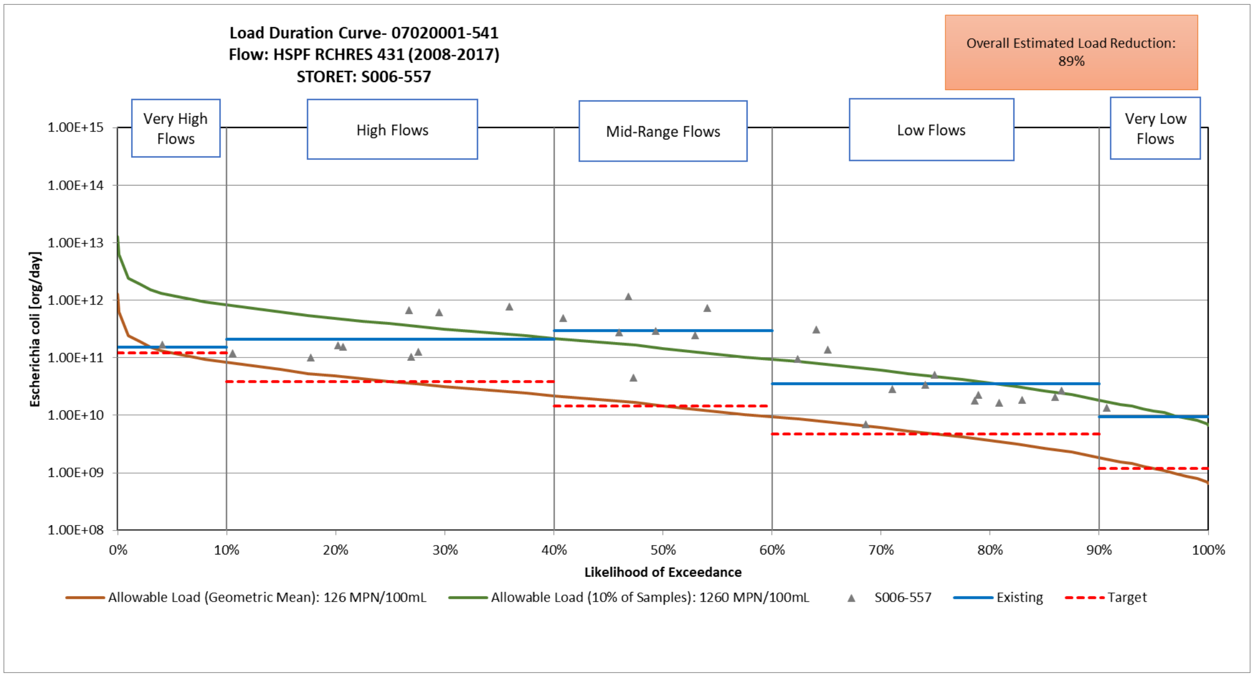


Figure 22. Unnamed creek, Unnamed cr to Big Stone Lk (07020001-541) *E. coli* LDC.

Table 27. *E. coli* allocations for Unnamed creek, Unnamed cr to Big Stone Lk (07020001-541), based on the 126 organisms/100 mL standard.

Escherichia coli	Flow Condition				
	Very High	High	Mid-Range	Low	Very Low
	[Billion organisms/day]				
Loading Capacity[1]	122	39	15	4.7	1.2
Wasteload Allocation	0	0	0	0	0
Load Allocation	110	35	13	4.2	1.1
Margin of Safety (MOS)	12	3.9	1.5	0.47	0.12
Average existing monthly geometric mean	1,108 org/100 mL				
Overall estimated percent reduction[2]	89%				

[1] Baseline year is 2015 for this TMDL.

[2] The overall estimated percent reduction is the reduction in the average geometric mean to meet the 126 org/100 mL standard.

Emily Creek, Unnamed cr to Lac qui Parle Lk (07020001-547)

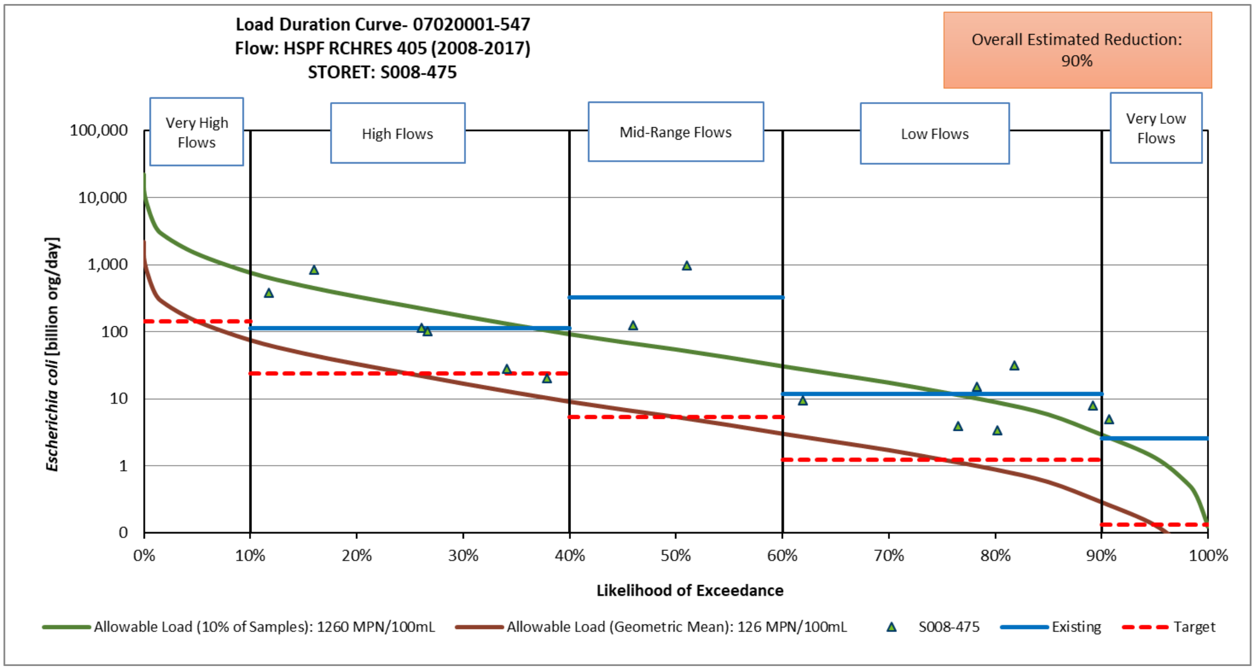


Figure 23. Emily Creek, Unnamed cr to Lac qui Parle Lk (07020001-547) *E. coli* LDC.

Table 28. *E. coli* allocations for Emily Creek, Unnamed cr to Lac qui Parle Lk (07020001-547), based on the 126 organisms/100 mL standard.

Escherichia coli		**Flow Condition**				
		Very High	**High**	**Mid-Range**	**Low**	**Very Low**
		[Billion organisms/day]				
Loading Capacity[1]		**144**	**24**	**5.4**	**1.3**	**0.13**
Wasteload Allocation	*ISD 2853 Lac qui Parle Valley High School*	1.4	1.4	1.4	###[3]	###[2]
	Total WLA	**1.4**	**1.4**	**1.4**	**###[3]**	**###[2]**
Load Allocation	**Total LA**	**129**	**20**	**3.5**	**###[4]**	**###[3]**
Margin of Safety (MOS)		**14**	**2.4**	**0.54**	**0.13**	**0.013**
Average existing monthly geometric mean		**1,299 org/100 mL**				
Overall estimated percent reduction[4]		**90%**				

[1] Baseline year is 2015 for this TMDL.

[2] ### = The permitted wastewater design flows exceed the stream flow in the indicated flow zone(s). The allocations are expressed as an equation rather than an absolute number, WLA = (flow contribution from a given source) x (126 org per 100 mL) x conversion factor (see Section 4.3.3).

[3] WLA exceeded load capacity for this zone, therefore LA is determined by the formula: Allocation = (flow from a given source) X (*E. coli* concentration standard).

[4] The overall estimated percent reduction is the reduction in the average geometric mean to meet the 126 org/100 mL standard.

Unnamed creek, Headwaters to S Fk Yellow R (07020001-551)

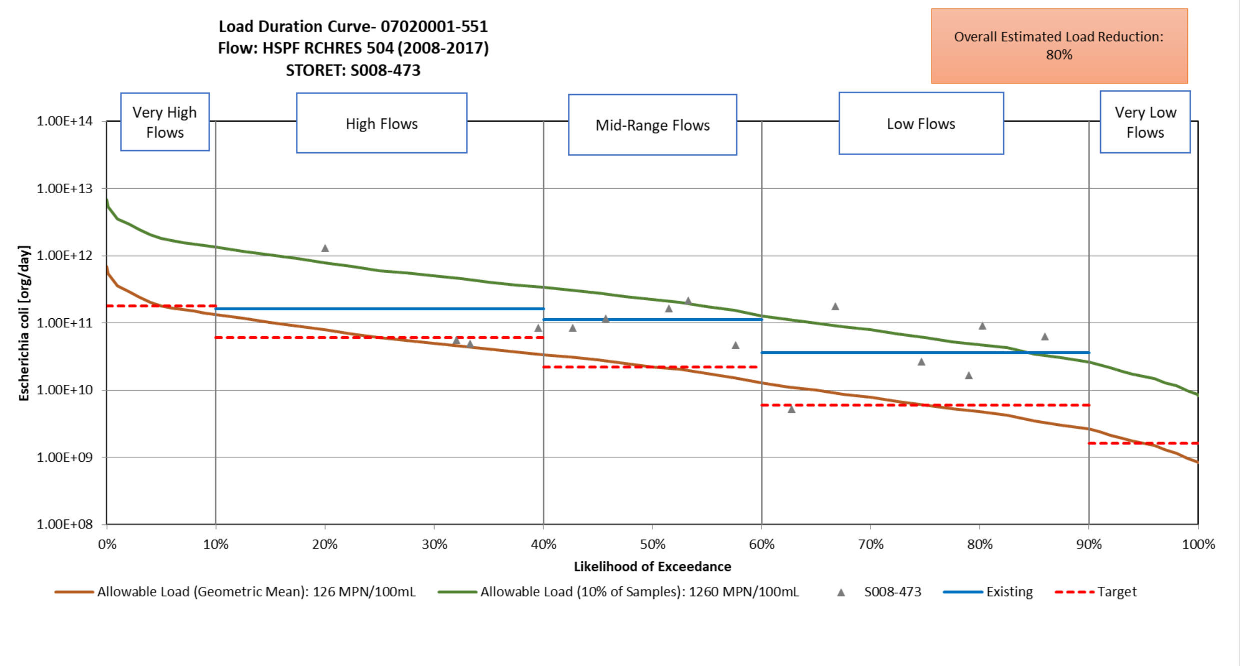


Figure 24. Unnamed creek, Headwaters to S Fk Yellow R (07020001-551) *E. coli* LDC.

Table 29. Total and Minnesota load capacities for Unnamed creek, Headwaters to S Fk Yellow R (07020001-551), based on the 126 organisms/100 mL standard.

Escherichia coli	Flow Condition				
	Very High	High	Mid-Range	Low	Very Low
	[Billion organisms/day]				
Total Load	181	60	22	6	1.6
MN Load	8.7	2.9	1.1	0.29	0.08

Table 30. *E. coli* allocations for Unnamed creek, Headwaters to S Fk Yellow R (07020001-551). Loading capacity and allocations are for Minnesota only and are based on the 126 organisms/100 mL standard.

Escherichia coli	Flow Condition				
	Very High	High	Mid-Range	Low	Very Low
	[Billion organisms/day]				
Loading Capacity[1]	**8.7**	**2.9**	**1.1**	**0.29**	**0.08**
Wasteload Allocation	0	0	0	0	0
Load Allocation	7.8	2.6	1.0	0.26	0.07
Margin of Safety (MOS)	0.87	0.29	0.11	0.029	0.008
Average existing monthly geometric mean	**638 org/100 mL**				
Overall estimated percent reduction[2]	**80%**				

[1] Baseline year is 2015 for this TMDL.

[2] The overall estimated percent reduction is the reduction in the average geometric mean to meet the 126 org/100 mL standard.

Unnamed creek (Meadowbrook Creek), 340th St to Big Stone Lk (07020001-568)

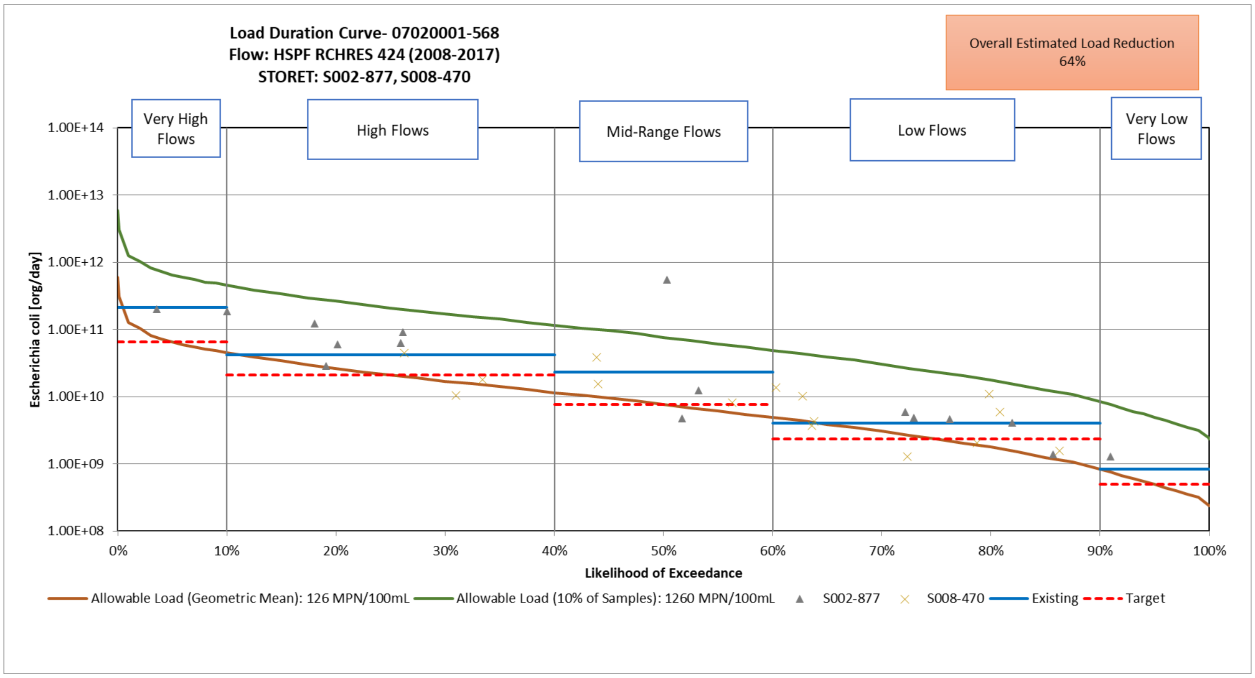


Figure 25. Unnamed creek (Meadowbrook Creek), 340th St to Big Stone Lk (07020001-568) *E. coli* LDC.

Table 31. *E. coli* allocations for Unnamed creek (Meadowbrook Creek), 340th St to Big Stone Lk (07020001-568), based on the 126 organisms/100 mL standard.

Escherichia coli	Flow Condition				
	Very High	High	Mid-Range	Low	Very Low
	[Billion organisms/day]				
Loading Capacity[1]	**65**	**21**	**7.7**	**2.3**	**0.50**
Wasteload Allocation	**0**	**0**	**0**	**0**	**0**
Load Allocation	**59**	**19**	**6.9**	**2.1**	**0.45**
Margin of Safety (MOS)	**6.5**	**2.1**	**0.77**	**0.23**	**0.05**
Average existing monthly geometric mean	**276 org/100 mL**				
Overall estimated percent reduction[2]	**64%**				

[1] Baseline year is 2015 for this TMDL.

[2] The overall estimated percent reduction is the reduction in the average geometric mean to meet the 126 org/100 mL standard.

Unnamed creek, CSAH 38 to Marsh Lk (07020001-570)

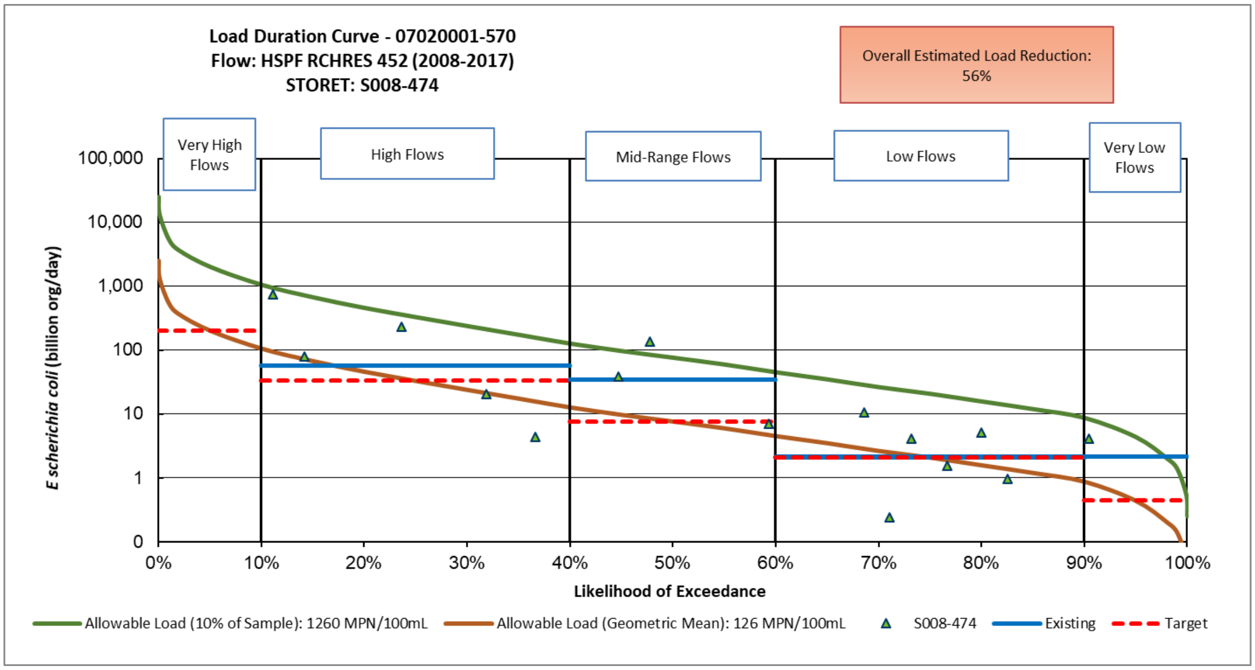


Figure 26. Unnamed creek, CSAH 38 to Marsh Lk (07020001-570) *E. coli* LDC.

Table 32. *E. coli* allocations for Unnamed creek, CSAH 38 to Marsh Lk (07020001-570), based on the 126 organisms/100 mL standard.

Escherichia coli		**Flow Condition**				
		Very High	**High**	**Mid-Range**	**Low**	**Very Low**
		[Billion organisms/day]				
Loading Capacity[1]		**204**	**33**	**7.7**	**2.1**	**0.44**
Wasteload Allocation	*Bellingham WWTP*	1.6	1.6	1.6	1.6	###[2]
	Total WLA	**1.6**	**1.6**	**1.6**	**1.6**	**###[2]**
Load Allocation	**Total LA**	**182**	**28**	**5.3**	**0.27**	**###[3]**
Margin of Safety (MOS)		**20**	**3.3**	**0.77**	**0.21**	**0.044**
Average existing monthly geometric mean		**289 org/100 mL**				
Overall estimated percent reduction[4]		**56%**				

[1] Baseline year is 2015 for this TMDL.

[2] ### = The permitted wastewater design flows exceed the stream flow in the indicated flow zone(s). The allocations are expressed as an equation rather than an absolute number, WLA = (flow contribution from a given source) x (126 org per 100 mL) x conversion factor (see Section 4.3.3).

[3] WLA exceeded load capacity for this zone, therefore LA is determined by the formula: Allocation = (flow from a given source) X (*E. coli* concentration standard).

[4] The overall estimated percent reduction is the reduction in the average geometric mean to meet the 126 org/100 mL standard.

Fish Creek, Headwaters to CSAH 33 (07020001-571)

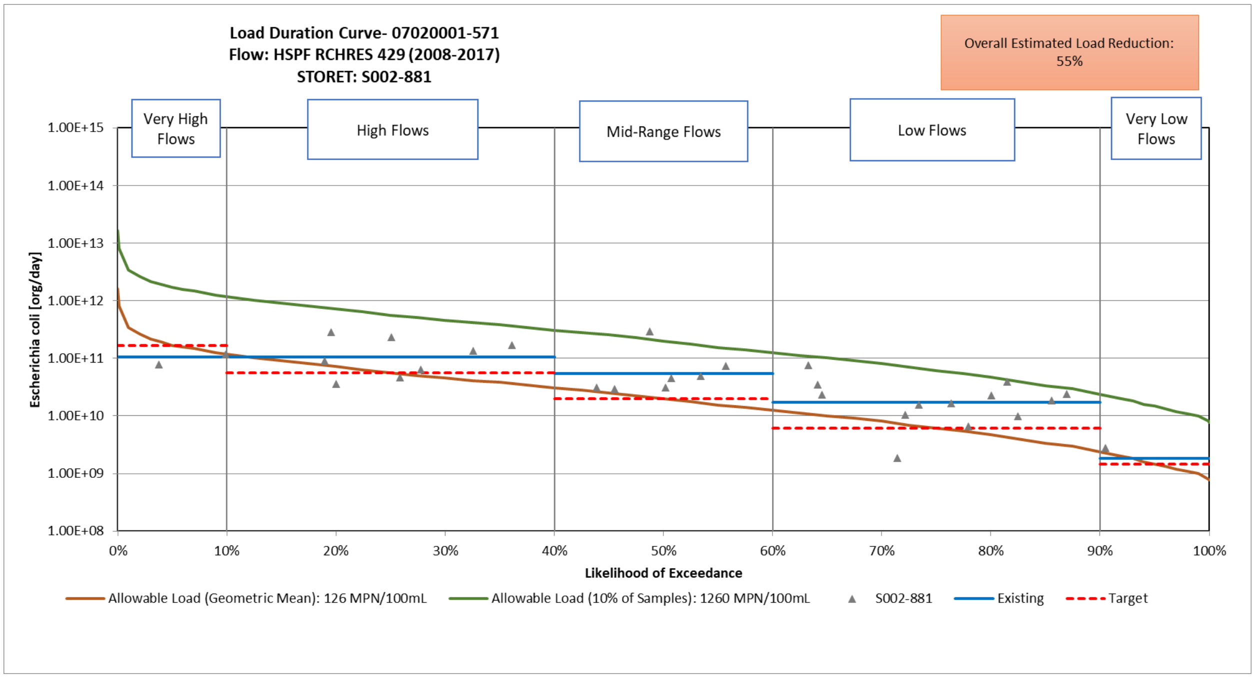


Figure 27. Fish Creek, Headwaters to CSAH 33 (07020001-571) *E. coli* LDC.

Table 33. *E. coli* allocations for Fish Creek, Headwaters to CSAH 33 (07020001-571), based on the 126 organisms/100 mL standard.

Escherichia coli	Flow Condition				
	Very High	High	Mid-Range	Low	Very Low
	[Billion organisms/day]				
Loading Capacity[1]	169	56	20	6.1	1.5
Wasteload Allocation	0	0	0	0	0
Load Allocation	152	50	18	5.5	1.3
Margin of Safety (MOS)	17	5.6	2.0	0.61	0.15
Average existing monthly geometric mean	282 org/100 mL				
Overall estimated percent reduction[2]	55%				

[1] Baseline year is 2015 for this TMDL.

[2] The overall estimated percent reduction is the reduction in the average geometric mean to meet the 126 org/100 mL standard.

4.4 Lake Nutrients

4.4.1 Loading capacity methodology

The LC of a lake represents the daily load of nutrients to a lake before it exceeds the numeric water quality standard. The LCs of impaired lakes in the watershed were determined using a spreadsheet version of the BATHTUB model currently available as a “beta” version from Dr. William W. Walker (http://www.wwwalker.net/bathtub/index.htm). BATHTUB is steady-state model that simulates eutrophication-related water quality conditions in lakes and reservoirs by applying a suite of empirical eutrophication models. It formulates water and nutrient balances that account for advective transport, diffuse transport, and nutrient sedimentation.

The primary modification to the standard spreadsheet version of BATHUB is the ability to use a stochastic approach, via Monte Carlo simulation, which allows selected modeling inputs to vary, based upon known or assumed statistical distributions within the parameter data, and for that variability to be reflected in the forecasted results. The Monte Carlo simulation generates a statistical distribution of the yearly, or seasonal, mean TP and Chl-*a* concentrations and Secchi disk depth, reflecting the uncertainty in the model parameters and normal variability in inputs (e.g., annual TP load from surface runoff) while taking into account the correlation among inputs (e.g., runoff and load). Crystal Ball (a proprietary software developed by Oracle; https://www.oracle.com/applications/crystalball/) was used to perform the Monte Carlo simulations in the spreadsheet version of BATHTUB. The benefit of using the stochastic approach is the presentation of model results in the form of a statistical distribution of responses, which steady state models cannot achieve.

Big Stone Lake, Lac qui Parle Lake – NW Bay, and Lac qui Parle Lake – SE Bay drain part of South Dakota and North Dakota, therefore, a percentage of the load capacity to represent Minnesota's portion was used to develop the TMDLs. For these lakes, the Minnesota portion was determined using the "Basin Fate" functionality in HSPF-SAM. The "Basin Fate" function provides the load for each HSPF subwatershed for the reach at a specified endpoint (e.g. the outlet). By aggregating all the subwatershed loads for "Basin Fate", the average annual total load is calculated for the outlet reach (specified reach). For the "Basin Fate" loads for the HPSF subwatersheds that are only partially in Minnesota, a percentage of the subwatershed load was taken based on the percentage of area in Minnesota. For subwatersheds wholly in Minnesota the whole subwatershed load was taken, and for subwatershed wholly outside of Minnesota loads were zero. The subwatershed loads were summed and compared to the total load at the outlet to get a percentage of the existing load coming from Minnesota. The portion of TMDL loads from Minnesota were assumed to be consistent with the existing loads from the model, i.e. use the same percentage of total load where relevant.

Watershed Loading Rates

The overland flows and phosphorus loading rates were extracted from the MRHW, Lac qui Parle River, Pomme de Terre River, and Chippewa River HSPF Models. The HSPF models simulate hydrology and water quality for the period 1996 through 2017 (MRHW and Lac qui Parle River), 1995 through 2016 (Pomme de Terre River), and 1995 through 2012 (Chippewa River). The BATHTUB models simulated water quality on either a seasonal (June to September) scale or an annual scale, depending on the hydraulic residence time (i.e. the time it takes to completely replace the water in the lake) of the modeled lake.

Upstream Lakes

Some lakes were modeled together, including Long Tom and Unnamed Lakes and the Lac qui Parle Lakes system, due to reductions in upstream lakes directly providing improvements in the downstream lakes. Alternatively, improvements in upstream lakes were not accounted for when developing the lake model for Big Stone Lake. For lakes with impaired lakes upstream, tributary inflows were extracted from the HSPF model and it was assumed that the existing conditions in the lakes were represented in the HSPF model. When estimating the needed load reduction to meet the water quality standard, tributary and overland loading were taken equally, and only the overall required load reduction was estimated. No accounting for upstream impaired waters meeting the water quality standards were factored into the modeling effort.

Atmospheric Deposition

Atmospheric deposition refers to the phosphorus inputs to the lake surface directly from the atmosphere. The modeled lakes use an estimated mean annual atmospheric deposition load of 41.7 kg/km^2/year which is 0.37 lbs/acre/year (Barr 2007). When summer values are used, the ratio of summer precipitation to average annual precipitation is used to estimate the summer atmospheric deposition.

Internal Loading

Internal loading is the re-release of TP from sediments, usually due to anoxic conditions (dissolved oxygen concentrations < 2.0 mg/L) near the bed of the lake. Internal phosphorus loading can be a substantial part of the mass balance in a lake, especially in lakes with a history of high phosphorus loads. If a lake has a long history of high phosphorus concentrations, it is possible to have internal loading rates higher than external loads. There was no information on internal loading in lakes at the time of this report; therefore, internal loading rates (if needed) were determined using a mass balance approach.

Internal loading can be estimated using methodology developed by Nürnberg (1984). Internal loading is estimated by adding an internal loading term to the current models based on external loading and predicted retention (Nürnberg 1984):

$$TP = {}^{L_{ext}}\!/_{q_s}\left(1 - R_{pred}\right) + {}^{L_{int}}\!/_{q_s} \tag{1}$$

where TP is the in-lake TP concentration (ug/L); L_{ext} is the external load (kg/yr), q_s is the lake outflow (hm^3/yr), R_{pred} is the predicted retention coefficient, and L_{int} is the internal loading (kg/yr). The retention coefficient can be estimated using:

$$R_{pred} = {}^{15}\!\Big/\!\left(18 + {}^{q_s}\!/_{A}\right) \tag{2}$$

Where A = surface area of the lake in square kilometers (km^2). The only unknown in [1] and [2] is internal loading and it can be estimated by solving for L*int*.

Using [1] and [2], the potential for internal loading was checked for the modeled lakes. Unnamed Lake was the only lake to show potential internal loading using this methodology.

Internal loading was assumed to be negligible for the remaining lakes in this study. Although no information on internal loading exists, if any internal loading exists in lakes assumed with no internal loading, it is assumed to be included in the nonpoint source loading and LA.

It should be noted, Big Stone Lake and Lac qui Parle Lake have short hydrologic residence times and it is unlikely that they stratify and become anoxic, leading to re-release of the sediment phosphorus. The hydrologic residence times for Big Stone and Lac qui Parle Lake is discussed below. The hydraulic residence times throughout the year are shown for Big Stone Lake (**Figure 28**), Lac qui Parle Lake-NW Bay (**Figure 29**), and Lac qui Parle Lake-SE Bay **(Figure 30**).

The hydraulic residence times are based on average model flow volumes (1996 through 2017) at the outlet of the lake, based on flows from the HSPF model. The average annual hydraulic residence times for Big Stone Lake is 0.71 years, 0.038 year for Lac qui Parle Lake-NW Bay, and 0.062 years for Lac qui Parle Lake-SE Bay. The annual distribution for each lake shortens during the spring and early summer months when flows are typically high and increases in the fall and winter, when flows are lower.

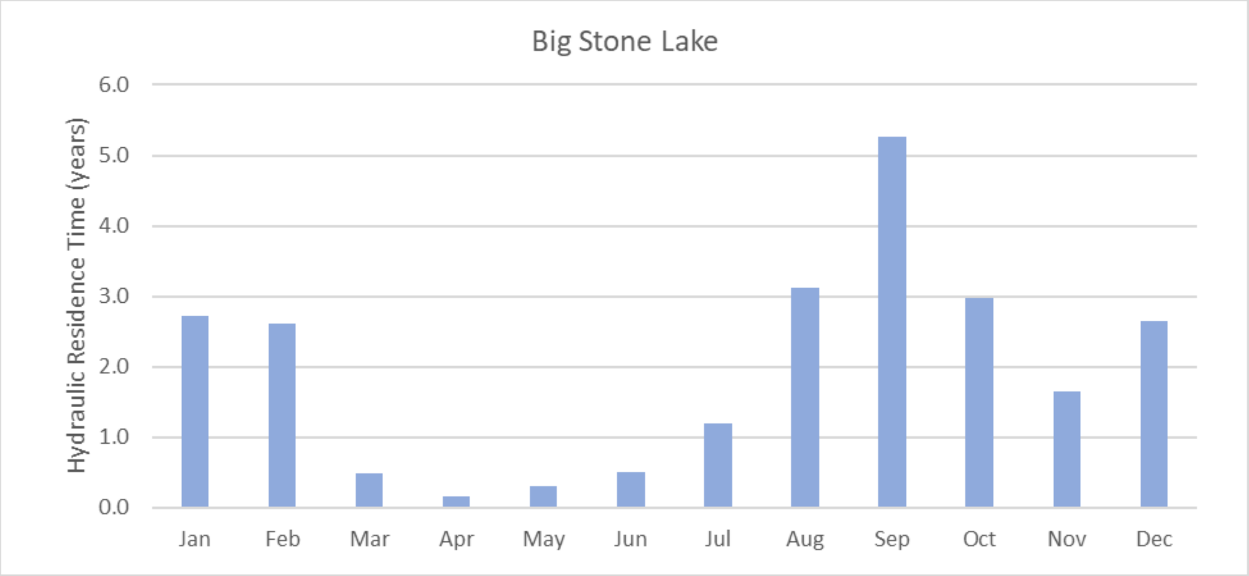


Figure 28. Change in Hydraulic residence times for Big Stone Lake, based on average monthly flow volumes from the HSPF model.

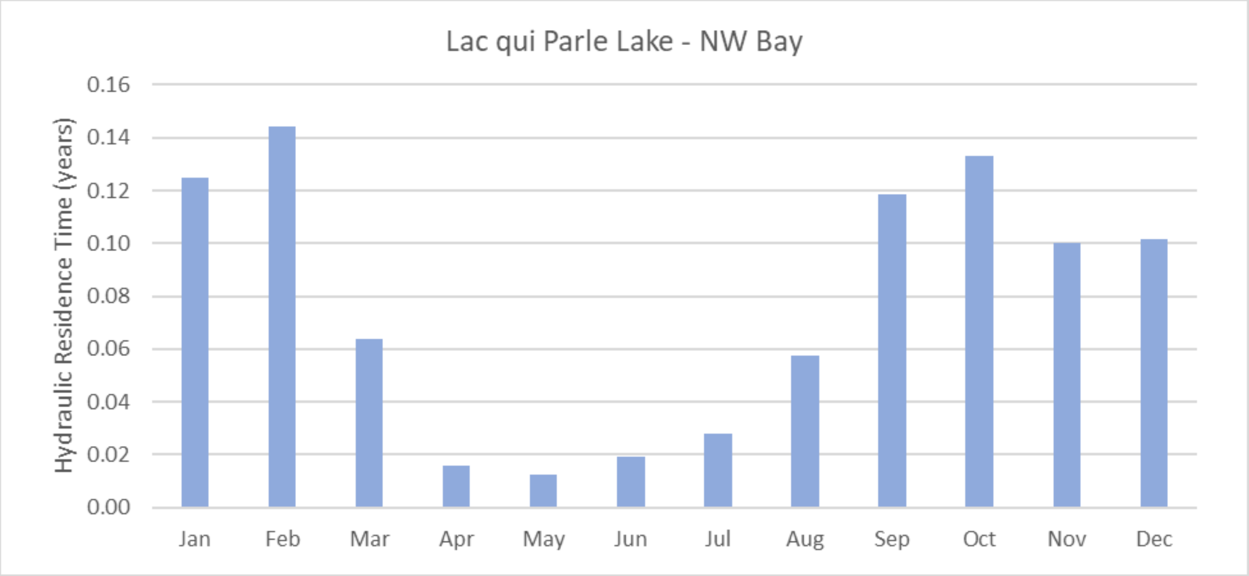


Figure 29. Change in Hydraulic residence times for Lac qui Parle Lake – NW Bay, based on average monthly flow volumes from the HSPF model.

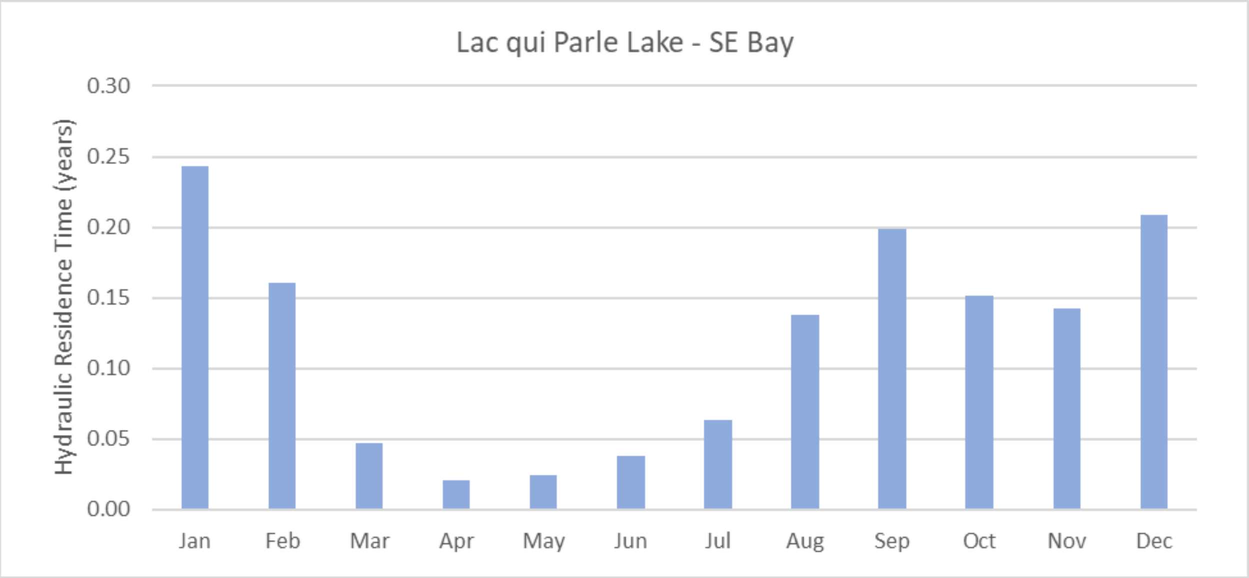


Figure 30. Change in Hydraulic residence times for Lac qui Parle Lake – SE Bay, based on average monthly flow volumes from the HSPF model.

Hydraulic residence time is the time it takes for a lake to turn over its water completely. Short hydrologic residence times usually means the lake is polymictic or mixes multiple times a year. If the lake mixes multiple times a year or multiple times in a short duration, the potential for the lake to stratify and become anoxic, re-releasing phosphorus from the sediment (internal loading) is low. Therefore, it is unlikely that internal loading is a significant source of phosphorus in Big Stone Lake, Lac qui Parle Lake-NW Bay, and Lac qui Parle Lake-SE Bay.

Internal loading can be a relatively important part of the phosphorus balance in a lake, especially lakes in this part of the state. Additional data, such as sediment cores, will be needed to quantify any such internal loading. Independent verification of internal loading is not available at this time, and more data is needed to determine if internal loading is an issue in these lakes, and if internal control measures are necessary.

The MPCA recommends feasibility studies for any lakes in which water level drawdown or chemical treatment is considered. *The Minnesota State and Regional Government Review of Internal Phosphorus Load Control* (MPCA 2020b) paper provides more information on internal phosphorus load BMPs and considerations.

The stochastic BATHUB modeling

The benefit of using stochastic modeling over the traditional BATHTUB modeling is the ability to capture the natural variation in the forcing data. Stochastic modeling is an approach where model input values (e.g. terms in hydrologic budget) and model parameters used in the equations to compute the in-lake mean concentration of TP and Chl-*a* and Secchi disk depth, are allowed to vary according to their observed statistical distribution and therefore their probability of occurrence. This allows the effect of parameter uncertainty and normal variability in the inputs (e.g., amount of surface runoff and nutrient load, which varies depending upon the amount of precipitation) to be quantified when computing the in-lake mean concentration of TP and Chl-*a,* as well as Secchi disk depth.

Crystal Ball software was used to develop the model input statistical distributions based on the previously mentioned HSPF hydrologic and TP loading seasonal or yearly values for the period 1994 through 2014. Crystal Ball was used to fit the data to distributions and provide correlations between statistical distributions to simulate natural conditions of the forcing data.

Using Monte Carlo simulation through the Crystal Ball software allowed for multiple probabilistic model computations. Select inputs, primarily those components of the water budget or TP mass balance, were allowed to vary during the Monte Carlo simulation. The selected model inputs are precipitation, evaporation, atmospheric deposition, direct drainage inflows and loadings, and tributary inflows and loadings. Many trial values (10,000 trials in this modeling effort) were generated with each trial representing a different permutation of model input values within the bounds established by the statistical distributions. The many trials resulted in a computed distribution of expected in-lake water quality for each lake rather than a single, deterministic output that was based upon only one possible combination of model inputs.

Once the BATHTUB models were built and calibrated, load reduction scenarios were developed to estimate the required load reduction to meet the water quality standard. The load reduction needed to meet the numeric water quality standard was calculated from the median (50th percentile) lake concentration. Only load reductions in tributary flows and overland (direct) drainage were made to reach the target load reduction in the lake. No reductions in atmospheric deposition were considered.

Additional information on the lake modeling efforts for this TMDL report are provided in **Appendix B**.

Load Reductions

Load reductions in phosphorus needed to meet water quality standards were estimated using the lake models. Typically, load reductions apply across the drainage area; equally applied to tributaries and direct loading. To ensure no tributary has an unrealistic load reduction, load reductions were applied to tributaries to reduce the tributary's FWMC TP to the river eutrophication standard (RES; 0.15 mg/L for the Southern Rivers Nutrient Region) and if additional load reductions were needed, the remaining load reduction was applied equally (based on the FWMC) to all tributaries flowing to an individual lake or lake segment. For the tributaries that drain South Dakota and/or North Dakota, the reductions are modeled to meet Minnesota standards. Surface waters in other states were not assumed to achieve standards more stringent than Minnesota water quality standards. The out-of-state tributaries are displayed to show necessary reductions for the lakes to meet loading capacities. Surface waters in other states are not assigned allocations in this TMDL.

Some of the lakes (Big Stone and Lac qui Parle Lake) are reservoir lakes and were modeled with multiple segments with varying in-lake water quality. For these lakes, load reductions were applied to individual model segments, which allowed for more pointed load reductions to be estimated. For example, in-lake phosphorus concentrations in Big Stone Lake are much higher in the upper half of the lake when compared to the lower half, and it was found that if loading to the upper half of the lake is reduced the lower half will meet water quality standards without further load reductions.

The following discusses the load reductions needed to meet water quality standards for each impaired lake covered in this TMDL.

Unnamed Lake (06-0060-00)

The annual runoff, phosphorus load, and needed load reductions for Unnamed Lake are shown in **Table 34**. In addition, the existing and needed FWMCs of phosphorus are provided by major tributary or source. The modeling effort determined a 72% load reduction across all tributaries and internal loading is needed to meet water quality standards in Unnamed Lake.

Table 34. Average annual load reductions for Unnamed Lake (06-0060-00), based on HSPF model results.

Major Tributary/Source	Average Annual Loads[1]			Load Reduction		Portion of Load Capacity [lbs/yr]	Needed TP FWMC [mg/L]
	Runoff [acre-ft/yr]	TP [lbs/yr]	Existing TP FWMC [mg/L]	[%]	lbs/yr		
Atmospheric Deposition[2]	134	24				24	
Direct Drainage	1,715	1,450	0.311	69%	1,007	443	0.095
Stony Run Creek (538)	16,045	10,507	0.241	61%	6,362	4,145	0.095
Unassessed Reach (999)	3,622	1,933	0.196	52%	997	936	0.095
Internal Load		6,434		97%	6,267	167	
Total	21,516	20,348		72%	14,633	5,714	0.098

[1]Derived from the HSPF model (1996-2017).

[2]Direct precipitation to lake surface.

Long Tom Lake (06-0029-00)

The annual runoff, phosphorus load, and needed load reductions for Long Tom Lake are shown in **Table 35.** In addition, the existing and needed FWMCs of phosphorus are provided by major tributary or source. Overall, 71% load reduction is needed in Long Tom Lake. No load reduction is needed in the direct drainage area of Long Tom Lake as all of the reductions will come from Unnamed Lake's drainage area. If Unnamed Lake meets water quality standards, Long Tom Lake will too.

Table 35. Average annual load reductions for Long Tom Lake (06-0029-00), based on HSPF model results.

Major Tributaries/Source	Average Annual Loads[1]			Load Reduction		Portion of Load Capacity [lbs/yr]	Needed TP FWMC [mg/L]
	Runoff [acre-ft/yr]	TP [lbs/yr]	Existing TP FWMC [mg/L]	[%]	lbs/yr		
Atmospheric Deposition[2]	310	55				55	
Direct Drainage	275	143	0.191	0%	0	143	0.191
Unnamed Lake	21,201	15,914	0.276	72%	11,445	4,469	0.078
Total	21,786	16,112	0.272	71%	11,445	4,667	0.079

[1]Derived from the HSPF model (1996-2017).

[2]Direct precipitation to lake surface.

Big Stone Lake (06-0152-00)

The annual runoff, phosphorus load, and needed load reductions for Big Stone Lake are shown in **Table 36**. In addition, the existing and needed FWMCs of phosphorus are provided by major tributary or source. The modeling effort determined an overall reduction of 42% is needed to meet water quality standards in Big Stone Lake. As stated earlier, the in-lake phosphorus concentrations are much higher in the upper half of the lake. Therefore, all of the load reductions are needed in streams that drain to the upper half of the lake, where a 49% reduction is needed. No load reduction is needed in tributaries draining to the lower half. If the upper half of the lake meets water quality standards, the lower half will too. It should be noted, the Whetstone River currently drains to Big Stone Lake near the outlet but was not included in the modeling effort and TMDL calculations. A stream restoration is currently under way to move the river to its natural channel which will not drain into Big Stone Lake. Because of the restoration project, it was not included in the TMDL calculations. Because the lower half of Big Stone Lake needs no load reduction, the impact of this decision to not include it in the TMDL is minimal.

Table 36. Load reductions for Big Stone Lake (06-0152-00).

Major Tributary/Source	Average Annual Loads[1]			Load Reduction		Portion of Load Capacity [lbs/yr]	Needed TP FWMC [mg/L]
	Runoff [acre-ft/yr]	TP [lbs/yr]	Existing TP FWMC [mg/L]	[%]	lbs/yr		
Atmospheric Deposition[2]	24,818	4,428				4,428	
Direct Drainage	19,551	13,804	0.260	18%	2,466	11,338	0.213
Little Minnesota River (508)	82,325	46,412	0.207	53%	24,717	21,695	0.097
Unassessed Reach (999)	1,072	585	0.201	52%	302	283	0.097
Unnamed Creek	6,909	5,134	0.273	64%	3,311	1,823	0.097
Fish Creek (572)	15,592	10,989	0.259	63%	6,878	4,111	0.097
South Dakota Tributary #1[3]	3,246	1,904	0.216	55%	1,048	856	0.097
Unnamed Cr (West Salmonsen Ck)	5,646	4,776	0.311	0%	0	4,776	0.311
Unnamed Ck (Meadowbrook Ck)	3,688	2,822	0.281	0%	0	2,822	0.281
South Dakota Tributary #2[3]	2,281	1,370	0.221	0%	0	1,370	0.221
Total	165,128	92,224	0.205	42%	38,722	53,502	0.109

[1] Derived from the HSPF model (1996-2017).

[2] Direct precipitation to lake surface.

[3] These represent load reductions to achieve load capacities. Surface waters in other states are not assigned allocations.

Lac qui Parle -NW Bay (37-0046-02)

The annual runoff, phosphorus load, and needed load reductions for Lac qui Parle – NW Bay are shown in **Table 37**. In addition, the existing and needed FWMCs of phosphorus are provided by major tributary or source. The modeling effort determined an overall reduction of 63% is needed to meet water quality standards in Lac qui Parle Lake-NW Bay. The load reductions by tributary range from 55% to 69%.

Table 37. Load reductions for Lac qui Parle Lake NW Bay (32-0046-02).

Major Tributary/Source	Average Annual Loads[2]			Load Reduction		Portion of Load Capacity [lbs/yr]	Needed TP FWMC [mg/L]
	Runoff [acre-ft/yr]	TP [lbs/yr]	Existing TP FWMC [mg/L]	[%]	lbs/yr		
Atmospheric Deposition[1]	11,501	780				780	
Direct Drainage	2,379	1,222	0.189	55%	666	556	0.086
Emily Creek (547)	7310	9,032	0.454	84%	7,619	1,413	0.071
Minnesota River, Marsh Lake to Lac qui Parle Lake-NW Bay (Direct Drainage)	1,641	877	0.197	56%	493	384	0.086
Marsh Lake Outflow	324,910	204,800	0..232	66%	134,447	70,353	0.080
Pomme de Terre River	194,681	108,120	0.204	58%	62,591	45,529	0.086
Total	542,422	324,831	0.220	63%	205,816	119,015	0.081

[1] Direct precipitation to lake surface.

[2] Derived from the HSPF model (1996-2017).

Lac qui Parle-SE Bay (37-0046-01)

The annual runoff, phosphorus load, and needed load reductions for Lac qui Parle Lake – SE Bay are shown in **Table 38**. In addition, the existing and needed FWMCs of phosphorus are provided by major tributary or source. The modeling effort determined an overall reduction of 41% is needed to meet water quality standards in Lac qui Parle Lake-SE Bay. The load reductions by tributary range from 15% to 48%.

Table 38. Load reductions for Lac qui Parle Lake SE Bay (23-0046-01).

Major Tributary/Source	Average Annual Loads[1]			Load Reduction		Portion of Load Capacity [lbs/yr]	Needed TP FWMC [mg/L]
	Runoff [acre-ft/yr]	TP [lbs/yr]	Existing TP FWMC [mg/L]	[%]	lbs/yr		
Atmospheric Deposition[2]	7,515	1,329				1,329	
Direct Drainage	4,112	2,828	0.253	43%	1,212	1,616	0.145
Direct Drainage, near outlet	183	120	0.241	39%	47	73	0.147
Unnamed Ditch (Watson Sag Div)(518)	3,700	2,542	0.253	43%	1,089	1,453	0.144
Lac qui Parle River	219,482	101,880	0.171	15%	15,683	86,197	0.144
Chippewa R Overflow	260,003	187,091	0.265	45%	84,977	102,114	0.144
Direct Drainage near Chippewa River overflow	1,447	958	0.243	41%	389	569	0.145
Lac qui Parle Lake-NW Bay Outflow	529,003	263,510	0.183	48%	126,633	136,877	0.095
Total	1,025,445	560,258	0.201	41%	230,030	330,228	0.118

[1] Derived from the HSPF model (1996-2017).

[2] Direct precipitation to lake surface.

The Lac qui Parle Lake-SE Bay drains a portion of the Chippewa River through the Watson Sag Diversion. The diversion is upstream of Montevideo, Minnesota, where the Chippewa River flows into the Minnesota River, just downstream of Lac qui Parle Lake. Slightly more than half of the flow in the Chippewa River is diverted into Lac qui Parle Lake. This was determined using the Chippewa River HSPF model, which simulated the diversion and estimated flows into Lac qui Parle Lake and the flow continuing down the Chippewa River. The Watson Sag Diversion is represented in **Table 38** with two parts, the Chippewa River Overflow and the Unnamed Ditch (Watson Sag Div). The Unnamed Ditch (Watson Sag Div) is the direct drainage into the Watson Sag Diversion between the Chippewa River and Lac qui Parle Lake. The Chippewa River Overflow is the water from the Chippewa River.

4.4.2 Load allocation methodology

LA represents the portion of the LC designated for NPS of phosphorus. The LA is the remaining load once the WLA and MOS are determined and subtracted from the LC. The LA includes all sources of TP that do not require NPDES permit coverage, including unregulated watershed runoff, internal loading, groundwater, atmospheric deposition, and a consideration for "natural background" conditions. "Natural background", as defined in Minn. R. 7050.0150, subp. 4, can be described as physical, chemical, or biological conditions that would exist in a waterbody that are not a result of human activity. NPS of TP were previously discussed in **Section 3.6.2**.

4.4.3 Wasteload allocation methodology

WLAs were developed for any permitted discharge that discharges into an impaired lake. These are discharges requiring an NPDES permit, and typically may include wastewater treatment facilities, MS4s, industrial dischargers, construction sites managing for stormwater, and permitted feedlots. Stormwater WLAs are calculated in accordance with EPA guidance (EPA 2002) and are presented as categorical WLAs. Categorical WLAs are pollutant loads that are equivalent for a group of permittees (e.g. construction or ISW).

Wastewater Treatment Plants

WWTPs are NPDES/SDS permitted facilities that process primarily wastewater from domestic sanitary sewer sources (i.e. sewage). Existing loads are calculated using actual effluent flow and concentrations. It is not unusual for existing loads to be lower than the WLAs. It is anticipated that facilities whose existing loads are lower than their WLAs will maintain their performance, although permit limits will be equivalent to the TMDL's WLAs and will allow for increased effluent loads from these facilities. Facilities whose existing effluent loads exceed their WLAs will need to achieve effluent phosphorus load reductions. Future NPDES permits will include phosphorus effluent limits that are consistent with the TMDL's WLAs. Facilities that will require a new or potentially revised phosphorus effluent permit limit are listed in **Table 11**. A meeting was held with the permitted facilities to present the TMDLs and explain the impacts to permit limits, and is summarized in **Section 9**. Relevant WWTPs for impaired lakes in the MRHW are shown in **Table 39** and include the WWTP name, permit number, flow type, HUC-08 and major watershed name, and relevant impaired lake where the WLA will be included. Domestic and Industrial WWTPs from four HUC-08 watershed (MRHW, Lac qui Parle River, Chippewa River, and Pomme de Terre River watersheds) are included in **Table 39.** Many of the WLAs for WWTPs in watersheds outside of the MRHW are included in other TMDL reports (MPCA 2015a, 2017a, 2017b, 2021b).

Table 39. WWTP permits applicable to impaired lakes in this TMDL report.

Facility	Permit Number	Domestic vs. Industrial	Flow Type	HUC-08	Major Watershed	Lake WID
Ag Processing Inc	MN0040134	Industrial	Continuous	7020003	Lac qui Parle River	37-0046-01
Alberta WWTP	MNG580002	Domestic	Controlled	7020002	Pomme de Terre River	37-0046-01, 37-0046-02
Appleton WWTP	MN0021890	Domestic	Continuous	7020002	Pomme de Terre River	37-0046-01, 37-0046-02
Ashby WWTP	MNG580087	Domestic	Controlled	7020002	Pomme de Terre River	37-0046-01, 37-0046-02
Barrett WWTP	MNG580173	Domestic	Controlled	7020002	Pomme de Terre River	37-0046-01, 37-0046-02
Bellingham WWTP	MNG580152	Domestic	Controlled	7020001	Minnesota River Headwaters	37-0046-01, 37-0046-02
Benson WWTP	MN0020036	Domestic	Continuous	7020005	Chippewa River	37-0046-01
Canby WWTP	MNG580154	Domestic	Controlled	7020003	Lac qui Parle River	37-0046-01
Chokio WTP	MNG640022	Industrial	Intermittent	7020002	Pomme de Terre River	37-0046-01, 37-0046-02
Chokio WWTP	MNG580007	Domestic	Controlled	7020002	Pomme de Terre River	37-0046-01, 37-0046-02
Clinton WWTP	MNG580193	Domestic	Controlled	7020001	Minnesota River Headwaters	06-0060-00, 06-0029-00, 37-0046-01, 37-0046-02

Facility	Permit Number	Domestic vs. Industrial	Flow Type	HUC-08	Major Watershed	Lake WID
Clontarf WWTP	MNG580108	Domestic	Controlled	7020005	Chippewa River	37-0046-01
Danvers WWTP	MNG585119	Domestic	Controlled	7020005	Chippewa River	37-0046-01
Dawson WWTP	MN0021881	Domestic	Continuous	7020003	Lac qui Parle River	37-0046-01
DeGraff WWTP	MN0071234	Domestic	Controlled	7020005	Chippewa River	37-0046-01
DENCO II LLC	MN0060232	Industrial	Continuous	7020002	Pomme de Terre River	37-0046-01, 37-0046-02
Duininck Inc – SD113	MNG490046	Industrial	Periodic/Seasonal	7020005	Chippewa River	37-0046-01
Evansville WWTP	MNG585074	Domestic	Controlled	7020005	Chippewa River	37-0046-01
Farwell Kensington Sanitary District WWTP	MNG585220	Domestic	Controlled	7020005	Chippewa River	37-0046-01
Hancock WWTP	MNG585299	Domestic	Controlled	7020005	Chippewa River	37-0046-01
Hendricks WWTP	MN0021121	Domestic	Controlled	7020003	Lac qui Parle River	37-0046-01
Hoffman WWTP	MNG585134	Domestic	Controlled	7020005	Chippewa River	37-0046-01
ISD 2853 Lac qui Parle Valley High School	MNG580091	Domestic	Controlled	7020001	Minnesota River Headwaters	06-0060-00, 06-0029-00, 37-0046-01, 37-0046-02
Kerkhoven WWTP	MN0020583	Domestic	Continuous	7020005	Chippewa River	37-0046-01
LG Everist Inc – SD001	MN0068764	Industrial	Intermittent, Periodic/Seasonal	7020001	Minnesota River Headwaters	37-0046-01
Lowry WWTP	MNG585123	Domestic	Controlled	7020005	Chippewa River	37-0046-01
Madison WWTP	MN0051764	Domestic	Continuous	7020003	Lac qui Parle River	37-0046-01
Marietta WWTP	MNG580160	Domestic	Controlled	7020003	Lac qui Parle River	37-0046-01
Milan WWTP	MNG580141	Domestic	Controlled	7020001	Minnesota River Headwaters	37-0046-01
Millerville WWTP	MN0054305	Domestic	Controlled	7020005	Chippewa River	37-0046-01
Morris WWTP	MN0021318	Domestic	Controlled	7020002	Pomme de Terre River	37-0046-01, 37-0046-02
Murdock WWTP	MNG585086	Domestic	Controlled	7020005	Chippewa River	37-0046-01
Odessa WWTP	MNG580099	Domestic	Controlled	7020001	Minnesota River Headwaters	37-0046-01, 37-0046-02
Ortonville WWTP	MNG580151	Domestic	Controlled	7020001	Minnesota River Headwaters	37-0046-01, 37-0046-02
PURIS Proteins LLC	MN0048968	Industrial	Continuous	7020003	Lac Qui Parle River	37-0046-01
Starbuck WWTP	MN0021415	Domestic	Continuous	7020005	Chippewa River	37-0046-01
Sunburg WWTP	MNG585125	Domestic	Controlled	7020005	Chippewa River	37-0046-01
Urbank WWTP	MNG585343	Domestic	Controlled	7020005	Chippewa River	37-0046-01

WLAs for WWTPs are based on the average wet weather flow and effluent TP concentration assumptions, depending on the assumptions provided in **Table 40**.

Table 40. WLA effluent phosphorus concentrations assumptions.

Facility Type and Flow (AWWDF or MDF*)	Annual WLA to meet Lac qui Parle TMDL
Domestic Continuous 0.2 – 1.0 mgd	AWWDF x 1.0 mg/L
Domestic Continuous <0.2 mgd	AWWDF x 3.50 mg/L or maintain current discharge
Domestic Stabilization ponds	AWWDF x 1.0 or 2.0 mg/L or maintain current discharge
Industrial Discharge with concentration > 1.0 mg/L and MDF > 1.0 mgd	MDF x 1.0 mg/L
Industrial Discharge	MDF x 1.0 mg/L
MNG49 Pit Dewatering	MDF x 0.15 mg/L**

*AWWDF = Average Wet Weather Design Flow; MDF = Maximum Design Flow

**Average TP reported by Minnesota River Basin MG49 dewatering operations (2017-2019) = 0.072 mg/L.

The WLAs for individual WWTPs are provided in **Table 41**. To calculate the WLA, flow is multiplied by the assumed concentration and multiplied by a conversion factor (8.34). The conversion factor converts liters to gallons (3.78 liter per gallon) and kilograms to pounds (2.205 pounds per kilogram). The WLAs are reported as a daily and annual LA. The annual LA multiplies the daily WLA by 365 days.

Table 41. Individual WLA calculations for WWTPs draining to impaired lakes covered in this TMDL.

NAME	Station	[A]	[B]	[C]	[D] (A*B*C)	[D*365 days]
		Average Wet Weather Flow (mgd)	TP Concentration Assumption (mg/L)	Conversion Factor	Phosphorus WLA (lbs/day)	Phosphorus WLA (lbs/yr)
Alberta WWTP	SD001	0.023	2	8.34	0.384	140
Appleton WWTP	SD001	0.44	1	8.34	3.67	1,339
Ashby WWTP	SD001	0.1011	2	8.34	1.686	616
Barrett WWTP	SD002	0.106	2	8.34	1.768	645
Bellingham WWTP	SD001	0.03	2	8.34	0.5	183
Benson WWTP	SD001	0.985	1	8.34	8.215	2,998
Canby WWTP	SD001	0.339	2	8.34	5.655	2,064
Chokio WWTP	SD001	0.098	2	8.34	1.635	597
Clinton WWTP	SD001	0.099	1	8.34	0.826	301
Clontarf WWTP	SD001	0.024	2	8.34	0.4	146
Danvers WWTP	SD001	0.023	2	8.34	0.384	140
Dawson WWTP	SD002	0.471	1	8.34	3.928	1,434
DeGraff WWTP	SD001	0.0214	2	8.34	0.357	130
Evansville WWTP	SD001	0.1	1	8.34	0.833	304
Farwell Kensington Sanitary District WWTP	SD001	0.076	2	8.34	1.274	465
Hancock WWTP	SD005	0.183	2	8.34	3.049	1,113
Hendricks WWTP	SD002	0.185	2	8.34	3.086	1,126
Hoffman WWTP	SD001+ SD003	0.159	2	8.34	2.651	968
ISD 2853 Lac qui Parle Valley High School	SD001	0.023	2	8.34	0.384	140
Kerkhoven WWTP	SD001	0.15	3.5	8.34	4.378	1,598
Lowry WWTP	SD001	0.049	0.9	8.34	0.368	134
Madison WWTP	SD002	0.48	1	8.34	4.003	1,461

NAME	Station	[A] Average Wet Weather Flow (mgd)	[B] TP Concentration Assumption (mg/L)	[C] Conversion Factor	[D] (A*B*C) Phosphorus WLA (lbs/day)	[D*365 days] Phosphorus WLA (lbs/yr)
Marietta WWTP	SD001	0.033	2	8.34	0.55	201
Milan WWTP	SD001	0.067	2	8.34	1.118	408
Millerville WWTP	SD001	0.02	2	8.34	0.326	119
Morris WWTP	SD003 + SD004	0.964	1	8.34	8.04	2,935
Murdock WWTP	SD001	0.043	2	8.34	0.718	262
Odessa WWTP	SD002	0.026	2	8.34	0.434	158
Ortonville WWTP	SD001	0.43	1	8.34	3.586	1,309
Starbuck WWTP	SD003	0.35	0.86	8.34	2.5	912
Sunburg WWTP	SD001	0.0157	2	8.34	0.26	95
Urbank WWTP	SD001	0.011	2	8.34	0.181	66
Ag Processing Inc	SD001	1.761	1	8.34	14.69	5,361
Chokio WTP	SD001	0.006	1	8.34	0.05	18.26
Duininck Inc	SD113	2.6	0.15	8.34	3.253	1187.2
LG Everist Inc	SD001+ SD002	0.78	0.15	8.34	0.975	356.16
PURIS Proteins LLC	SD001	0.3	1	8.34	2.5	912.46
DENCO II LLC	SD002	0.25	1	8.34	2.09	761

The WLAs provided in **Table 41** are based on 365 days of discharge and the basis for WLAs in the TMDL tables (see **Section 4.4.7**). For controlled systems, this may underestimate their daily limit, since they only discharge part of the year. Controlled systems are designed to store 180 days' worth of flow and discharge during the spring and fall periods of relatively high stream flow and/or low receiving water temperatures. Since these facilities discharge intermittently, their assigned daily WLAs (annual WLA divided by 365 days) will not represent their actual daily discharge when they do discharge.

Straight Pipe Septic Systems

Straight pipe septic systems are illegal and unpermitted, and receive a WLA of zero.

Municipal Separate Storm Sewer System

The WLA for communities subjected to MS4 NPDES stormwater permit requirements is taken as a percentage of the LC based on the percentage of land area in the impaired reach that the MS4 permit area covers. There is one MS4 permitted area, the city of Morris (MS4 Permit #MS400274) in the Pomme de Terre River Watershed, which covers about 4.9 sq mi. This is 0.17% of the drainage area of Lac qui Parle Lake – NW Bay and 0.08% of the drainage are of Lac qui Parle Lake – SE Bay.

Construction and Industrial Stormwater

WLAs for construction stormwater discharges are covered by the State's general permits. These were combined and addressed through a categorical allocation. Stormwater runoff from construction sites that disturb: (a) one acre of soil or more, (b) less than one acre of soil and are part of a "larger common plan of development or sale" that is greater than one acre, or (c) less than one acre, but determined to pose a risk to water quality are regulated under the state's NPDES/SDS General Stormwater Permits for Construction Activity (MNR1000001). This permit identifies and requires BMPs to be implemented to protect water resources from mobilized sediment and other pollutants of concern. If the owner/operator of impacted construction sites, obtain and abide by the NPDES/SDS General Construction Stormwater Permit, the stormwater discharges associated with those sites are expected to meet the WLAs set in this TMDL report.

ISW sites are regulated under general permits, in this case either the NPDES/SDS ISW Multi-Sector General Permit (MNR050000) or the NPDES/SDS General Permit for Construction Sand & Gravel, Rock Quarrying, and Hot Mix Asphalt Production facilities (MNG490000). Like the NPDES/SDS General Construction Stormwater Permit, these permits identify BMPs to be implemented to protect water resources from pollutant discharges at the site. If the owner/operator of industrial sites abide by the necessary NPDES/SDS General Stormwater Permits, the discharges associated with those sites are expected to meet the WLAs set in this TMDL report.

Due to the transient nature of construction activities and the minimal amount of industrial activity, it is assumed that 0.1% of the drainage area is under construction or industrial activities at any given time. Therefore, to calculate the WLA for construction and ISW, this TMDL report assigns 0.1% of the LC to the construction/ ISW WLA.

Livestock Facilities

NPDES permitted feedlot facilities are assigned a WLA of zero. This is consistent with the conditions of the permits, which allow no pollutant discharge from the livestock housing facilities and associated sites. A list of CAFOs and the WIDs they contribute to is included in **Appendix E**.

4.4.4 Margin of safety

The MOS accounts for uncertainty with the allocations resulting in attaining water quality standards. An explicit 10% MOS is applied to all impaired lake TMDLs. The 10% accounts for uncertainty associated with data collection, lab analysis, data analysis, modeling error, and implementation activities. The MOS accounts for:

- Uncertainty in the lake models;
- Uncertainty in observed water quality data; and
- Uncertainty in the results from the HSPF models.

The majority of the MOS is apportioned to uncertainty related to the HSPF model. The hydrologic calibration statistics for the HSPF model at the Minnesota River at Ortonville, Minnesota (USGS station ID 05292000) were:

- -0.7% Error in total flow volume;
- -5.9% Error in bottom 50% low flows;
- 1.0% Error in the top 10% high flows;
- A Nash-Sutcliffe coefficient of model fit efficiency (NSE) of 0.947 for daily flows;
- And, an NSE of 0.935 for monthly flows.

Overall, the HSPF model was determined to be “Very Good”. More information on the calibration of the HSPF model can be found in Tetra Tech (2016).

For phosphorus loading, the HSPF model has two sites within the MRHW, Whetstone River at Big Stone and Yellow Bank River near Odessa. The phosphorus calibration statistics for those sites were:

- -16% and -2.2% relative error in average concentration (respectively);
- -10% and 10% relative error for concentration median;
- -36% and -36% relative error for paired loading; and
- -1.0% and 0.3% for paired load median error.

More information on the calibration of the HSPF model can be found in Tetra Tech (2016).

In addition, the nature of the stochastic version of BATHUB model, which uses distributions for the forcing data, accounts for the uncertainty in the forcing data and can be used to investigate the needed MOS. Each lake model was simulated for 10,000 runs to account for the variability in the forcing data (climate and loadings). The loading reduction needed to meet the water quality standard was assumed to occur when the model simulated TP concentration at the 50th percentile, meaning the lake will meet the water quality standard 50% of the time, resulting in the summer average TP concentration to meet the standard that is a summer average. To investigate a potential MOS, the load reductions needed to reach the water quality standard at the 90th percentile, meaning the water quality standard will be met 90% of the time, were estimated. The difference between the 50th and 90th percentile can estimate the errors in the stochastic models and provide a level of uncertainty used to investigate an appropriate MOS.

Using this method, the lake models’ uncertainty ranged from 6% to 33%, with most under 10%. Big Stone Lake and Lac qui Parle Lake-SE Bay have values of 33% and 27% respectively. The high uncertainties for Big Stone Lake and Lac qui Parle Lake-SE Bay were unexpectedly high and warranted further investigation into the drivers of the uncertainty. Upon further review, it was determined the high uncertainty values for Big Stone Lake and Lac qui Parle Lake-SE Bay can be attributed to model complexity and not necessarily uncertainty in the forcing data (climate and loading data) and model results (observed TP concentrations). These higher values can be attributed to being segmented with only one segment requiring a load reduction to bring all other segments within the water quality standard as well as influences from the simulated loading distributions when using the stochastic approach.

Big Stone Lake was modeled with two model segments, but loads were combined to give a summary of the lake. The overall load reduction to meet the 50th percentile was 49% from the tributaries contributing to the upper model segment and 0% from the tributaries contributing to the lower model segment. In addition, the spread in the distribution of simulated in-lake TP concentrations for an individual load reduction scenario was greater than expected (see Appendix B, Figure 24), that is not seen within the observed TP data. This large spread leads to questions about quality of the assumed distribution of the forcing data and the appropriateness of using this method to determine the MOS for these complex lake models.

Lac qui Parle Lake – SE Bay was modeled as part of one system with Lac qui Parle Lake – NW Bay and Marsh Lake and included three segments to account for tributaries entering the lake. The majority of the load reductions are needed upstream of Marsh Lake and Lac qui Parle Lake – NW Bay, requiring a 71% reduction. Similar to the Big Stone Lake model, some sections of the Lac qui Parle Lake model have large distributions of in-lake TP results for a single load reduction scenario (see Appendix B, Figures 56, 62 and 68) and lead to questioning of the appropriateness of using this method for determining MOS.

Given the model complexities and professional judgement, it was determined the stochastic method for establishing MOS resulted in unwarranted, higher than expected, uncertainty values and not appropriate for this TMDL. With HSPF modeling errors, lake modeling errors and adaptive management that will create “course corrections” based on future monitoring efforts, an overall 10% MOS is appropriate.

4.4.5 Reserve Capacity

The RC represents a set-aside for potential future loading sources. In this TMDL report, the RC accounts for currently “unsewered” communities that may become “sewered” and discharge to a WWTP in the future.

The potential need for RC for these situations has been estimated based on the assumption that 10% of the unsewered population within an impaired lake drainage basin may discharge to WWTPs in the future. The potential TP load from future WWTPs serving these populations has been calculated based on an assumption of 0.8 kg/capita/year of TP load to the WWTP and a reduction efficiency of 80% at the WWTP, resulting in a load to the receiving water of 0.16 kg/capita/year (MPCA 2012b).

A RC was allocated for Lac qui Parle Lake-NW Bay and Lac qui Parle Lake-SE Bay. These lakes are most likely to have “unsewered” communities become “sewered” in the future. A summary of the RC calculations for future “sewered” communities is presented in **Table 42**.

Table 42. Reserve capacity for future “sewered” communities.

Lake (AUID)	Estimated population not currently connected to NPDES permitted WWTP	Estimated required future permit population[1]	Estimated untreated annual TP load[2]	Reserve Capacity [80% removal] (kg/yr)	Reserve Capacity [80% removal] (kg/day)	Reserve Capacity [80% removal] (lbs/day)
Lac qui Parle Lake-NW Bay (37-0046-02**)**	11,527	1,153	922	184	0.51	1.11
Lac qui Parle Lake-SE Bay (37-0046-01)	31,387	3,139	2,511	502	1.38	3.03

[1] Not currently connected to NPDES permitted WWTP that may require a TP WLA in the future (10%).
[2] For population not currently connected to NPDES permitted WWTP that may require a TP WLA in the future (0.8 kg/capita/yr).

4.4.6 Seasonal variation

Lakes are generally not sensitive to short term changes in water quality, rather respond to long-term changes and variation in seasonal and/or annual loads. Water quality monitoring suggests in-lake water quality varies over the course of the growing season and generally peaks in mid to late summer. The standard applies from June through September and MPCA guidelines for assessing lake TP is defined as the June through September mean concentration. The BATHTUB models were used to calculate the load capacities for each lake, incorporating mean growing season TP values and seasonal or annual loads, depending on the hydrologic residence time. Calibration to the summer critical period provides adequate protection during times of the year with reduced loading.

4.4.7 TMDL summary

The allowable TP load (TMDL) for each lake was divided among the WLA, LA, and the MOS as described in the above sections. The following tables summarize the existing and allowable TP loads (Total Load and LC, respectively), the TMDL allocations (WLAs and LAs) and required reductions for each lake.

The following rounding conventions were used in the TMDL tables:

- Values ≥10 reported in lbs/yr have been rounded to the nearest pound.
- Values <10 and ≥1 reported in lbs/yr have been rounded to the nearest tenth of a pound.
- Values ≥0.01 reported in lbs/day have been rounded to the nearest hundredth of a pound
- Values <0.01 reported in lbs/day have been rounded to enough significant digits so that the value is greater than zero and a number is displayed in the table.
- While some of the numbers in the tables show multiple digits, they are not intended to imply great precision.
- Some small arithmetic errors may exist due to rounding errors.

Table 43. TP TMDL for Unnamed Lake (06-0060-00).

Unnamed Lake (06-0060-00)		Existing Phosphorus Load		Allowable Phosphorus Load		Estimated Load Reduction	
		lbs/yr	lbs/day[1]	lbs/yr	lbs/day[1]	lbs/yr	%
Total Load/Loading Capacity		**20,348**	**56**	**5,714**	**16**	**14,633**	**72%**
Wasteload Allocation	**Total WLA**	**118.7**	**0.33**	**307**	**0.84**	**0**	**0%**
	Clinton WWTF[2]	113	0.31	301	0.83	0	0%
	Construction/Industrial Stormwater[3]	5.7	0.016	5.7	0.016	0	0%
Load Allocation	**Total LA**	**20,229**	**55**	**4,836**	**13**	**15,393**	**76%**
	Nonpoint Sources	13,771	37	4,645	12.7	9,126	66%
	Internal Loading	6,434	18	167	0.46	6,267	97%
	Atmosphere	24	0.066	24	0.066	0	0%
Margin of Safety (MOS)[4]				**571**	**1.6**		

[1] Based on Annual Loads divided by 365 days.
[2] Based on average annual loads available for 2008-2018 (MPCA 2020c). Baseline Year is 2016.
[3] Assumes 0.1% of allowable load capacity. Assumes existing permits are being met with current BMPs.
[4] Based on explicit 10% MOS.

Table 44. TP TMDL for Long Tom Lake (06-0029-00).

Long Tom Lake (06-0029-00)		Existing Phosphorus Load		Allowable Phosphorus Load		Estimated Load Reduction	
		lbs/yr	lbs/day[1]	lbs/yr	lbs/day[1]	lbs/yr	%
Total Load/Loading Capacity		**16,111**	**44**	**4,667**	**13**	**11,444**	**71%**
Wasteload Allocation	**Total WLA**	**118**	**0.32**	**306**	**0.84**	**0**	**0%**
	Clinton WWTF[2]	113	0.31	301	0.83	0	0%
	Construction/Industrial Stormwater[3]	4.7	0.013	4.7	0.013	0	0%
Load Allocation	**Total LA**	**15,993**	**44**	**3,894**	**11**	**12,099**	**76%**
	Nonpoint Sources	142	0.39	142	0.39	0	0%
	Atmosphere	55	0.15	55	0.15	0	0%
	Unnamed Lake[4]	15,796	43	3,697	10	12,099	77%
Margin of Safety (MOS)[5]				**467**	**1.3**		

[1] Based on Annual Loads divide by 365 days.
[2] Based on average annual loads available for 2008-2018 (MPCA 2020c). Baseline Year is 2016.
[3] Assumes 0.1% of allowable load capacity. Assumes existing permits are being met with current BMPs.
[4] Outflow from Unnamed Lake, based on CNET modeling.
[5] Based on Explicit 10% MOS.

Table 45. Minnesota's phosphorus load capacity for Big Stone Lake (06-0152-00).

Big Stone (06-0152-00)	Existing Phosphorus Load		Allowable Phosphorus Load		Estimated Load Reduction	
	lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Total Load	92,224	253	53,502	147	38722	42%
MN Load	29,235	80	16,960	46	12,275	42%

Table 46. TP TMDL for Big Stone Lake (06-0152-00).

Big Stone (06-0152-00)		Existing Phosphorus Load		Allowable Phosphorus Load		Estimated Load Reduction	
		lbs/yr	lbs/day[1]	lbs/yr	lbs/day[1]	lbs/yr	%
Total Load/Loading Capacity		**29,235**	**80**	**16,960**	**46**	**12,275**	**42%**
Wasteload Allocation	**Total WLA**	**17**	**0.046**	**17**	**0.046**	**0**	**0%**
	Construction/Industrial Stormwater[2]	17	0.046	17	0.046	0	0%
Load Allocation	**Total LA**	**29,218**	**80**	**15,247**	**41**	**13,971**	**48%**
	Atmosphere	4,428	12	4,428	12	0	0%
	Nonpoint Sources	24,790	68	10,819	29	13,971	56%
Margin of Safety (MOS)[3]				**1,696**	**4.6**		

[1] Based on Annual Loads divided by 365 days.

[2] Assumes 0.1% of allowable load capacity. Assumes existing permits are being met with current BMPs.

[3] Based on explicit 10% MOS.

Table 47. Minnesota's phosphorus load capacity for Lac qui Parle Lake – NW Bay (37-0046-02).

Lac qui Parle Lake-NW Bay (37-0046-02)	Existing Phosphorus Load		Allowable Phosphorus Load		Estimated Load Reduction	
	lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Total Load	324,831	890	119,015	326	205,816	63%
MN Load	214,064	586	78,431	215	135,633	63%

Table 48. TP TMDL for Lac qui Parle Lake – NW Bay (37-0046-02).

Lac qui Parle Lake-NW Bay (37-0046-02)		Existing Phosphorus Load		Allowable Phosphorus Load		Estimated Load Reduction	
		lbs/yr	lbs/day[1]	lbs/yr	lbs/day[1]	lbs/yr	%
Total Load/Loading Capacity		**214,064**	**586**	**78,431**	**215**	**135,633**	**63%**
Wasteload Allocation	**Total WLA**	**4,844**	**13**	**9,353**	**26**	**210**	**4.5%**
	Alberta WWTP	41	0.11	140	0.38	0	0%
	Appleton WWTP	1,534	4.2	1,339	3.67	195	13%
	Ashby WWTP	362	0.99	616	1.69	0	0%
	Barrett WWTP	140	0.38	645	1.77	0	0%
	Bellingham WWTP	52	0.14	183	0.50	0	0%
	Chokio WTP	33	0.09	18	0.05	15	45%
	Chokio WWTP	63	0.17	597	1.64	0	0%
	Clinton WWTP	113	0.31	301	0.83	0	0%
	DENCO II LLC	417	1.14	761	2.09	0	0%
	ISD 2853 Lac qui Parle Valley High School	21	0.06	140	0.38	0	0%
	Morris WWTP	1,288	3.5	2,935	8.04	0	0%
	Odessa WWTP	28	0.077	158	0.43	0	0%
	Ortonville WWTP	541	1.5	1,309	3.6	0	0%
	Morris MS400274[2]	133	0.37	133	0.37	0	0%
	Construction/Industrial Stormwater[3]	78	0.21	78	0.21	0	0%
Load Allocation	**Total LA**	**209,220**	**573**	**60,830**	**167**	**148,390**	**71%**
	Atmosphere	780	2.1	780	2.1	0	0%
	Pomme de Terre River	104,197	285	33,636	92	70,561	68%
	Nonpoint Sources	104,243	286	26,414	73	77,829	75%
Margin of Safety (MOS)[4]				**7,843**	**21**		
Reserve Capacity				**405**	**1.1**		

[1] Based on Annual Loads divided by 365 days. Baseline Year is 2016.

[2] WLA for Morris MS4 area is taken as 0.17% of the load capacity.

[3] Assumes 0.1% of allowable load capacity. Assumes existing permits are being met with current BMPs.

[4] Based on explicit 10% MOS.

Table 49. Minnesota's portion of the total load capacity for Lac qui Parle Lake - SE Bay (37-0046-01).

Lac qui Parle Lake-SE Bay (37-0046-01)	Existing Phosphorus Load		Allowable Phosphorus Load		Estimated Load Reduction	
	lbs/yr	lbs/day	lbs/yr	lbs/day[2]	lbs/yr	%
Total Load	560,258	1,535	330,228	905	230,030	41%
MN Load	403,075	1,104	244,149	669	158,926	39%

Table 50. TP TMDL for Lac qui Parle Lake – SE Bay (37-0046-01).

Lac qui Parle Lake-SE Bay (37-0046-01)		**Existing Phosphorus Load**		**Allowable Phosphorus Load**		**Estimated Load Reduction**	
		lbs/yr	**lbs/day[1]**	**lbs/yr**	**lbs/day[1]**	**lbs/yr**	**%**
Total Load/Loading Capacity		**403,075**	**1,104**	**244,149**	**669**	**158,926**	**39%**
Wasteload Allocation	**Total WLA**	**12,507**	**34**	**33,541**	**92**	**966**	**8%**
	WWTF[2]	12,068	33	33,102	90.7	966	8%
	Morris MS400274[3]	195	0.54	195	0.54	0	0%
	Construction/Industrial Stormwater[4]	244	0.67	244	0.67	0	0%
Load Allocation	**Total LA**	**390,568**	**1,070**	**185,087**	**507**	**205,481**	**53%**
	Atmosphere	1,329	3.6	1,329	3.6	0	0%
	Chippewa River	185,796	509	82,002	225	103,794	56%
	Lac qui Parle River	84,806	232	55,264	151	29,542	35%
	Nonpoint Sources	3,468	9	1,376	3	2,092	60%
	Lac qui Parle NW Bay	115,169	316	45,116	124	70,053	61%
Margin of Safety (MOS)[5]				**24,415**	**67**		
Reserve Capacity				**1,106**	**3.0**		

[1] Based on Annual Loads divided by 365 days. Baseline Year is 2016.

[2] List of individual WWTP provide in Table 51.

[3] WLA for Morris MS4 is taken as 0.08% of load capacity.

[4] Categorical Construction and ISW, Assumed 0.1% of LC for each.

[5] Based on explicit 10% MOS.

Table 51. WWTP WLAs for Lac qui Parle Lake – SE Bay (37-0046-01).

Major Watershed	**Facility**	**Existing Phosphorus Load**		**Allowable Phosphorus Load**		**Estimated Load Reduction**	
		lbs/yr	**lbs/day**	**lbs/yr**	**lbs/day**	**lbs/yr**	**%**
Chippewa River	*Benson WWTP*	947	2.59	2,998	8.22	0	0%
	Clontarf WWTP	85	0.23	146	0.40	0	0%
	Danvers WWTP	66	0.18	140	0.38	0	0%
	DeGraff WWTP	ND	ND	130	0.36		
	Duininck Inc – SD113	ND	ND	1,187	3.25		
	Evansville WWTP	247	0.68	304	0.83	0	0%
	Farwell Kensington Sanitary District WWTP	169	0.46	465	1.27	0	0%
	Hancock WWTP	415	1.14	1,113	3.05	0	0%
	Hoffman WWTP	325	0.89	968	2.65	0	0%
	Kerkhoven WWTP	99	0.27	1,598	4.38	0	0%
	Lowry WWTP	37	0.10	134	0.37	0	0%
	Millerville WWTP	30	0.08	119	0.33	0	0%
	Murdock WWTP	262	0.72	262	0.72	0.44	0.2%
	Starbuck WWTP	302	0.83	912	2.50	0	0%
	Sunburg WWTP	850	2.33	95	0.26	755	89%
	Urbank WWTP	3.4	0.009	66	0.18	0	0%
Lac qui Parle River	*Ag Processing Inc*	413	1.13	5,361	14.69	0	0%

Major Watershed	Facility	Existing Phosphorus Load		Allowable Phosphorus Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
	Canby WWTP	912	2.50	2,064	5.66	0	0%
	Dawson WWTP	1,356	3.71	1,434	3.93	0	0%
	Hendricks WWTP	231	0.63	1,126	3.09	0	0%
	Madison WWTP	533	1.46	1,461	4.00	0	0%
	Marietta WWTP	59	0.16	201	0.55	0	0%
	PURIS Proteins LLC	ND	ND	912	2.50		
Minnesota River Headwaters	*Bellingham WWTP*	52	0.14	183	0.50	0	0%
	Clinton WWTP	113	0.31	301	0.83	0	0%
	ISD 2853 Lac qui Parle Valley High School	21	0.06	140	0.38	0	0%
	LG Everist Inc	16	0.04	356	0.98	0	0%
	Milan WWTP	79	0.22	408	1.12	0	0%
	Odessa WWTP	28	0.077	158	0.43	0	0%
	Ortonville WWTP	541	1.5	1,309	3.59	0	0%
Pomme de Terre River	*Alberta WWTP*	41	0.11	140	0.38	0	0%
	Appleton WWTP	1,534	4.2	1,339	3.67	195	13%
	Ashby WWTP	362	0.99	616	1.69	0	0%
	Barrett WWTP	140	0.38	645	1.77	0	0%
	Chokio WTP	33	0.09	18	0.05	15	45%
	Chokio WWTP	63	0.17	597	1.64	0	0%
	DENCO II LLC	417	1.14	761	2.09	0	0%
	Morris WWTP	1,288	3.5	2,935	8.04	0	0%
Total WLA for WWTPs		**12,068**	**33.06**	**33,102**	**90.7**	**966**	**8%**

5. Future growth considerations

Potential changes in population and land use/land cover over time in the MRHW could result in changing sources of pollutants. According to the Minnesota State Demographic Center (MDA 2015), over the next 20 years (2015 to 2035), the populations in the MRHW are projected to decrease in all counties (Big Stone -8.0%, Chippewa -5.4%, Lac qui Parle -22.9%, Swift -14.1%, and Traverse -23.5%), with the exception of Stevens County (+1.1%). As with the majority of Minnesota, this loss of population will likely occur in the rural areas and small towns and will result in a negligible amount of change in land use. The overall population projection for all six counties is -9.9%. Possible changes and how they may or may not impact TMDL allocations are discussed below.

5.1 New or expanding permitted MS4 WLA transfer process

Future transfer of watershed runoff loads in this TMDL 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 nonregulated MS4 becomes 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 would be existing state highways that were outside of an urban area at the time the TMDL 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. 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 (*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 *E. coli* TMDL. This procedure will be used to update WLAs in approved TMDLs for new or expanding wastewater dischargers whose permitted effluent limits are at or below the instream target and will ensure that the effluent concentrations will not exceed applicable water quality standards or surrogate measures. The process for modifying 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

A TMDL report needs to provide reasonable assurance that water quality targets will be achieved through the specified combination of point and NPS reductions reflected in the LAs and WLAs. According to EPA guidance (EPA 2002), "When a TMDL is developed for waters impaired by both point and NPS, and the WLA is based on an assumption that nonpoint-source load reductions will occur... the TMDL report should provide reasonable assurances that nonpoint-source control measures will achieve expected load reductions in order for the TMDL report to be approvable. This information is necessary for the EPA to determine that the TMDL, including the LA and WLAs, has been established at a level necessary to achieve water quality standards." In the MRHW considerable reductions in NPS are required.

The MPCA, other state agencies, and local partners will:

- Evaluate existing programmatic, funding, and technical capacity to implement basin and watershed strategies.
- Identify gaps in current programs, funding, and local capacity to achieve the needed controls.
- Build program capacity for short-term and long-term goals. Demonstrate increased implementation and/or pollutant reductions.
- Commit to track/monitor/assess and report progress at set regular times.

6.1 Regulatory

Construction Stormwater

Regulated construction stormwater was given a categorical WLA is this study. Construction activities disturbing one acre or more are required to obtain NPDES permit coverage through the MPCA. Compliance with TMDL requirements are assumed when a construction site owner/operator meets the conditions of the Construction General Permit and properly selects, installs, and maintains all BMPs required under the permit, including any applicable additional BMPs required in Section 23 of the Construction General Permit for discharges to impaired waters, or compliance with local construction stormwater requirements if they are more restrictive than those in the State General Permit.

Industrial Stormwater

ISW was given a categorical WLA in this study. Industrial activities require permit coverage under the state's NPDES/SDS ISW Multi-Sector General Permit (MNR050000) or NPDES/SDS Nonmetallic Mining/Associated Activities General Permit (MNG490000). If a facility owner/operator obtains stormwater coverage under the appropriate NPDES/SDS permit and properly selects, installs, and maintains BMPs sufficient to meet the benchmark values in the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL report.

Wastewater NPDES and SDS Permits

The MPCA issues permits for WWTPs and industrial facilities that discharge into waters of the state. Permits have site specific effluent limits for bacteria (if necessary) that are protective of applicable water quality standards. WWTPs discharging into impaired reaches did not require any changes to their discharge permit limits for bacteria due to the WLAs calculated in this TMDL report. Changes may be necessary by facilities to address TP on a case-by-case basis. Based on Lac qui Parle Lake TMDLs, 16 facilities from 4 watersheds will require a new or potentially revised phosphorus permit limit. A meeting was held with permitted facilities to present the phosphorus TMDLs and explain the impacts to the permit limits; see **Section 9**. Permits regulate discharges with the goals of 1) protecting public health and aquatic life, and 2) assuring that every facility treats wastewater. In addition, NPDES and SDS permits set limits and establish controls for land application of waste and byproducts. Since 1996, the MPCA southwest wastewater staff have helped 3 small communities upgrade their sewer systems throughout the region that includes the MRHW. Permits for municipal and industrial wastewater dischargers that are found to cause or have a reasonable potential to cause or contribute to the exceedance of nutrient/eutrophication water quality standard must contain phosphorus effluent limits. Limits must be derived from the standard and be consistent with the assumptions and requirements of EPA approved TMDLs.

NPDES/SDS permits for discharges that may cause or have reasonable potential to cause or contribute to an exceedance of a water quality standard are required to contain water quality-based effluent limits (WQBELs) consistent with the assumptions and requirements of the WLAs in this TMDL report. Attaining the WLAs, as developed and presented in this TMDL report, is assumed to ensure meeting the water quality standards for the relevant impaired waters listings. During the permit issuance or reissuance process, wastewater discharges will be evaluated for the potential to cause or contribute to violations of water quality standards. WQBELs will be developed for facilities whose discharges are found to have a reasonable potential to cause or contribute to pollutants above the water quality standards. The WQBELs will be calculated based on low flow conditions, may vary slightly from the TMDL WLAs, and will include concentration based effluent limitations.

Subsurface Sewage Treatment Systems Program

SSTS, commonly known as septic systems, are regulated by Minn. Stat. §§ 115.55 and 115.56. Counties and other local government units (LGUs) that regulate SSTS must meet the requirements for local SSTS programs in Minn. R. ch. 7082. Counties and other LGUs must adopt and implement SSTS ordinances in compliance with Minn. R. chs. 7080 - 7083.

These regulations detail:

- Minimum technical standards for individual and mid-size SSTS.
- A framework for LGUs to administer SSTS programs.
- Statewide licensing and certification of SSTS professionals, SSTS product review and registration, and establishment of the SSTS Advisory Committee.
- Various ordinances for SSTS installation, maintenance, and inspection.

Each county maintains an SSTS ordinance, in accordance with Minnesota statutes and rules, establishing minimum requirements for regulation of SSTS, for the treatment and dispersal of sewage within the applicable jurisdiction of the county, to protect public health and safety, to protect groundwater quality, and to prevent or eliminate the development of public nuisances. Ordinances serve the best interests of the county's citizens by protecting health, safety, general welfare, and natural resources. In addition, each county zoning ordinance prescribes the technical standards that on-site septic systems are required to meet for compliance, and outlines the requirements for the upgrade of systems found not to be in compliance. This includes systems subject to inspection at transfer of property, upon the addition of living space that includes a bedroom and/or a bathroom, and at discovery of the failure of an existing system. In order to increase the number of compliance inspections, the MPCA has developed and administers several grants to LGUs for various ordinances. Additional grant dollars are awarded to counties that have additional provisions in their ordinance above the minimum program requirements. The MPCA has worked with counties through the SSTS Implementation and Enforcement Task Force to identify the most beneficial way to use these funds to accelerate SSTS compliance statewide. **Figure 31** shows the number of SSTS replaced in the counties that are included in the MRHW between 2002 and 2016.

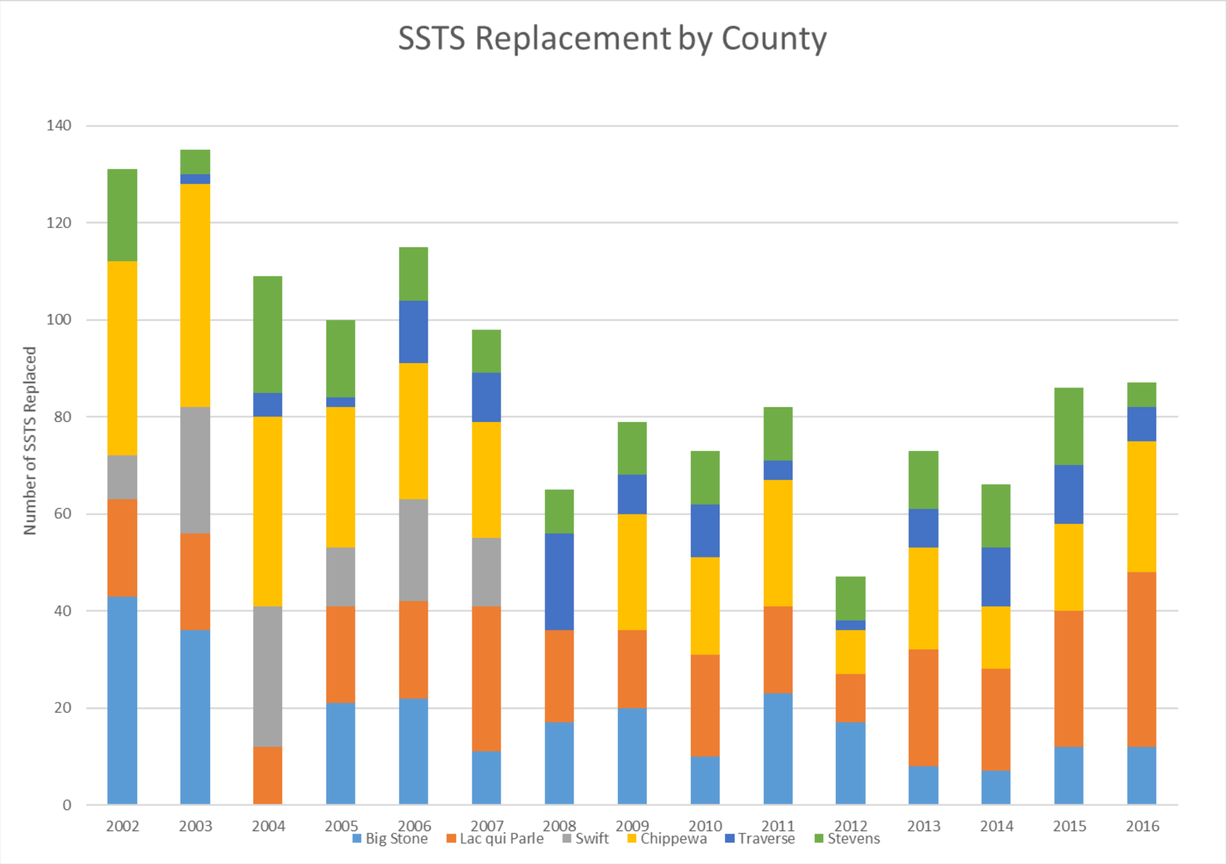


Figure 31. SSTS replacements by County and year in the Minnesota River Headwaters Watershed.

The MPCA staff keep a statewide database of potentially small communities with wastewater needs that could include IPHT systems. Some of those systems potentially could be straight pipe systems. The counties and LGUs are working on assessing these areas and determining if any individual straight pipes exist. Upon confirmation of a straight pipe system, the county sends out a notice of noncompliance, which starts a 10-month deadline to bring the system into compliance.

Permitted MS4s

The MPCA is responsible for applying federal and state regulations to protect and enhance water quality in Minnesota. The MPCA oversees stormwater management accounting activities for the MS4 entity listed in this TMDL report – the City of Morris. The Small MS4 General Permit requires regulated municipalities to implement BMPs that reduce pollutants in stormwater to the maximum extent practicable. A critical component of permit compliance is the requirement for the owners or operators of a regulated MS4 conveyance to develop a Stormwater Pollution Prevention Plan (SWPPP). The SWPPP addresses all permit requirements, including the following six measures:

- Public education and outreach
- Public participation
- Illicit discharge detection and elimination program
- Construction site runoff controls
- Post-construction runoff controls
- Pollution prevention and municipal good housekeeping measures

A SWPPP is a management plan that describes the MS4 permittee's activities for managing stormwater within their regulated area. In the event of a completed TMDL study, MS4 permittees must document the WLA in their future NPDES/SDS permit application and provide an outline of the BMPs to be implemented that address needed reductions. The MPCA requires MS4 owners or operators to submit their application and corresponding SWPPP document to the MPCA for review. Once the application and SWPPP are deemed adequate by the MPCA, all application materials are placed on 30-day public notice, allowing the public an opportunity to review and comment on the prospective program. Once NPDES/SDS permit coverage is granted, permittees must implement the activities described within their SWPPP and submit an annual report to the MPCA documenting the implementation activities completed within the previous year, along with an estimate of the cumulative pollutant reduction achieved by those activities. For information on all requirements for annual reporting, please see the *Minnesota Stormwater Manual* (Minnesota Stormwater Manual contributors 2019): *Guidance for completing the TMDL reporting form*.

This TMDL report assigns a WLA to the permitted MS4 in the study area. The Small MS4 General Permit requires permittees to develop compliance schedules for EPA approved TMDL WLAs not already being met at the time of permit application. A compliance schedule includes BMPs that will be implemented over the permit term, a timeline for their implementation, and a long-term strategy for continuing progress towards assigned WLAs. For WLAs being met at the time of permit application, the same level of treatment must be maintained in the future. Regardless of WLA attainment, all permitted MS4s are still required to reduce pollutant loadings to the maximum extent practicable.

The MPCA's stormwater program and its NPDES permit program are regulatory activities providing reasonable assurance that implementation activities are initiated, maintained, and consistent with WLAs assigned in this study.

Feedlots

All feedlots in Minnesota are regulated by Minn. R. ch. 7020. The MPCA has regulatory authority for feedlots, but counties may choose to participate in a delegation of the feedlot regulatory authority to the LGU for nonpermitted facilities. Delegated counties are then able to enforce Minn. R. ch. 7020 (along with any other local rules and regulations) within their respective counties for facilities that are under the Large CAFO threshold. In the MRHW, the counties of Big Stone, Lac qui Parle, Stevens, Swift, and Traverse are delegated the feedlot regulatory authority. The counties will continue to implement the feedlot program and work with producers on manure management plans.

The MPCA regulates the collection, transportation, storage, processing and disposal of animal manure and other livestock operation waste. 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.
- Ensuring that manure is applied to cropland at a rate, time and method that prevents bacteria, nitrogen, and other possible contaminants from entering streams, lakes and ground water.

Nonpoint Sources

Existing regulations on NPS of pollution are limited. The following are the current, existing nonpoint source statutes/rules in Minnesota:

- 50-foot buffer required for the shore impact zone of streams classified as protected waters (Minn. Stat. § 103F.201) for agricultural land uses and 16.5-foot minimum width buffer required on public drainage ditches (Minn. Stat. § 103E.021). As of March 2021, all the counties in the MRHW are 95% to 100% in compliance (BWSR 2021a).
- 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).

6.2 Nonregulatory

Pollutant Load Reduction

Reliable means of reducing nonpoint source pollutant loads are fully addressed in the *Minnesota River Headwaters Watershed WRAPS Report* (MPCA 2022), a document that is written to be a companion to this TMDL report. In order for the impaired waters to meet water quality standards, the majority of pollutant reductions in the watershed will need to come from NPS. Agricultural drainage and surface runoff are major contributors of nutrients, bacteria, sediment, and increased flows throughout the watershed. The BMPs selected in the WRAPS report strategies table have demonstrated effectiveness in reducing contributions of pollutants to surface water. The combinations of BMPs discussed throughout the WRAPS process were derived from Minnesota's Nutrient Reduction Strategy (NRS; MPCA 2014a) and related tools. As such, they were vetted by a statewide engagement process prior to being applied in the MRHW.

Selection of sites for BMPs will be led by LGUs, county SWCDs, watershed districts, and counties, with support from state and federal agencies. These BMPs are supported by programs administered by the SWCDs and the Natural Resource Conservation Service (NRCS). Local resource managers are well-trained in promoting, placing, and installing these BMPs. Some counties within the watershed have shown significant levels of adoption of these practices. State and local agencies will need to work with landowners to identify priority areas for BMPs and practices that will help reduce nutrient runoff, as well as streambank and overland erosion. Agencies, organizations, LGUs, and citizens alike recognize that resigning waters to an impaired condition is not acceptable. Throughout the course of the WRAPS and TMDL meetings, local stakeholders endorsed the BMPs selected in the WRAPS report. These BMPs reduce pollutant loads from runoff (i.e. phosphorus, sediment, and pathogens) and loads delivered through drainage tiles or groundwater flow.

Several nonpermitted reduction programs exist to support implementation of NPS reduction BMPs in the MRHW. These programs identify BMPs, provide means of focusing BMPs, and support their implementation via state initiatives, ordinances, and/or dedicated funding.

From 2004 to 2020, over 1,600 BMPs were installed in the MRHW by local partners (MPCA 2021a). **Figure 32** depicts the number of BMPs per subwatershed in the MRHW. Additional information about the BMPs may be found on the MPCA's Healthier Watershed website.

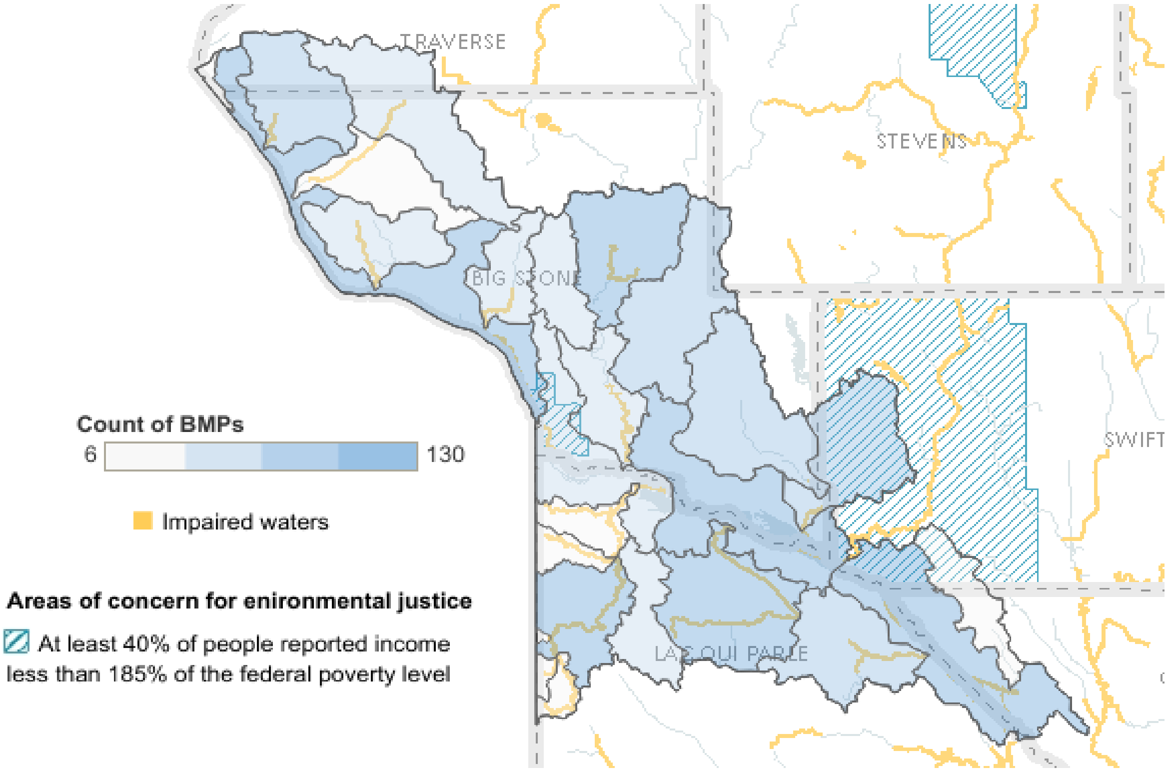


Figure 32. Number of BMPs installed in the Minnesota River-Headwaters by subwatershed from 2004 - 2020 (MPCA 2021a).

To help achieve NPS reductions, a large emphasis has been placed on public participation, where the citizens and communities that hold the power to improve water quality conditions are involved in discussions and decision making. The watershed's citizens and communities will need to voluntarily adopt the practices at the necessary scale and rates to achieve the 10-year targets presented in the Minnesota River Headwaters WRAPS report (MPCA 2022). The WRAPS report also presents the pollutant reduction goals and targets for the primary sources, and the estimated years to meet the goals developed with input by the WRAPS Local Work Group. The strategies identified and relative adoption rates developed with input by the WRAPS Local Work Group were used to calculate the adoption rates needed to meet the pollutant/stressor 10-year targets. In addition to public participation, several government programs are in place to support a political and social infrastructure that aims to increase the adoption of strategies that will improve watershed conditions and reduce loading from NPS. Funding spent in the watershed through these government programs as well as local and landowner contributions is provided later in this section.

Minnesota Nutrient Reduction Strategy

The *Minnesota Nutrient Reduction Strategy* (MPCA 2014a) and the Five-Year Progress Report on Minnesota's NRS (MPCA 2020d) guides activities that support nitrogen and phosphorus reductions in Minnesota waterbodies and those downstream of the state (e.g., Lake Winnipeg, Lake Superior, and the Gulf of Mexico). The NRS was developed by an interagency coordination team with help from public input. Fundamental elements of the NRS include:

- Defining progress with clear goals
- Building on current strategies and success
- Prioritizing problems and solutions

- Supporting local planning and implementation

Included within the strategy discussion are alternatives and tools for consideration by drainage authorities, information on available tools and approaches for identifying areas of phosphorus and nitrogen loading and tracking efforts within a watershed, and additional research priorities. The NRS is focused on incremental progress and provides meaningful and achievable nutrient load reduction milestones that allow for better understanding of incremental and adaptive progress toward final goals. It has set a reduction of 45% for both phosphorus and nitrogen in the Mississippi River, downstream of the MRHW.

Successful implementation of the NRS will require broad support, coordination, and collaboration among agencies, academia, local government, and private industry. The MPCA is implementing a framework to integrate its water quality management programs on a major watershed scale, a process that includes:

- Intensive watershed monitoring
- Assessment of watershed health
- Development of WRAPS reports
- Management of NPDES and other regulatory and assistance programs

This framework will result in nutrient reduction for the basin as a whole and the major watersheds within the basin.

Minnesota Agricultural Water Quality Certification Program

The Minnesota Agricultural Water Quality Certification Program (MAWQCP) is a voluntary opportunity for farmers and agricultural landowners to take the lead in implementing conservation practices that protect waters. Those who implement and maintain approved farm management practices are certified and in turn obtain regulatory certainty for a period of 10 years.

Through this program, certified producers receive:

- **Regulatory certainty**: Certified producers are deemed to be in compliance with any new water quality rules or laws during the period of certification
- **Recognition**: Certified producers may use their status to promote their business as protective of water quality
- **Priority for assistance**: Producers seeking certification can obtain specially designated technical and financial assistance to implement practices that promote water quality

Through this program, the public receives assurance that certified producers are using conservation practices to protect Minnesota's lakes, rivers, and streams. Since the start of the program in 2014, through September 2021, the Ag Water Quality Certification Program has:

- Enrolled over 794,000 acres;
- Included 1,119 producers;
- Added more than 2,200 new conservation practices;

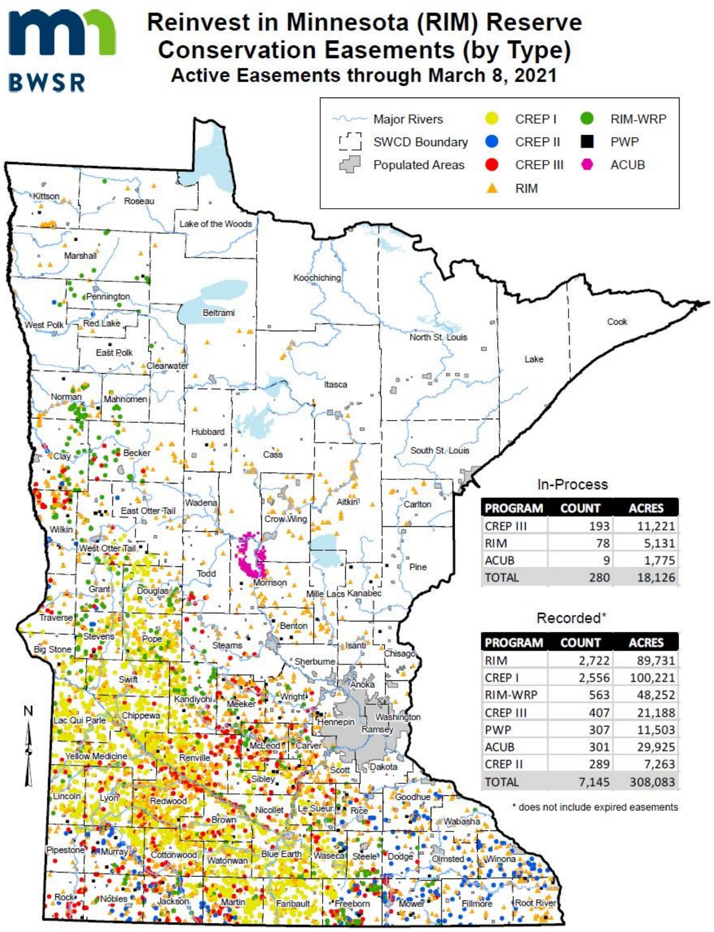
- Kept over 39,000 tons of sediment out of Minnesota rivers;
- Saved over 114,000 tons of soil and 50,000 pounds of phosphorus on farms; and
- As of December 2021, there are 9,514 acres certified under the MAWQCP in the MRHW.

Other NPS Implementation Programs

Water Quality Trends for Minnesota Rivers and Streams at Milestone Sites (MPCA 2014c) notes that sites across Minnesota show reductions over the period of record for total suspended solids (TSS), phosphorus, ammonia, and biochemical oxygen demand. The Minnesota NRS documented a 33% reduction of the phosphorus load leaving the state via the Mississippi River from the pre-2000 baseline to current (MPCA 2014a). These reports generally agree that while further reductions are needed, municipal and industrial phosphorus loads, as well as loads of runoff-driven pollutants (i.e. TSS and TP) are decreasing; a conclusion that lends assurance that the *Minnesota River Headwaters Watershed WRAPS Report* (MPCA 2022) and TMDL goals and strategies are reasonable and that long-term, enduring efforts to decrease erosion and nutrient loading to surface waters have the potential to reduce pollutant loads.

Conservation easements are a critical component of the state's efforts to improve water quality by reducing soil erosion, phosphorus and nitrogen loading, and improving wildlife habitat and flood attenuation on private lands. Easements protect the state's water and soil resources by permanently restoring wetlands, adjacent native grassland wildlife habitat complexes and permanent riparian buffers. In cooperation with counties and SWCDs, USDA NRCS and the Board of Water and Soil Resources (BWSR) programs compensate landowners for granting conservation easements and establishing native vegetation habitat on economically marginal, flood-prone, environmentally sensitive or highly erodible lands. These easements vary in length of time from 10 years to permanent/perpetual easements. Types of conservation easements include: Conservation Reserve Program (CRP); Conservation Reserve Enhancement Program (CREP); Reinvest in Minnesota (RIM); and the Wetland Reserve Program (WRP) or Permanent Wetland Preserve (PWP) and are implemented throughout Minnesota (**Figure 33)**. As of August 2021 in the counties of Big Stone, Chippewa, Lac qui Parle, Stevens, Swift and Traverse, there were 95,126 acres of short-term conservation easements such as CRP and 42,883 acres of long term or permanent easements (CREP, RIM, WRP; BWSR 2021b).

Figure 33. Reinvest in Minnesota Reserve conservation easements in Minnesota (BWSR 2021b).



In-Process

PROGRAM	COUNT	ACRES
CREP III	193	11,221
RIM	78	5,131
ACUB	9	1,775
TOTAL	280	18,126

Recorded*

PROGRAM	COUNT	ACRES
RIM	2,722	89,731
CREP I	2,556	100,221
RIM-WRP	563	48,252
CREP III	407	21,188
PWP	307	11,503
ACUB	301	29,925
CREP II	289	7,263
TOTAL	7,145	308,083

* does not include expired easements

Prioritization

The *Minnesota River Headwaters Watershed WRAPS Report* (MPCA 2022) details a number of tools that provide means for identifying priority pollutant sources and implementation work in the watershed. Further, LGUs in the MRHW often employ their own local analysis for determining priorities for work.

Light Detection and Ranging (LiDAR) data is available for all of the MRHW within Minnesota. It is being increasingly used by LGUs to examine landscapes, understand watershed hydrology, and prioritize BMP targeting.

Funding

On November 4, 2008, Minnesota voters approved the Clean Water, Land and Legacy Amendment to the state's constitution to:

- protect drinking water sources;
- protect, enhance, and restore wetlands, prairies, forests, and fish, game, and wildlife habitat;
- preserve arts and cultural heritage;
- support parks and trails; and
- protect, enhance, and restore lakes, rivers, streams, and groundwater

This is a secure funding mechanism with the explicit purpose of supporting water quality improvement projects.

Additionally, there are many other funding sources for nonpoint pollutant reduction work; they include but are not limited to CWA Section 319 grant programs, the state Clean Water Partnership zero-interest loan program, the Agricultural BMP Loan Program, and several NRCS incentive programs. Programs and activities are also occurring at the local government level, where county staff, commissioners, and residents work together to address water quality issues.

Since 2004, over $53 million dollars have been spent addressing water quality issues in the MRHW (MPCA 2020a; **Figure 34**). Additional information about funding may be found on the MPCA's Healthier Watersheds website.

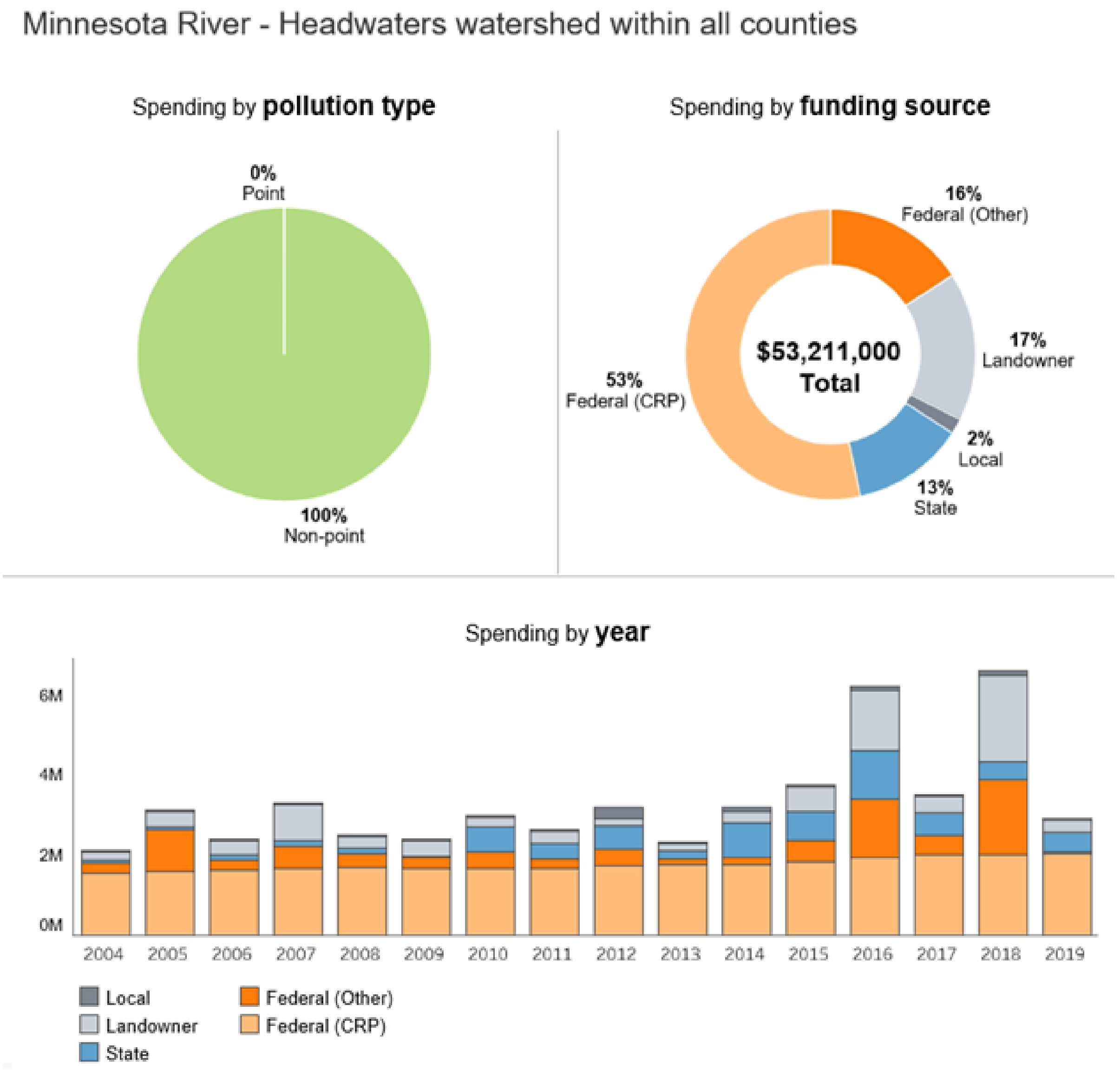


Figure 34. Spending addressing water quality issues in the Minnesota River Headwaters Watershed (MPCA 2020a).

Planning and Implementation

The WRAPS, TMDLs, and all the supporting documents provide a foundation for planning and implementation. Subsequent planning, including development of a “One Watershed, One Plan” (1W1P) for the MRHW, will draw on the goals, technical information, and tools to choose actions for implementation. For the purposes of reasonable assurance, the WRAPS report is sufficient in that it provides strategies for achieving pollutant reduction goals. However, many of the goals outlined in this TMDL report are very similar to objectives outlined in County Water Plans. County plans have the same goal of removing streams from the 303(d) impaired waters list. These plans provide watershed-specific strategies for addressing water quality issues. In addition, the commitment and support from the local governmental units will ensure that this TMDL report is carried successfully through implementation.

6.3 Reasonable Assurance Summary

In summary, significant time and resources have been devoted to identifying the best BMPs for the MRHW, providing means of focusing them, and supporting their implementation via state initiatives and dedicated funding. The MRHW WRAPS and TMDL process engaged partners to arrive at reasonable examples of BMP combinations that attain pollutant reduction goals. Minnesota is a leader in watershed planning, as well as monitoring and tracking progress toward water quality goals and pollutant load reductions. Finally, examples cited herein confirm that BMPs and restoration projects have proven to be effective over time and as stated by the State of Minnesota Court of Appeals in A15-1622 MCEA vs MPCA and MCES:

Substantial evidence exists to conclude that voluntary reductions from NPS have occurred in the past and can be reasonably expected to occur in the future. The NRS (MPCA 2014a, and 2020 progress report) provides substantial information of existing state programs designed to achieve reductions in NPS pollution, as evidence that reductions in nonpoint pollution have been achieved and can reasonably be expected to continue to occur.

7. Monitoring plan

Data from three water quality monitoring programs enables water quality condition assessment and creates a long-term data set to track progress towards water quality goals. BMPs implemented by LGUs will continue to be tracked through BWSR’s e-Link system. These programs will continue to collect and analyze data in the MRHW as part of Minnesota’s Water Quality Monitoring Strategy (MPCA 2011). Data needs are considered by each program and additional monitoring is implemented when deemed necessary and feasible. These monitoring programs are summarized below:

Intensive Watershed Monitoring (MPCA 2012a) data provides a periodic but intensive “snapshot” of water quality throughout the watershed. This program collects water quality and biological data at roughly 13 stream and 7 lake monitoring stations across the watershed for 1 to 2 years, every 10 years. To measure pollutants across the watershed the MPCA will re-visit and re-assess the watershed starting in 2026, as well as have capacity to visit new sites in areas with BMP implementation activity.

Watershed Pollutant Load Monitoring Network (MPCA 2013b) data provide a continuous and long-term record of water quality conditions at the major watershed and subwatershed scale. This program collects pollutant samples and flow data to calculate continuous daily flow, sediment, and nutrient loads. In the MRHW in Minnesota, there is a year-round site on the Minnesota River near Lac qui Parle and one seasonal (spring through fall) site on the Yellow Bank River.

Citizen Stream and Lake Monitoring Program (MPCA 2013a) data provide a continuous record of waterbody transparency throughout much of the watershed. This program relies on a network of private citizen volunteers who make monthly lake and river measurements annually. Three citizen-monitoring locations exist in the MRHW.

8. Implementation strategy summary

The strategies described in this section are potential actions to reduce bacteria (*E. coli*) and phosphorus in the MRHW in Minnesota. A more detailed discussion on implementation strategies can be found in the *Minnesota River Headwaters Watershed WRAPS Report* (MPCA 2022).

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 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 Minnesota'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. Construction activity must also meet all local government construction stormwater requirements.

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 ISW 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 BMPs and other stormwater control measures that should be implemented at the industrial sites are defined in Minnesota's NPDES/SDS ISW Multi- Sector General Permit (MNR050000), or NPDES/SDS General Permit for Construction Sand and 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. Industrial activity must also meet all local government construction stormwater requirements.

8.1.3 MS4

The General NPDES/SDS Permit requirements must be consistent with the assumptions and requirements of an approved TMDL and associated WLAs. The BMP stormwater control measure requirements are defined in the State's General Stormwater NPDES/SDS Permit (MNR040000). For the purposes of this TMDL report, the baseline year for implementation is 2016. For the permitted MS4, nutrient loading does not need to be reduced to meet the WLA.

8.1.4 Wastewater

The MPCA issues permits for WWTPs that discharge into waters of the state. The permits have site specific limits that are based on water quality standards. WWTPs discharging into impaired watersheds did not require any changes to their discharge permit limits due to bacteria WLAs calculated in this TMDL report. Based on this TMDL, 16 facilities will have a new or potentially revised TP permit limit as described in **Section 3.6.2**. A meeting was held with the permitted facilities to present the TMDLs and explain the impacts to the permit limits which is described in **Section 9**. Permits regulate discharges with the goals of protecting public health and aquatic life and assuring that every facility treats wastewater. In addition, SDS permits set limits and establish controls for land application of sewage.

8.2 Nonpermitted sources

A summary of potential BMPs to reduce NPS is provided in **Table 52**. Potential BMPs and implementation strategies are explored more thoroughly in the *Minnesota River Headwaters Watershed WRAPS Report* (MPCA 2022).

Table 52. Summary of agricultural BMPs for agricultural sources and their primary targeted pollutants.

Land use	Minnesota River Headwaters Watershed BMPs	Targeted Pollutant	
		Bacteria	Phosphorus
Cultivated Crops	Improved fertilizer management		X
	Grassed waterway	X	X
	Conservation tillage		X
	Crop rotation (including small grain)		X
	Critical area planting		X
	Improved manure field application	X	X
	Cover crops		X
	WASCOBS, terraces, flow-through basins	X	X
	Buffers, border filter strips	X	X
	Contour strip cropping (50% crop in grass)	X	X
	Wind Breaks		X
	Conservation cover (replacing marginal farmed areas)	X	X
	In/near ditch retention/treatment	X	X
	Alternative tile intakes	X	X
	Treatment wetland (for tile drainage system)		X
	Controlled drainage, drainage design		X
	Saturated buffers		X
	Wood chip bioreactor		X
	Wetland Restoration	X	X
	Retention Ponds	X	X

Land use	Minnesota River Headwaters Watershed BMPs	Targeted Pollutant	
		Bacteria	Phosphorus
	Mitigate agricultural drainage projects	X	X
	Maintenance and new enrollment of BMPs, CRP, RIM, etc.	X	X
Pastures	Rotational grazing/improved pasture vegetation management	X	X
	Livestock stream exclusion and watering facilities	X	X
Cities & yards	Nutrient/fertilizer and lawn mgt.		X
	Infiltration/retention ponds, wetlands		X
	Trees/native plants		X
	Construction site erosion control		X
SSTS	Maintenance and replacement/upgrades	X	X
Feedlots	Feedlot runoff controls including buffer strips, clean water diversions, etc. on feedlots with runoff	X	X
Streams, ditches, & ravines	Streambank stabilization		X
	Ravine/stream (grade) stabilization		X
	Stream channel restoration and floodplain reconnection		X
Lakes & Wetlands	Near-water vegetation protection and restoration		X
	In-water management and species control		X
Grassland & Forest	Protect and restore areas in these land uses, increase native species populations		X

8.3 Cost

The CWLA requires that a TMDL report include an overall approximation of the cost to implement a TMDL [Minn. Stat. 2007 § 114D.25]. The costs to implement the activities outlined in the *Minnesota River Headwaters Watershed WRAPS Report* (MPCA 2022) are approximately $20 to $40 million over the next 20 years. This range reflects the level of uncertainty in the source assessment and addresses the high priority sources identified in **Section 3.6**. The cost includes increasing local capacity to oversee implementation in the watershed and the voluntary actions needed to achieve reductions. Required buffer installation and replacement of IPHT systems are not included.

8.4 Adaptive management

Adaptive management is an iterative implementation process that makes progress toward achieving water quality goals while using new data and information to reduce uncertainty and adjust implementation activities. The State of Minnesota has a unique opportunity to adaptively manage water resource plans and implementation activities every 10 years. This opportunity resulted from a voter-approved tax increase to improve state waters. The resulting interagency coordination effort is referred to as the Minnesota Water Quality Framework, which works to monitor and assess Minnesota's major watersheds every 10 years. This framework supports ongoing implementation and adaptive management of conservation activities and watershed-based local planning efforts utilizing regulatory and nonregulatory means to achieve water quality standards.

Implementation of TMDL-related activities can take many years, and water quality benefits associated with these activities can also take many years. As the pollutant source dynamics within the watershed are better understood, implementation strategies and activities will be adjusted and refined to efficiently meet the TMDL and lay the groundwork for de-listing the impaired reaches and lakes. The follow-up water monitoring program outlined in **Section 7** will be integral to the adaptive management approach, providing assurance that implementation measures are succeeding in achieving water quality standards. Adaptive management does not include changes to water quality standards or LC. Any changes to water quality standards or LC must be preceded by appropriate administrative processes, including public notice and an opportunity for public review and comment.

A list of implementation strategies in the WRAPS report prepared in conjunction with this TMDL report will focus on adaptive management (**Figure 35**). Continued monitoring and "course corrections" responding to monitoring results are the most appropriate strategy for achieving the water quality goals established in this TMDL report. Management activities will be changed or refined to efficiently meet the TMDLs and lay the groundwork for de-listing the impaired waterbodies.

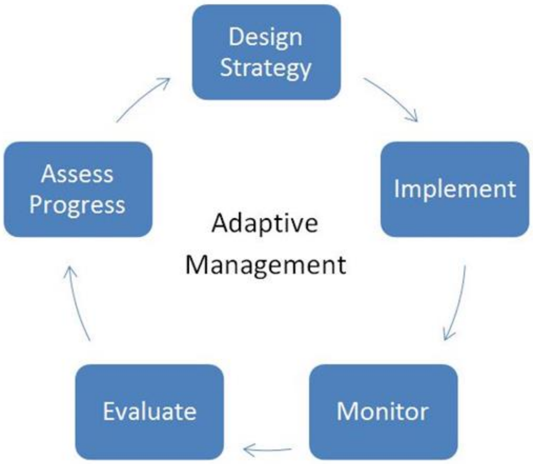


Figure 35. The cycle of adaptive management.

9. Public participation

Public participation was a major focus during the MRHW project related to WRAPS and the TMDL reports. The MPCA worked with county and SWCD staff, the Upper Minnesota River and Lac qui Parle Yellow Bank watershed districts, and state agency staff in the six counties to help with education on water quality and impaired reaches. Local partner involvement related to the TMDL report include report development and editing, and setting pollution reduction goals.

A meeting was held in October 2020 with NPDES/SDS permit holders that contribute to the impaired waterbodies in the MRHW. This includes permit holders that are also located in the Lac qui Parle River, Pomme de Terre River and Chippewa River watersheds as they contribute to Lac qui Parle Lake – NW Bay and Lac qui Parle Lake SE Bay. The purpose of the meeting was to review the development of the

TMDLs, discuss the implications they have on permits, and allow attendees to ask questions about the process.

Public notice

An opportunity for public comment on the draft TMDL report was provided via a public notice in the State Register from January 10, 2022 through February 9, 2022. There was one comment letter received and responded to as a result of the public comment period.

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Appendices

Appendix A. Load Duration Curve Reductions

The tables below contain the existing load, load reduction, and percentage of load reduction needed to meet the water quality standard for each flow regime for each impaired reach.

Unnamed creek (West Salmonsen Creek), Unnamed cr to Big Stone Lk (07020001-504)

Escherichia coli	**Flow Condition**				
	Very High	**High**	**Mid-Range**	**Low**	**Very Low**
	[Billions organisms/day]				
Loading Capacity	**98**	**32**	**12**	**3.8**	**0.9**
Existing Load	219	131	52	32	6.2
Load Reduction	121	99	40	28	5.3
Percent Load Reduction	55%	76%	77%	88%	85%

Little Minnesota River, MN/SD border to Big Stone Lk (07020001-508)

Escherichia coli	**Flow Condition**				
	Very High	**High**	**Mid-Range**	**Low**	**Very Low**
	[Billions organisms/day]				
Loading Capacity	**1,353**	**489**	**157**	**53**	**9.7**
Existing Load	998	1,247	493	177	8.1
Load Reduction	-355	758	337	123	-1.7
Percent Load Reduction	-36%	61%	68%	70%	-21%

Unnamed creek (Five Mile Creek), Unnamed cr to Marsh Lk (07020001-521)

Escherichia coli	**Flow Condition**				
	Very High	**High**	**Mid-Range**	**Low**	**Very Low**
	[Billions organisms/day]				
Loading Capacity	**413**	**90**	**22**	**3.6**	**0.82**
Existing Load	NA[1]	247	60	10	1.9
Load Reduction	NA[1]	157	38	6.9	1.1
Percent Load Reduction	NA[1]	64%	63%	66%	58%

[1] No observed water quality data available for this flow regime.

Stony Run Creek, Unnamed cr to Minnesota R (07020001-531)

Escherichia coli	Flow Condition				
	Very High	High	Mid-Range	Low	Very Low
	[Billions organisms/day]				
Loading Capacity	**750**	**247**	**90**	**22**	**5.6**
Existing Load	NA[1]	172	186	96	NA[1]
Load Reduction	NA[1]	-75	97	74	NA[1]
Percent Load Reduction	NA[1]	-44%	52%	77%	NA[1]

[1] No observed water quality data available for this flow regime.

Stony Run Creek, Long Tom Lk to Unnamed cr (07020001-536)

Escherichia coli	Flow Condition				
	Very High	High	Mid-Range	Low	Very Low
	[Billions organisms/day]				
Loading Capacity	**492**	**137**	**41**	**4.7**	**0.15**
Existing Load	355	63	199	21	1.3
Load Reduction	-137	-74	158	16	1.2
Percent Load Reduction	-39%	-117%	79%	77%	88%

Unnamed creek, Unnamed cr to Big Stone Lk (07020001-541)

Escherichia coli	Flow Condition				
	Very High	High	Mid-Range	Low	Very Low
	[Billions organisms/day]				
Loading Capacity	**122**	**39**	**15**	**4.7**	**1.19**
Existing Load	153	209	299	35	9.4
Load Reduction	31	170	284	30	8.2
Percent Load Reduction	20%	81%	95%	87%	87%

Emily Creek, Unnamed cr to Lac qui Parle Lk (07020001-547)

Escherichia coli	Flow Condition				
	Very High	High	Mid-Range	Low	Very Low
	[Billions organisms/day]				
Loading Capacity	**144**	**24**	**5.4**	**1.3**	**0.1**
Existing Load	NA[1]	113	328	12	2.5
Load Reduction	NA[1]	89	323	11	2.4
Percent Load Reduction	NA[1]	79%	98%	89%	95%

[1] No observed water quality data available for this flow regime.

Unnamed creek, Headwaters to S Fk Yellow R (07020001-551)

Escherichia coli	**Flow Condition**				
	Very High	**High**	**Mid-Range**	**Low**	**Very Low**
	[Billions organisms/day]				
Loading Capacity	**181**	**60**	**22**	**6.0**	**1.6**
Existing Load	NA[1]	163	113	36	NA[1]
Load Reduction	NA[1]	103	90	30	NA[1]
Percent Load Reduction	NA[1]	63%	80%	83%	NA[1]

[1] No observed water quality data available for this flow regime.

Unnamed creek (Meadowbrook Creek), 340th St to Big Stone Lk (07020001-568)

Escherichia coli	**Flow Condition**				
	Very High	**High**	**Mid-Range**	**Low**	**Very Low**
	[Billions organisms/day]				
Loading Capacity	**65**	**21**	**7.7**	**2.3**	**0.50**
Existing Load	214	42	23	4.1	0.85
Load Reduction	149	21	16	1.7	0.35
Percent Load Reduction	70%	50%	67%	42%	41%

Unnamed creek, CSAH 38 to Marsh Lk (07020001-570)

Escherichia coli	**Flow Condition**				
	Very High	**High**	**Mid-Range**	**Low**	**Very Low**
	[Billions organisms/day]				
Loading Capacity	**204**	**33**	**7.7**	**2.08**	**0.44**
Existing Load	NA[1]	56	34	2.13	2.1
Load Reduction	NA[1]	23	27	0.05	1.7
Percent Load Reduction	NA[1]	41%	78%	2%	79%

[1] No observed water quality data available for this flow regime.

Fish Creek, Headwaters to CSAH 33 (07020001-571)

Escherichia coli	**Flow Condition**				
	Very High	**High**	**Mid-Range**	**Low**	**Very Low**
	[Billions organisms/day]				
Loading Capacity	**169**	**56**	**20**	**6.1**	**1.5**
Existing Load	NA[1]	106	54	17	NA[1]
Load Reduction	NA[1]	50	34	11	NA[1]
Percent Load Reduction	NA[1]	47%	63%	65%	NA[1]

[1] No observed water quality data available for this flow regime.

Appendix B. Lake Modeling

The technical memorandum below describes the methodology for the development of lake models for the MRHW impaired lakes. Since the submittal of this memo, the TMDL tables were reviewed and necessary corrections/changes were made. As a result, the tables in the memo do not always match the tables in the MRHW TMDL Report. The MPCA is submitting Minnesota allocations presented in the TMDL report for approval.

Of particular importance, the technical memo lists out-of-state allocations in the total loading capacity for lakes. These are included to show a complete accounting of sources and to balance the total loading capacity and are not intended to assign allocations to neighboring states. This TMDL assigns allocations only to Minnesota surface waters. Differences between the TMDL tables and the tech memo result from a change to margin of safety and reserve capacities, inclusion of an additional MS4, an error in the lake model that lead to a difference in total phosphorus concentrations in lake direct drainage areas, and other minor corrections.

Three lakes within the MRHW have drainage areas in South Dakota and/or North Dakota. All modeling is based on the assumption that waters in other states will meet Minnesota standards. This TMDL does not assume surface waters of other states will achieve standards more stringent than Minnesota water quality standards. While reductions and loads are shown for these tributaries, the MPCA is requesting approval for allocations in Minnesota.

Technical Memorandum

To: Katherine Pekarek-Scott, Project Manager, Minnesota Pollution Control Agency

From: Timothy Erickson, PE, Drew Kessler, PhD
Houston Engineering, Inc.

Subject: Minnesota River Headwaters Watershed Lake Modeling

Date: October 27, 2019

Project: 6074-0017

Introduction

This technical memorandum (TM) summarizes the in-lake water quality modeling efforts for impaired lakes in the Minnesota River Headwaters Watershed (MRHW) as part of the Minnesota Pollution Control Agency's (MPCA) MRHW's watershed-wide Total Maximum Daily Load (TMDL) Study. The modeling effort includes lakes in the Minnesota portion of the MRHW; 8-digit hydrologic unit code (HUC) 07200001.

The in-lake water quality modeling utilizes a modified version of the BATHTUB model called CNET. BATHTUB and CNET are steady-state models that simulate eutrophication-related water quality conditions in lakes and reservoirs. They are designed to facilitate the application of empirical eutrophication models to reservoirs or lakes, formulating water and nutrient balances that account for advective transport, diffuse transport, and nutrient sedimentation. CNET is a spreadsheet version of the BATHTUB model currently available as a "beta" version from Dr. William W. Walker (http://www.wwwalker.net/bathtub/index.htm).

The overall goal of this TM is to establish the loading capacities for total phosphorus (TP) in impaired lakes, determine the load reduction needed to meet the water quality standards, and provide information for future management of local water quality. Results of the lake modeling include the predicted average nutrient load reduction required to meet current lake eutrophication water quality standards in each lake. The following describes the data and methodology used to develop the lake models and summarizes the results, including the loading capacity of each lake, any waste load allocations, load allocations, and the TMDL for each lake.

Impaired Lakes in the Minnesota River Headwaters Watershed

Impaired Lakes

Models were developed for five impaired lakes in the MRHW, which are all impaired for nutrients/eutrophication biological indicators. In addition, Marsh Lake (06-0001-00) was modeled since it is upstream and a major contributor to Lac qui Parle Lake NW Bay. **Table 1** provides a list of the impaired lakes, along with their ecoregion and depth class. **Figure 1** provides the location of these impaired lakes and Marsh Lake.

Table 1. Impaired lakes in the Minnesota River Headwaters Watershed.

Waterbody	Assessment Unit ID	Ecoregion	Impairment/Parameter	Designated Class	Beneficial Use[1]	Listing Year
Long Tom, Lake or Reservoir	06-0029-00	NGP	Nutrient/eutrophication biological indicators	2B	AQR	2018
Unnamed, Lake or Reservoir	06-0060-00	NGP	Nutrient/eutrophication biological indicators	2B	AQR	2018
Big Stone, Lake or Reservoir	06-0152-00	NGP	Nutrient/eutrophication biological indicators	2B	AQR	2018
Lac qui Parle (SE Bay), Lake or Reservoir	37-0046-01	NGP	Nutrient/eutrophication biological indicators	2B	AQR	2018
Lac qui Parle (NW Bay), Lake or Reservoir	37-0046-02	NGP	Nutrient/eutrophication biological indicators	2B	AQR	2018

[1]AQR = Aquatic recreation.

Applicable Water Quality Standards and Numeric Water Quality Targets

Lake eutrophication standards are written to protect lakes as a function of their designated beneficial use. The lakes of the MRHW are considered Class 2B waters, which are protected for aquatic life and recreation. According to Minn. R. 7050.0222[1]:

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[1] https://www.revisor.mn.gov/rules/?id=7050.0222

These waters shall be suitable for aquatic recreation of all kinds, including bathing, for which the waters may be usable. This class of surface water is not protected as a source of drinking water.

Minnesota categorizes its lake water quality standards by depth classification and ecoregion. Lakes in the MRHW are in the Northern Glacial Plains (NGP) ecoregion. **Table 2** displays the standards for the NGP ecoregion. The water quality standards in **Table 2** provide target concentrations for determining the surface water load reduction needed to meet the water quality standards. The MPCA considers a lake impaired when phosphorus and a least one of the response variables (Chl-*a* or Secchi depth) fail to demonstrate compliance with the standards (MPCA 2018).

Table 2. Lake water quality standards for lakes in the Minnesota River Headwaters Watershed.

Ecoregion	Phosphorus [µg/L]	Chl-*a* [µg/L]	Secchi Disk Depth [m]
Northern Glacial Plains (NGP) - Shallow Lakes	< 90	< 30	> 0.7

[1] Shallow lakes are classified as having a maximum depth less than 15 feet or greater than 80% of the lake is part of the littoral zone.

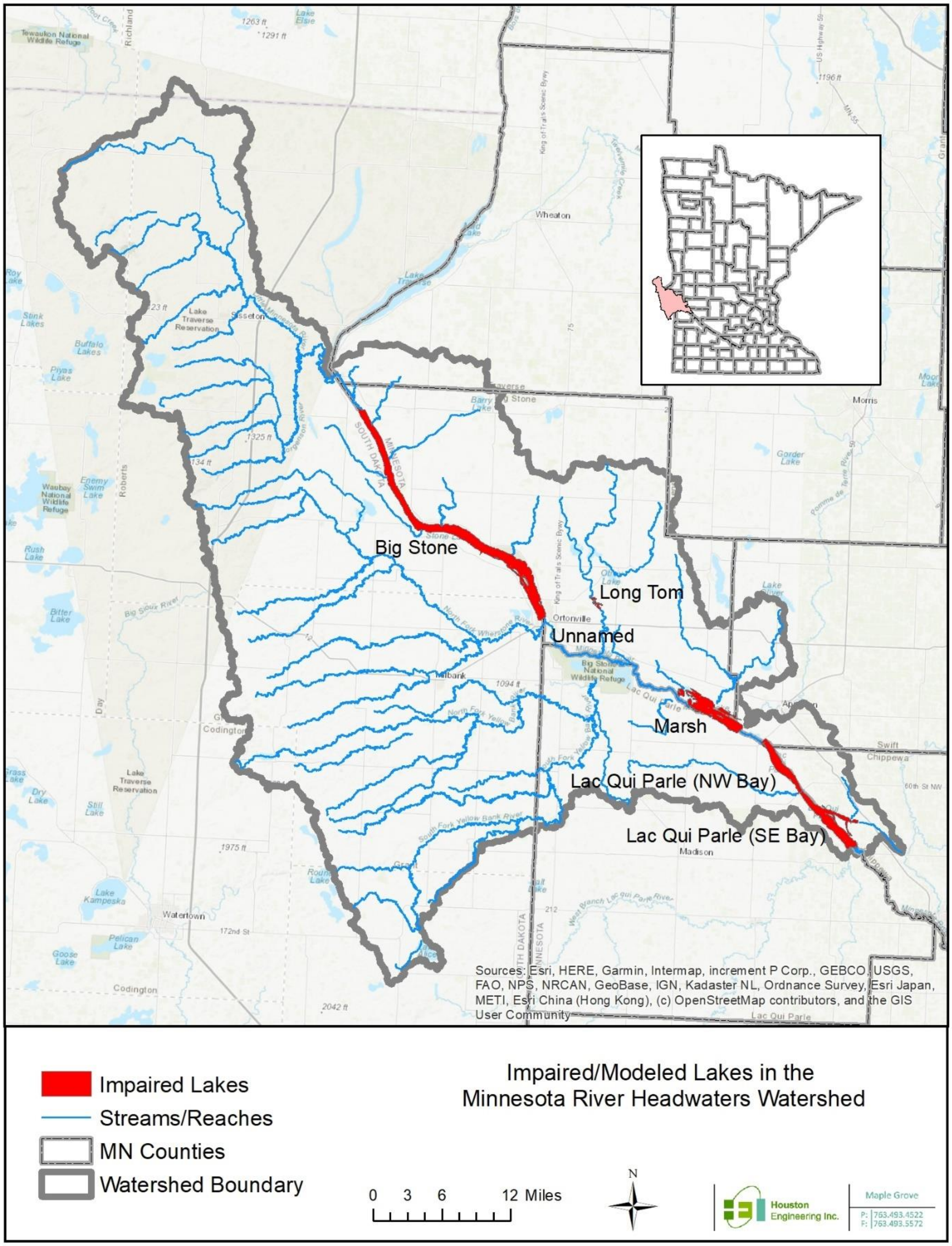


Figure 1. Modeled lakes in the Minnesota River Headwaters Watershed.

In-Lake Water Quality

Water quality data for lakes in the MRHW were obtained from the MPCA through their EQuIS database and Environmental Data Application (EDA) data portal (https://www.pca.state.mn.us/quick-links/eda-surface-water-data). For this modeling effort, the average water quality condition is taken as the period from 1996 through 2017. The runoff (RO) and loading information were extracted from the Hydrological Simulation Program-FORTRAN (HSPF) model. For purposes of this study, the average water quality condition is defined as the mean of all available data during the summer months for which the standard applies (June through September). In addition to the average water quality conditions, **Table 3** shows the observation period and the number of observations for each lake eutrophication parameter used in computing the average condition. The average water quality conditions provided in **Table 3** were used to calibrate the CNET/BATHUB model.

Table 3. Average observed water quality condition in modeled lakes.

Lake Name	Station	Observation Period	TP		Chl-*a*		Secchi Disk Depth	
			n	Average [µg/L]	n	Average [µg/L]	n	Average [m]
Long Tom	06-0029-00-101	2011-2012	11	422	11	60	11	0.434
Unnamed	06-0060-00-201	2015-2016	5	648	5	84	5	2.4
Big Stone-Upper Segment	06-0152-00-107	2011-2017	14	219.9	14	24.4	14	0.667
	06-0152-00-108	2007-2011	25	215	25	30.2	25	0.854
	06-0152-00-212	1996-2004					136	1.57
	06-0152-00-216	1996-2002					99	2.16
	Upper Segment Average	1996-2017	37	221	36	29	269	1.69
Big Stone-Lower Segment	06-0152-00-100	2015	1	60	1	4.28		
	06-0152-00-101	2008	1	78	1	9.62		
	06-0152-00-102	2015					10	2.18
	06-0152-00-205	2010-2015	23	103.6	22	26.8	20	1.68
	06-0152-00-206	1996					10	1.98
	06-0152-00-208	2007-2017			1	5	35	2.92
	06-0152-00-217	2005-2017					88	2.01
	06-0152-00-218	2005					4	1.94
	06-0152-00-303	2012			1	39.9	1	1.6
	Lower Segment Average	1996-2017	25	101	26	25	141	2.02
Marsh	06-0001-00-101	2008-2009	10	189.7	10	52.2	10	2.85
	06-0001-00-201	2002	1	91				
	06-0001-00-202	2007-2015	6	189.2	5	113.6	5	0.24
	06-0001-00-203	2004	1	0.28			1	0.15
	Average	2002-2015	18	189	15	73	16	0.26

Lake Name	Station	Observation Period	TP		Chl-*a*		Secchi Disk Depth	
			n	Average [µg/L]	n	Average [µg/L]	n	Average [m]
Lac qui Parle (NW Bay) -Upper Segment	37-0046-02-202	2008-2015	15	161	15	69.5	15	0.47
Lac qui Parle (NW Bay) Lower Segment	NA							
Lac qui Parle (SE Bay) Upper Segment	37-0046-01-202	2015	5	124.2	5	54.8	5	0.70
Lac qui Parle (SE Bay) Middle Segment	NA							
Lac qui Parle (SE Bay) Lower Segment	37-0046-01-203	2008-2009	10	153	52.9	10	10	0.57

Model Development

Two models were used to develop the lake water quality estimates and TMDL components for lakes in the MRHW. The HSPF watershed model was used to provide surface RO and TP loadings to the lakes. In-lake water quality was modeled using a modified version of the BATHTUB model called CNET. The CNET model was developed for use with a spreadsheet program (e.g. EXCEL). This spreadsheet version allows the use of Crystal Ball^{TM}, a Monte Carlo simulator, to create stochastic simulations and develop distributions of in-lake eutrophication conditions based on statistical distributions of input parameters. The stochastic modeling approach reflects the variability in forcing data (e.g., the terms in the hydrologic budget and mass balance) and model parameters used to represent processes in natural systems (e.g., nitrification rate). This allows for a more realistic prediction of long-term water quality condition. CNET models and provides a summary of the predicted distributions of mean annual TP, chlorophyll-*a* (Chl-*a*), and Secchi disk depths in the lakes. Load reduction scenarios were developed for each lake to estimate the required load reduction needed to meet current lake eutrophication water quality standards. The following provides a summary of the watershed models, lake models, input data, and mass balances.

Watershed Model

The flow and nutrient loadings were extracted for the HSPF watershed model. The HSPF model is a comprehensive package for simulation of watershed hydrology sediment transportation, and water quality for conventional and toxic organic pollutants. HSPF incorporates the watershed-scale Agricultural Runoff Model (ARM) and nonpoint source (NPS) models into a basin-scale analysis framework that includes fate and transport in one dimensional stream channels. It is a comprehensive model of watershed hydrology and water quality that allows the integrated simulation of point sources, land and soil contaminant RO processes, along with in-stream hydraulic and sediment-chemical interactions. The result of this simulation is a time history of the RO flow rate, sediment load, nutrient and pesticide concentrations, and water quantity and quality at the outlet of any subwatershed. The hydrologic/nutrient budget components taken from the HSPF model include precipitation, potential evapotranspiration (assumed to be equal to evaporation), contributing drainage area RO volume, contributing drainage area phosphorus loads, tributary flow, and tributary phosphorus loads.

Modeling results from the MRHW's HSPF model (TetraTech 2017) were used to develop the inputs to the in-lake water quality CNET models. In addition, modeling results from the Chippewa River HSPF model and Pomme de Terre River HSPF where extracted for loads into Lac qui Parle Lake. Data from the MRHW HSPF model were available from 1996 through 2017 for daily, monthly, and annual timescales at the sub-basin scale, 1996-2012 for the Chippewa River HSPF model, and 1996-2016 for the Pomme de Terre River HSPF model. Sub-basin information utilized in the HSPF models are included in **Table 4**.

Table 4. HSPF sub-basin IDs for modeled lakes in the Minnesota River Headwaters Watershed.

Lake Name	AUID	Total Drainage Area (acres)	HSPF Sub-basin ID	HSPF Sub-basin ID(s) for Tributary inflows
Long Tom (06-0029-00)	06-0029-00	75,227	418	Unnamed Lake
Unnamed	06-0060-00	74,046	418	421, 422
Big Stone	06-0152-00	503,870	423, 427	433, 432,431, 430, 428, 424, 425, 426
Marsh	06-0001-00	1,826,153	409	410, 412, 451, 452, PdT 10
Lac qui Parle (SE Bay)	37-0046-01	3,934,166	402, 400	403, 401, 100, CRW 103
Lac qui Parle (NW Bay)	37-0046-02	1,844,808	404	406, 405

In-lake Water Quality Model

In-lake water quality was simulated using the CNET program. CNET is a spreadsheet version of the BATHTUB model currently available as a "beta" version from Dr. William W. Walker (http://www.wwwalker.net/bathtub/index.htm). BATHTUB and CNET are steady-state models that simulate eutrophication-related water quality conditions in lakes and reservoirs. They are designed to facilitate the application of empirical eutrophication models to reservoirs or lakes, formulating water and nutrient balances that account for advective transport, diffuse transport, and nutrient sedimentation.

The primary modification to BATHUB to develop the CNET model was to implement a Monte Carlo approach, which allowed selected modeling inputs to vary based upon known or assumed statistical distributions as opposed to single input values. The variability of inputs is reflected in the forecast results. The Monte Carlo approach generates a statistical distribution of the yearly mean TP and Chl-*a* concentrations and Secchi disk depth, reflecting the uncertainty in the model parameters and normal variability in inputs (e.g., annual TP load from surface RO) as well as correlation among inputs (e.g., RO and load). Crystal Ball (a proprietary software developed by Oracle; http://www.oracle.com/appserver/business-intelligence/crystalball/crystalball.html) was used to perform the Monte Carlo simulations. The benefits of using the stochastic approach is the addition of probabilistic variability of the forcing data allowing for the calculation of a distribution of responses that cannot usually be achieve in steady-state model.

Lake Morphology

The required inputs to the lake models include basic morphology characteristics such as surface area, mean depth, and drainage area. **Table** 5 lists the required morphometric characteristics for the modeled lakes in the MRHW. The morphometric characteristics displayed in **Table** 5 are in U.S. customary units and are converted to the international system of units (SI) (i.e., the metric system) for use in the CNET lake models. The primary data sources used for lake morphometric characteristics were the MN DNR LakeFinder website (http://www.dnr.state.mn.us/lakefind/index.html) and the *Minnesota River Headwaters Watershed Monitoring and Assessment Report* (MPCA 2018).

Table 5. Lake morphology in lakes in Minnesota River Headwaters Watershed.

Lake Name	DNR ID	Surface Area [acres]	Max depth [ft]	Drainage Area [acres]
Long Tom	06-0029-00	135	15	75,227
Unnamed	06-0060-00	55	13	74,046
Big Stone	06-0152-00	11,889	15	503,870
Lac qui Parle (SE Bay)	37-0046-01	3,573	10	3,934,166
Lac qui Parle (NW Bay)	37-0046-02	2,095	10	1,844,808

Model Description

Unnamed Lake and Long Tom Lake Model

Unnamed Lake and Long Tom Lake were modeled together since Unnamed Lake drains into Long Tom Lake, and the drainage area of Long Tom Lake consists mostly of the drainage area of Unnamed Lake (98% of Long Tom's drainage area). In addition, modeling the lakes together allows the impact of load reductions for Unnamed Lake to be seen in Long Tom Lake so a more accurate load reduction estimate can be made. The lakes were modeled in series where the outflows from Unnamed Lake were inflows into Long Tom Lake. **Figure 2** provides the drainage areas for Unnamed Lake and Long Tom Lake.

Big Stone Lake Model

The Big Stone Lake model was separated into to two model segments to account for the gradient in TP concentrations (see **Table 3**) between the upper section of the lake and the lower section. Advection and dispersion were added to the model segments to represent the segmented lake. The lake was segmented near the boundaries of the two sub-basins in the HSPF model draining directly to the lake (see **Figure 3**). **Figure 3** shows the model segments and major drainage areas of Big Stone Lake.

Lac qui Parle Lake Model

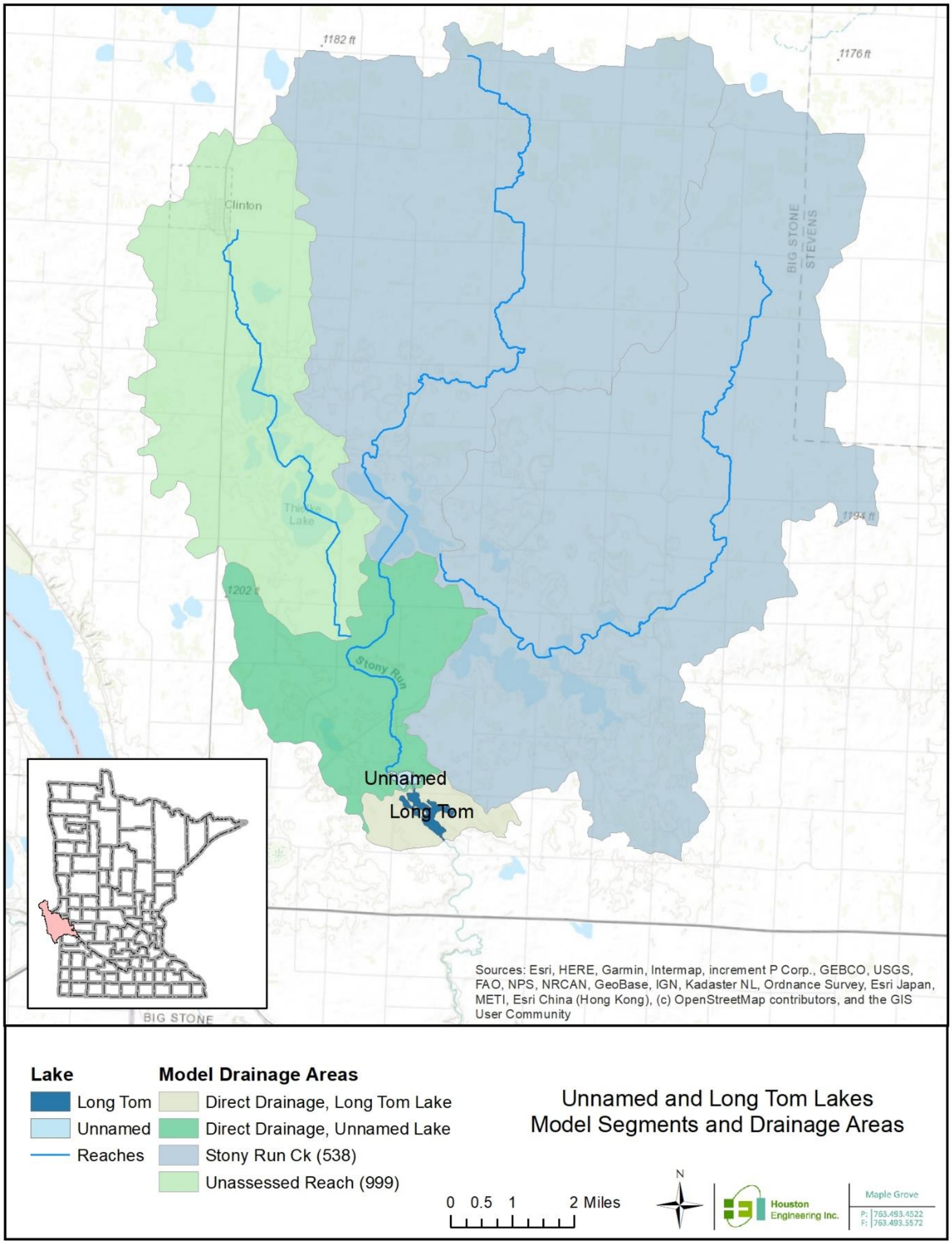
The Lac qui Parle Lake model contains six model segments representing three lakes (Marsh, Lac qui Parle Lake NW Bay, and Lac qui Parle SE Bay). The Lac qui Parle Lake NW Bay is broken into two model segments (upper and lower segments) based on the lake's bathymetry. The Lac qui Parle Lake SE Bay is broken into three model segments (upper, middle, and lower segments) based on the lake's bathymetry and major tributaries into the lake (namely the Chippewa River and Lac qui Parle River). **Figure 4** shows the model segments of the Lac qui Parle Lake model. **Figure 5** shows the major drainage areas of the lake model. Advection and dispersion were added to model segments in the same water body. The connection between upper and lower Lac qui Parle Lake NW Bay had advection and dispersion modeled and the connections between upper, middle, and lower Lac qui Parle Lake SE Bay modeled advection and dispersion as well. This allowed the lake model to represent any gradient in TP concentrations that exists in the lakes due to various loading form the major tributaries.

Water Mass Balance

A lake's water mass balance, or water budget, is an accounting of the amount of water entering and leaving a lake over a given time period. This modeling effort assumes a seasonal (summer months June-September) time period for modeling the lakes in the MRHW. The hydrologic residence time is less than one year. The amount of water moving in and out of a system varies from year-to-year, dictated primarily by the seasonal variation of precipitation occurring in the area. It is important to quantify the water budget because different sources of water can contain different quantities of pollutants, and the amount of water entering and leaving the lake determines the hydraulic residence time, which impacts the lake's eutrophication response. Additionally, the water budget is important because it is used during hydrologic and water quality modeling for model calibration and validation purposes. A water budget accounts for "gains" in water to the lake (e.g., precipitation, surface water RO, tributary inflow, advection flow, or groundwater inflow) as well as "losses" (e.g., evaporation, surface outflow, and groundwater outflow). Each of these affects the volume of water in the lake (i.e., storage).

The water budget components accounted for in this study are: **Precipitation**, the amount of water entering the lake directly from precipitation landing on the lake's surface; **Direct drainage inflow**, the water flowing to the lake from the contributing drainage area, including both surface and groundwater inputs; **Tributary inflow**, the amount of water flowing into the lake from upstream basins, usually from stream sources; **Advection flow**, the water flowing from an upstream lake segment to a downstream lake segment; **Evaporation**, the water leaving the surface of the lake through evaporative processes; **Surface outflow**, the water leaving the lake through surface outlets (usually a stream); and **Storage**, the change in the water stored in the lake due to lake level increases or decreases. Any groundwater flows are lumped into direct drainage, tributary flow, and/or outflow. Advective flows only apply to multi-segment lakes and are equal to the upstream surface outflow. The lake models are steady-state models, meaning change in storage is zero.

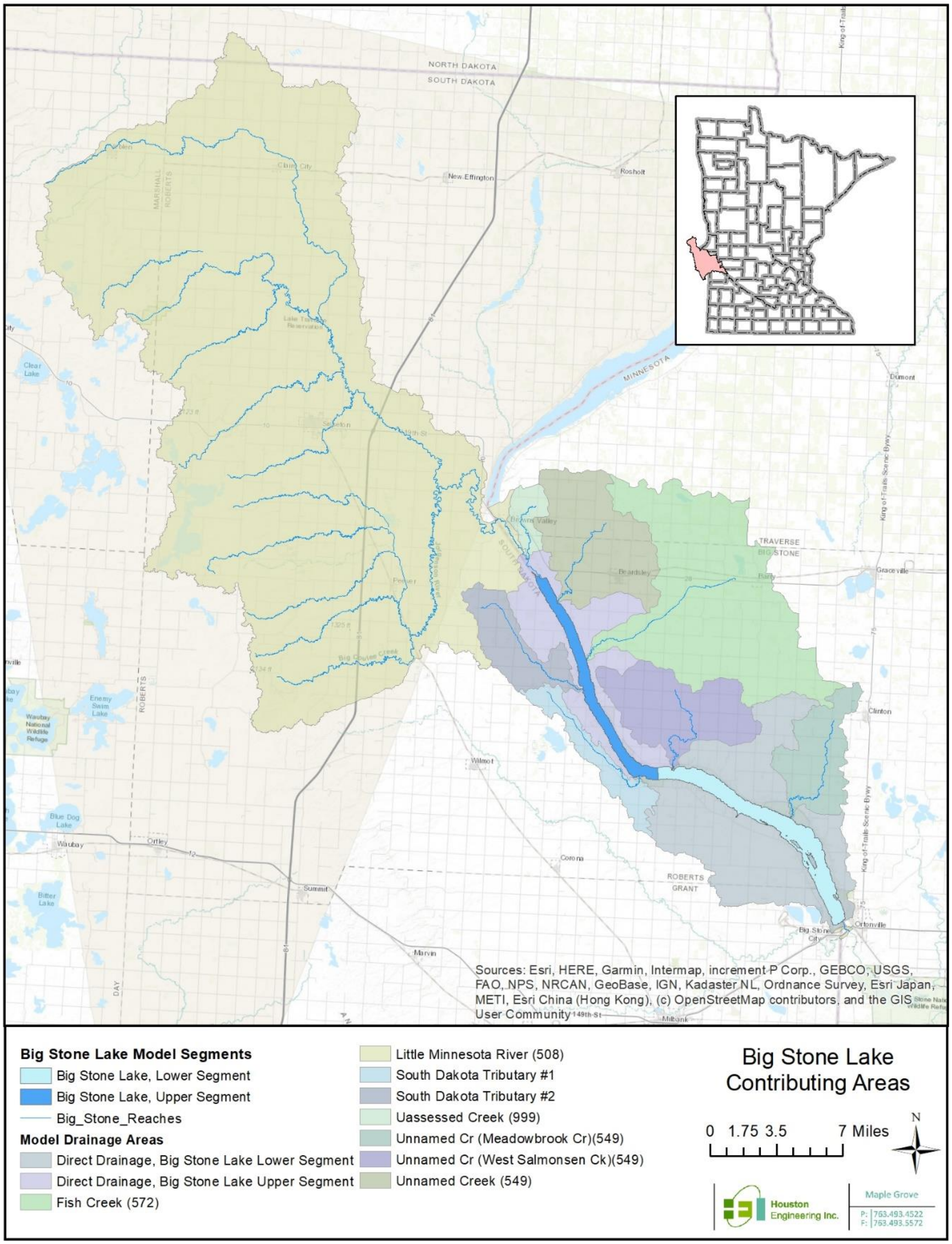
The average seasonal water budgets for the modeled lakes in the MRHW were estimated from the CNET simulation. The water budgets for the modeled lakes and any model segments are shown in **Table 6**, using units of acre-feet per year (ac-ft/yr).



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Unnamed and Long Tom Lakes
Model Segments and Drainage Areas

Figure 2. Unnamed Lake and Long Tom Lake models and drainage areas.



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Figure 3. Big Stone Lake model segments and drainage areas.

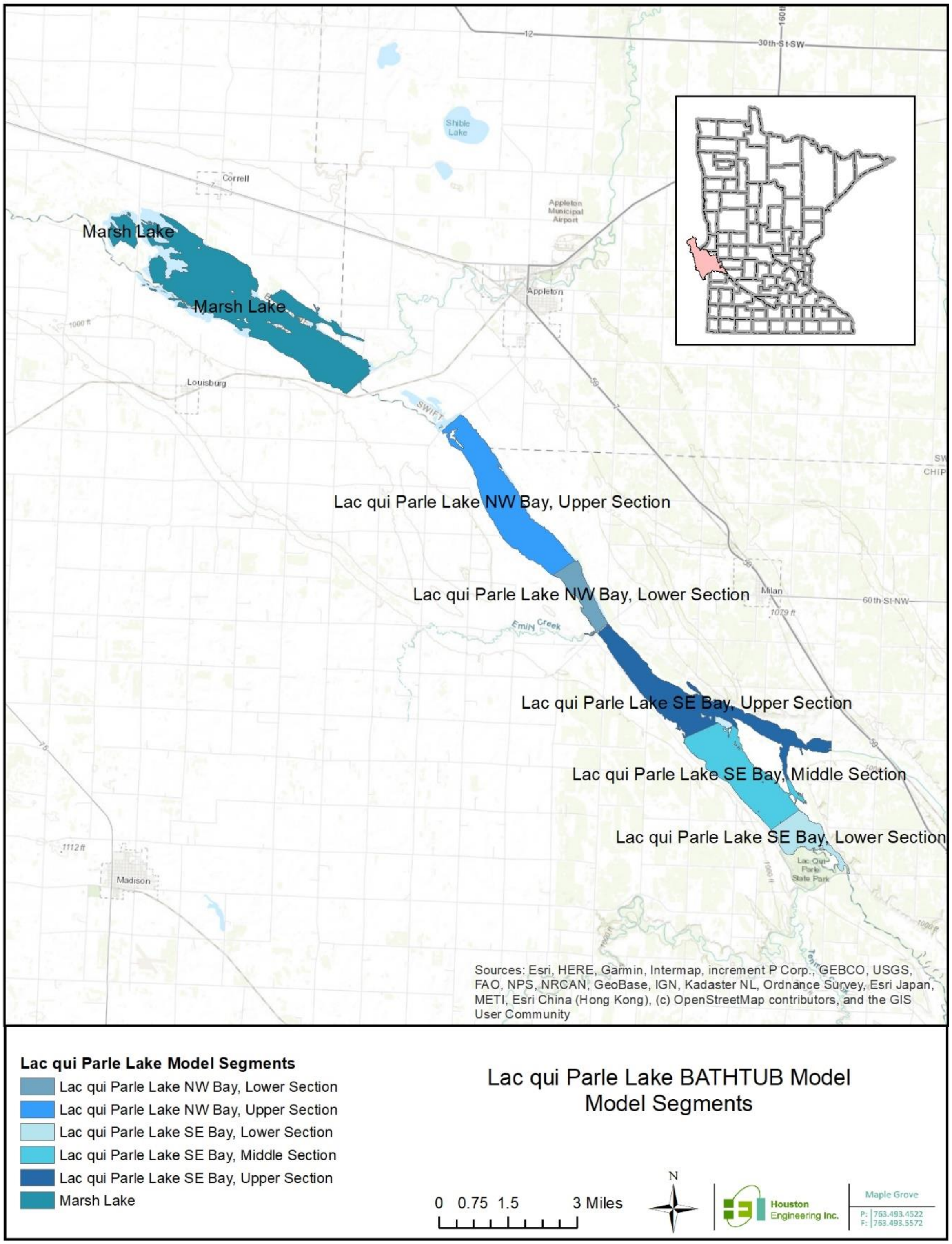


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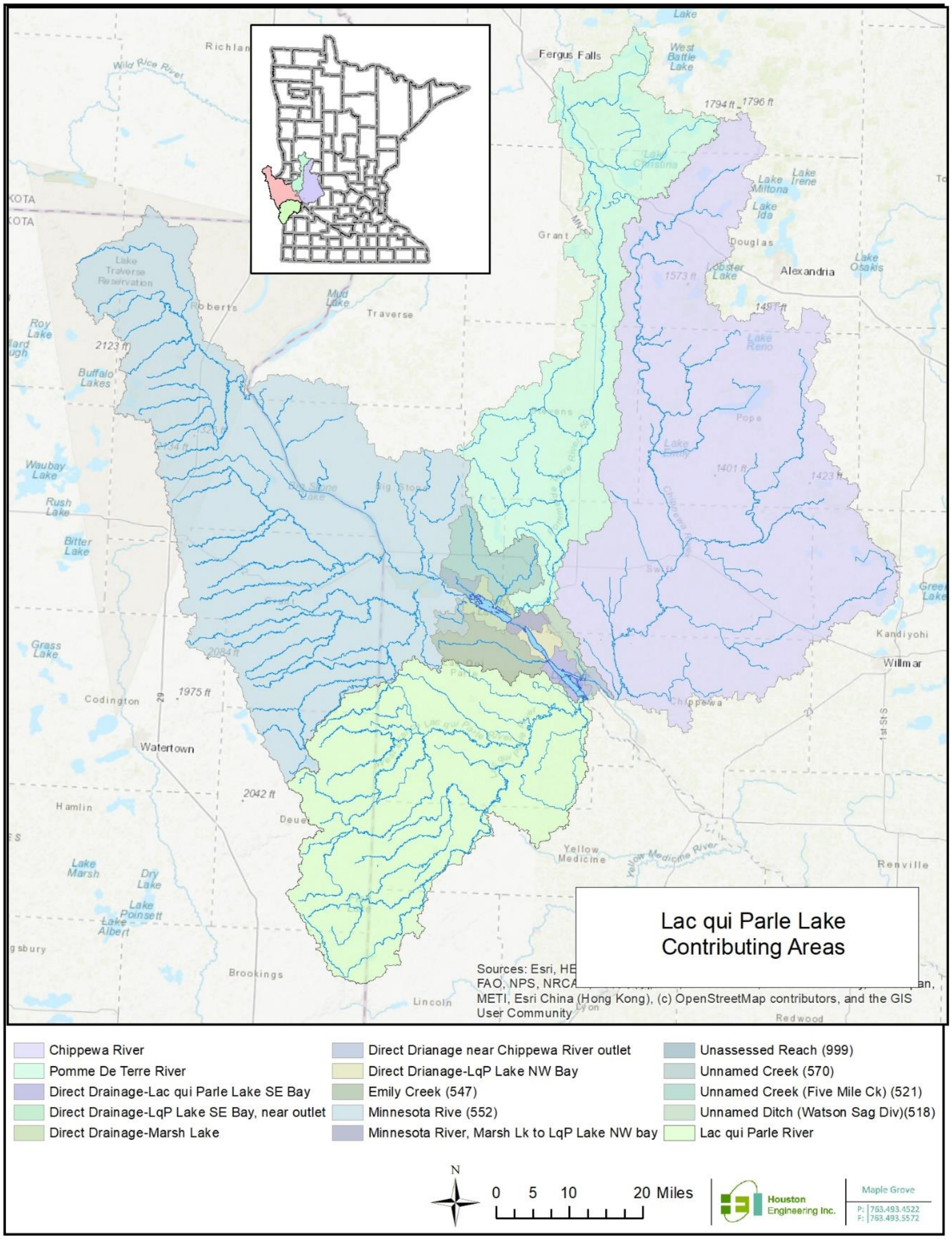
Figure 4. Model segments for the Lac qui Parle Lake model.



Sources: Esri, HE… FAO, NPS, NRCA… METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Figure 5. Drainage areas for the Lac qui Parle Lake model.

Table 6. Average water budgets for the modeled lakes in the Minnesota River Headwaters Watershed.

Lake Name (AUID)	Inflows (ac-ft/yr)				Outflows (ac-ft/yr)	
	Precipitation	Direct Drainage Inflow	Tributary Inflow	Total Inflow	Evaporation	Outflow
Long Tom	157	691	8,368	9,216	358	8,858
Unnamed	67.9	4,301	4,186	8,555	187	8,368
Big Stone	7,956	56,689	2,986	117,443	20,088	97,355
Lac qui Parle Lake – NW Bay	2,253	5,614	6,398	337,334	4,270	333,064
Lac qui Parle Lake – SE Bay	3,900	11,875	134,367	823,323	7,871	815,452

Phosphorus Mass Balance

Similar to a water budget, a TP mass balance accounts for the amount of TP entering and exiting a lake over a given time period. TP amounts are expressed as loads, in units of mass per time, or for the purposes of this study, pounds per season (lbs/season). The nutrient loads are estimated by considering the concentration of TP in the water and the amount of water entering and exiting the lake over the time period. The TP mass balance accounts for both “gains” (e.g., surface water RO) as well as “losses” (e.g., outflows) from the lake. A typical lake TP mass balance accounts for direct drainage area loading, tributary loading, atmospheric deposition, internal loading, sedimentation/retention, advection, dispersion, and outflow. Each of the phosphorus mass balance components is discussed in more detail below.

Direct Drainage Loading

The amount of phosphorus entering each lake from its direct drainage (nontributary) was estimated using the outputs of the HSPF model(s). Phosphorus loads for the sub-basins containing each lake were extracted from the model. Since all modeled lakes were explicitly modeled in the HSPF model, the TP loadings were extracted from the inflows to the model RCHRES (waterbody modeling unit) section.

Tributary Loading

Phosphorus entering a lake from upstream lakes and/or sub-basins, transported by a stream or river is known as tributary loading. Tributary loadings were extracted from the outflows of the HSPF modeled tributary RCHRES.

Atmospheric Loading

The rates of atmospheric deposition of phosphorus onto each of the simulated lakes were set equal to those found in the MPCA’s state-wide phosphorus study, more specifically the 2007 atmospheric deposition update (Barr 2007). An estimated total deposition rate of an average year for the Minnesota River (41.7 kg/ha/year) was used for modeling atmospheric deposition to the lakes in the MRHW. For seasonal rates, the ratio of summer precipitation to average annual precipitation is used to estimate the summer atmospheric deposition.

Potential Internal Loading

Internal loading is the re-release of TP from sediments, usually due to anoxic conditions (dissolved oxygen concentrations < 2.0 mg/L) near the bed of the lake. Internal phosphorus loading can be a substantial part of the mass balance in a lake, especially in lakes with a history of high phosphorus loads. If a lake has a long history of high phosphorus concentrations, it is possible to have internal loading rates higher than external loads.

Internal loading can be estimated using methodology developed by Nurnberg (1984, 1995, 2009). Internal loading is estimated by adding an internal loading term to the current models based on external loading and predicted retention (Nurnberg 1984):

$$TP = {}^{L_{ext}}\!/_{q_s}\left(1 - R_{pred}\right) + {}^{L_{int}}\!/_{q_s} \qquad [1]$$

where TP is the in-lake TP concentration (ug/L); Lext is the external load (kg/yr), qs is the lake outflow (hm3/yr), Rpred is the predicted retention coefficient, and Lint is the internal loading (kg/yr). The retention coefficient can be estimated using:

$$R_{pred} = {}^{15}\!\Big/\left(18 + {}^{q_s}\!/_{A}\right) \qquad [2]$$

Where A = surface area of the lake (km^2). The only unknown in [1] and [2] is internal loading and it can be estimated by solving for L*int*.

Using [1] and [2], the potential for internal loading was checked for the modeled lakes. Unnamed Lake was the only lake to show potential internal loading using this methodology. Years where observed in-lake phosphorus concentrations were not available, concentration were taken from the HSPF model.

Advection Loading

Advection is the net discharge of phosphorus from one model segment into another when a lake is segmented or multiple lakes are modeled in series, where one lake drains directly into another. The advection term is taken as the modeled outflow of the upstream lake.

Dispersion Loading

Dispersion, also called longitudinal dispersion, is the phosphorus transfer between two connected lake segments due to a gradient in in-lake phosphorus concentrations between the two lake segments. Phosphorus will transfer from a lake segment when the phosphorus concentration is higher than the connecting lake segment and the rate of transfer is related to the interface area between the lake segments and the difference of in-lake phosphorus concentrations between the lake segments.

Retained Mass & Error

Other in-lake processes (sedimentation, nutrient uptake, etc.) were not explicitly accounted for in the TP balances, but rather lumped into a retained mass and error term (sedimentation in **Table 7**). The retained mass and error term is the difference between TP inputs and TP outputs (i.e., retained mass + error = TP inputs – TP outputs).

Surface Outflow Loading

The amount of TP exiting each lake through surface water outflow is known as surface outflow load and was calculated (using CNET) by taking the in-lake TP concentration and applying it to the lake's outflow. The average surface water outflow loadings computed for each lake, in lbs/yr, are given in **Table 7**.

Summary of phosphorus mass balances

The phosphorus mass balances were estimated using the CNET model with forcing data from the HSPF models. The average seasonal phosphorus mass balances, as calculated by the CNET models, are provided in **Table 7**. A breakdown of TP loads for each model segment can be found in the **Appendix**. Advection and dispersion are not included in the loads provided in **Table 7**

Table 7. Average annual phosphorus nutrient mass balances for modeled lakes in the MRHW.

Lake Name	Gains [lbs/yr]				Losses [lbs/yr]	
	Atmospheric Deposition	Direct Drainage	Tributary	Total Load	Sedimentation	Outflow
Long Tom	28	40	10,282	10,350	447	9,902
Unnamed	12	12,108	4,170	16,291	6,009	10,282
Big Stone	2,267	6,269	42,841	51,376	33,582	17,794
Lac qui Parle (SE Bay)	685	937	139,828	340,636	119,084	221,552
Lac qui Parle (NW Bay)	398	340	43,387	168,396	71,391	97,005

Model Application

The following provides a summary of the lake model application, including calibration, stochastic simulation, load reduction scenarios, the eutrophication response (results) of the lake models, development of the loading capacity, and a brief discussion of the model results for each lake.

CNET Model Calibration

The CNET model relies on a variety of sub-models (i.e., empirical equations for estimating sedimentation) for computing eutrophication dynamics within a lake, providing the ability to simulate eutrophication dynamics in lakes with differing in-lake processes. The first step in calibrating the CNET models was to select the best (sub-) model for simulating in-lake TP, Chl-*a*, and Secchi depths. The "best" (sub-) models were determined by finding the model with its calibration coefficient closest to 1.

The selected models varied from lake to lake; the following were used in the lake models:

- TP Models
    - Model 4: Canfield & Bachmann (1981), Reservoirs, or
    - Model 8: Canfield & Bachmann (1981), Natural Lakes
- Chl-*a* Models
    - Model 2: P, Light, Flushing
    - Secchi Disk Models

- Model 1: Secchi vs Chl-*a* and Turbidity

Full descriptions of each (sub-) model can be found in the BATHUB documentation (Walker 1996).

The modeling period for the lake models was 1996-2017. All available in-lake water quality data was used in calibrating the CNET models, the models were calibrated to the period-averaged condition, and individual years were used to valid the models. The average condition was used to calibrate the models due to differing years of available water quality data between monitoring sites. Sometimes the calibration coefficients are outside of the expected range (0.5-2). These higher/lower than expected calibration coefficients are likely caused by a combination of multiple factors: (1) lack of extensive observed in-lake water quality data; (2) uncertainty within the HSPF model results; (3) the false assumption that the average loading used for calibration correlates to the average observed in-lake water quality data; (4) differences between the lakes used to develop the empirical eutrophication response models and the lake being modeled; and/or (5) lack of internal loading data. The quality of each lake's CNET model calibration (i.e., the final values of the calibration coefficients) was considered when interpreting the results of the modeling, including the recommended TP load reductions.

Stochastic Simulations

The benefit of using CNET over the traditional BATHTUB model is the ability to perform stochastic simulations. Stochastic modeling is an approach where model input values (e.g., terms in hydrologic budget) and model parameters used in the equations to compute the in-lake mean concentration of TP and Chl-*a* and Secchi disk depth, are allowed to vary according to their observed statistical distribution and therefore their probability of occurrence. This allows the effect of parameter uncertainty and normal variability in the inputs (e.g., amount of surface RO and nutrient load, which varies depending upon the amount of precipitation) to be quantified when computing the in-lake mean concentration of TP and Chl-*a* and Secchi disk depth.

Crystal Ball software was used to develop the model input statistical distributions based on the previously mentioned HSPF hydrologic and TP loading values for the period 1996 through 2017. Crystal Ball was used to choose the distribution based on the best fit of the data for most parameters. In addition to the probability distributions, correlation coefficients were added to account for links between certain hydrologic and loading parameters (e.g., direct drainage inflow is driven by, and therefore, correlated to precipitation). Correlations between precipitation and evaporation, atmospheric deposition, direct drainage RO and loading, and tributary RO and loadings were applied. In addition, surface RO and tributary flow was correlated to TP loading.

Using the Crystal Ball software allowed for multiple probabilistic model computations. Many trial values were generated with each trial (10,000 trials in this modeling effort) representing a different permutation of model input values within the bounds established by the statistical distributions. The many trials resulted in a computed distribution of expected in-lake water quality for each lake rather than a single, deterministic output based upon only one possible combination of model inputs. Select inputs, primarily those components of the water budget or TP mass balance, were allowed to vary during the Monte Carlo simulation. The selected inputs are precipitation, evaporation, atmospheric deposition, direct drainage inflows and loadings, and tributary inflows and loadings.

Load Reduction Scenarios

The purpose of this CNET modeling effort is to determine the loading scenario(s) under which applicable water quality standards (**Table** 2) will be met in the impaired lakes and improve the in-lake water quality conditions. For the load reduction scenarios, TP loadings were reduced incrementally within the CNET model. It is assumed all load reductions come from the contributing drainage area and/or internal loading (for Unnamed Lake). Each CNET model started with the calibrated average condition (i.e., the current condition) and a set of standard reductions: 10%, 25%. 50%, 75%, and 90% load reduction scenarios. After the models were run using the general load reduction scenarios, the reductions were refined to find the necessary load reduction to meet the TP water quality standard for each individual lake. Other reduction percentages may also stray from standard reductions to better display the frequency distributions on each graph.

This approach is consistent with MPCA guidance (MPCA 2007), which assumes that if a lake meets the state’s TP water quality standard that Chl-*a* and Secchi disk depth within the system will respond accordingly and eventually also reach the state-defined goals (even if the results of the CNET modeling do not predict this result). This approach assumes that data collected and extensively analyzed by the MPCA during standards development provides a more accurate estimate of how lakes will respond when moved from an impaired to unimpaired state than the relationships that exist within the CNET program. This reduction process was applied to all lakes and results are summarized below. Detailed results are provided by lake at the end.

Eutrophication Response

The CNET models are used to determine the eutrophication response to TP loading. The stochastic nature of the modeling provides a range of responses. **Figure 6** shows an example of the frequency distribution of TP concentrations and **Table 8** shows the numeric values used to construct the figure**.** **Figure 6** and **Table 8** illustrate the results of incrementally reducing loads within the CNET model. This example is taken from analysis for Big Stone Lake (upper model segment). The reduced loads were assumed to come from contributing drainage area loading and any tributary loading. However, the same response would occur regardless of the sources (e.g., including internal load). Each line in **Figure 6** represents a different loading scenario and the red dashed line represents the TP water quality standard target. It is assumed the lake will meet the water quality standard if the in-lake TP concentrations are lower than the water quality standard 50% of the time.

For the example, the median initial in-lake TP concentration is 155.5 µg/L and the TP loading is 39,600 lbs/season. **Figure 6** and **Table 8** show a reduction of 49% is needed to meet the water quality standard of 90 µg/L, 50% of the time. This results in a loading capacity of 20,196 lbs/season and an in-lake TP concentration of 88.8 µg/L (**Table 8**). Results for TP, Chl-*a*, and Secchi disc for the modeled lake in the MRHW are provided.

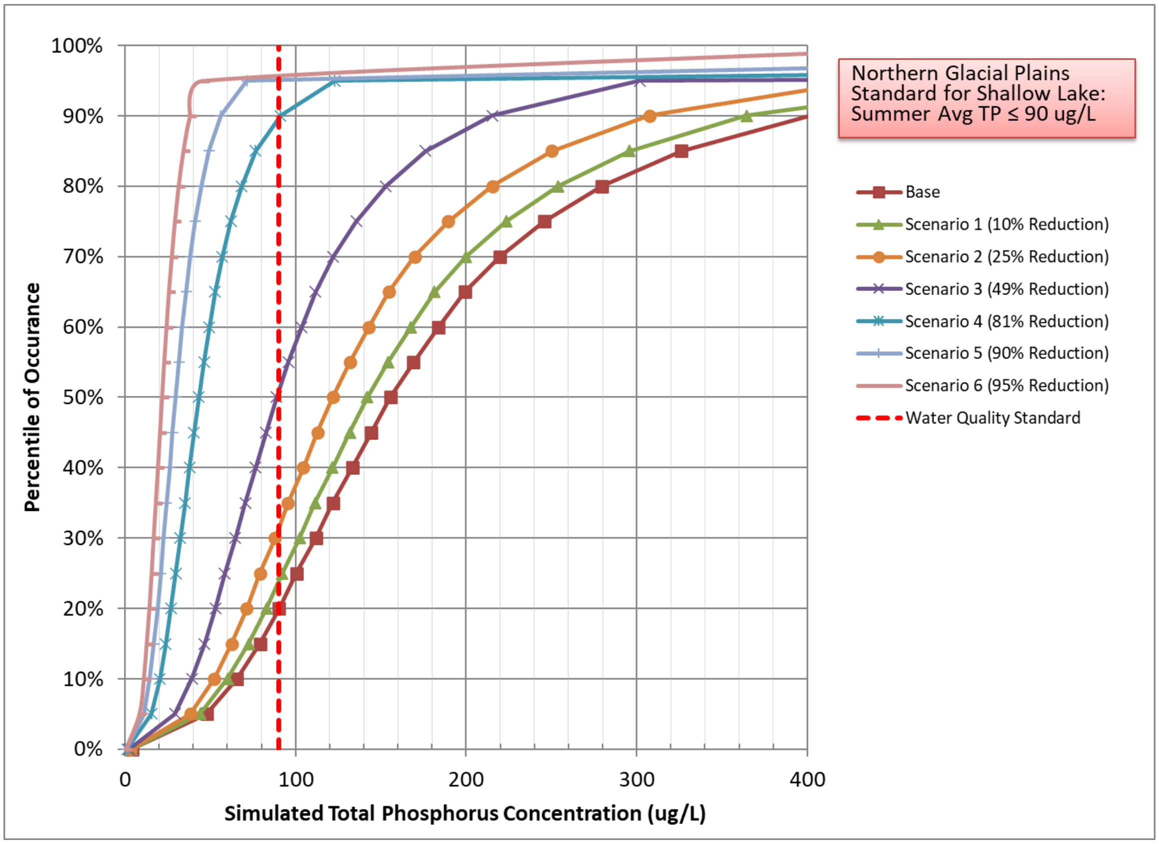


Figure 6. Sample of frequency distribution of mean TP concentrations resulting from select load reduction scenarios for Big Stone Lake (upper segment).

Table 8. Frequency distribution of Monte Carlo simulation of TP loading reduction results (µg/L) for Big Stone Lake (upper segment).

Nonexceedance Percentile	Base Year	10% Load Reduction	25% Load Reduction	49% Load Reduction	81% Load Reduction	90% Load Reduction	95% Load Reduction
Total Load (lbs/season)	39,600	35,640	29,700	20,196	7,524	3,960	1,980
0%	4.2	3.9	3.4	2.6	1.4	0.9	0.6
10%	65.7	60.3	52.2	39.3	20.6	14.7	10.9
20%	90.3	82.9	71.4	53.1	26.9	19.1	14.2
30%	111.9	102.4	88.0	64.7	32.4	22.8	16.7
40%	133.2	121.7	104.5	76.5	37.8	26.2	19.2
50%	155.5	142.0	121.9	88.8	43.4	29.8	21.6
60%	183.7	167.5	143.1	103.5	49.5	33.7	24.2
70%	219.8	199.8	169.9	122.1	57.1	38.3	27.3
80%	279.5	254.1	215.3	152.9	68.4	44.7	31.3
90%	402.2	364.3	307.3	215.2	91.3	56.1	38.0
100%	9,234.9	8,339.8	6,990.6	4,813.0	1,854.4	1,000.8	516.5

In some cases, not all of the frequency distribution for a given load reduction is shown on the graph. **Figure 6** is a good example of this. In these cases, extreme values in the distribution, typically resulting from combinations of extreme RO, precipitation, and/or other parameters, lead to occurrences with very high concentrations. The x-axis display scale was chosen to ensure all load reduction scenarios and the average year scenario were clearly displayed up to the point of expected maximum TP concentration within reason.

Recommended Reductions and Loading Capacity

The results of the CNET modeling and load reduction scenarios for each of the impaired lakes are summarized in **Table 9. Table 9** includes the specific TP water quality standard that applies to the individual lake, the simulated existing TP concentration and loading into the lake as estimated by the average condition, the absolute load reduction required to meet the TP water quality standard, the percent load reduction required to meet the TP water quality standard, and the loading capacity of the lake (i.e., the TP loading when the water quality standard is met). It should be noted that the lake models were developed on the seasonal (June through September) timescale to determine load reductions, then the load reductions were applied to annual loads to get the reported values in the following tables. These results provide the loading capacity of the lake to meet water quality standards. Detailed loads and load reductions for individual lakes are provide in **Tables 10 – 12** for each individual lake and their tributaries. Loads, load reductions, and loading capacity include loads for upstream lakes, and the reported values do not account for reductions needed for those lakes. **Tables 10 – 12** provide load reduction for individual tributaries and upstream lakes.

Table 9. Results of the load reduction scenarios for modeled lakes in the Minnesota River Headwaters Watershed.

Lake Name	TP Water Quality Standard [µg/L]	In-Lake TP Conc. [µg/L]	Existing Conditions TP Load (lbs/yr)	TP Load Reduction [%]	Margin of Safety [%]	Total Load Reduction [%]	Loading Capacity [lbs/yr]
Long Tom	90	422	103,329	80%	6%	86%	14,438
Unnamed	90	648	103,131	80%	6%	86%	14,636
Big Stone	90	113	92,224	35%	32%	65%	30,247
Lac qui Parle (SE Bay)	90	161	296,650	27%	27%	54%	271,243
Lac qui Parle (NW Bay)	90	138.6	588,256	71%	10%	81%	56,365

The TP load reductions range from 54% to 86%. The modeling results may be influenced by one or a combination of factors:

1. Lack of extensive observed in-lake water quality data;
2. uncertainty within the HSPF model results;
3. the assumption that the mean annual loading used for calibration correlates to the mean observed in-lake water quality data;

4. unknown sources/sinks of phosphorus or inflows.

To account for this uncertainty in the development of the TMDL, a margin of safety was added (see ***Total Maximum Daily Load*** section).

Table 10. Loads, load reductions, and load capacity for Unnamed Lake and Long Tom Lake.

Unnamed & Long Tom Lake		Current Loads		Load Reduction	Margin of Safety	Total Load Reduction	Estimated Load Reduction		Load Capacity	
		Annual	Seasonal				Annual	Seasonal	Annual	Seasonal
		TP [lbs/yr]	TP [lbs/seas.]	[%]	[%]	[%]	TP [lbs/yr]	TP [lbs/seas.]	TP [lbs/yr]	TP [lbs/seas.]
Unnamed Lake	Atmospheric Deposition	24	12	0%	0%	0%	0	0	24	12
	Direct Drainage, Unnamed Lake	1,450	513	80%	6%	86%	1,247	441	203	72
	Stony Run Creek (538)	10,507	3,065	80%	6%	86%	9,036	2,636	1,471	429
	Unassessed Reach (999)	1,933	745	80%	6%	86%	1,662	641	271	104
	Internal Load	89,217	10,624	80%	6%	86%	76,727	9,136	12,490	1,487
	Total Loading	**103,131**	**14,958**	**80%**	**6%**	**86%**	**88,693**	**12,864**	**14,438**	**2,094**
Long Tom Lake	Atmospheric Deposition	55	27	0%	0%	0%	0	0	55	27
	Direct Drainage, Long Tom Lake	143	40	0%	0%	0%	0	0	143	40
	Unnamed Lake	103,131	14,958	80%	6%	86%	88,693	12,864	14,438	2,094
	Total Loading	**103,329**	**15,026**	**80%**	**6%**	**86%**	**88,693**	**12,864**	**14,636**	**2,162**

Table 11. Loads, load reductions, and load capacity for Big Stone Lake.

Big Stone Lake		Existing Loads		Load Reduction	Margin of Safety	Total Load Reduction	Estimated Load Reduction		Load Capacity	
		Annual	Seasonal				Annual	Seasonal	Annual	Seasonal
		TP [lbs/yr]	TP [lbs/seas.]	[%]	[%]	[%]	TP [lbs/yr]	TP [lbs/seas.]	TP [lbs/yr]	TP [lbs/seas.]
Upper Segment	Direct Drainage-Big Stone Lake, Upper Reach	4,123	1,544	49%	32%	81%	3,340	1,251	783	293
	Little Minnesota River (508)	46,412	20,514	49%	32%	81%	37,594	16,616	8,818	3,898
	Unassessed Reach (999)	585	233	49%	32%	81%	474	188	111	44
	Unnamed Creek	5,134	1,904	49%	32%	81%	4,159	1,542	975	362
	Fish Creek (572)	10,989	3,975	49%	32%	81%	8,901	3,219	2,088	755
	South Dakota Tributary #1	1,904	660	49%	32%	81%	1,542	534	362	125
Lower Segment	Direct Drainage-Big Stone Lake, Lower Reach	9,681	3,672	0%	32%	32%	3,098	1,175	6,583	2,497
	Unnamed Cr (West Salmonsen Ck)	4,776	1,531	0%	32%	32%	1,528	490	3,247	1,041
	Unnamed Ck (Meadowbrook Ck)	2,822	907	0%	32%	32%	903	290	1,919	617
	South Dakota Tributary #2	1,370	431	0%	32%	32%	438	138	932	293
Big Stone Lake	Atmospheric Deposition	4,428	2,231	0%	0%	0%	0	0	4,428	2,231
	Total Loading	**92,224**	**37,600**	**35%**	**32%**	**67%**	**61,977**	**25,444**	**30,247**	**12,156**

Table 12. Loads, load reductions, and load capacity for Lac qui Parle Lake.

Lac qui Parle Lake and Marsh Lake		Existing Loads		Load Reduction	Margin of Safety	Total Load Reduction	Estimated Load Reduction		Load Capacity	
		Annual	Seasonal				Annual	Seasonal	Annual	Seasonal
		TP [lbs/yr]	TP [lbs/seas.]	[%]	[%]	[%]	TP [lbs/yr]	TP [lbs/seas.]	TP [lbs/yr]	TP [lbs/seas.]
Marsh Lake	Atmospheric Deposition	1,435	715						1,435	715
	Direct Drainage-Marsh Lake	2,579	722	71%	10%	81%	2,089	585	490	137
	Unnamed Creek (Five Mile Ck)(521)	12,302	3,367	71%	10%	81%	9,965	2,727	2,337	640
	Unassessed Reach (999)	695	173	71%	10%	81%	563	140	132	33
	Minnesota River (552)	150,524	43,629	71%	10%	81%	121,925	35,340	28,600	8,290
	Unnamed Creek (570)	1,979	534	71%	10%	81%	1,603	433	376	102
	Pomme de Terre River	108,120	41,438	71%	10%	81%	87,578	33,565	20,543	7,873
	Total Loading	**277,636**	**90,578**	**71%**	**10%**	**81%**	**224,885**	**73,368**	**52,751**	**17,210**
Lac qui Parle Lake-NW Bay	Atmospheric Deposition	780	389						780	389
	Direct Drainage-Lac qui Parle Lake-NW Bay	1,222	337	50%	10%	60%	733	202	489	135
	Emily Creek (547)	11,091	3,078	74%	10%	84%	9,316	2,585	1,774	492
	Minnesota River, Marsh Lake to Lac qui Parle Lake-NW Bay	877	238	25%	10%	35%	307	83	570	155
	Marsh Lake	277,636	90,578	71%	10%	81%	224,885	73,368	52,751	17,210
	Total Loading	**291,606**	**94,618**	**71%**	**10%**	**81%**	**235,241**	**76,238**	**56,365**	**18,380**
Lac qui Parle Lake-SE Bay	Atmospheric Deposition	1,350	673				0	0	1,350	673
	Direct Drainage-Lac qui Parle Lake-SE Bay	2,708	767	0%	27%	27%	731	207	1,977	560
	Direct Drainage-Lac qui Parle Lake-SE Bay, near outlet	120	34	2%	27%	29%	35	10	85	24
	Unnamed Ditch(Watson Sag Div)(518)	2,542	706	0%	27%	27%	686	191	1,856	515
	Lac qui Parle River	101,880	32,029	2%	27%	29%	29,545	9,288	72,335	22,741
	Chippewa R Overflow	187,091	88,671	0%	27%	27%	50,515	23,941	136,577	64,730

Lac qui Parle Lake and Marsh Lake		Existing Loads		Load Reduction	Margin of Safety	Total Load Reduction	Estimated Load Reduction		Load Capacity	
		Annual	Seasonal				Annual	Seasonal	Annual	Seasonal
		TP [lbs/yr]	TP [lbs/seas.]	[%]	[%]	[%]	TP [lbs/yr]	TP [lbs/seas.]	TP [lbs/yr]	TP [lbs/seas.]
	Direct Drainage near Chippewa River overflow	958	256	0%	27%	27%	259	69	699	187
	Lac qui Parle Lake-NW bay	291,606	94,618	71%	10%	81%	235,241	76,238	56,365	18,380
	Total Loading	**588,256**	**217,753**	**27%**	**27%**	**54%**	**317,012**	**109,944**	**271,243**	**107,809**

Results Discussion

The following discusses the results for each lake model.

Unnamed Lake and Long Tom Lake

Unnamed Lake and Long Tom Lake were modeled in series since the drainage area of Unnamed Lake makes up 98% of the drainage area of Long Tom Lake. As can be seen in **Table 10**, the majority of the load entering Long Tom Lake comes from the outflow of Unnamed Lake and all of the required reduction in Long Tom Lake comes from the drainage area of Unnamed Lake, meaning if Unnamed Lake meets water quality standards, Long Tom Lake will also meet the standard. **Table 10** also shows the load reductions needed in each major tributary to Unnamed Lake and Long Tom Lake.

There is significant internal loading in Unnamed Lake, as determined by **Equation 1**. Load reductions were applied evenly across the internal loading and overland loading to determine the magnitude of the load reduction needed. In practice, the load reduction can come from either source and still have the same impact as long as the quantity of the load reduction is met.

The margin of safety for the Unnamed Lake and Long Tom Lake model was determined to be 6%, meaning the 90th percentile concentration meets the standard when the margin of safety and load reduction are met. This small load reduction means the models do a good job simulating conditions in the lake.

Overall, Unnamed Lake and Long Tom Lake require an 86% load reduction to meet water quality standards, with a significant amount coming from internal sources.

Big Stone Lake

Big Stone Lake was modeled with two model segments but loads and reductions were combined to give a summary of the lake. The upper segment showed much higher TP concentrations than the lower segment (see **Table 3**). Therefore, the segments were modeled individually to simulate the TP concentration gradient in the lake, and load reductions were applied so that each segment meets the water quality standard. **Table 11** provides the loading and load reductions by major tributary. All of the required load reductions for Big Stone Lake come from the upper tributaries. This makes sense since the upper segment had much higher TP concentrations. The overall load reduction to meet the 50th percentile TP concentration was 49% from the tributaries contributing to the upper model segment (see **Table 11**). The margin of safety was applied across both model segments because both contain uncertainty. In reality, reducing the load to the upper segment would accomplish the same impact, i.e. both segments would meet the standard at 90% exceedance.

The margin of safety, as estimated by the CNET model, is 32%. This high margin of safety shows the level of uncertainty in the lake model and its forcing data, plus the ability of the model to simulate a reservoir with a quick hydraulic residence time (0.28 years). In addition, it is possible the overland TP loads from the HSPF model might be underestimated as the upper model segment required a lower calibration coefficient (<0.1) to meet the observed in-lake TP concentrations and may be the cause of the significant margin of safety.

Overall, Big Stone Lake requires a 67% load reduction in TP to meet water quality standards.

Lac qui Parle Lake

Lac qui Parle Lake-NW Bay and Lac qui Parle Lake-SE Bay were modeled together in one system of connected lakes, including the upstream lake, Marsh Lake. Marsh Lake was modeled as a single model segment, Lac qui Parle Lake-NW Bay was model as two model segments, and Lac qui Parle Lake-SE Bay was model as three model segments to account for the various major tributaries entering each lake. **Table 12** provides the loads and load reductions for the various tributaries entering the lake system. The majority of load reductions are needed above Marsh Lake and Lac qui Parle Lake-NW Bay (71%). Little reduced load is needed in Lac qui Parle Lake-SE Bay (2%). Reducing the loading upstream of Lac qui Parle Lake-NW Bay will have significant impact on Lac qui Parle Lake-SE Bay.

The margin of safety varies across the lake system. A 10% margin of safety is applied to Marsh Lake and Lac qui Parle Lake-NW Bay, where a 27% margin of safety is need in Lac qui Parle Lake-SE Bay. This high margin of safety shows the level of uncertainty in the lake model and its forcing data, plus the ability of the model to simulate a reservoir with a quick hydraulic residence time (0.017 years). In addition, it is possible the overland TP loads from the HSPF model might be underestimated as some model segments required a lower calibration coefficient (0.1) to meet the observed in-lake TP concentrations and may be the cause of the significant margin of safety.

Total Maximum Daily Load

A TMDL represents the maximum mass of a pollutant that can be assimilated by a receiving waterbody without causing an impairment in that receiving waterbody. TMDLs are developed based on the following equation:

$$\mathbf{TMDL = LC = \sum WLA + \sum LA + MOS} \qquad [3]$$

Where:

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

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

LA = load allocation, or the portion of the loading capacity allocated for existing or future NPS;

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

Per Code of Federal Regulations (40 CFR 130.2(1)), TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures. For lakes, the TMDLs, allocations, and margins of safety are expressed in pounds of phosphorus/day. Each TMDL component is discussed in greater detail below.

Load Allocation

Load allocations represent the portion of the loading capacity designated for NPS of phosphorus. The LA is the remaining load once the waste load allocation, reserve capacity, and margin of safety are determined and subtracted from the loading capacity. The LA includes all sources of TP that do not require NPDES permit coverage, including unregulated watershed RO, internal loading, groundwater, atmospheric deposition, and a consideration for "natural background" conditions. "Natural background", as defined in Minn. R. 7050.0150, subp. 4, can be described as physical, chemical, or biological conditions that would exist in a waterbody that are not a result of human activity.

Wasteload allocation

Wasteload allocations were developed for any permitted discharge in the drainage area of an impaired lake. These are discharges requiring an NPDES permit, and typically include water treatment facilities, municipal separate storm sewer systems (MS4s), industrial dischargers, construction sites managing for stormwater, and permitted feedlots. WLA are provided by category in the TMDL summary tables.

Wastewater Treatment Plants

WLAs for WWTPs are based on the reported maximum allowable discharge and the permitted concentration limits. Methodology for calculating the WLA is provided in **Table 13.** The WWTPs in the MRHW is provided in **Table 14**, along with the impaired lake with a WLA for the WWTP, daily maximum flow, and the TP WLA for the WWTP. In addition, WLAs were developed for WWTPs in Lac qui Parle River Watershed (**Table 15**), Pomme de Terre River Watershed (**Table** 16), and Chippewa River Watershed (**Table 17**); each drain to the Lac qui Parle Lake NW Bay and/or Lac qui Parle Lake SE Bay. It is assumed each WWTP will be assigned a 1 mg/L discharge limit.

Table 13. Converting flow and permit limit concentrations into TP loads.

Wasteload (lbs/day) = Assumed TP Limit (1 mg/L) * Flow (mgd) * Conversion Factors			
Multiple by **3.785** to convert	mg/L	→	mg/gallon
Multiple by Flow (mgd)	mg/gallon*mgd	→	pounds/day
Multiply by **2.2046**	mg/gallon	→	micro-pounds/gallon
Multiply by flow (mgd)	micro-pounds/gallon*mgd	→	pounds/day

Table 14. WLAs for NPDES permits in impaired lakes of the Minnesota River Headwaters Watershed.

Facility	Permit Number	Lake(s)	Maximum Daily Flow [mgd]	TP [lbs/day]
Bellingham WWTP	MNG580152	Lac qui Parle, SE Bay	0.344	2.87
Clinton WWTP	MNG580193	Unnamed, Long Tom, Lac qui Parle NW Bay, Lac qui Parle SE Bay	0.749	6.25
ISD 2853 Lac qui Parle Valley High School	MNG580091	Lac qui Parle, SE Bay	0.293	2.45
Milan WWTP	MNG580141	Lac qui Parle, SE Bay	3.3	27.54
Odessa WWTP	MNG580099	Lac qui Parle NW Bay, Lac qui Parle, SE Bay	1.2	10.01
Ortonville WWTP	MNG580151	Lac qui Parle NW Bay, Lac qui Parle, SE Bay	22	183.58

Table 15. WLAs for NPDES permits in impaired lakes of the Lac qui Parle River Watershed.

Facility	Permit Number	Lake(s)	Maximum Daily Flow [mgd]	TP [lbs/day]
Canby WWTP	MNG580154	Lac qui Parle, SE Bay	2.607	21.75
Dawson WWTP	MN0021881	Lac qui Parle, SE Bay	0.471	3.93
Hendricks WWTP	MN0021121	Lac qui Parle, SE Bay	2.449	20.43
Madison WWTP	MN0051764	Lac qui Parle, SE Bay	0.48	4.01
Marietta WWTP	MNG580160	Lac qui Parle, SE Bay	0.334	2.79
PURIS Proteins LLC	MN0048968	Lac qui Parle, SE Bay	2.444	20.39

Table 16. WLAs for NPDES permits in impaired lakes of the Pomme de Terre River Watershed.

Facility	Permit Number	Lake(s)	Maximum Daily Flow [mgd]	TP [lbs/day]
Ashby WWTP	MNG580087	Lac qui Parle NW Bay, Lac qui Parle, SE Bay	0.101	0.085
Barrett WWTP	MNG580173	Lac qui Parle NW Bay, Lac qui Parle, SE Bay	0.106	0.094
Chokio WWTP	MNG580007	Lac qui Parle NW Bay, Lac qui Parle, SE Bay	0.098	0.080
Morris WWTP	MN0021318	Lac qui Parle NW Bay, Lac qui Parle, SE Bay	0.964	7.755
Alberta WWTP	MNG580002	Lac qui Parle NW Bay, Lac qui Parle, SE Bay	0.023	0.004

Table 17. WLAs for NPDES permits in impaired lakes of the Chippewa River Watershed.

Facility	Permit Number	Lake(s)	Maximum Daily Flow [mgd]	TP [lbs/day]
Benson WWTP	MN0020036	Lac qui Parle, SE Bay	0.985	8.10
Clontarf WWTP	MNG580108	Lac qui Parle, SE Bay	0.189	0.30
Danvers WWTP	MNG585119	Lac qui Parle, SE Bay	0.212	0.38
Evansville WWTP	MNG585074	Lac qui Parle, SE Bay	0.749	4.68
Farwell Kensington Sanitary District WWTP	MNG585220	Lac qui Parle, SE Bay	0.57	2.71
Hancock WWTP	MNG585299	Lac qui Parle, SE Bay	1.372	15.71
Hoffman WWTP	MNG585134	Lac qui Parle, SE Bay	2.5	52.15
Kerkhoven WWTP	MN0020583	Lac qui Parle, SE Bay	0.15	0.19
Lowry WWTP	MNG585123	Lac qui Parle, SE Bay	0.422	1.49
Millerville WWTP	MN0054305	Lac qui Parle, SE Bay	0.254	0.54
Murdock WWTP	MNG585086	Lac qui Parle, SE Bay	0.319	0.85
Starbuck WWTP	MN0021415	Lac qui Parle, SE Bay	0.35	1.02
Sunburg WWTP	MNG585125	Lac qui Parle, SE Bay	0.119	0.12
Urbank WWTP	MNG585343	Lac qui Parle, SE Bay	0.08	0.05

Straight Pipe Septic Systems

Straight pipe septic systems are illegal and unpermitted and receive WLA of zero.

Municipal Separation Storm Sewer System

There are no permitted MS4s within the drainage areas of any impaired lake, therefore no MS4 WLAs were calculated.

Industrial and Construction Permits

WLAs for construction and industrial stormwater discharges which are covered by the State's general permits were combined and addressed through a categorical allocation. Stormwater RO from construction sites that disturb: (a) one acre of soil or more, (b) less than one acre of soil and are part of a "larger common plan of development or sale" that is greater than one acre, or (c) less than one acre, but determined to pose a risk to water quality are regulated under the state's NPDES/State Disposal System (SDS) General Stormwater Permits for Construction Activity (MNR1000001). This permit requires and identifies BMPs to be implemented to protect water resources from mobilized sediment and other pollutants of concern. If the owner/operator of impacted construction sites, obtain and abide by the NPDES/SDS General Construction Stormwater Permit, the stormwater discharges associated with those sites are expected to meet the WLAs set in this TMDL report.

Similar to construction activities, industrial sites are regulated under general permits, in this case either the NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000) or the NPDES/SDS General Permit for Construction Sand & Gravel, Rock Quarrying, and Hot Mix Asphalt Production facilities (MNG490000). Like the NPDES/SDS General Construction Stormwater Permit, these permits identify BMPs to be implemented to protect water resources from pollutant discharges at the site. If the owner/operator of industrial sites abide by the necessary NPDES/SDS General Stormwater Permits, the discharges associated with those sites are expected to meet the WLAs set in this TMDL report.

There are numerous industrial stormwater NPDES permits within the drainage areas of the impaired lakes. These only are for stormwater discharges; pit dewatering discharges; and/or noncontact cooling water, boiler blowdown, water softener backwash, greensand filter backwash, and reverse osmosis reject water. These permits will be covered under the categorical WLA for construction and industrial stormwater WLAs. It is assumed that 0.1% of the drainage area is under construction and industrial activities at any given time. Therefore, to calculate the WLA for construction and industrial stormwater, this TMDL report assumes that 0.1% of the load capacity for the reach is assigned to construction/industrial stormwater WLA.

Livestock Facilities

NPDES permitted feedlot facilities are assigned a WLA of zero. This is consistent with the conditions of the permits, which allow no pollutant discharge from the livestock housing facilities and associated sites.

Margin of Safety

The MOS accounts for uncertainty with the allocations resulting in attaining water quality standards. Uncertainty can be associated with data collection, lab analysis, data analysis, modeling error, and implementation activities. The MOS accounts for:

- Uncertainty in the lake models;
- Uncertainty in observed water quality data;
- Uncertainty in the results from the HSPF models.

The stochastic nature of the CNET model, and using distributions for the forcing data accounts for the uncertainty in the forcing data. Each lake model was simulated for 10,000 runs (i.e., 10,000 trials with varying input values) to account for the variability in the forcing data (climate and loadings). The loading reductions needed to meet the water quality standard were assumed to occur when the models simulated TP concentration at the 50th percentile, meaning the lake will meet the water quality standard 50% of the time. To account for the uncertainty in the lake models, the load reductions needed to reach the water quality standard at the 90th percentile was used to determine the MOS, meaning the water quality standard will be met 90% of the time. The MOS was established as the difference between load reductions at the 50th percentile and 90th percentile. This accounts for the uncertainty within the lake models and forcing data. The MOS for each lake are provided in **Table 18.**

Table 18. Margin of safety for modeled lakes in the Minnesota River Headwaters Watershed.

Lake Name	AUID	Load Capacity [lbs/yr]	Load Reduction {B}	90th Percentile Load Reduction {A}	Margin of Safety {A-B}	Margin of Safety [lbs/yr]
Long Tom	06-0029-00	14,636	80%	86%	6%	878
Unnamed	06-0060-00	14,438	80%	86%	6%	866
Big Stone	06-0152-00	30,247	35%	67%	33%	9,982
Lac qui Parle (SE Bay)	37-0046-01	271,243	27%	54%	27%	73,236
Lac qui Parle (NW Bay)	37-0046-02	56,365	71%	81%	10%	5,636

After further review of the MOSs and causes of the high MOSs in Big Stone Lake and Lac qui Parle Lake-SE Bay, it was determined it would be better to use an explicit 10% MOS for all lakes.

TMDL Summary

The allowable TP load (TMDL) for each lake was divided among the WLA, LA, and the MOS as described in the above sections. The following tables summarize the existing and allowable TP loads (Total Load and Load Capacity, respectively, in tables), the TMDL allocations (WLA and LA in tables) and required reductions for each lake.

The following rounding conventions were used in the TMDL tables:

- Values ≥10 reported in lbs/yr have been rounded to the nearest pound.
- Values <10 and ≥1 reported in lbs/yr have been rounded to the nearest tenth of a pound.
- Values <1 and ≥0.01 reported in lbs/day have been rounded to the nearest hundredth of a pound
- Values <0.01 reported in lbs/day have been rounded to enough significant digits so that the value is greater than zero and a number is displayed in the table.
- While some of the numbers in the tables show multiple digits, they are not intended to imply great precision.
- Some small arithmetic errors may exist; this is due to rounding errors.

Table 19. DRAFT TP TMDL for Long Tom Lake (06-0029-00). Reference TMDL report for FINAL allocations.

DRAFT Long Tom Lake (06-0029-00)		DRAFT Existing Phosphorus Load		DRAFT Allowable Phosphorus Load		DRAFT Estimated Load Reduction	
		lbs/yr	lbs/day[2]	lbs/yr	lbs/day[2]	lbs/yr	%
Wasteload Allocation	**Total WLA**			**318**	**0.87**		
	Clinton WWTF			301	0.82[2]		
	Construction/Industrial Stormwater			17	0.05		
	Straight Pipe Septic			0	0		
	NPDES Feedlots			0	0		
Load Allocation	**Total LA**	**80,190**	**220**	**16,315**	**45**	**63,874**	**80%[1]**
	Nonpoint Sources	143	0.39	140	0	3	2%
	Atmosphere	55	0.15	55	0.15	0	0%
	Unnamed Lake[3]	79,992	219	16,120	44	63,872	80%
	SSTS	0	0	0	0	0	0%
Margin of Safety (MOS)[4]				**1,663**	**4.6**		
Total Load/Loading Capacity		**80,190**	**220**	**16,633**	**46**	**63,557**	**79%**

[1] Load reduction comes from Unnamed Lake and its drainage area, i.e. if Unnamed Lake meets water quality standards, Long Tom Lake will meet the water quality standard.

[2] Based on Annual Loads divide by 365 days.

[3] Outflow from Unnamed Lake, based on CNET modeling.

[4] Based on Explicit 10% MOS.

Table 20. DRAFT TP TMDL for Unnamed Lake (06-0060-00). Reference TMDL report for FINAL allocations.

DRAFT Unnamed Lake (06-0060-00)		DRAFT Existing Phosphorus Load		DRAFT Allowable Phosphorus Load		DRAFT Estimated Load Reduction	
		lbs/yr	lbs/day[2]	lbs/yr	lbs/day[2]	lbs/yr	%
Wasteload Allocation	**Total WLA**			**318**	**0.87**		
	Clinton WWTP			301	0.82[2]		
	Construction/Industrial Stormwater			17	0.046		
	Straight Pipe Septic			0	0		
	NPDES Feedlots			0	0		
Load Allocation	**Total LA**	**103,938**	**285**	**14,667**	**40**	**89,271**	**86%**
	Nonpoint Sources	13,890	38	1,955	5.4	11,935	86%
	Internal Loading	90,024	247	12,689	35	77,335	86%
	Atmosphere	24	0.07	24	0.07	0	0%
	SSTS	0	0	0	0	0	0%
Margin of Safety (MOS)[1]					**1,665**	**4.6**	
Total Load/Loading Capacity		**103,131**	**282**	**14,438**	**40**	**88,693**	**86%**

[1] Based on explicit 10% MOS.

[2] Based on Annual Loads divide by 365 days.

Table 21. DRAFT TP TMDL for Big Stone Lake (06-0152-00). Reference TMDL report for FINAL allocations.

DDRAFT Big Stone (06-0152-00)		**DRAFT Existing Phosphorus Load**		**DRAFT Allowable Phosphorus Load**		**DRAFT Estimated Load Reduction**	
		lbs/yr	**lbs/day**	**lbs/yr**	**lbs/day**	**lbs/yr**	**%**
Wasteload Allocation	**Total WLA**			**54**	**0.15**		
	Construction/Industrial Stormwater			54	0.15		
	Straight Pipe Septic			0	0		
	NPDES Feedlots			0	0		
Load Allocation	**Total LA**	**92,224**	**253**	**48,185**	**132**	**44,039**	**48%**
	Atmosphere	4,428	12	4,428	12	0	0%
	Minnesota Nonpoint Sources[2]	31,840	87	17,945	49	13,895	44%
	South Dakota/North Dakota Nonpoint Sources[2]	55,956	153	25,811	71	30,144	54%
	SSTS	0	0	0	0	0	0%
Margin of Safety (MOS)[1]				**5,360**	**14.7**		
Total Load/Loading Capacity		**92,224**	**253**	**53,598**	**147**	**38,626**	**42%**

[1] Based on explicit 10% MOS.

Table 22. DRAFT TP TMDL for Lac qui Parle Lake – NW Bay (37-0046-02). Reference TMDL report for FINAL allocations.

DRAFT Lac qui Parle Lake-NW Bay (37-0046-02)		**DRAFT Existing Phosphorus Load**		**DRAFT Allowable Phosphorus Load**		**DRAFT Estimated Load Reduction**	
		lbs/yr	**lbs/day**	**lbs/yr**	**lbs/day**	**lbs/yr**	**%**
Wasteload Allocation	**Total WLA**			**8,462**	**23.2**		
	Bellingham WWTP			183	0.50		
	Clinton WWTP			301	0.83		
	Odessa WWTP			158	0.43		
	Ortonville WWTP			1,309	3.6		
	Alberta WWTP			140	0.38		
	Appleton WWTP			1,339	3.7		
	Ashby WWTP			616	1.7		
	Barrett WWTP			645	1.8		
	Chokio WWTP			597	1.6		
	Morris WWTP			2,935	8.0		
	Chokio WTP			18	0.050		
	Construction/Industrial Stormwater			221	0.61		
	Straight Pipe Septic			0	0		
	NPDES Feedlots			0	0		
Load Allocation	**Total LA**	**288,530**	**790**	**91,159**	**250**	**197,371**	**68%**
	Atmosphere	780	2.1	780	2.1	0	0%
	Pomme de Terre River	108,120	296	21,333	58.4	86,787	80%
	Minnesota Nonpoint Sources[2]	82,638	226	29,877	81.9	52,761	64%
	South Dakota/North Dakota Nonpoint Sources[2]	96,991	266	39,169	107.3	57,822	60%
	SSTS	0	0	0	0	0	0%
Margin of Safety (MOS)[1]				**11,069**	**30**		
Total Load/Loading Capacity		**288,530**	**790**	**110,690**	**303**	**177,839**	**62%**

[1] Based on explicit 10% MOS.

[2] Based on percentage of existing loads form each state (see Table 17).

Table 23. DRAFT TP TMDL for Lac qui Parle Lake – SE Bay (37-0046-01). Reference TMDL report for FINAL allocations.

DRAFT Lac qui Parle Lake-SE Bay (37-0046-01)		DRAFT Existing Phosphorus Load		DRAFT Allowable Phosphorus Load		DRAFT Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Wasteload Allocation	**Total WLA**			**32,492**	**89**		
	WWTFs[1]			24,508	67		
	Individual Industrial Stormwater[2]			7,226	20		
	Construction/Industrial Stormwater[3]			758	2.1		
	Straight Pipe Septic			0	0		
	NPDES Feedlots			0	0		
Load Allocation	**Total LA**	**576,705**	**12**	**308,395**	**844**	**268,310**	**47%**
	Atmosphere	1,329	3.6	1,329	3.6	0	0%
	Chippewa River	187,091	513	136,591	374	50,500	27%
	Lac qui Parle River (MN)[4]	88,311	242	53,605	147	34,705	39%
	Lac qui Parle River (SD)[4]	13,570	37	9,257	25	4,313	32%
	Minnesota Nonpoint Sources[4]	6,328	17	5,032	14	1,296	20%
	Lac qui Parle NW Bay (MN)[4]	127,327	349	42,221	116	85,106	67%
	Lac qui Parle NW Bay (SD/ND)[4]	152,749	418	60,360	165	92,390	60%
	SSTS	0	0.0	0	0	0	0%
Margin of Safety (MOS)[5]				**37,876**	**104**		
Total Load/Loading Capacity		**576,705**	**1,580**	**378,763**	**1,038**	**197,942**	**34%**

[1] List of individual WWTP provide in Table 24.

[2] List of individual ISW with individual WLA provide in Table 25.

[3] Categorical Construction and ISW, Assumed 0.1% of LC for each.

[4] Based on percentage of existing loads form each state (see).

[5] Based on explicit 10% MOS

Table 24. DRAFT WWTP WLAs for Lac qui Parle Lake – SE Bay (37-0046-01). Reference TMDL report for FINAL allocations.

Major Watershed	Facility	Permit Number	Flow [mgd]	TP WLA Concertation Assumption (mg/L)	DRAFT TP [lbs/yr]	DRAFT TP [lbs/day]
Chippewa River	Benson WWTP	MN0020036	0.985	1.0	2,998	8.215
	Clontarf WWTP	MNG580108	0.024	2.0	146	0.400
	Danvers WWTP	MNG585119	0.023	2.0	140	0.384
	DeGraff WWTP	MN0071234	0.0214	2.0	130	0.357
	Evansville WWTP	MNG585074	0.1	1.0	304	0.833
	Farwell Kensington Sanitary District WWTP	MNG585220	0.076	2.0	465	1.274
	Hancock WWTP	MNG585299	0.183	2.0	1,113	3.049
	Hoffman WWTP	MNG585134	0.159	2.0	968	2.651
	Kerkhoven WWTP	MN0020583	0.15	3.5	1,598	4.378
	Lowry WWTP	MNG585123	0.049	0.9	134	0.368
	Millerville WWTP	MN0054305	0.02	2.0	119	0.326
	Murdock WWTP	MNG585086	0.043	2.0	262	0.718
	Starbuck WWTP	MN0021415	0.35	0.86	912	2.500
	Sunburg WWTP	MNG585125	0.0157	2.0	95	0.260
	Urbank WWTP	MNG580154	0.011	2.0	66	0.181
Lac qui Parle River	Canby WWTP	MN0021881	0.339	2.0	2,064	5.655
	Dawson WWTP	MN0021121	0.471	1.0	1,434	3.928
	Hendricks WWTP	MN0051764	0.185	2.0	1,126	3.086
	Madison WWTP	MNG580160	0.48	1.0	1,461	4.003
	Marietta WWTP	MNG580152	0.033	2.0	201	0.550
Minnesota River - Headwaters	Bellingham WWTP	MNG580193	0.03	2.0	183	0.500
	Clinton WWTP	MNG580091	0.099	1.0	301	0.826
	ISD 2853 Lac qui Parle Valley High School	MNG580141	0.023	2.0	140	0.384
	Milan WWTP	MNG580099	0.067	2.0	408	1.118
	Odessa WWTP	MNG580151	0.026	2.0	158	0.434
	Ortonville WWTP	MNG580002	0.43	1.0	1,309	3.586
Pomme de Terre River	Alberta WWTP	MN0021890	0.023	2.0	140	0.384
	Appleton WWTP	MNG580087	0.44	1.0	1,339	3.670
	Ashby WWTP	MNG580173	0.1011	2.0	616	1.686
	Barrett WWTP	MNG580007	0.106	2.0	645	1.768
	Chokio WWTP	MN0021318	0.098	2.0	597	1.635
	Morris WWTP	MNG585343	0.964	1.0	2,935	8.040
				Total WLA for WWTPs	24,508	67

Table 25. Individual industrial WLAs for Lac qui Parle Lake – SE Bay (37-0046-01).

Major Watershed	Facility	Permit Number	Flow (mgd)	TP WLA Concertation Assumption (mg/L)	TP WLA (lbs/yr)	TP WLA (lbs/day)
Chippewa River	Chippewa Valley Ethanol Co LLLP	MN0062898	1.53	1	4657.5	12.76
	Duininck Inc	MNG490046	0.031	1	94.37	0.259
Lac qui Parle River	Ag Processing Inc	MN0040134	0.006	1	18.26	0.05
	PURIS Proteins LLC	MN0048968	2.6	0.15	1187.2	3.253
Minnesota River - Headwaters	LG Everist Inc	MN0068764	0.3	0.15	136.98	0.375
	LG Everist Inc	MN0068764	0.48	0.15	219.18	0.6
Pomme de Terre River	Chokio WTP	MNG640022	0.3	1	912.46	2.5
				Total WLA for ISWs	7,226	20

Lake Modeling Plots

The following, in plots, form the model simulation of the water balance, phosphorus balance, and in-lake concentrations of TP, Chl-*a*, and Secchi disk depth for each lake model.

Unnamed and Long Tom Lakes Model

Figure 7. Simulated water mass balance for Unnamed Lake and Long Tom Lake.

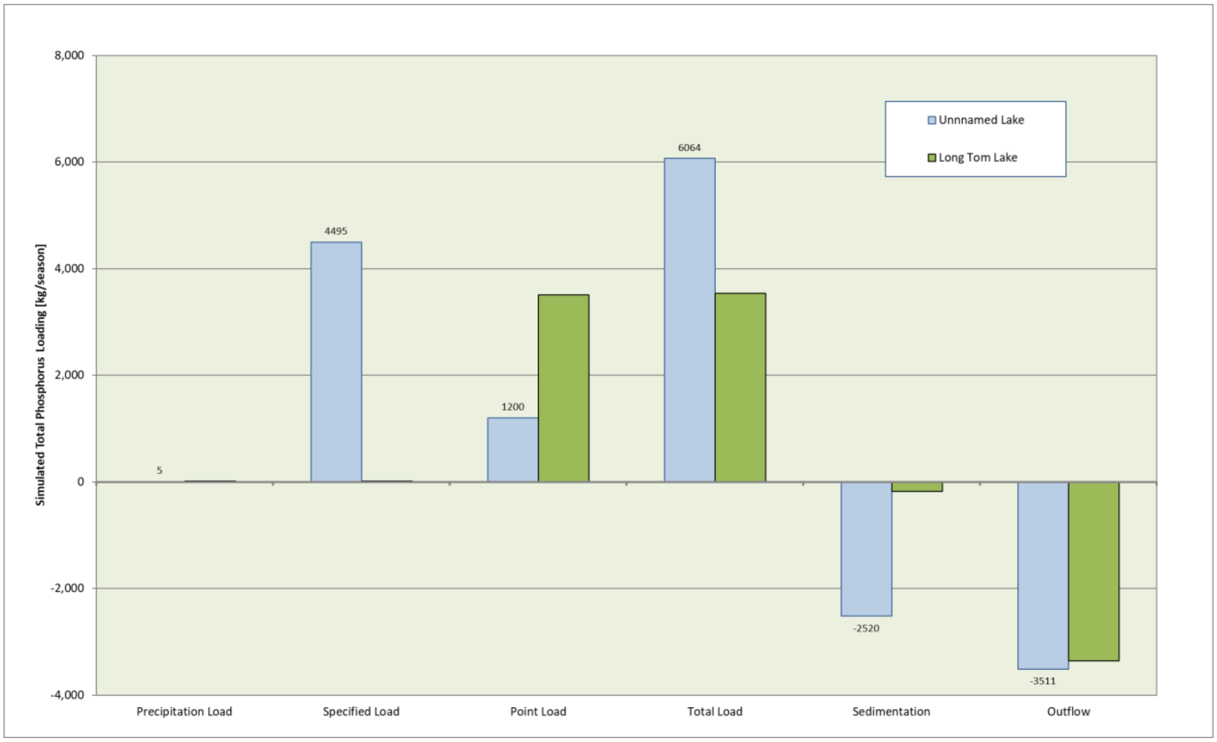


Figure 8. Simulated phosphorus mass balance for Unnamed Lake and Long Tom Lake.

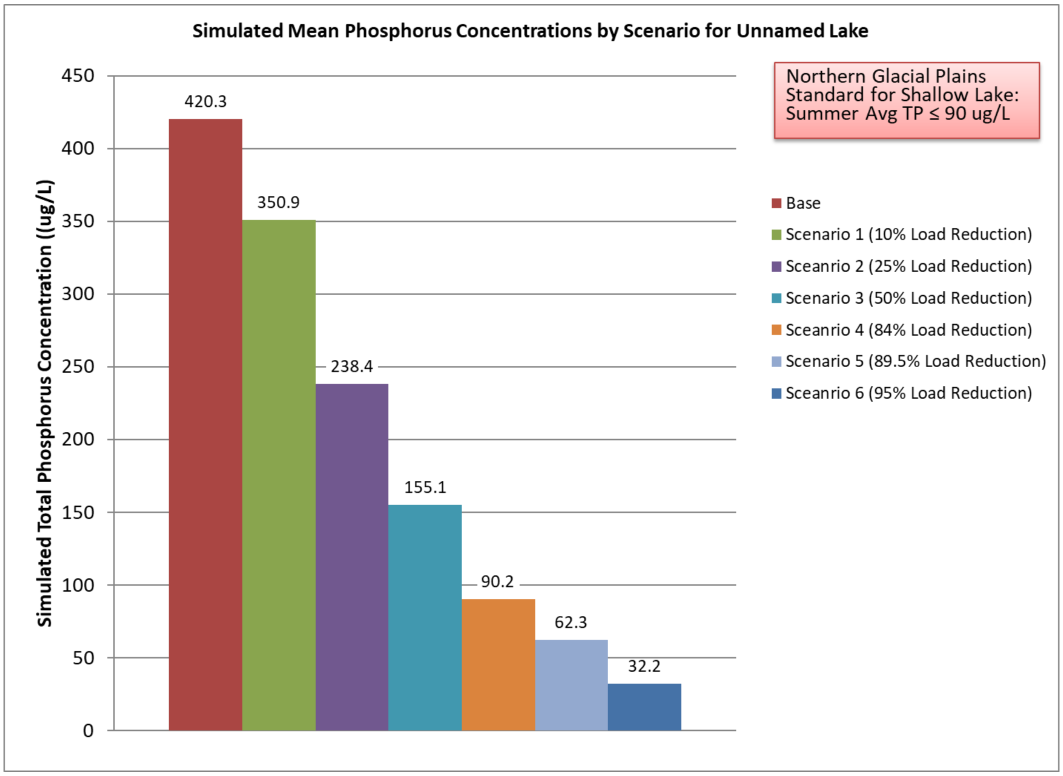


Figure 9. Simulated mean phosphorus concentrations in Unnamed Lake by load reduction scenario.

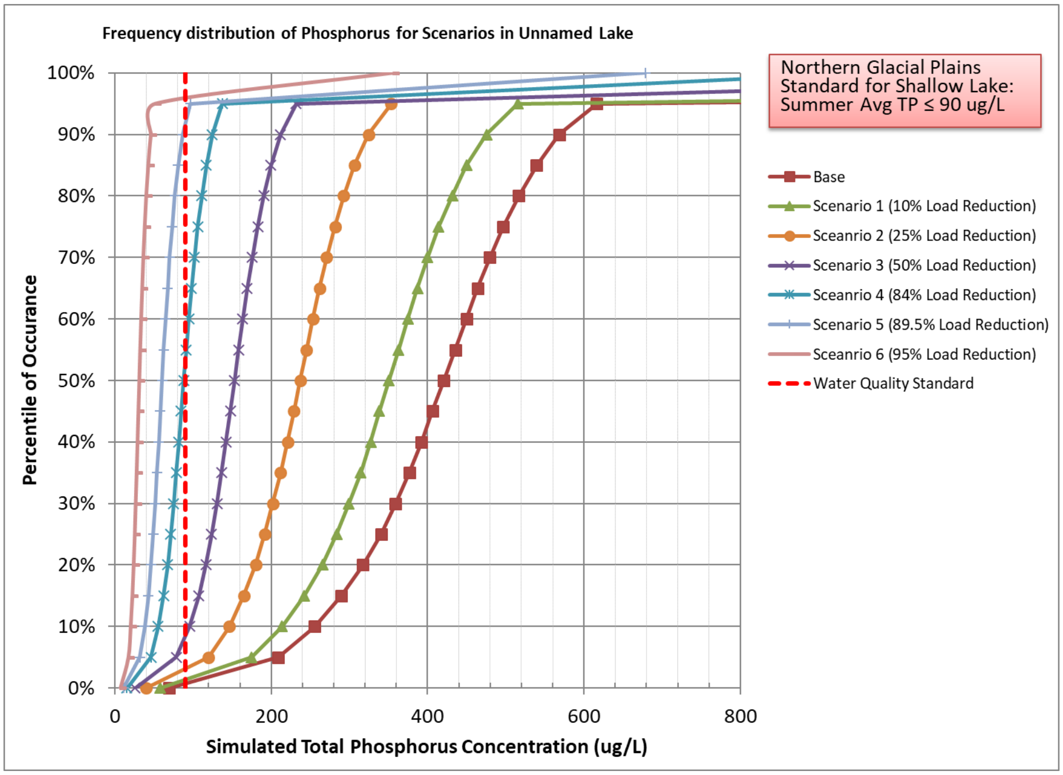


Figure 10. Frequency distribution of phosphorus concentrations in Unnamed Lake by load reduction scenario.

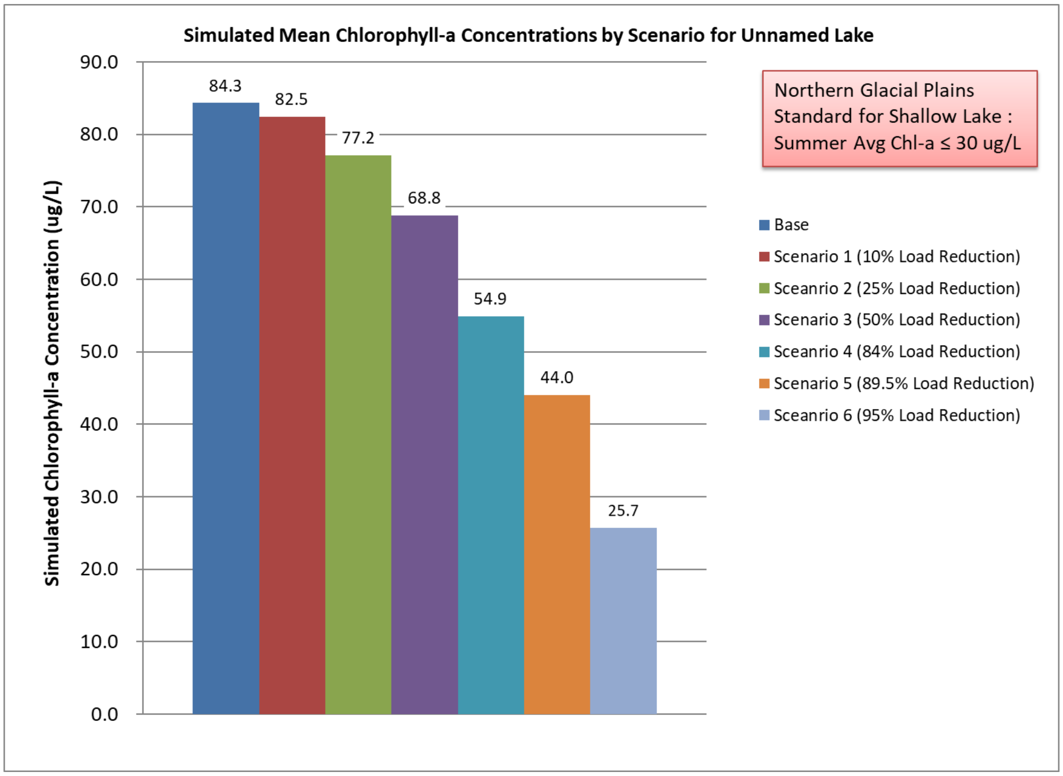


Figure 11. Simulated mean chlorophyll-*a* concentrations in Unnamed Lake by load reduction scenario.

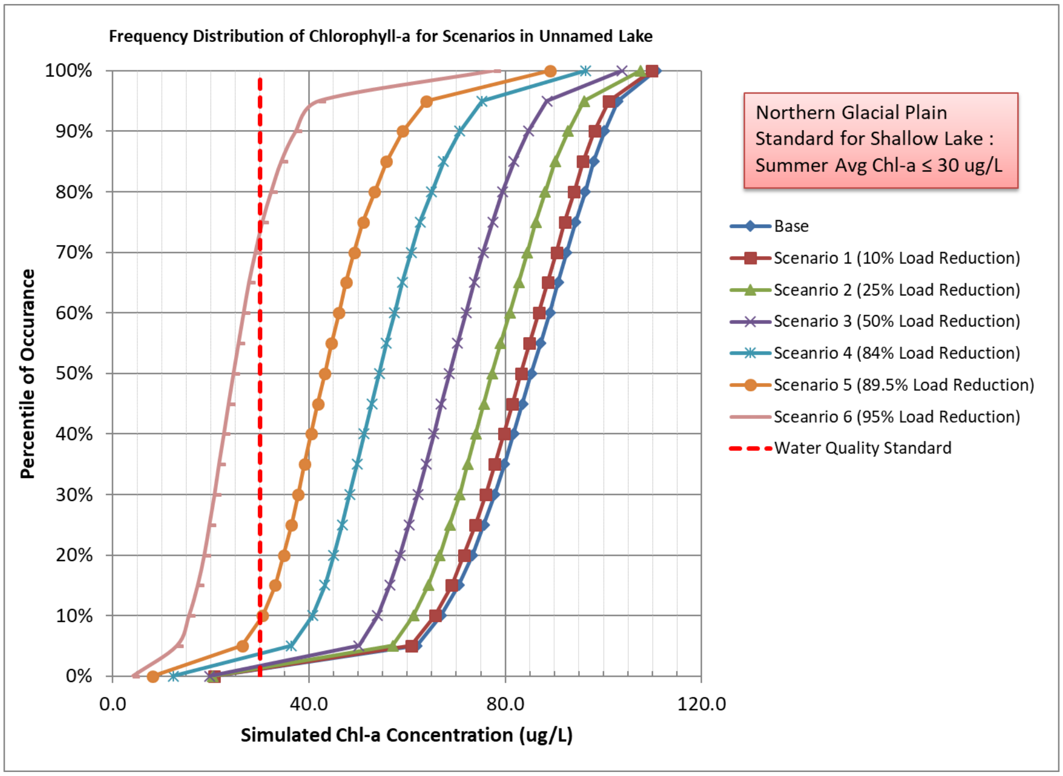


Figure 12. Frequency distribution of chlorophyll-*a* concentrations in Unnamed Lake by load reduction scenario.

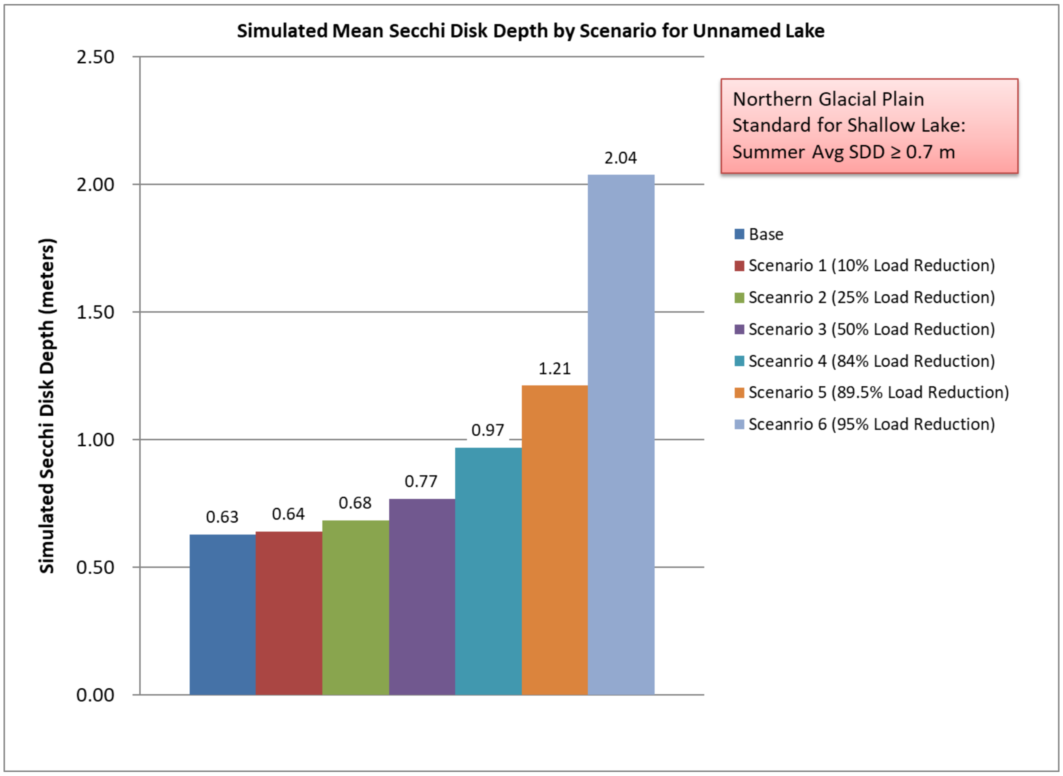


Figure 13. Simulated mean Secchi disk depths in Unnamed Lake by load reduction scenario.

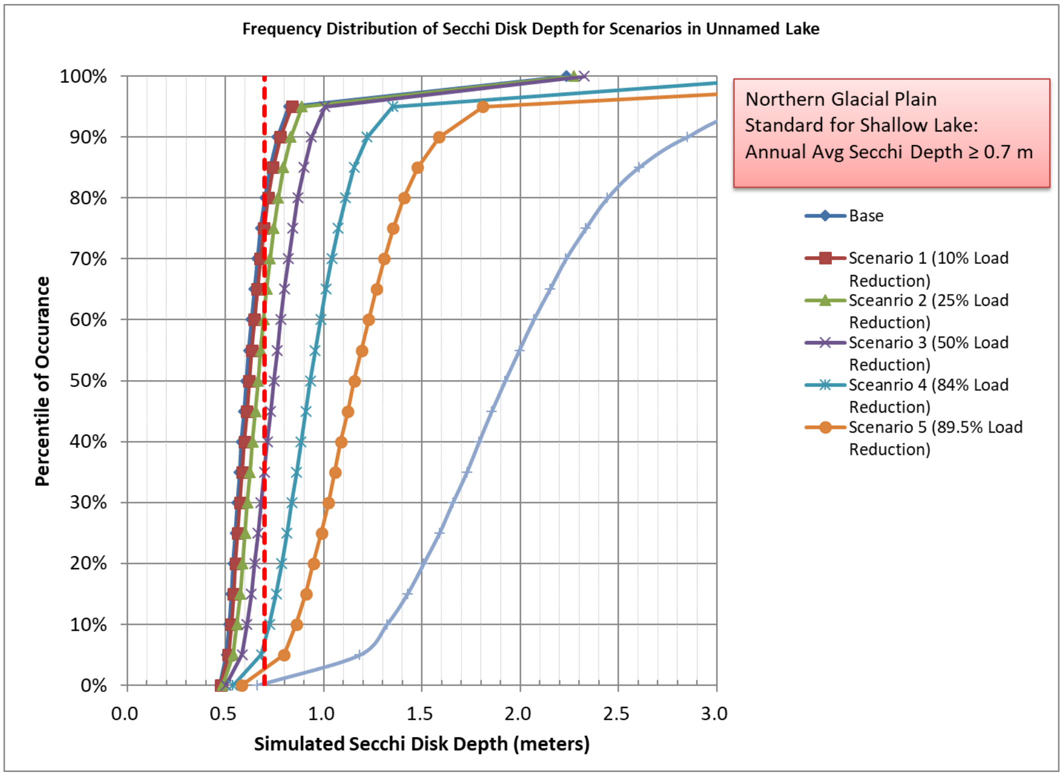


Figure 14. Frequency distribution of Secchi disk depths in Unnamed Lake by load reduction scenario.

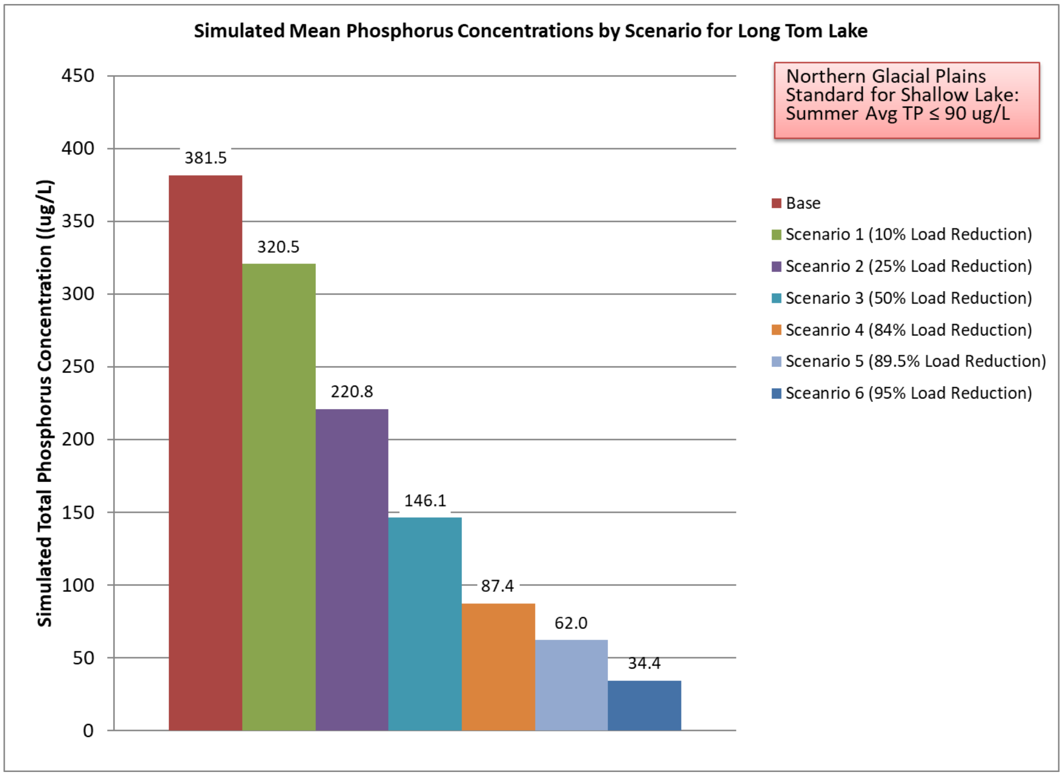


Figure 15. Simulated mean phosphorus concentrations in Long Tom Lake by load reduction scenario.

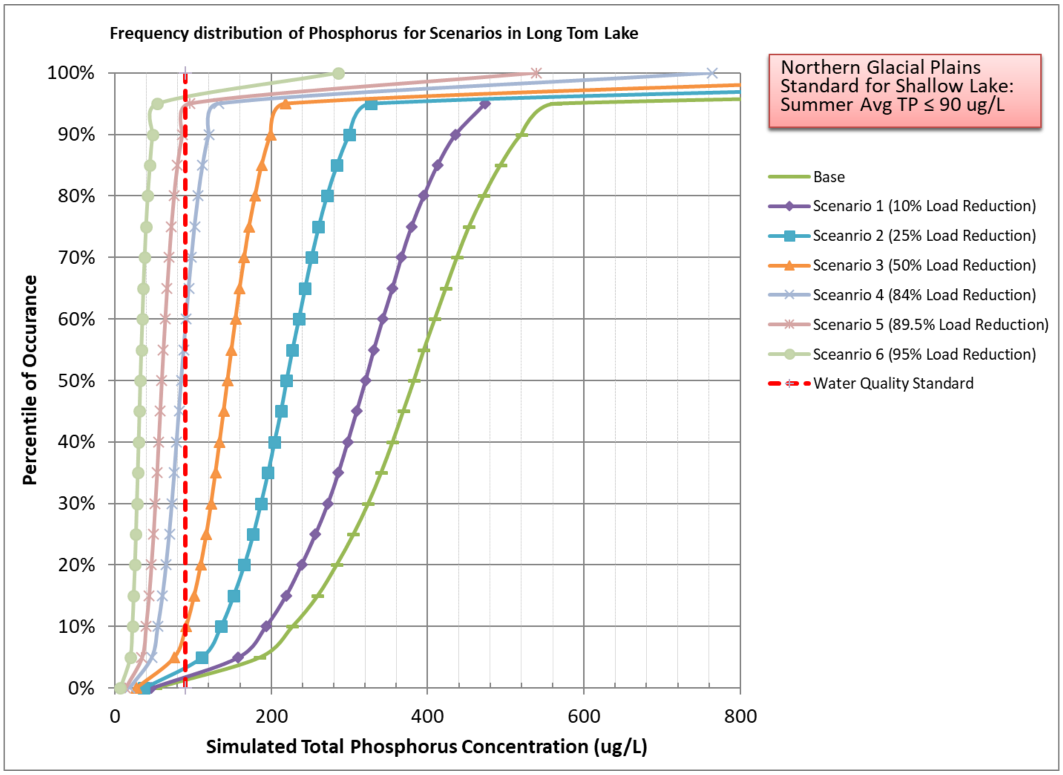


Figure 16. Frequency distribution of phosphorus concentrations in Long Tom Lake by load reduction scenario.

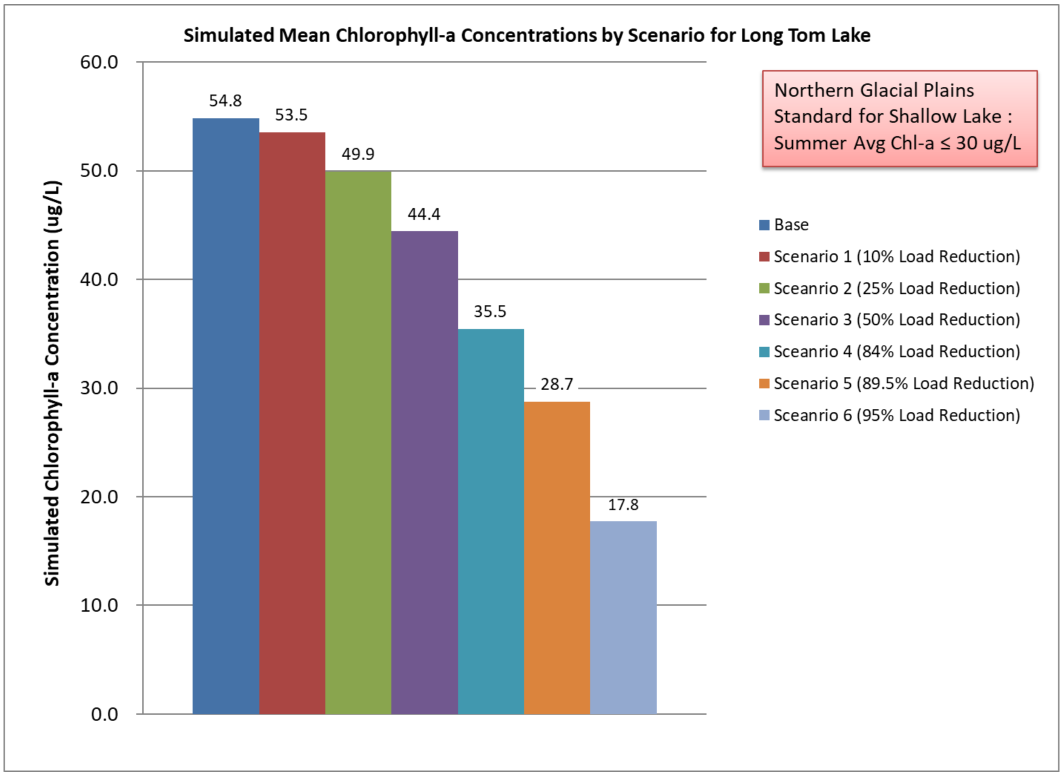


Figure 17. Simulated mean chlorophyll-*a* concentrations in Long Tom Lake by load reduction scenario.

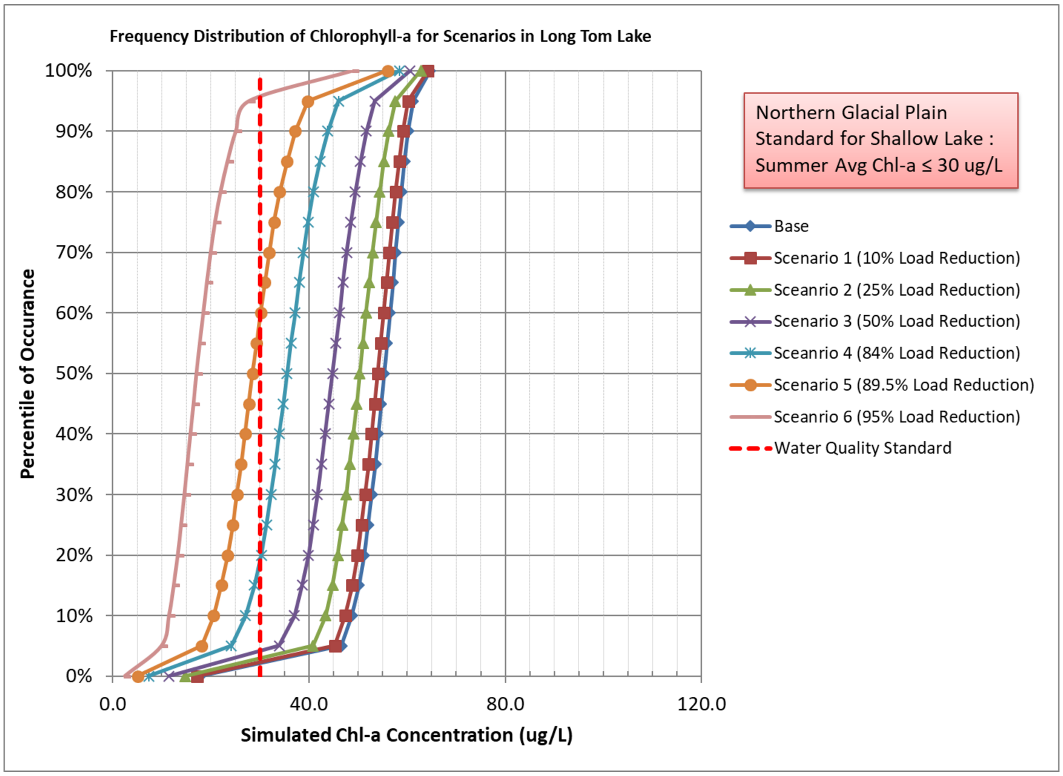
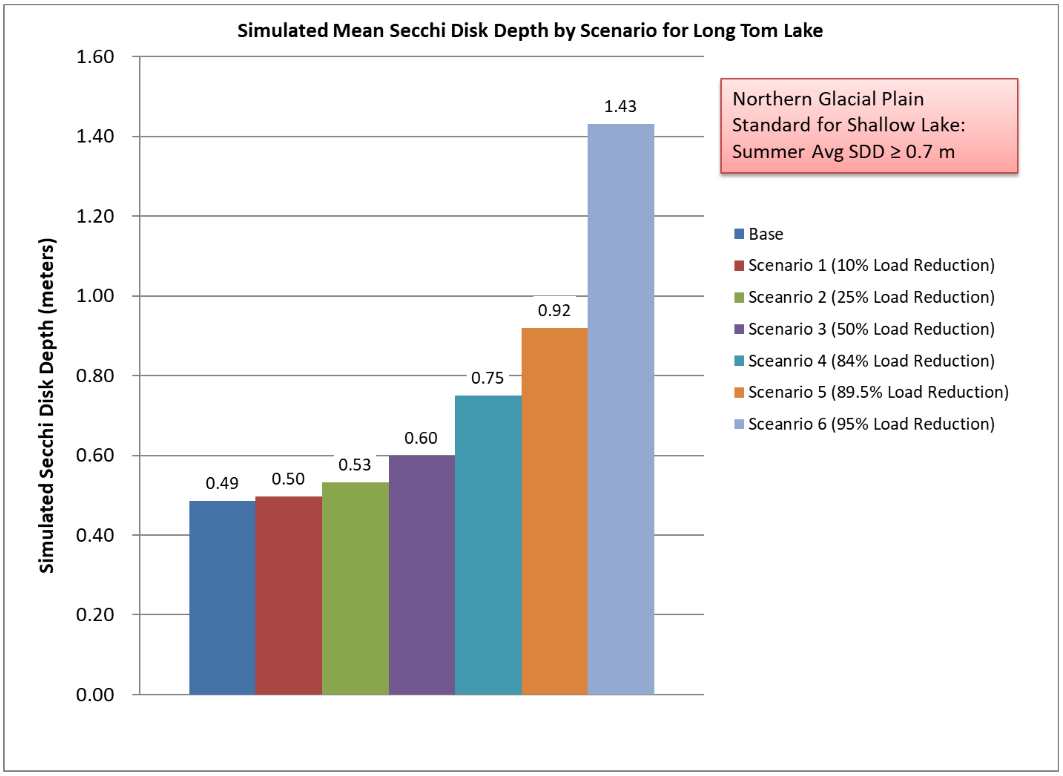


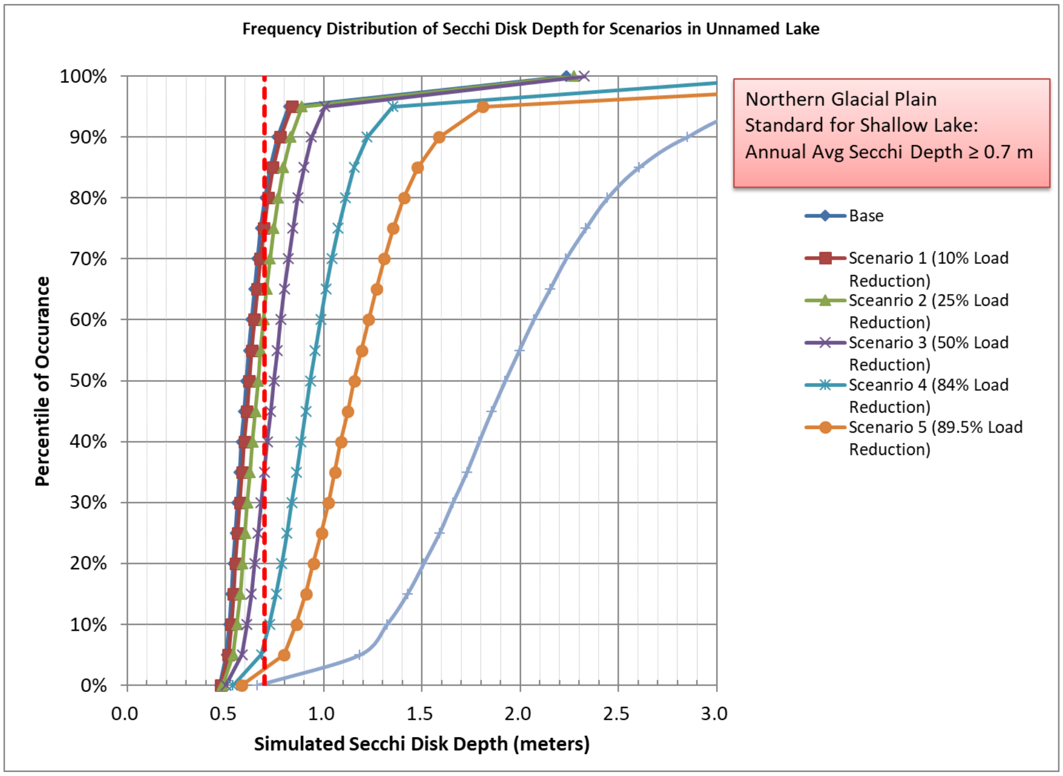
Figure 18. Frequency distribution of chlorophyll-*a* concentrations in Long Tom Lake by load reduction scenario.



Simulated Mean Secchi Disk Depth by Scenario for Long Tom Lake

Northern Glacial Plain
Standard for Shallow Lake:
Summer Avg SDD ≥ 0.7 m

Figure 19. Simulated mean Secchi disk depths in Long Tom Lake by load reduction scenario.



Frequency Distribution of Secchi Disk Depth for Scenarios in Unnamed Lake

Northern Glacial Plain
Standard for Shallow Lake:
Annual Avg Secchi Depth ≥ 0.7 m

Figure 20. Frequency distribution of Secchi disk depths in Long Tom Lake by load reduction scenario.

Big Stone Lake Model

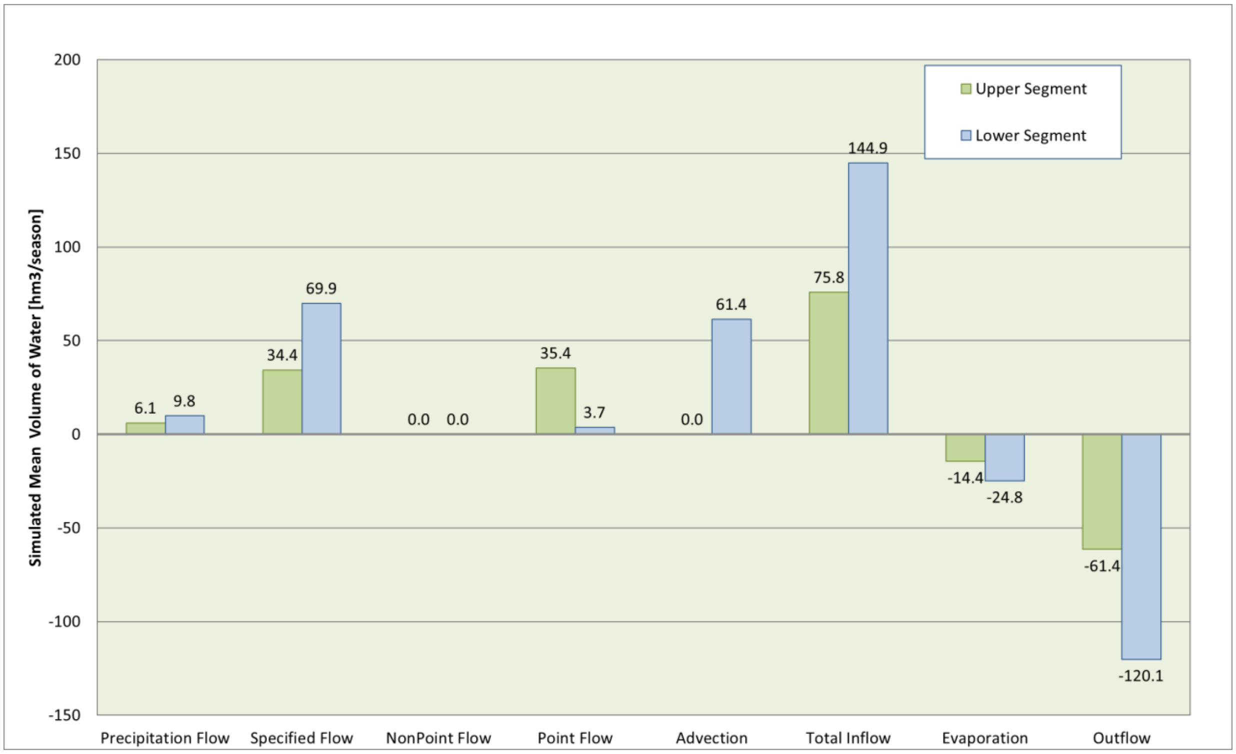


Figure 21. Simulated water mass balance for Big Stone Lake.

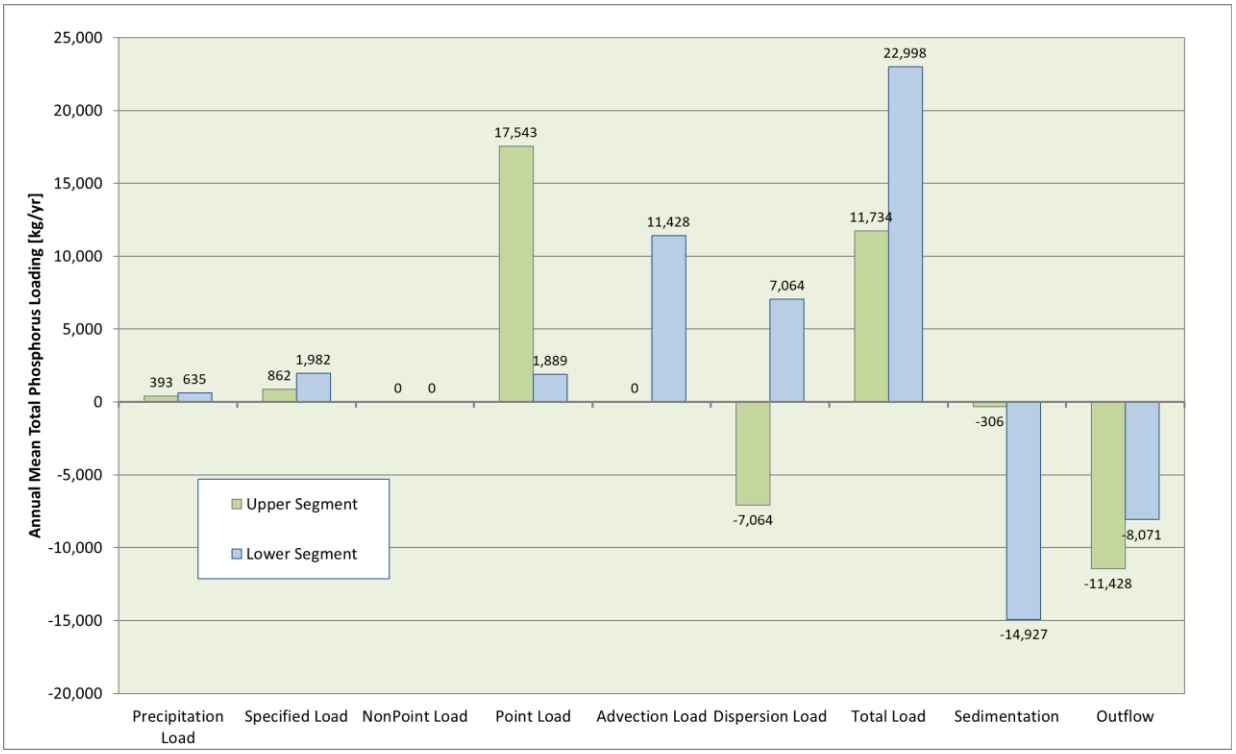


Figure 22. Simulated phosphorus mass balance for Big Stone Lake.

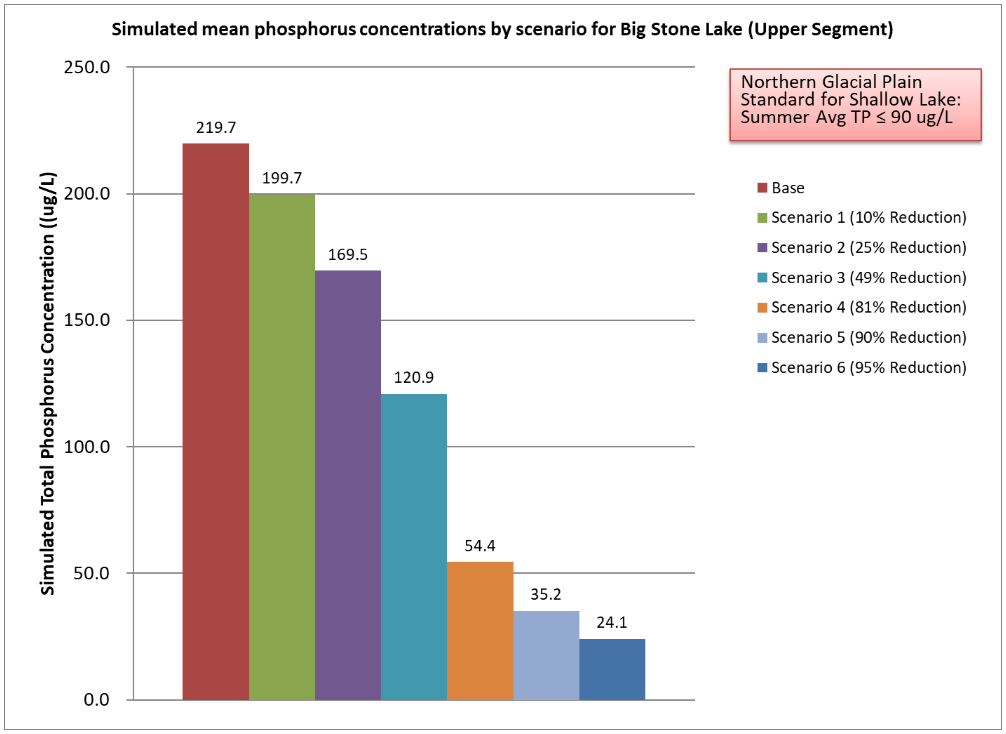


Figure 23. Simulated mean phosphorus concentrations in Big Stone Lake (Upper Segment) by load reduction scenario.

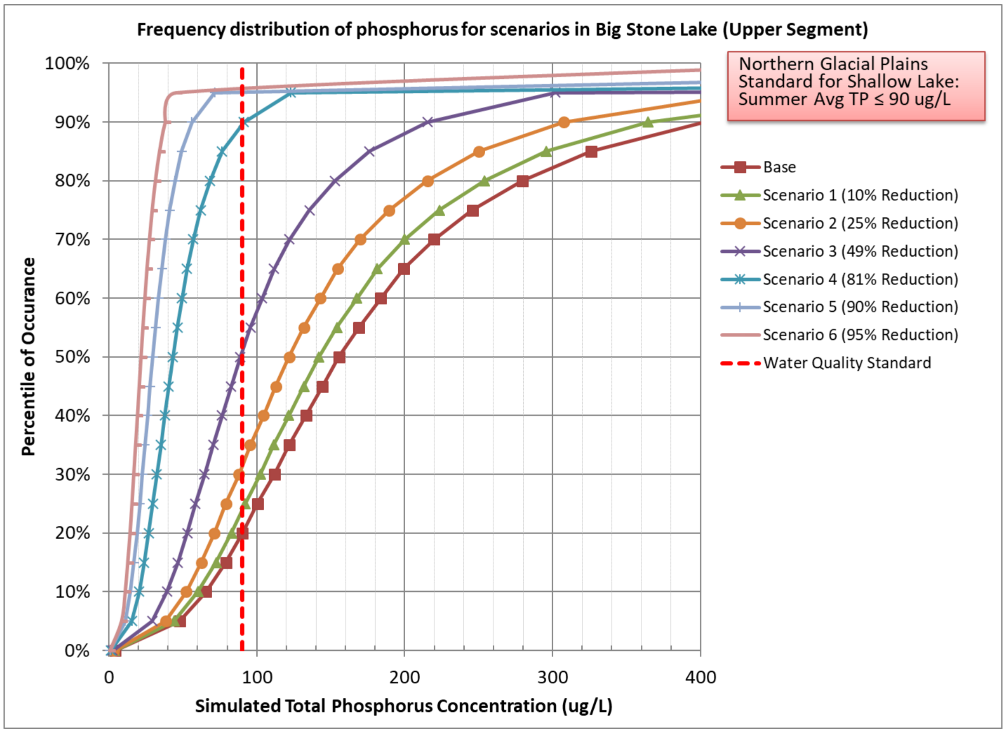


Figure 24. Frequency distribution of phosphorus concentrations in Big Stone Lake (Upper Segment) by load reduction scenario.

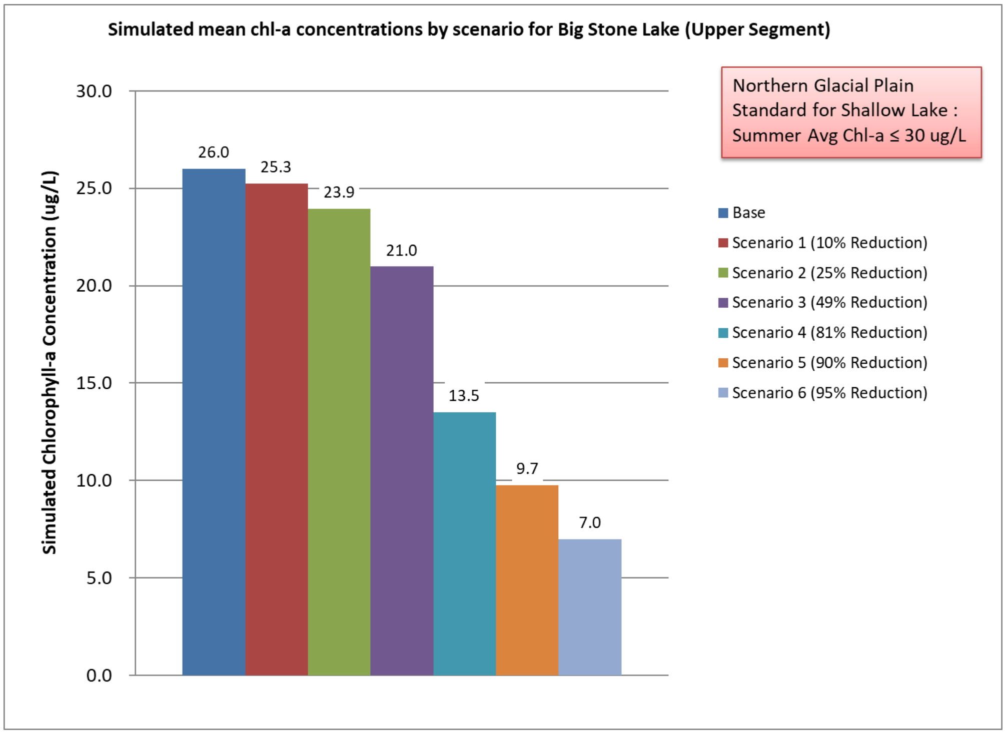


Figure 25. Simulated mean chlorophyll-*a* concentrations in Big Stone Lake (Upper Segment) by load reduction scenario.

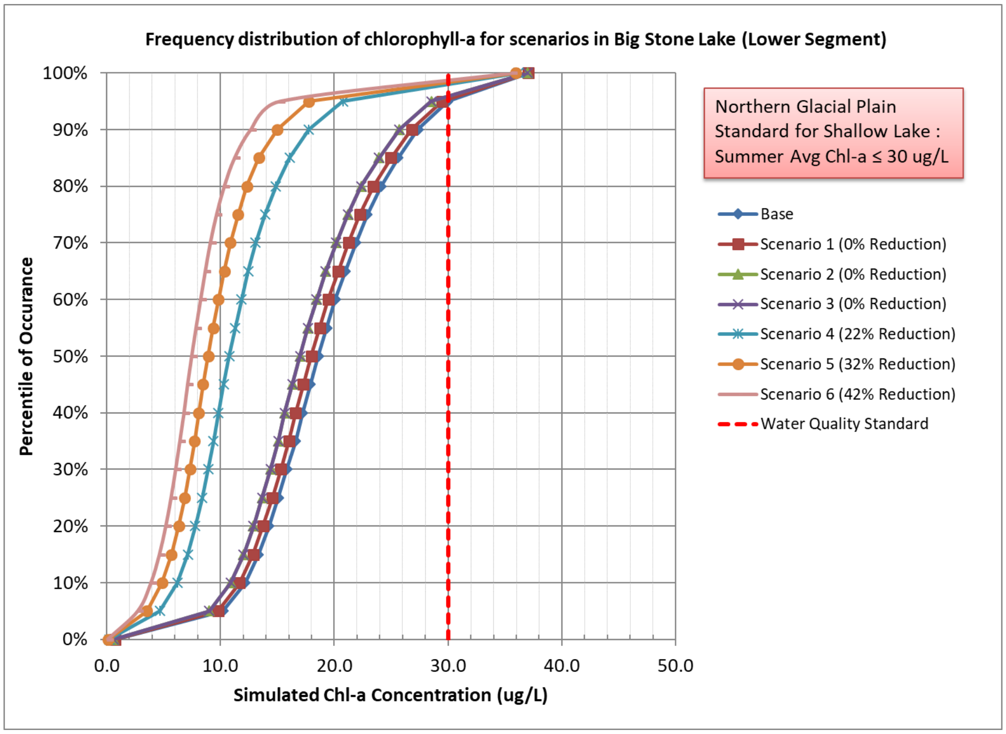


Figure 26. Frequency distribution of chlorophyll-*a* concentrations in Big Stone Lake (Upper Segment) by load reduction scenario.

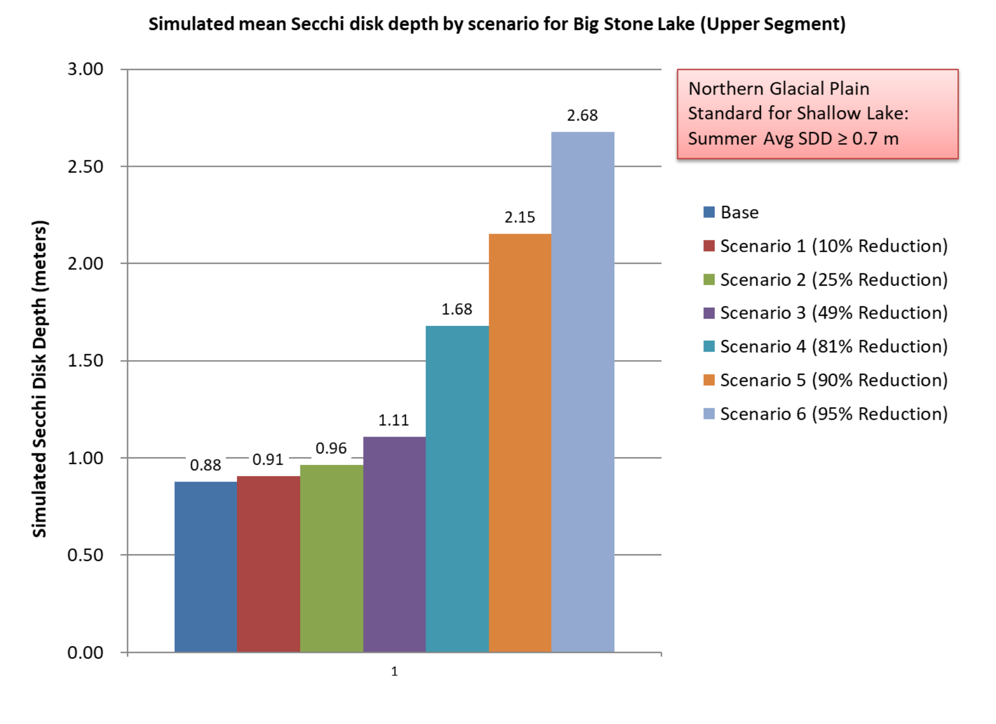


Figure 27. Simulated mean Secchi disk depths in Big Stone Lake (Upper Segment) by load reduction scenario.

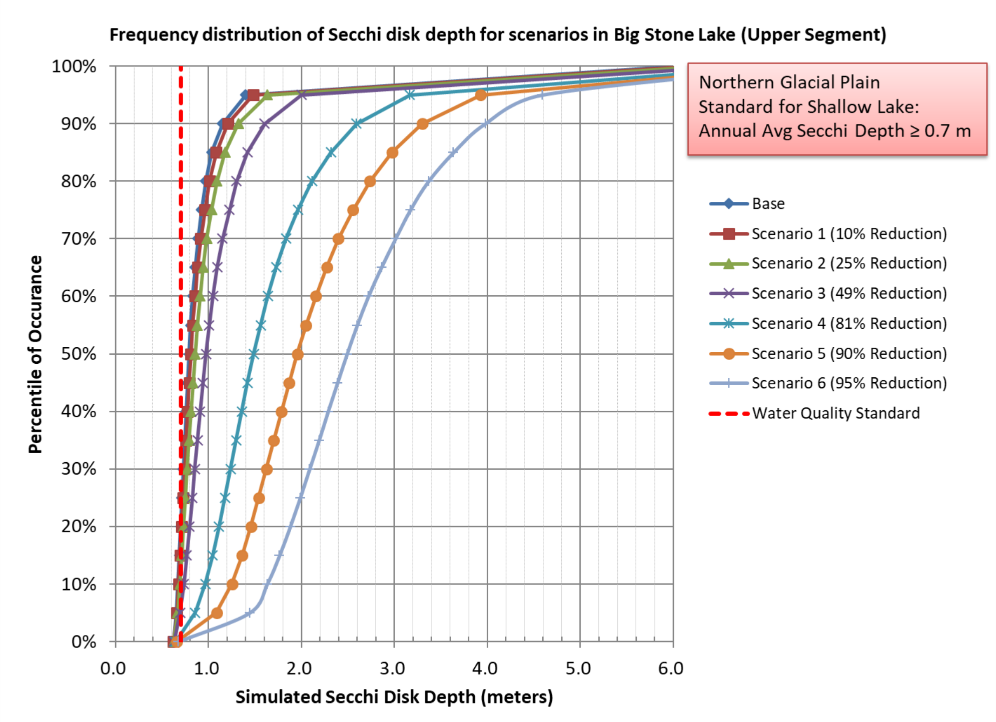


Figure 28. Frequency distribution of Secchi disk depths in Big Stone Lake (Upper Segment) by load reduction scenario.

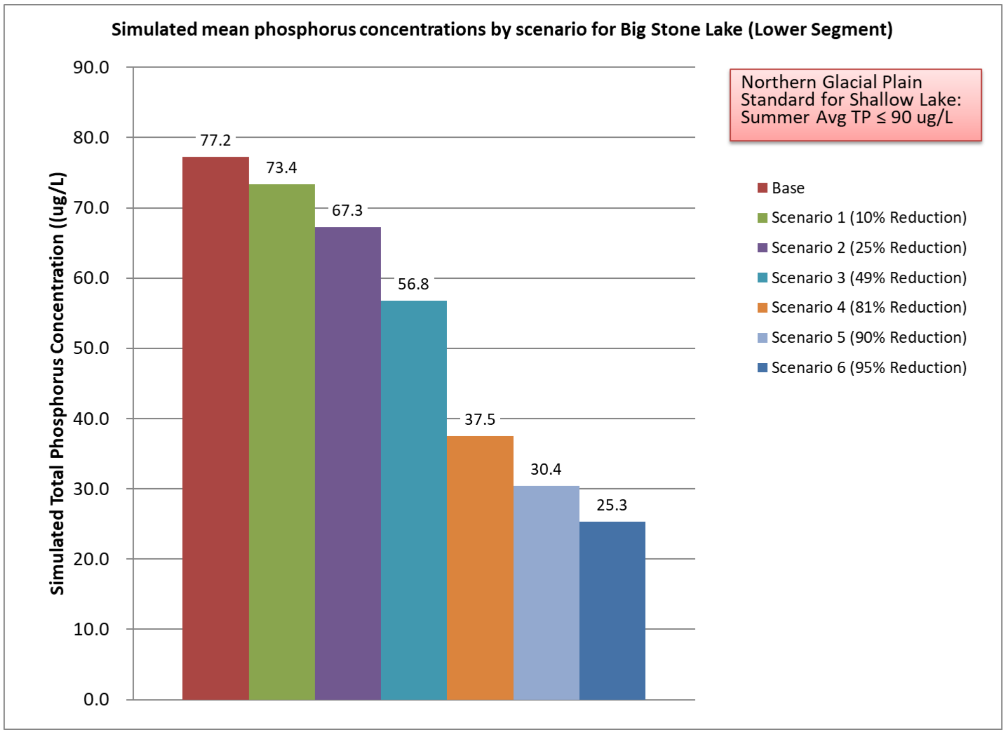


Figure 29. Simulated mean phosphorus concentrations in Big Stone Lake (Lower Segment) by load reduction scenario.

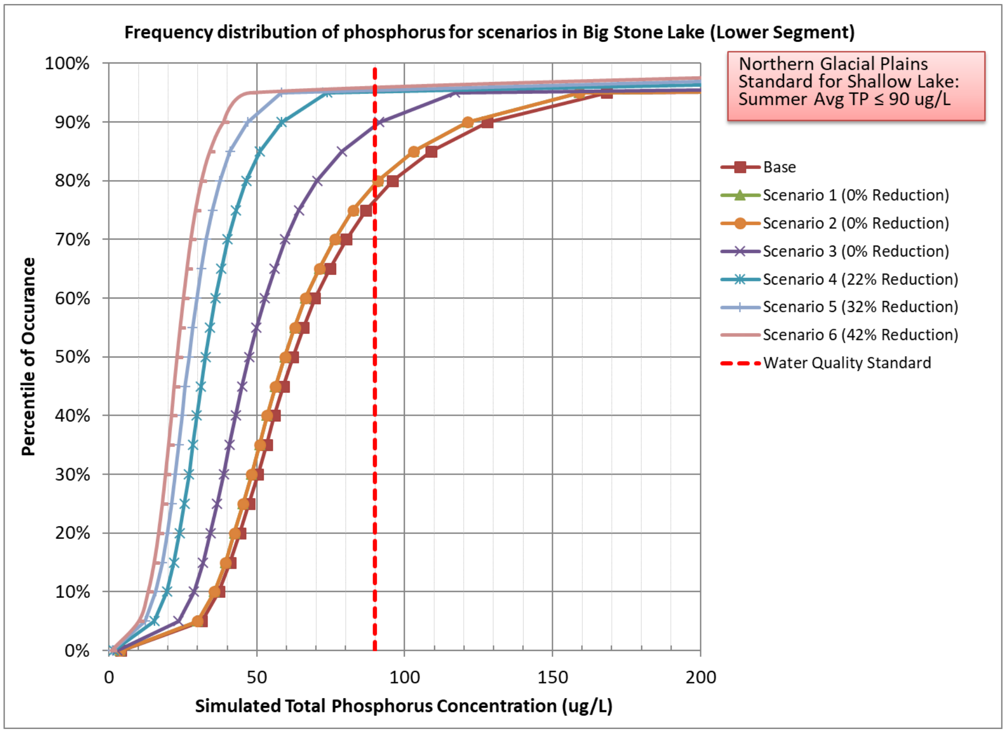


Figure 30. Frequency distribution of phosphorus concentrations in Big Stone Lake (Lower Segment) by load reduction scenario.

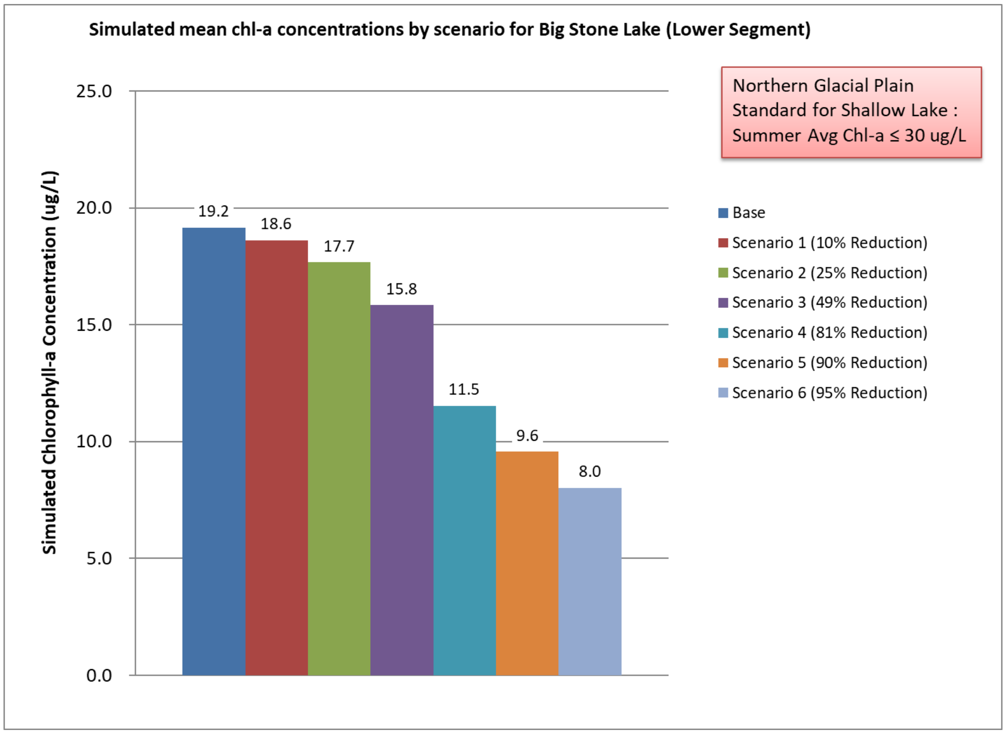


Figure 31. Simulated mean chlorophyll-*a* concentrations in Big Stone Lake (Lower Segment) by load reduction scenario.

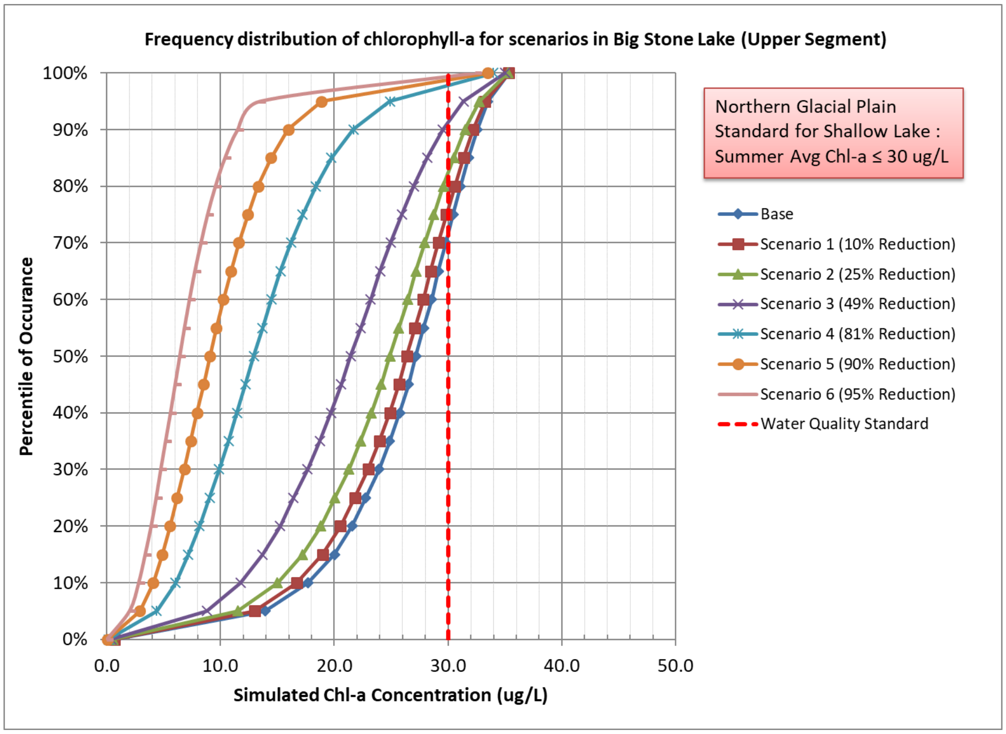


Figure 32. Frequency distribution of chlorophyll-*a* concentrations in Big Stone Lake (Lower Segment) by load reduction scenario.

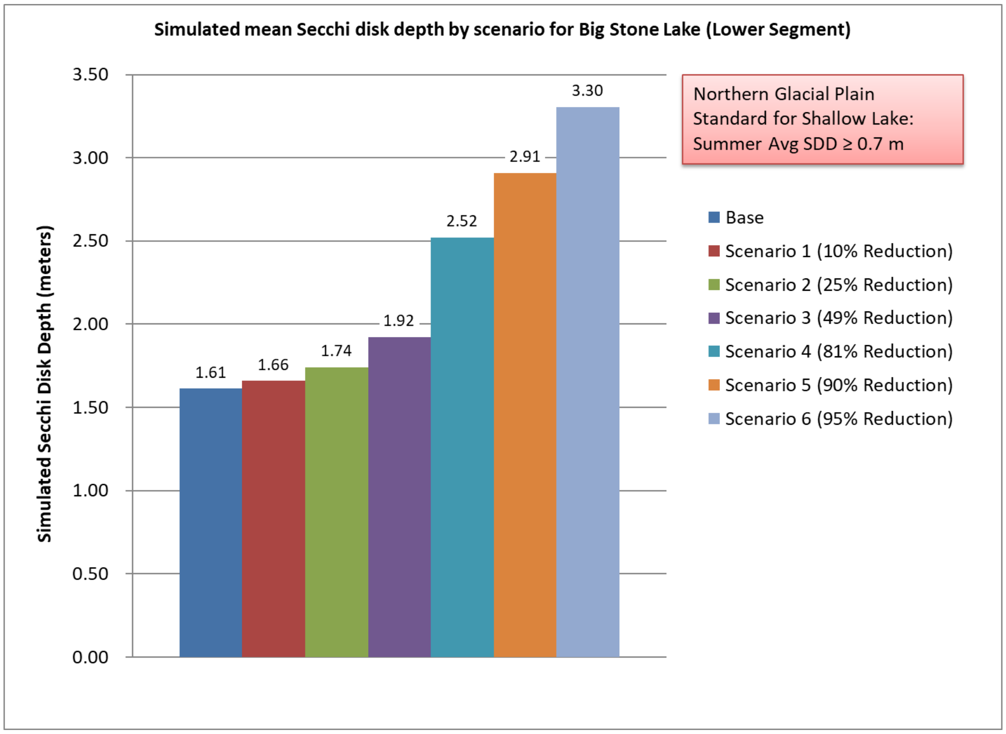


Figure 33. Simulated mean Secchi disk depths in Big Stone Lake (Lower Segment) by load reduction scenario.

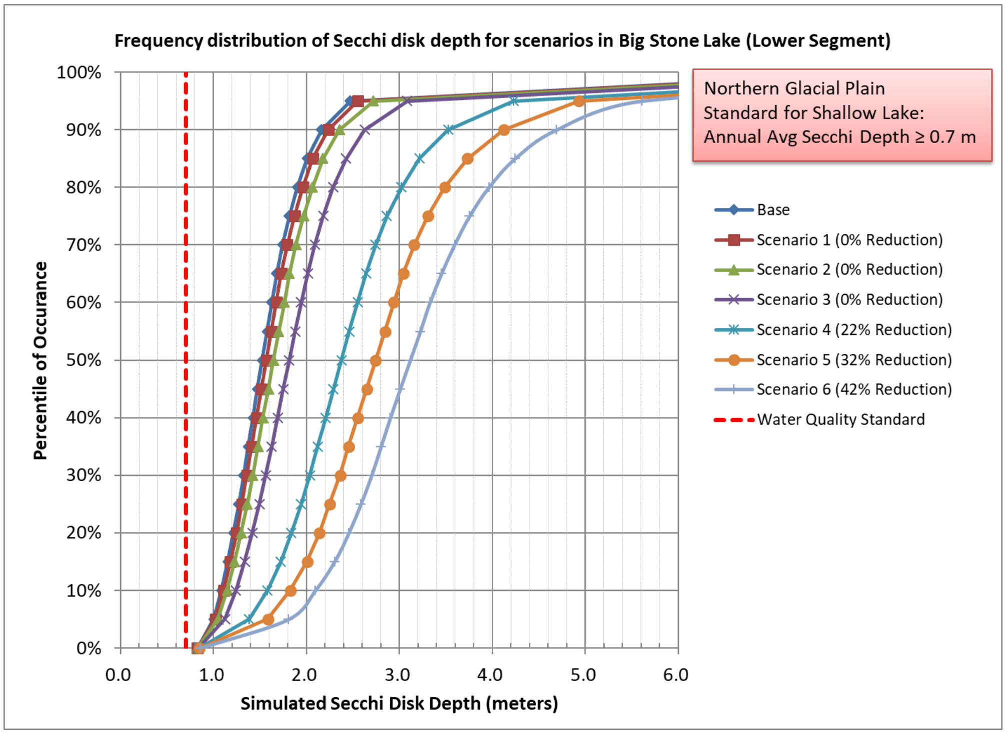


Figure 34. Frequency distribution of Secchi disk depths in Big Stone Lake (Lower Segment) by load reduction scenario.

Lac qui Parle Lake Model

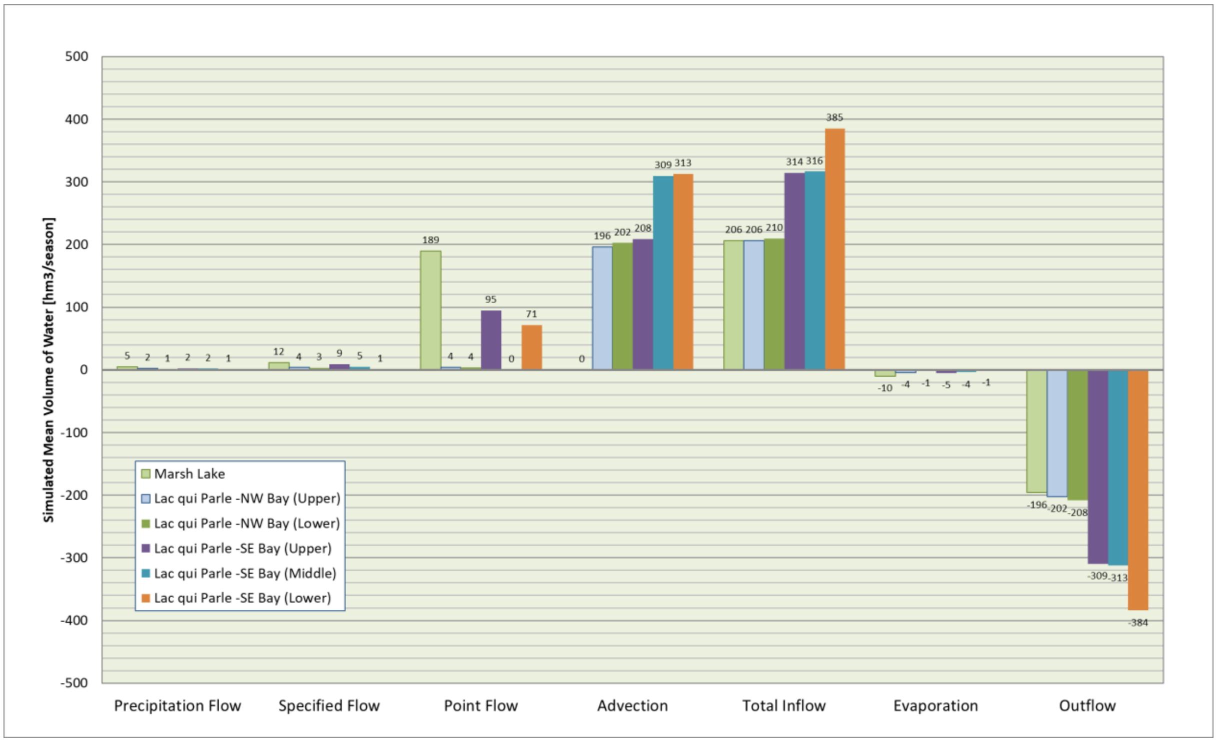


Figure 35. Simulated water mass balance for Lac qui Parle Lake.

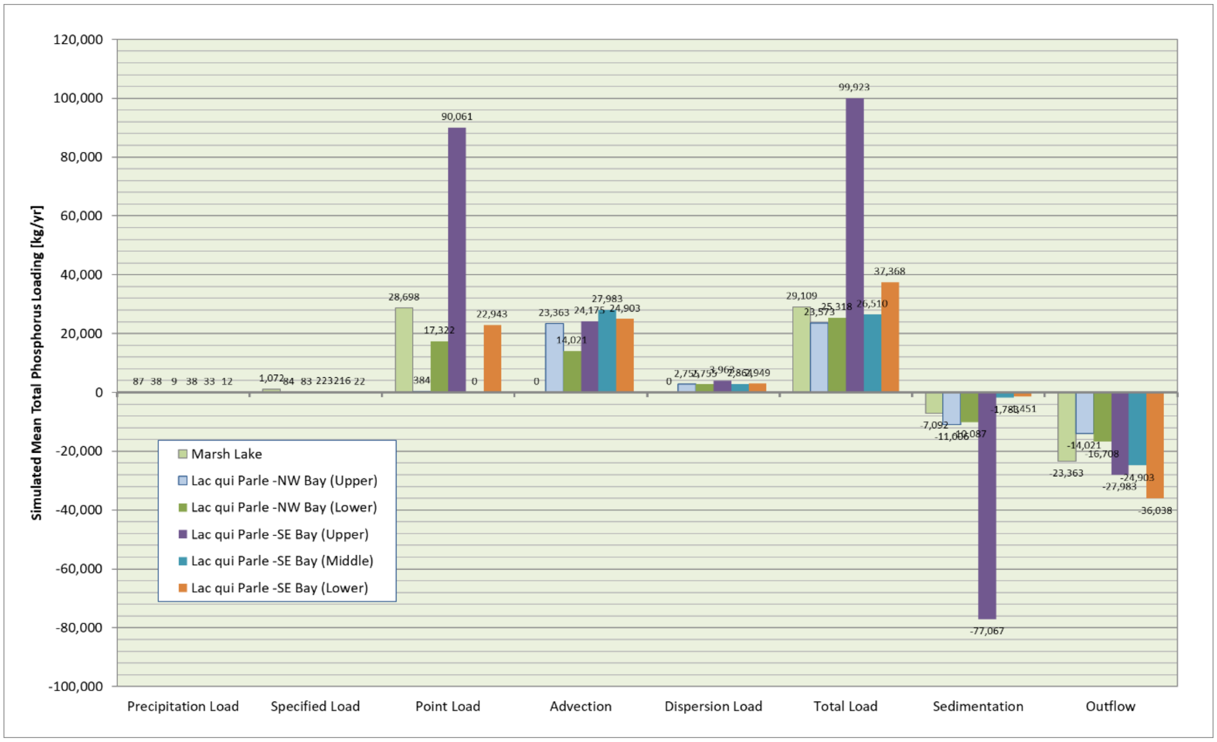


Figure 36. Simulated phosphorus mass balance for Lac qui Parle Lake.

Marsh Lake

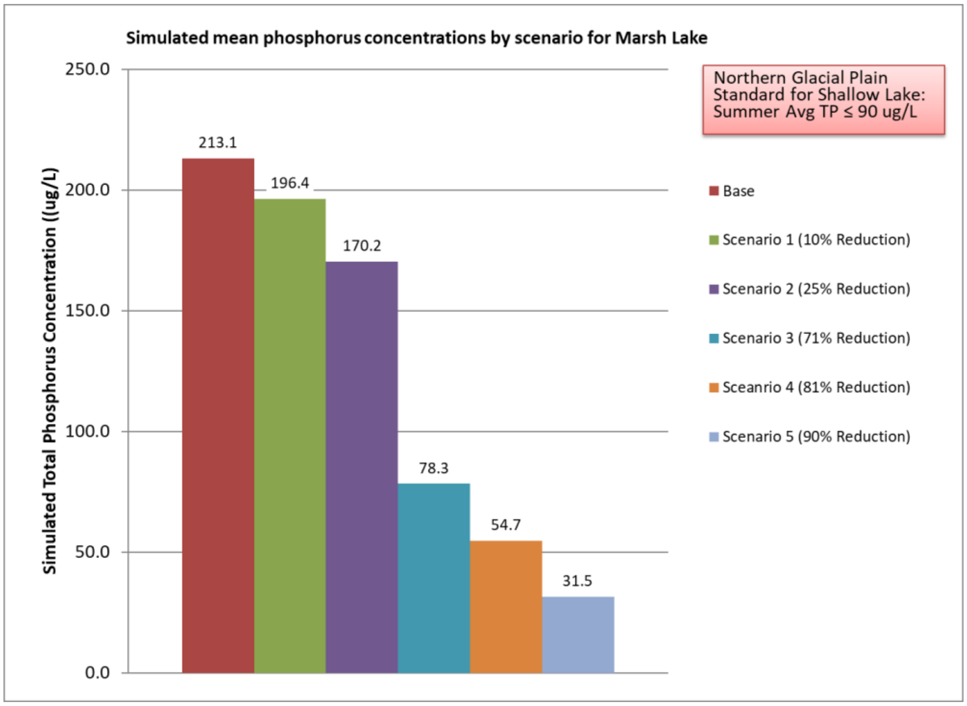


Figure 37. Simulated mean phosphorus concentrations in Marsh Lake by load reduction scenario.

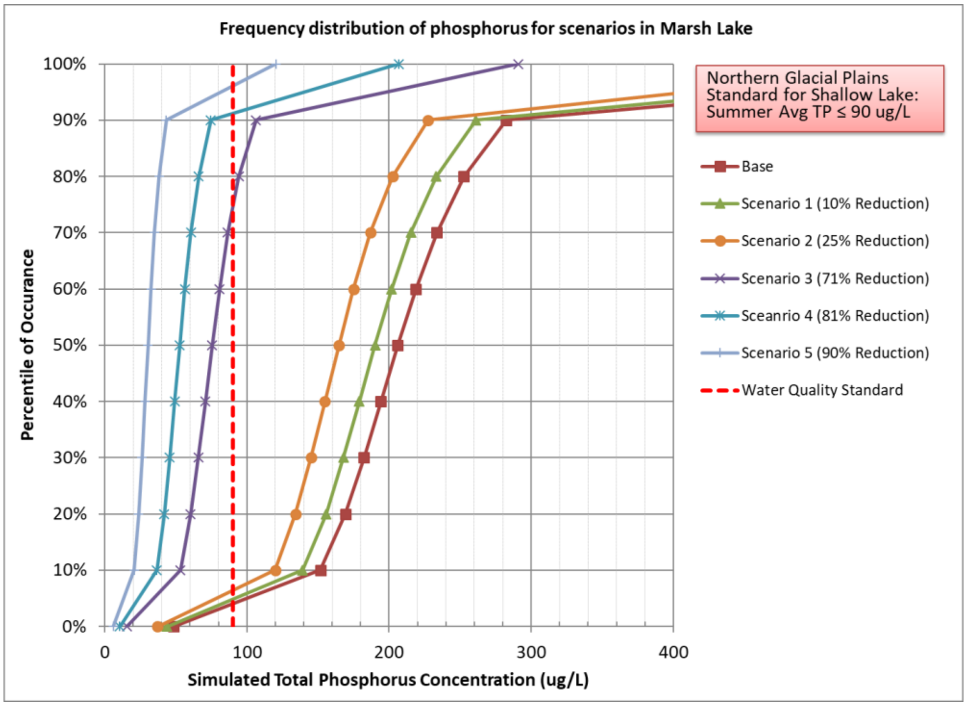


Figure 38. Frequency distribution of phosphorus concentrations in Marsh Lake by load reduction scenario.

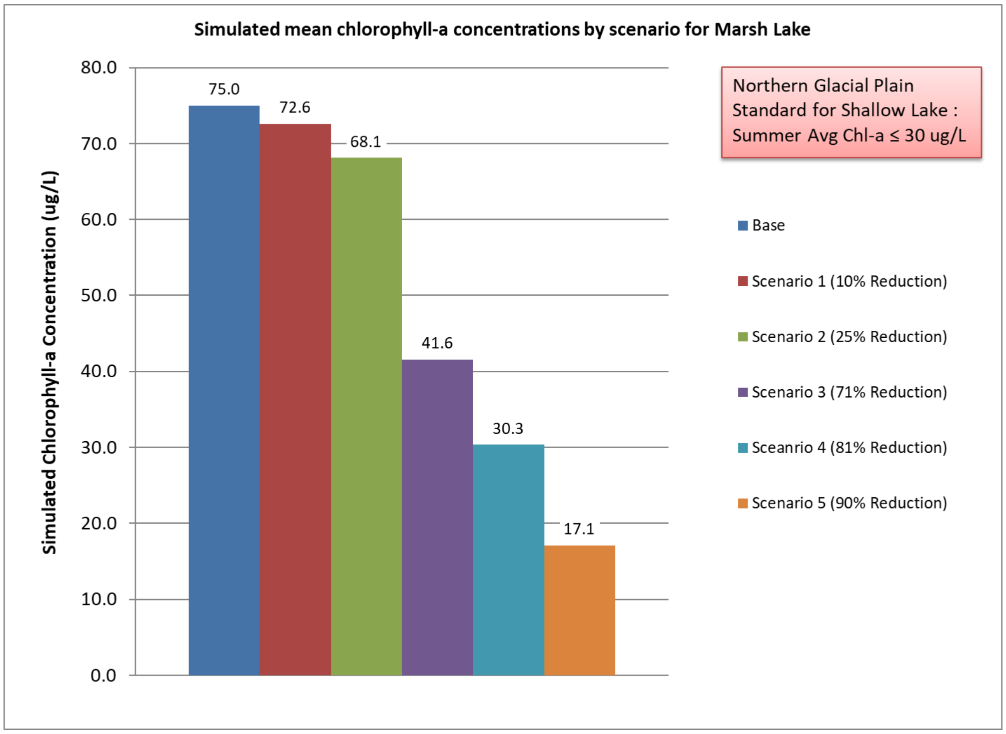


Figure 39. Simulated mean chlorophyll-*a* concentrations in Marsh Lake by load reduction scenario.

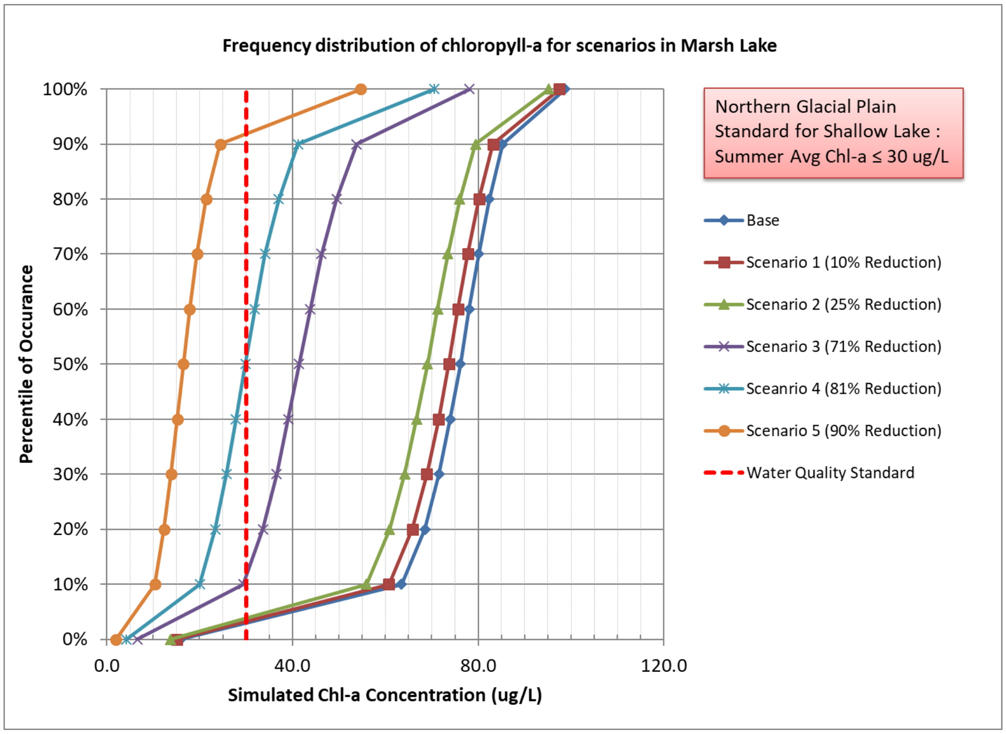


Figure 40. Frequency distribution of chlorophyll-*a* concentrations in Marsh Lake by load reduction scenario.

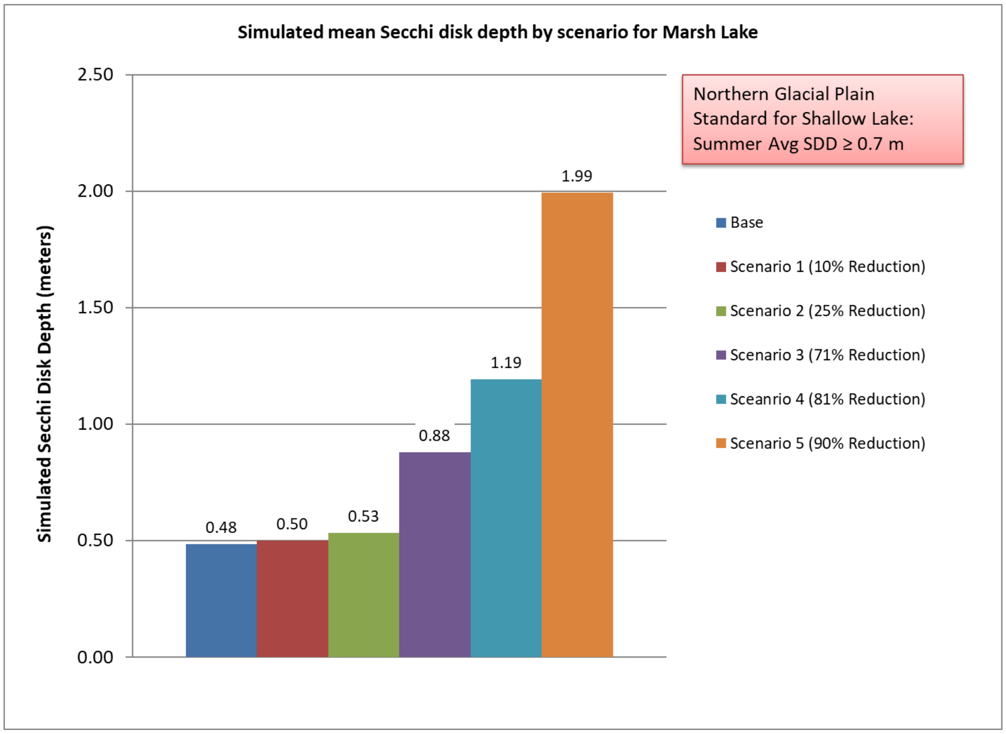


Figure 41. Simulated mean Secchi disk depths in Marsh Lake load reduction scenario.

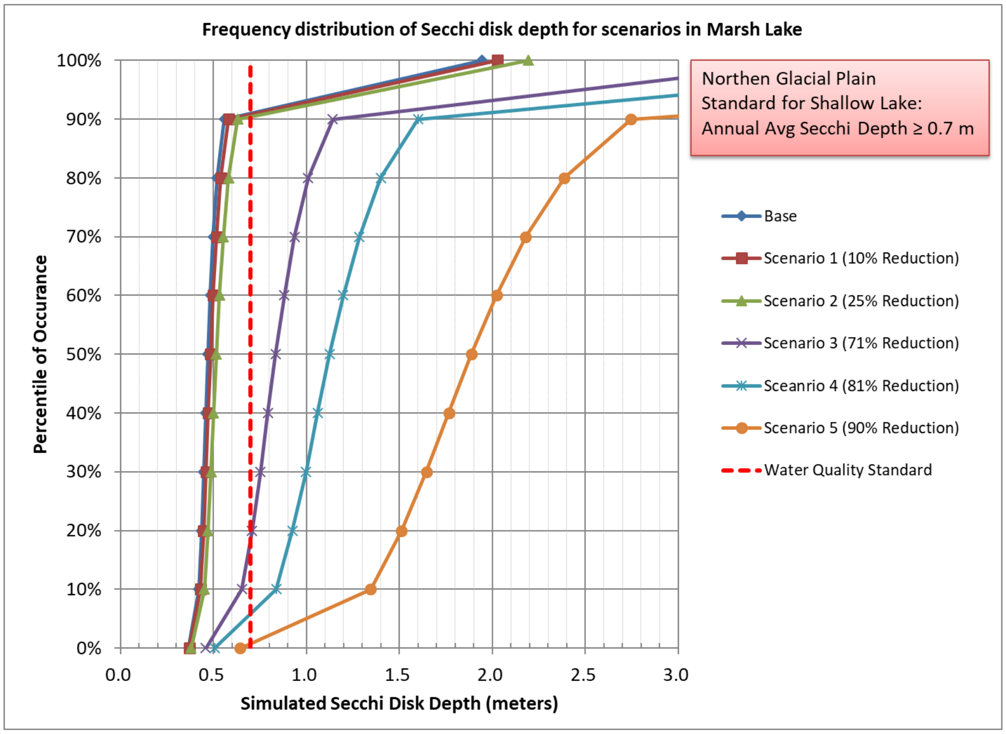


Figure 42. Frequency distribution of Secchi disk depths in Marsh Lake by load reduction scenario.

Lac qui Parle Lake-NW Bay

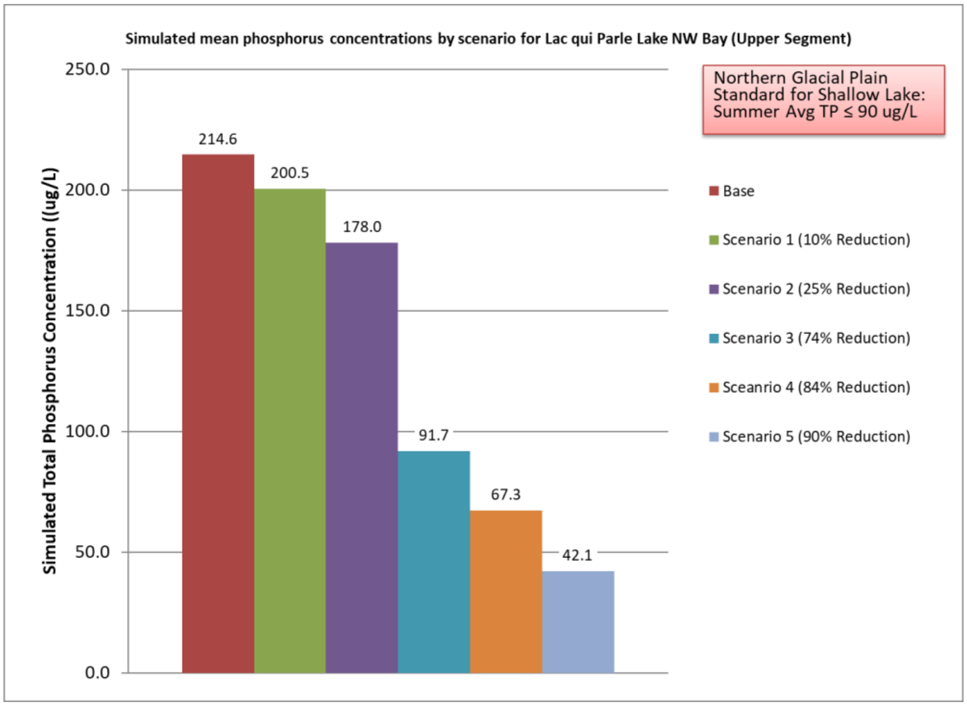


Figure 43. Simulated mean phosphorus concentrations in Lac qui Parle Lake-NW Bay (Upper Segment) by load reduction scenario.

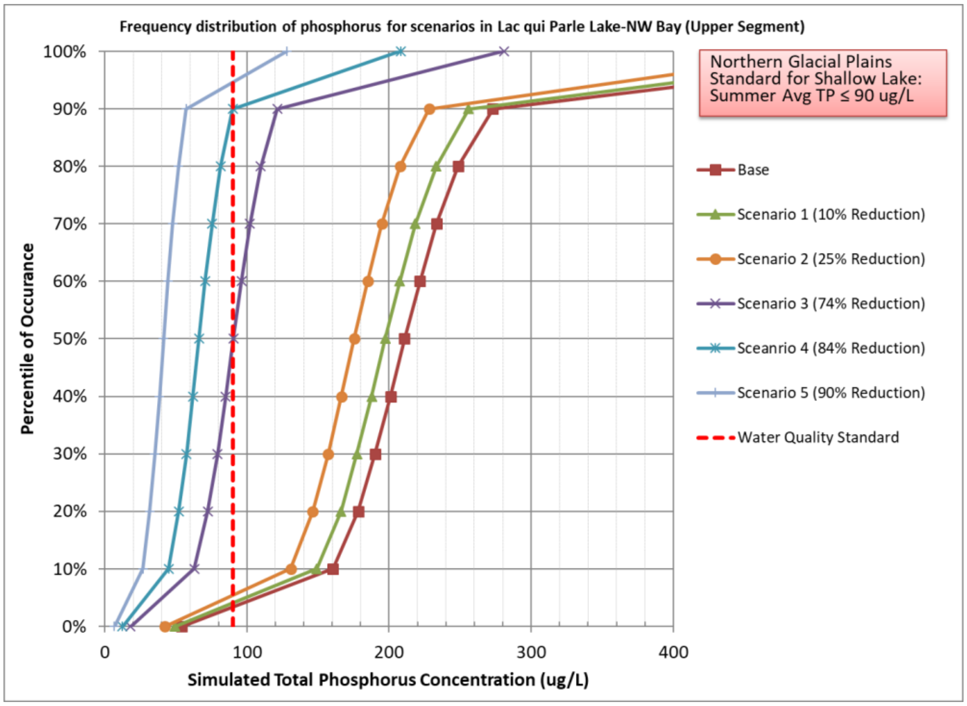


Figure 44. Frequency distribution of phosphorus concentrations in Lac qui Parle Lake-NW Bay (Upper Segment) by load reduction scenario.

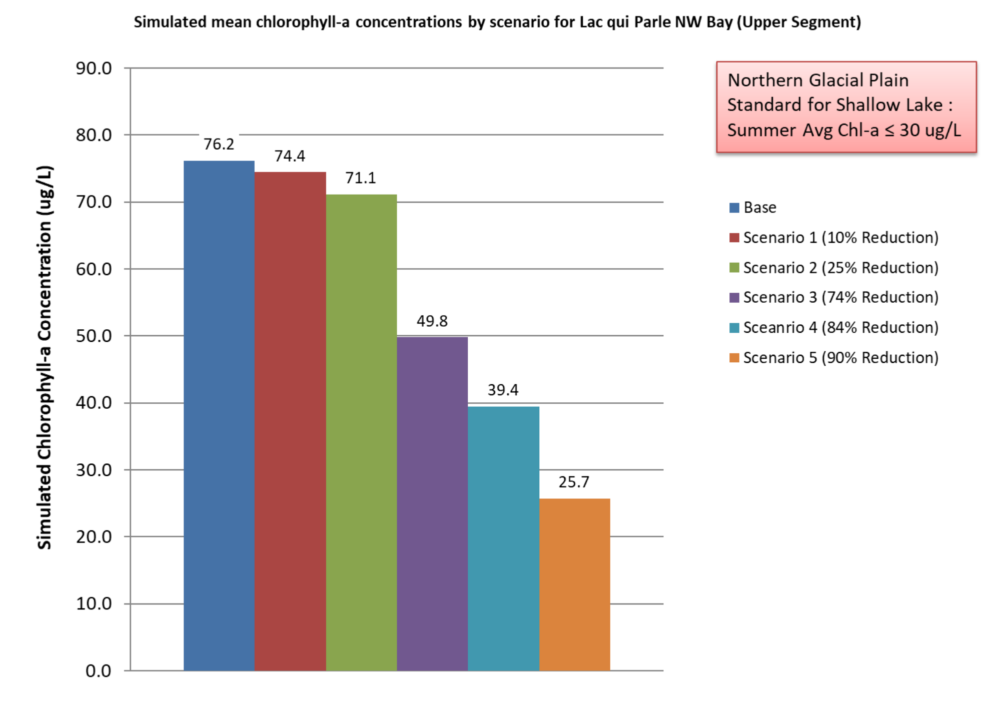


Figure 45. Simulated mean chlorophyll-*a* concentrations in Lac qui Parle Lake-NW Bay (Upper Segment) by load reduction scenario.

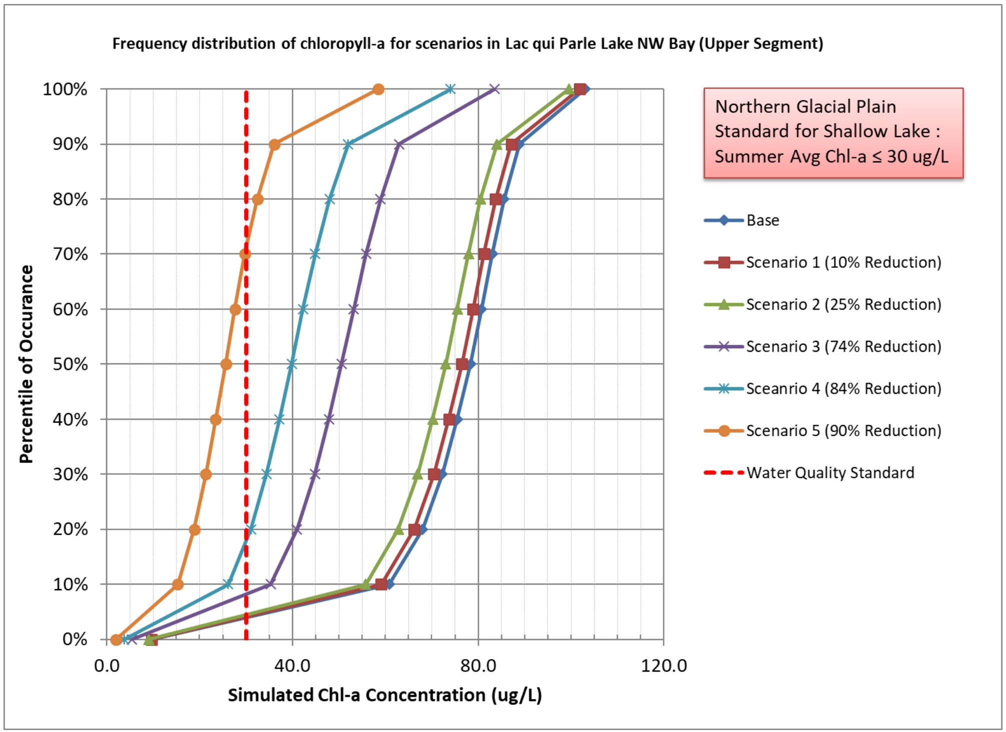


Figure 46. Frequency distribution of chlorophyll-*a* concentrations in Lac qui Parle Lake-NW Bay (Upper Segment) by load reduction scenario.

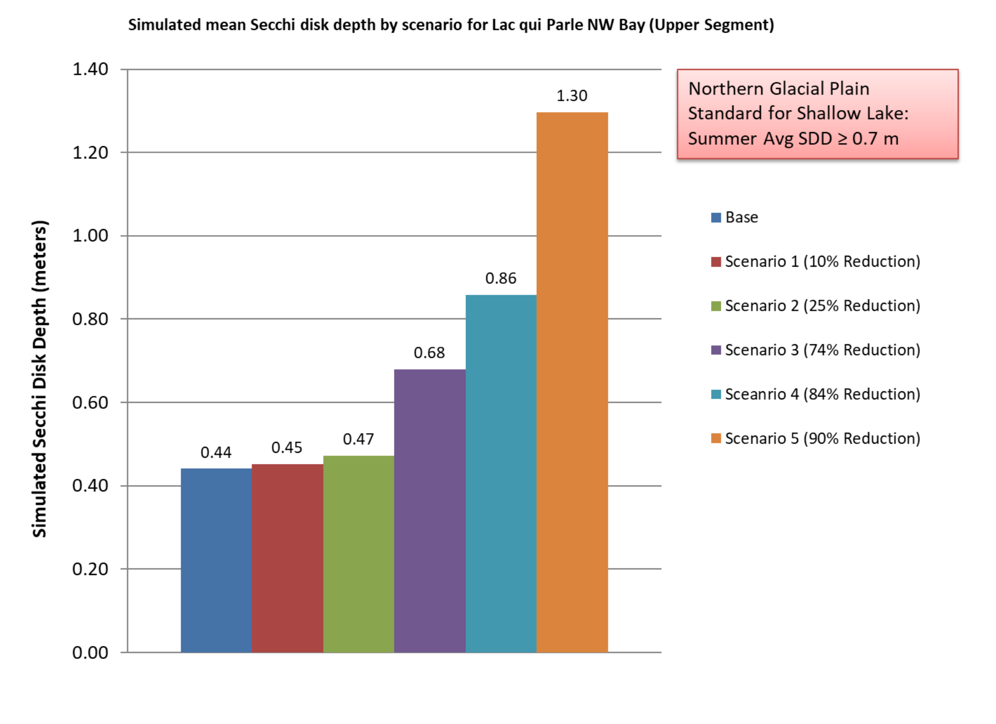


Figure 47. Simulated mean Secchi disk depths in Lac qui Parle Lake-NW Bay (Upper Segment) by load reduction scenario.

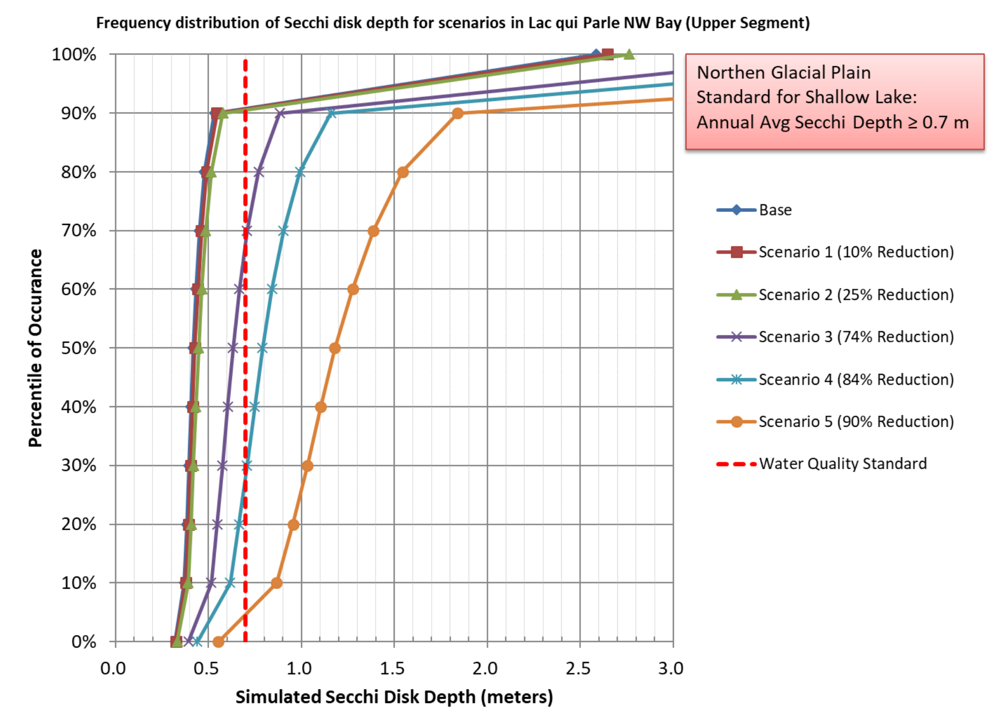


Figure 48. Frequency distribution of Secchi disk depths in Lac qui Parle Lake-NW Bay (Upper Segment) by load reduction scenario.

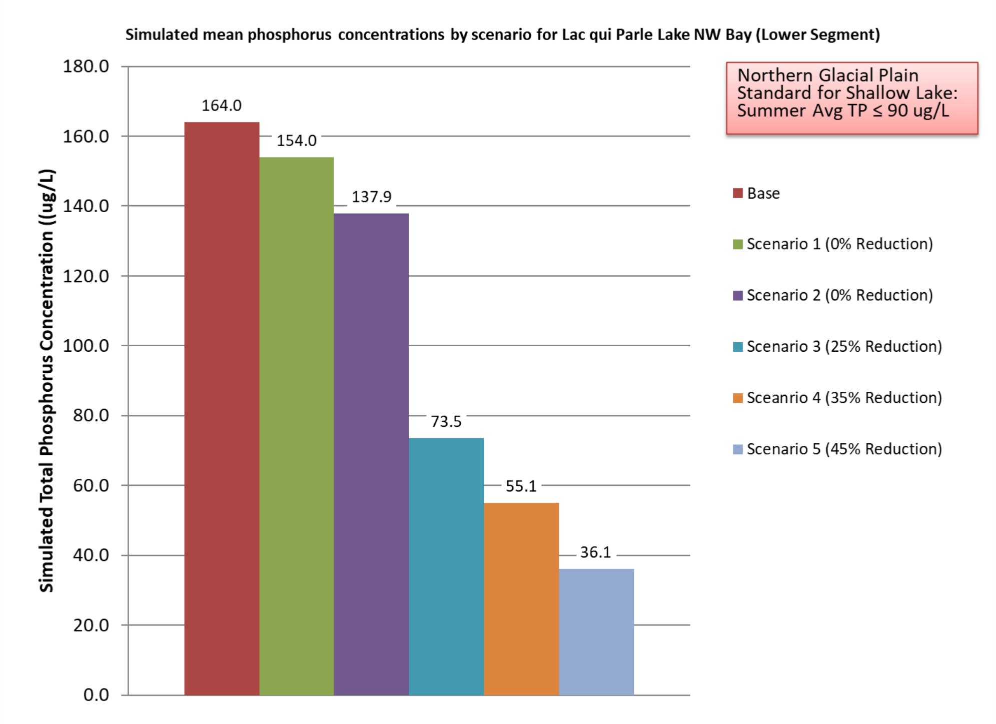


Figure 49. Simulated mean phosphorus concentrations in Lac qui Parle Lake-NW Bay (Lower Segment) by load reduction scenario.

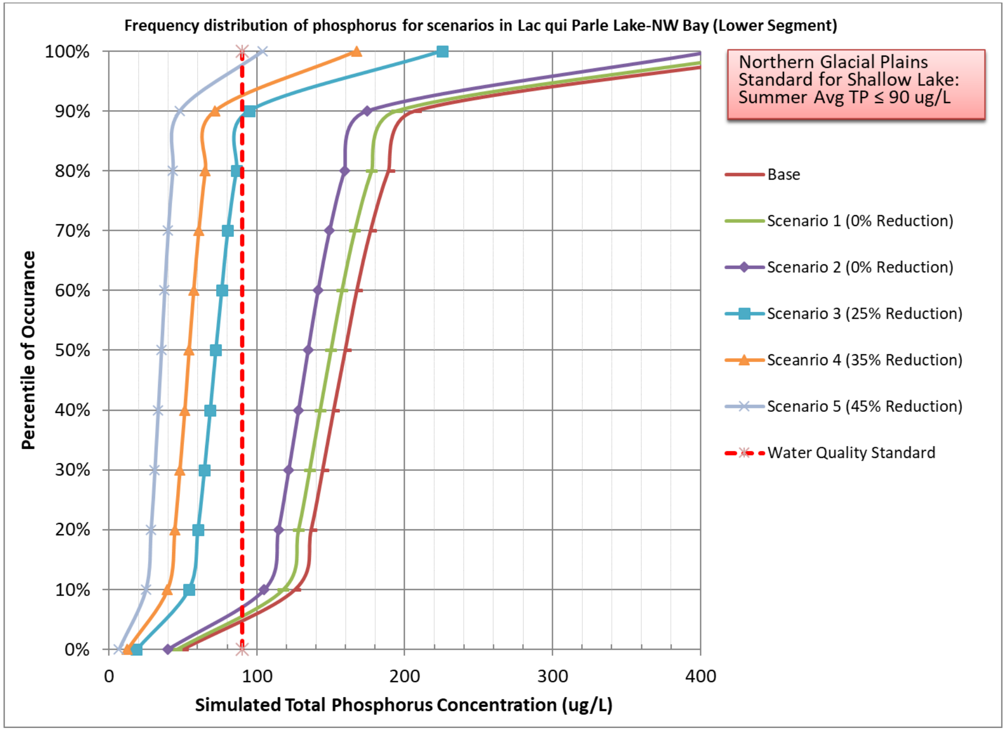


Figure 50. Frequency distribution of phosphorus concentrations in Lac qui Parle Lake-NW Bay (Lower Segment) by load reduction scenario.

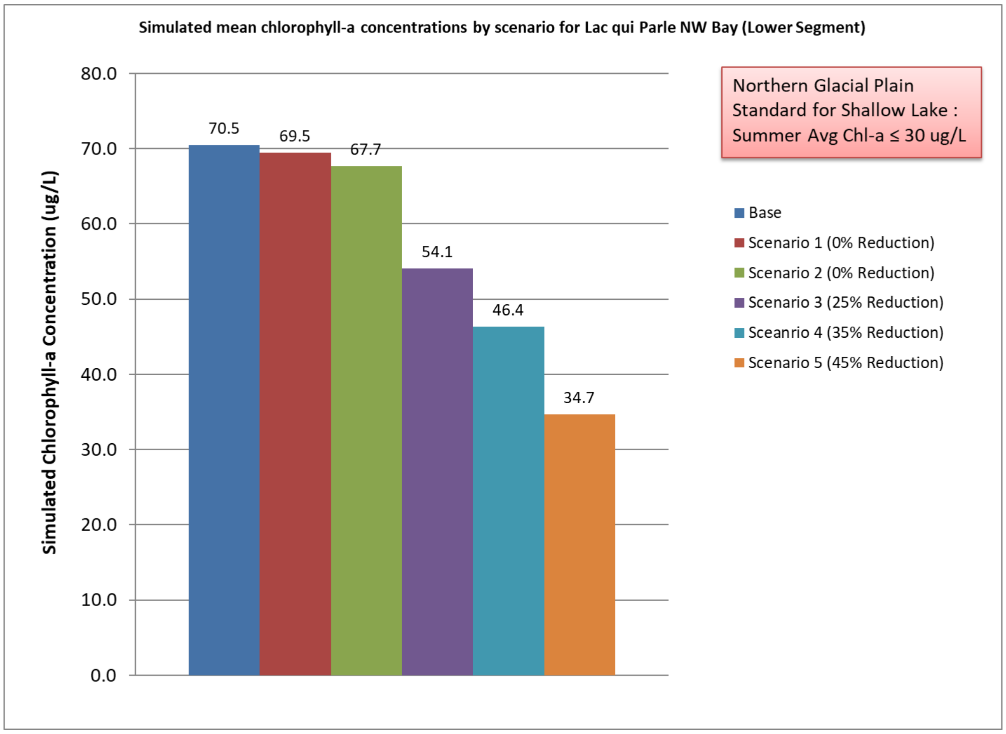


Figure 51. Simulated mean chlorophyll-*a* concentrations in Lac qui Parle Lake-NW Bay (Lower Segment) by load reduction scenario.

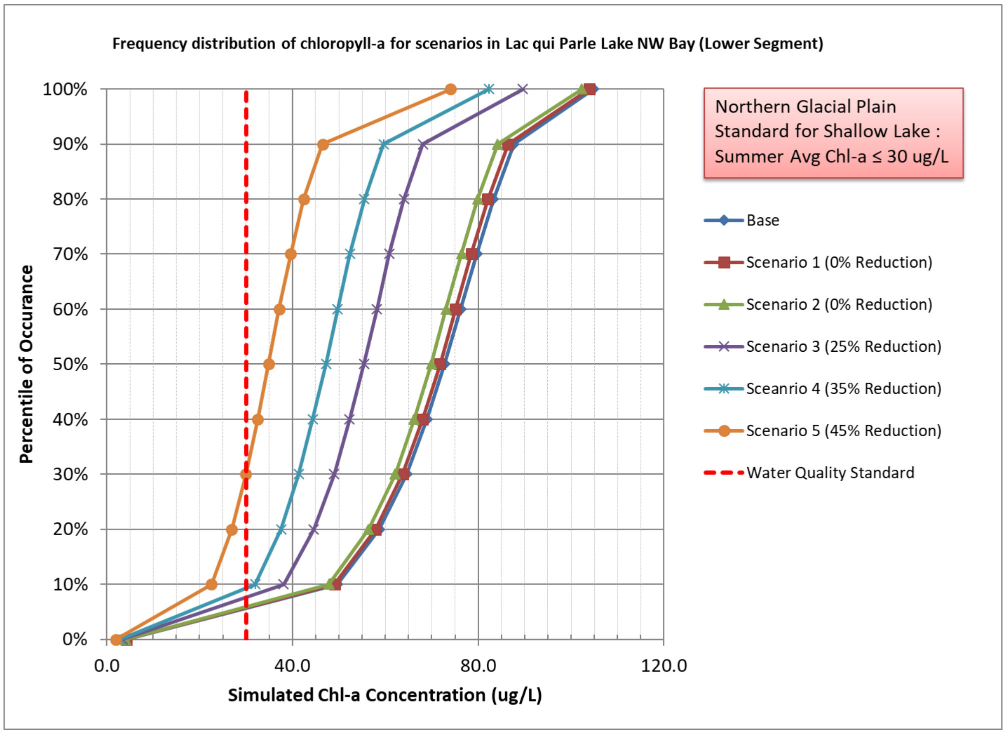


Figure 52. Frequency distribution of chlorophyll-*a* concentrations in Lac qui Parle Lake-NW Bay (Lower Segment) by load reduction scenario.

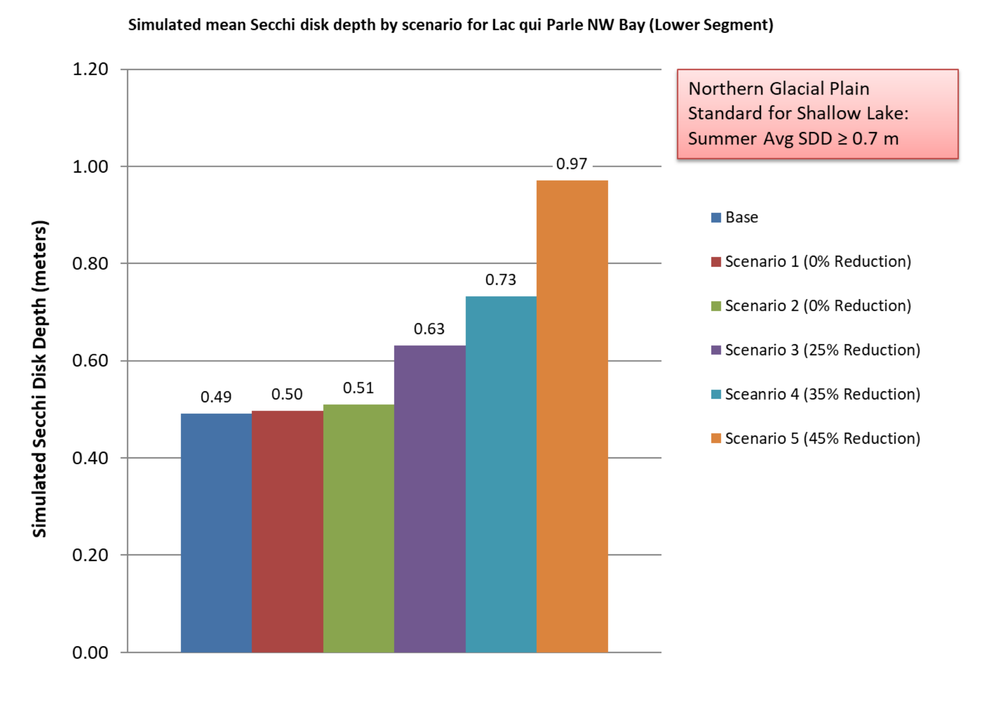


Figure 53. Simulated mean Secchi disk depths in Lac qui Parle Lake-NW Bay (Lower Segment) load reduction scenario.

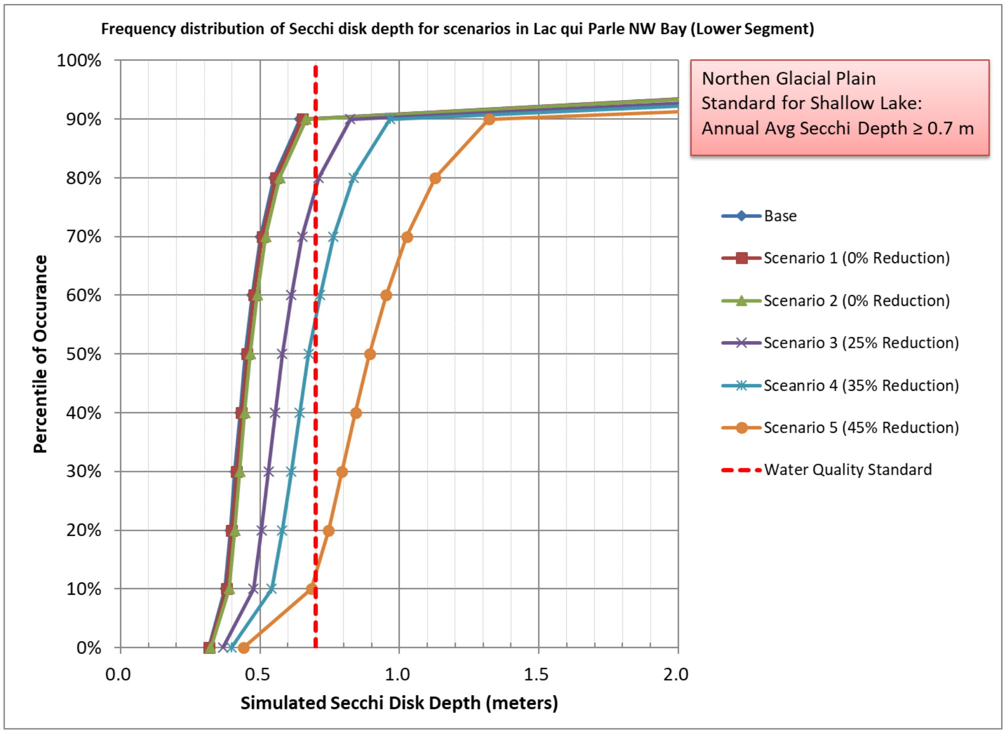


Figure 54. Frequency distribution of Secchi disk depths in Lac qui Parle Lake-NW Bay (Lower Segment) by load reduction scenario.

Lac qui Parle-SE Bay

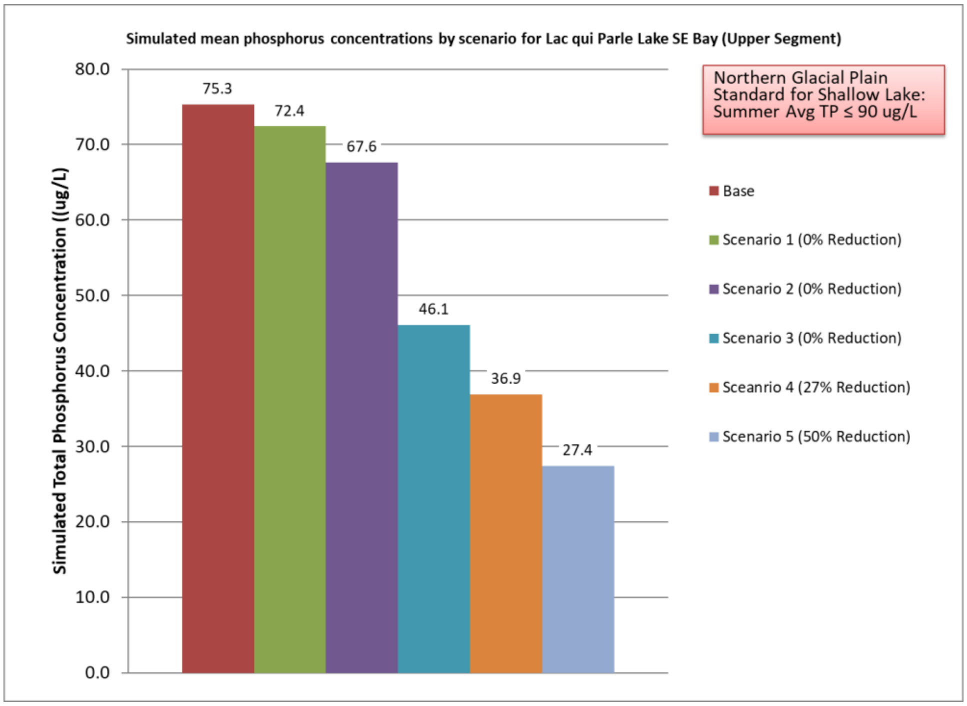


Figure 55. Simulated mean phosphorus concentrations in Lac qui Parle Lake-SE Bay (Upper Segment) by load reduction scenario.

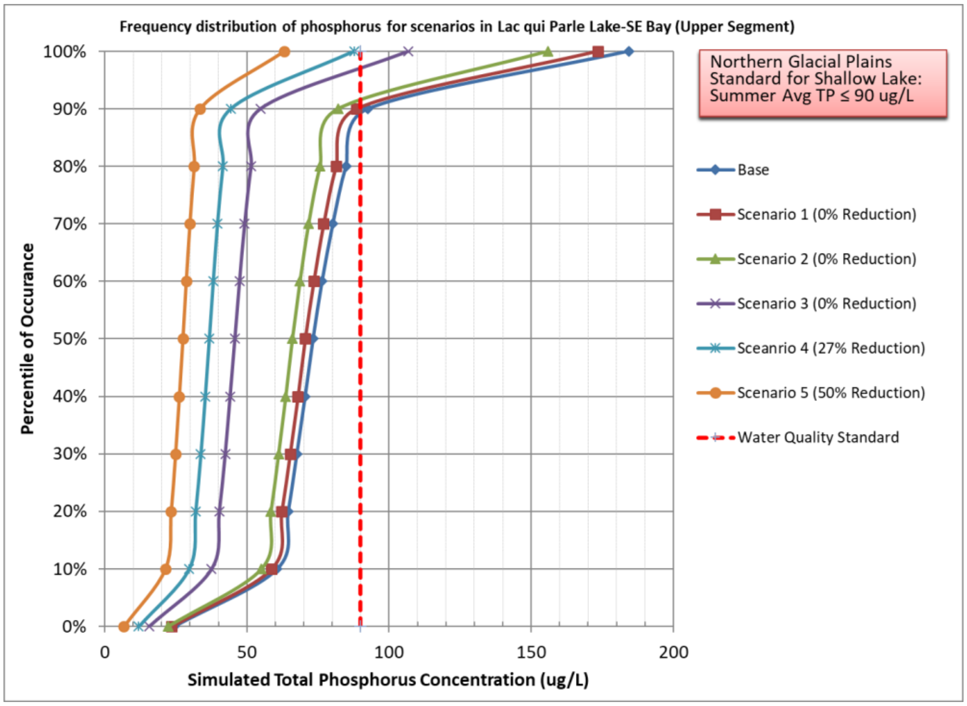


Figure 56. Frequency distribution of phosphorus concentrations in Lac qui Parle Lake-SE Bay (Upper Segment) by load reduction scenario.

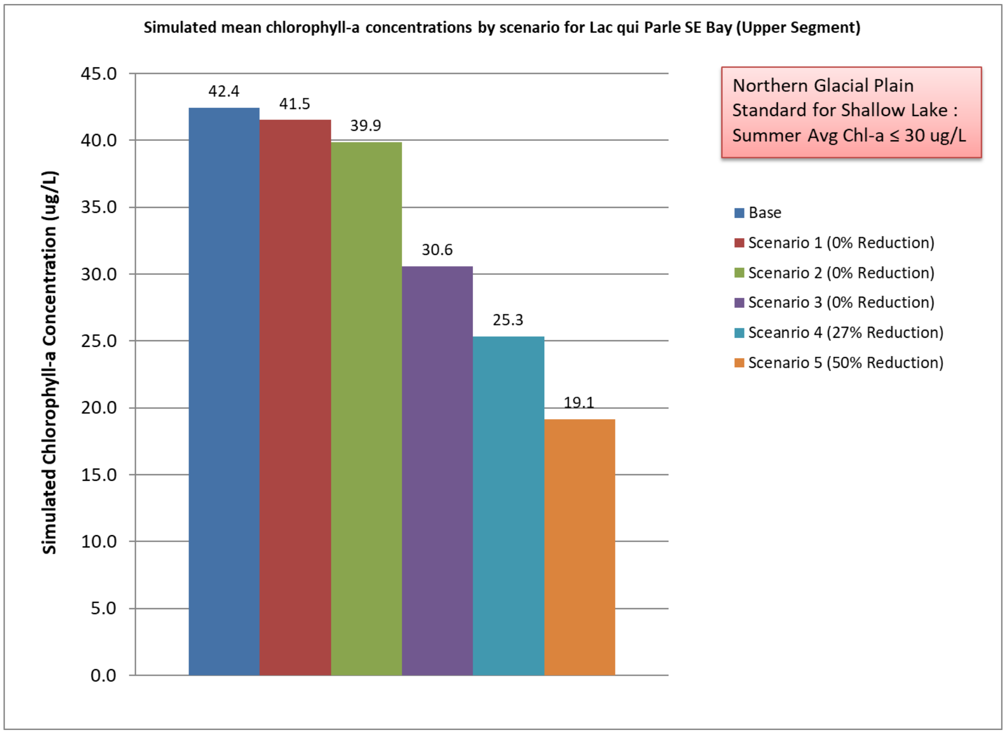


Figure 57. Simulated mean chlorophyll-*a* concentrations in Lac qui Parle Lake-SE Bay (Upper Segment) by load reduction scenario.

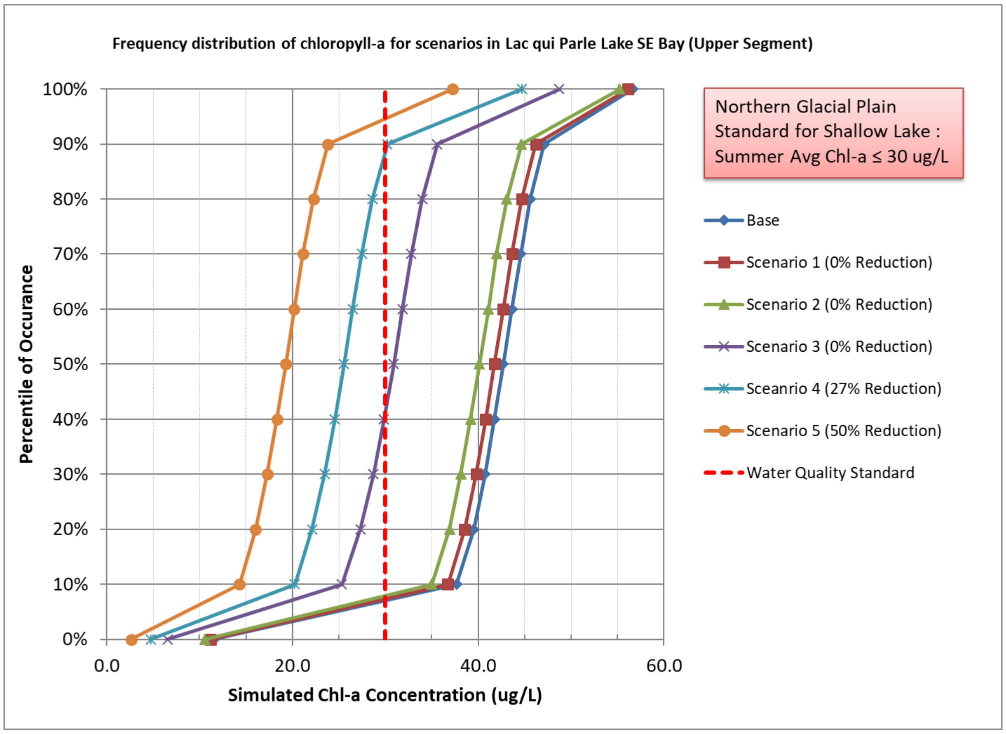


Figure 58. Frequency distribution of chlorophyll-*a* concentrations in Lac qui Parle Lake-SE Bay (Upper Segment) by load reduction scenario.

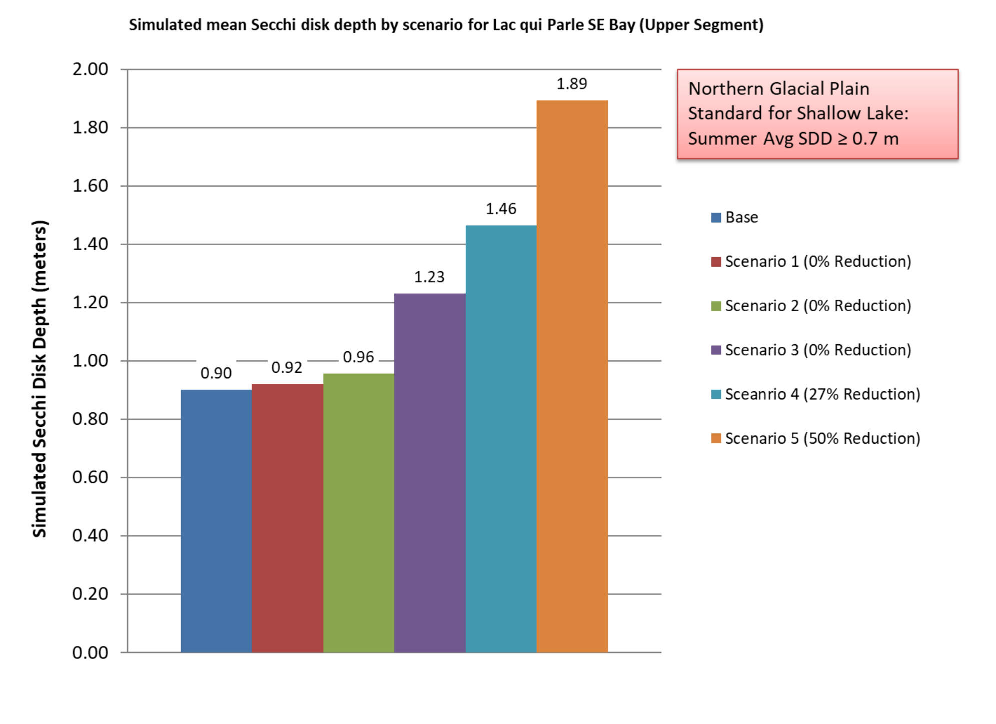


Figure 59. Simulated mean Secchi disk depths in Lac qui Parle Lake-SE Bay (Upper Segment) by load reduction scenario.

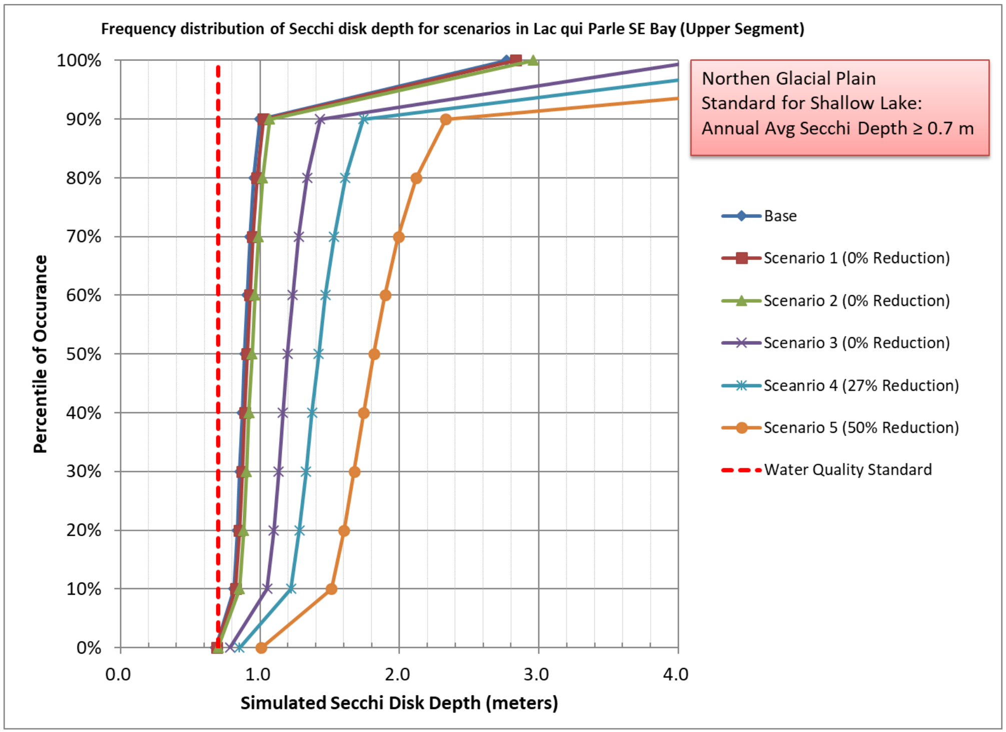


Figure 60. Frequency distribution of Secchi disk depths in Lac qui Parle Lake-SE Bay (Upper Segment) by load reduction scenario.

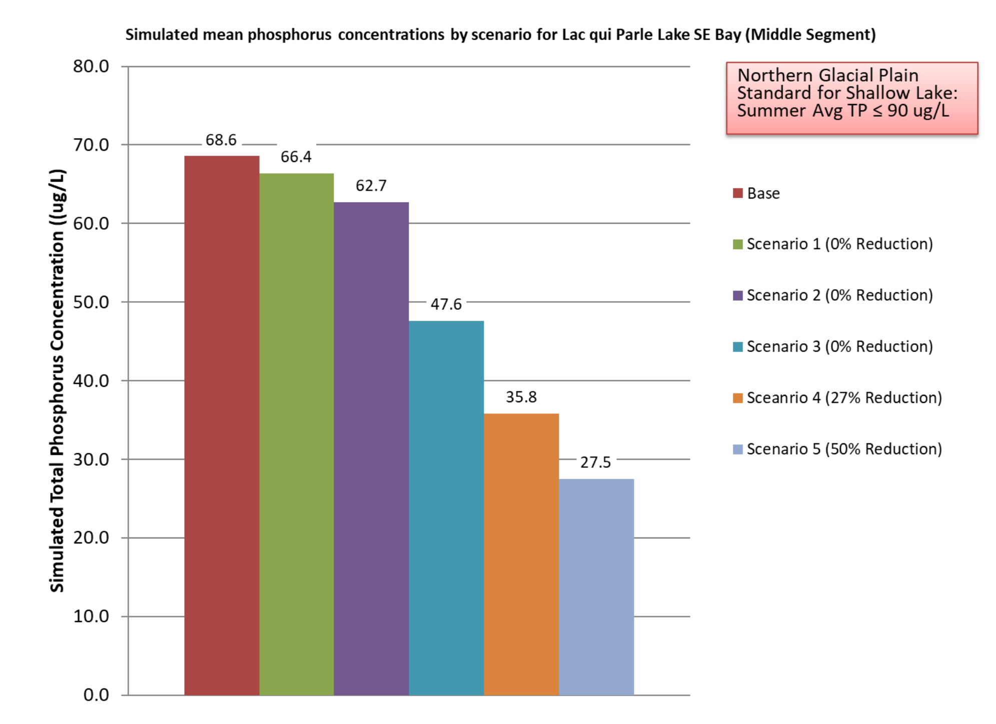


Figure 61. Simulated mean phosphorus concentrations in Lac qui Parle Lake-SE Bay (Middle Segment) by load reduction scenario.

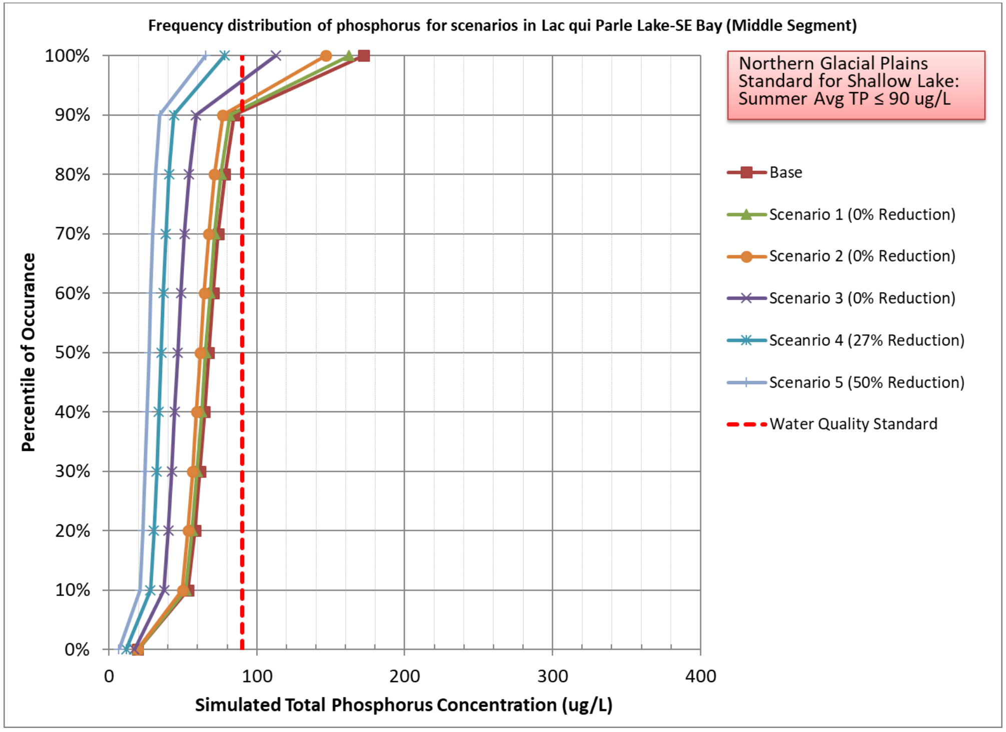


Figure 62. Frequency distribution of phosphorus concentrations in Lac qui Parle Lake-SE Bay (Middle Segment) by load reduction scenario.

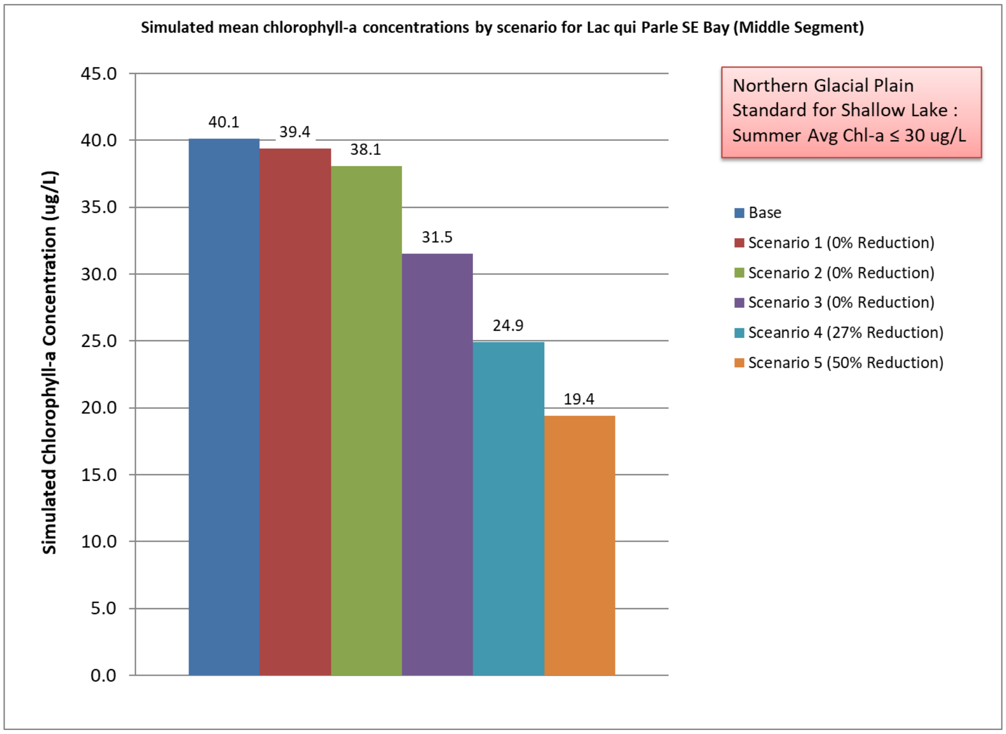


Figure 63. Simulated mean chlorophyll-*a* concentrations in Lac qui Parle Lake-SE Bay (Middle Segment) by load reduction scenario.

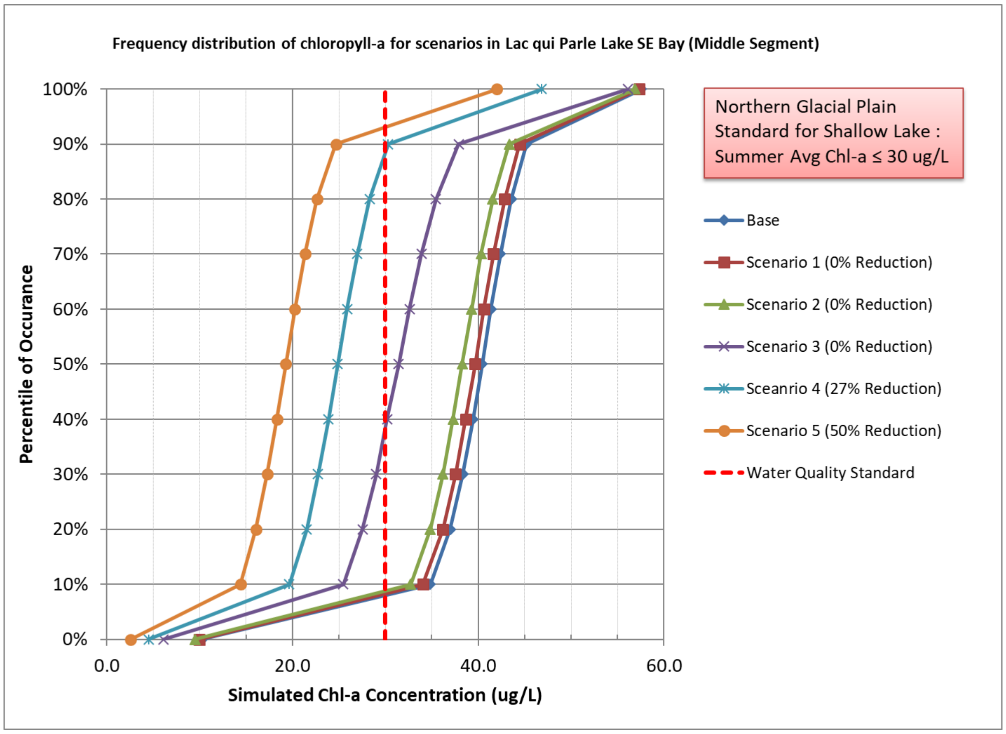


Figure 64. Frequency distribution of chlorophyll-*a* concentrations in Lac qui Parle Lake-SE Bay (Middle Segment) by load reduction scenario.

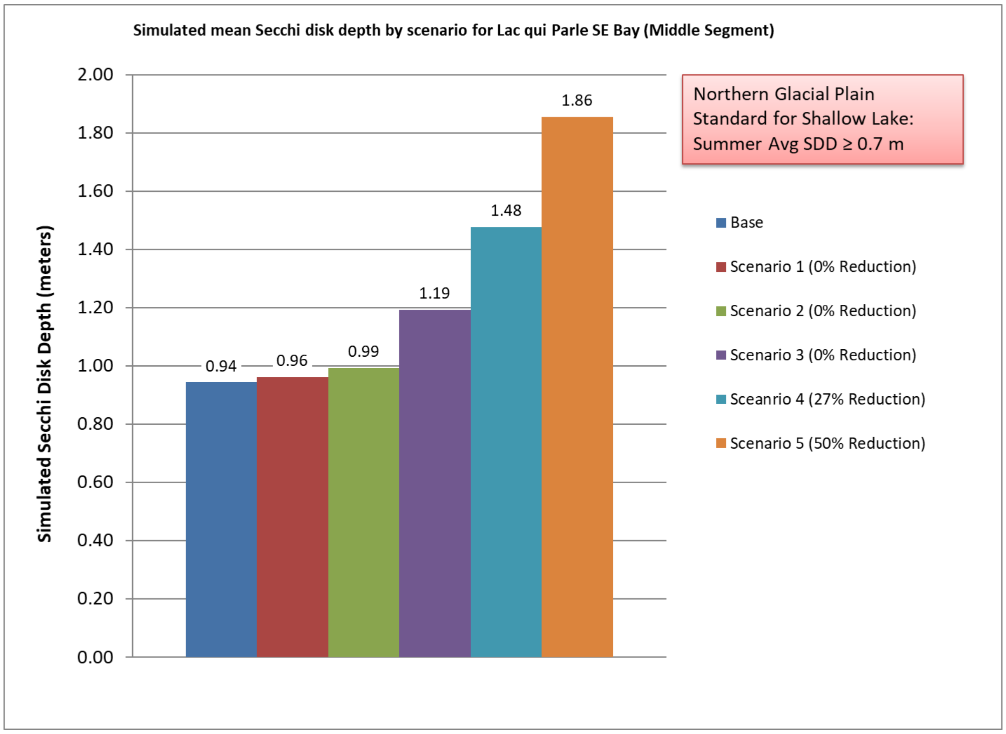


Figure 65. Simulated mean Secchi disk depths in Lac qui Parle Lake-SE Bay (Middle Segment) by load reduction scenario.

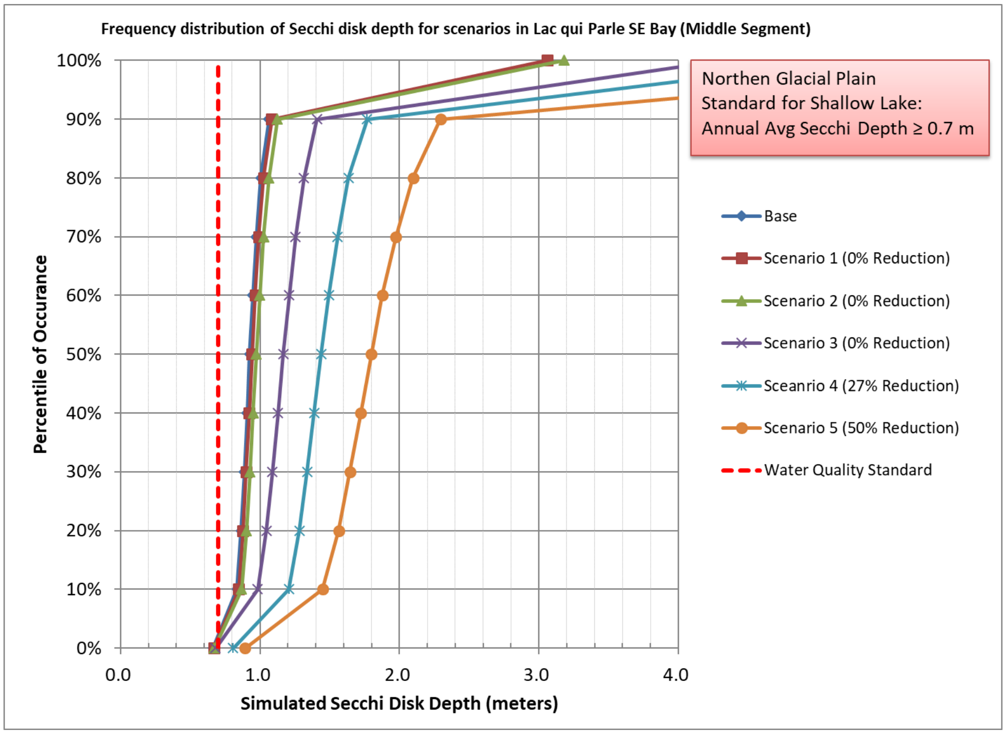


Figure 66. Frequency distribution of Secchi disk depths in Lac qui Parle Lake-SE Bay (Middle Segment) by load reduction scenario.

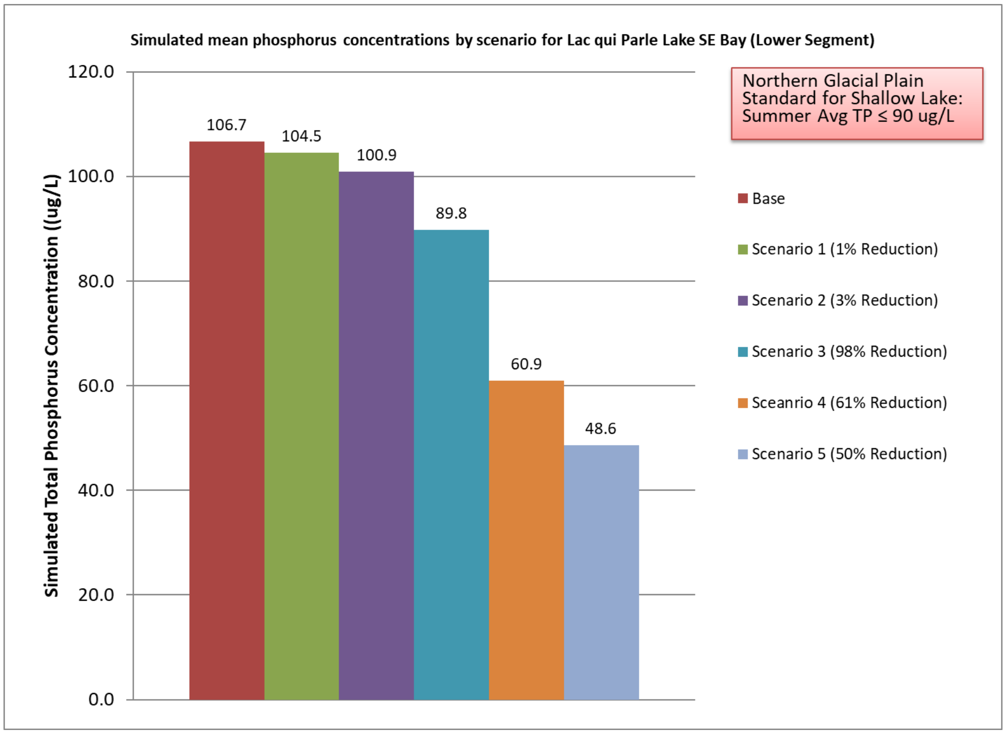


Figure 67. Simulated mean phosphorus concentrations in Lac qui Parle Lake-SE Bay (Lower Segment) by load reduction scenario.

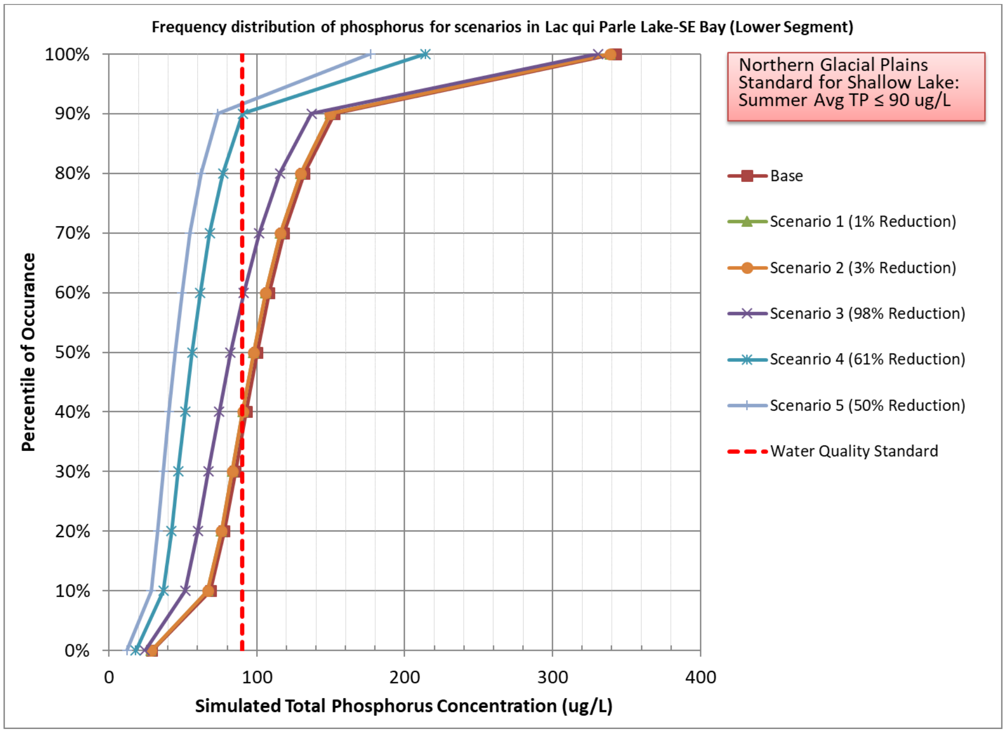


Figure 68. Frequency distribution of phosphorus concentrations in Lac qui Parle Lake-SE Bay (Lower Segment) by load reduction scenario.

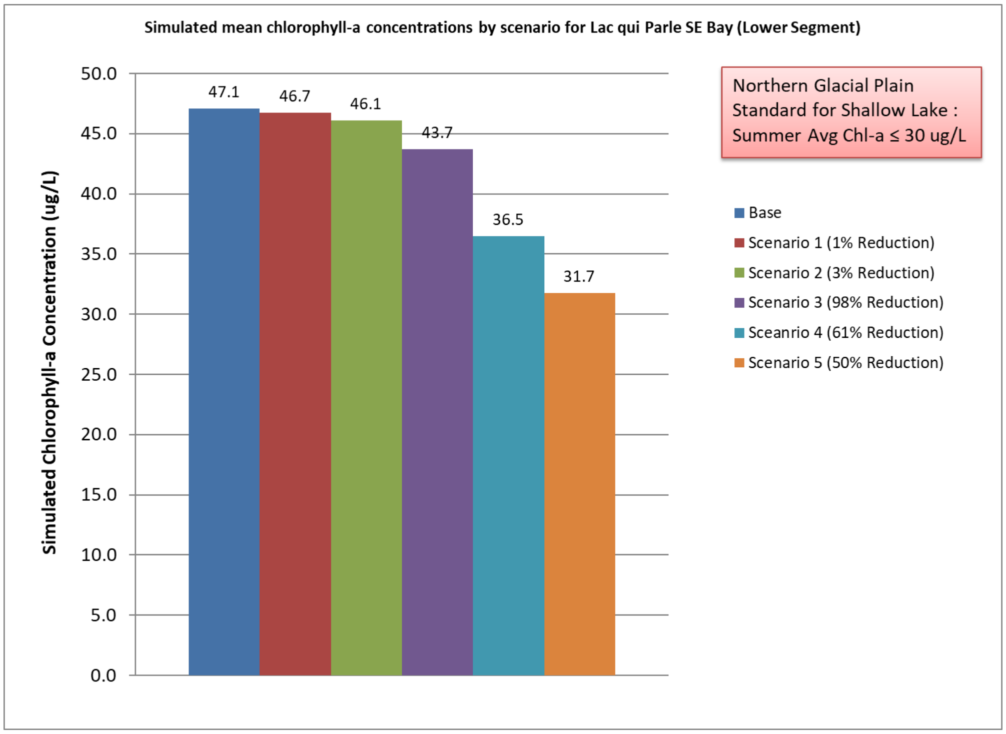


Figure 69. Simulated mean chlorophyll-*a* concentrations in Lac qui Parle Lake-SE Bay (Lower Segment) by load reduction scenario.

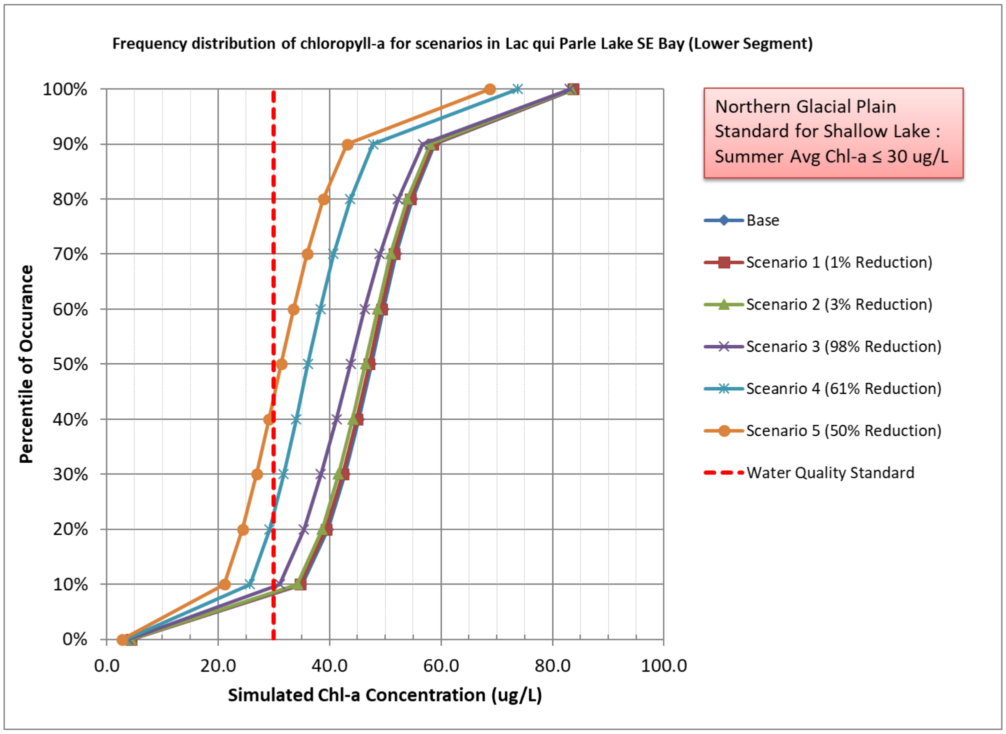


Figure 70. Frequency distribution of chlorophyll-*a* concentrations in Lac qui Parle Lake-SE Bay (Lower Segment) by load reduction scenario.

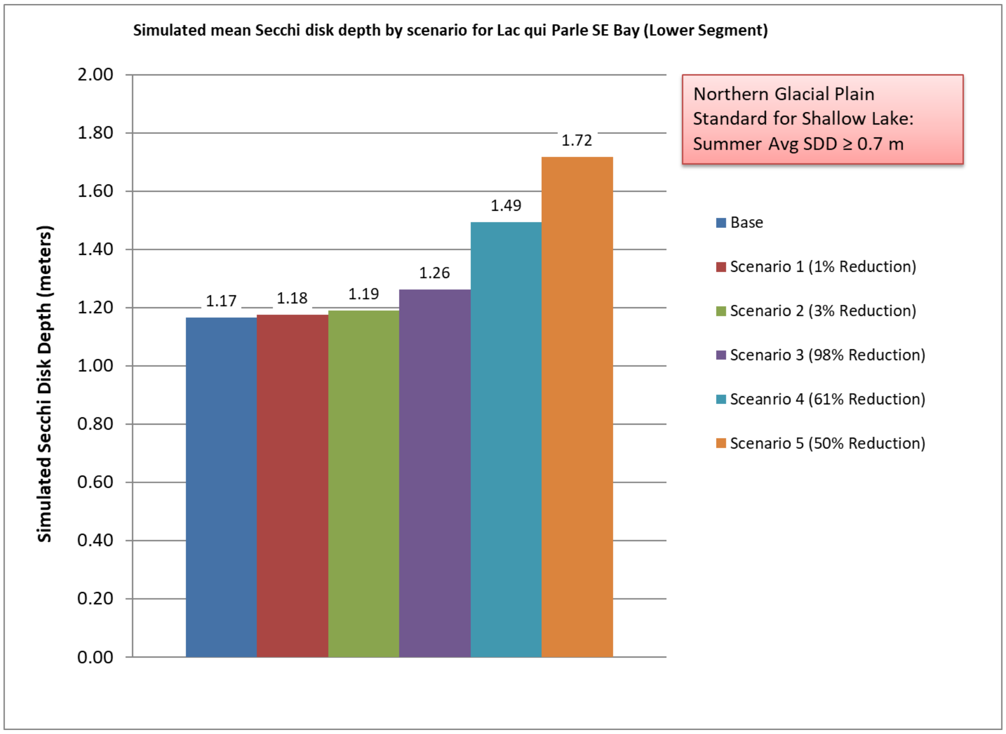


Figure 71. Simulated mean Secchi disk depths in Lac qui Parle Lake-SE Bay (Lower Segment) by load reduction scenario.

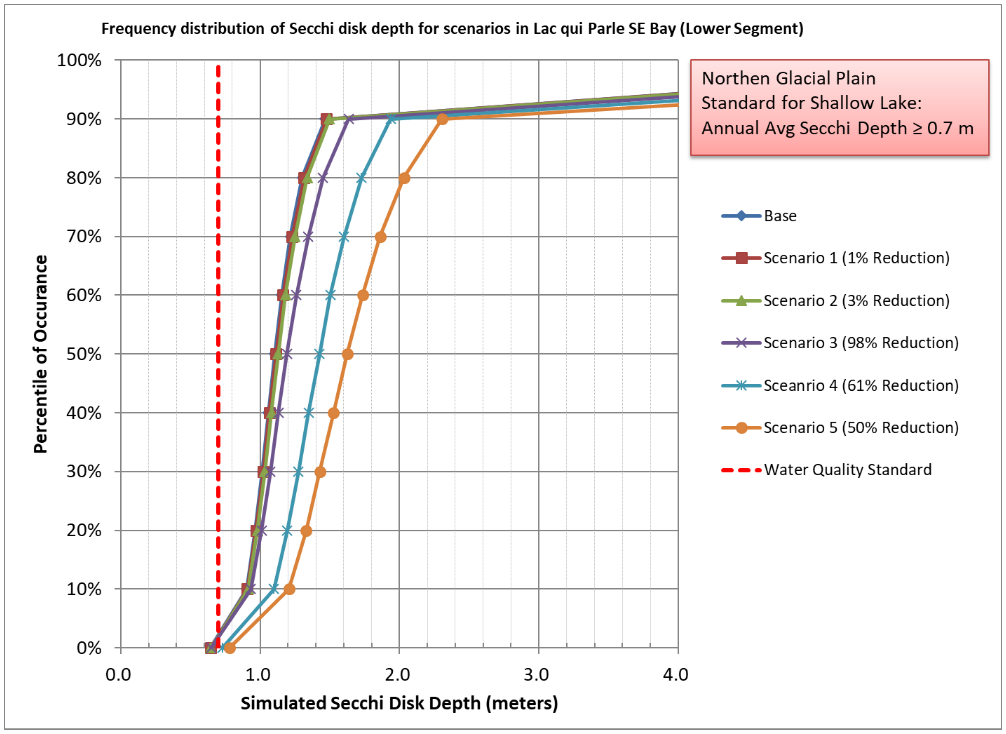


Figure 72. Frequency distribution of Secchi disk depths in Lac qui Parle Lake-SE Bay (Lower Segment) by load reduction scenario.

Appendix C. E. coli Sourcing Tables by Reach

The following tables provide a summary of *E. coli* sources for impaired reaches in the Minnesota portion of the MRHW.

Category	Source	Animal units or individuals	Category	Source	Animal units or individuals
Unnamed Creek (West Salmonsen Creek) (07020001-504)			Little Minnesota River (07020001-508)		
Livestock[1]	Horse	6	Livestock[1]	Horse	0
	Pig	0		Pig	1,819
	Cattle	724		Cattle	0
	Chicken/Turkey	0		Chicken/Turkey	0
	Other Livestock	0		Other Livestock	0
Wildlife[2]	Deer[3]	133	Wildlife[2]	Deer[3]	1,584
	Waterfowl[4]	161		Waterfowl[4]	89
	Geese[5]	115		Geese[5]	31
	Other[6]	133		Other[6]	1,584
Human (population #)	Failing Septic Systems[7]	100	Human (population #)	Failing Septic Systems[7]	8
	WWTP Effluent[8]	0		WWTP Effluent[8]	0
Domestic Animals	Improperly Managed Pet Waste[9]	67	Domestic Animals	Improperly Managed Pet Waste[9]	151
Unnamed Creek (Five Mile Creek) (07020001-521)			Stony Run Creek (07020001-531)		
Livestock[1]	Horse	5	Livestock[1]	Horse	3
	Pig	810		Pig	2,248
	Cattle	1,652		Cattle	1,409
	Chicken/Turkey	0		Chicken/Turkey	0
	Other Livestock	0		Other Livestock	0
Wildlife[2]	Deer[3]	446	Wildlife[2]	Deer[3]	643
	Waterfowl[4]	612		Waterfowl[4]	2,131
	Geese[5]	383		Geese[5]	553
	Other[6]	446		Other[6]	643
Human (population #)	Failing Septic Systems[7]	574	Human (population #)	Failing Septic Systems[7]	456
	WWTP Effluent[8]	0		WWTP Effluent[8]	1
Domestic Animals	Improperly Managed Pet Waste[9]	118	Domestic Animals	Improperly Managed Pet Waste[9]	235
Stony Run Creek (07020001-536)			Unnamed creek (07020001-541)		
Livestock[1]	Horse	3	Livestock[1]	Horse	0
	Pig	2,248		Pig	1,467
	Cattle	1,337		Cattle	1,879
	Chicken/Turkey	0		Chicken/Turkey	0

Category	Source	Animal units or individuals	Category	Source	Animal units or individuals
	Other Livestock	0		Other Livestock	0
Wildlife[2]	Deer[3]	600	Wildlife[2]	Deer[3]	166
	Waterfowl[4]	2,131		Waterfowl[4]	499
	Geese[5]	516		Geese[5]	142
	Other[6]	600		Other[6]	166
Human (population #)	Failing Septic Systems[7]	425	Human (population #)	Failing Septic Systems[7]	72
	WWTP Effluent[8]	1		WWTP Effluent[8]	0
Domestic Animals	Improperly Managed Pet Waste[9]	235	Domestic Animals	Improperly Managed Pet Waste[9]	100
Emily Creek (07020001-547)			Unnamed Creek (County Ditch 4) (07020001-551)		
Livestock[1]	Horse	20	Livestock[1]	Horse	0
	Pig	150		Pig	0
	Cattle	1,292		Cattle	0
	Chicken/Turkey	0		Chicken/Turkey	0
	Other Livestock	0		Other Livestock	0
Wildlife[2]	Deer[3]	359	Wildlife[2]	Deer[3]	245
	Waterfowl[4]	172		Waterfowl[4]	18
	Geese[5]	308		Geese[5]	10
	Other[6]	359		Other[6]	245
Human (population #)	Failing Septic Systems[7]	131	Human (population #)	Failing Septic Systems[7]	4
	WWTP Effluent[8]	2		WWTP Effluent[8]	0
Domestic Animals	Improperly Managed Pet Waste[9]	152	Domestic Animals	Improperly Managed Pet Waste[9]	20
Unnamed Creek (Meadowbrook Creek) (07020001-568)			Unnamed Creek (07020001-570)		
Livestock[1]	Horse	0	Livestock[1]	Horse	0
	Pig	0		Pig	825
	Cattle	270		Cattle	546
	Chicken/Turkey	0		Chicken/Turkey	0
	Other Livestock	15		Other Livestock	587
Wildlife[2]	Deer[3]	91	Wildlife[2]	Deer[3]	67
	Waterfowl[4]	229		Waterfowl[4]	57
	Geese[5]	78		Geese[5]	58
	Other[6]	91		Other[6]	67
Human (population #)	Failing Septic Systems[7]	66	Human (population #)	Failing Septic Systems[7]	25
	WWTP Effluent[8]	0		WWTP Effluent[8]	1

Category	Source	Animal units or individuals
Domestic Animals	Improperly Managed Pet Waste[9]	74
Fish Creek (Meadowbrook Creek) (07020001-571)		
Livestock[1]	Horse	2
	Pig	3,718
	Cattle	1,265
	Chicken/Turkey	0
	Other Livestock	26
Wildlife[2]	Deer[3]	398
	Waterfowl[4]	1,565
	Geese[5]	342
	Other[6]	398
Human (population #)	Failing Septic Systems[7]	232
	WWTP Effluent[8]	0
Domestic Animals	Improperly Managed Pet Waste[9]	71

Category	Source	Animal units or individuals
Domestic Animals	Improperly Managed Pet Waste[9]	27

[1] Animal units based on registered feedlots (https://gisdata.mn.gov/dataset/env-feedlots).

[2] Wildlife numbers represent total number of individual animals.

[3] Deer populations based on MNDNR "Status of Wildlife populations, Fall 2009" (https://www.dnr.state.mn.us/publications/wildlife/populationstatus2009.html).

[4] Duck population calculated by U.S. Fish and Wildlife Service utilizing "Thunderstorm" Maps for the Prairie Pothole Region.

[5] Geese population estimates were taken from the state-wide DNR's Minnesota Spring Canada Goose Survey, 2009 (Rave 2009).

[6] Other wildlife includes such animals as swallows, beaver, raccoons, coyote, foxes, and squirrels and taken as the same population as deer.

[7] Reported as population size in watershed based on county SSTS inventory (MPCA 2016) and drainage area size. Assumes three persons per failing system.

[8] Reported as number of WWTPs.

[9] Number of households in watershed multiplied by 0.58 dogs/ household.

Appendix D. Source Summary

Technical Memorandum

To:	Katherine Pekarek-Scott, Project Manager Minnesota Pollution Control Agency
From:	Timothy Erickson, PE and Drew Kessler, PhD Houston Engineering, Inc.
Subject:	Upper Minnesota River Watershed Prioritization and Source Assessment
Date:	June 29, 2018
Project:	6074-0017

Introduction

Using results from the Minnesota River-Headwaters and Lac qui Parle Rivers' Hydrologic Simulation Program Fortran (HSPF) model (Tetra Tech 2017), areas within the watershed were prioritized based upon the magnitude of NPS, to identify sources of pollutants and identify subwatersheds where restoration and protection strategies would be most beneficial. Sources of pollutants were identified and mapped by using yields leaving the landscape and within the channel for land use/land cover types and at the subwatershed scale. The HSPF model was utilized to estimate unit RO, TP, TN, and TS leaving the landscape and within the channel. The mapping of pollutants includes the annual average yields at the hydrologic response unit (HRU) scale, the average annual yield at the subwatershed scale, prioritization maps developed for several stressors including altered hydrology (expressed as RO), excess nutrients (TP, TN) and turbidity and habitat alteration/geomorphology (TS), and a FSI map, which compares the water quality load delivered to the stream to the flux in the channel segment and highlights sources and sinks in the watershed. Subwatersheds were prioritized by ranking the area-averaged yields (pounds/acre/year) from the HSPF model for unit RO, TP, TN, and TS. Prioritization is based solely on the estimated mass leaving the landscape. The consideration of other factors could change the prioritization outcome.

In addition, a bacteria source assessment was conducted to rank contributing sources and identify the potential sources within the watershed and within the drainage areas of impaired stream reaches. This technical memorandum covers the source assessment and prioritization of subwatershed within the Upper Minnesota River watershed (aka Minnesota River-Headwaters, 8-digit HRU (HUC 07200001) to inform the TMDL study and Watershed Restoration and Protection Strategies (WRAPS) project being performed within the watershed.

Land Use/Land Cover

Historically, land cover in the watershed during European settlement times (mid-late 1800s) consisted almost entirely of prairies in the western half of the watershed and a mix of mainly prairies and aspen-oak land in the eastern half (Marschner 1930). More current land use within the watershed can be described using the Multi-Resolution Land Characteristic Consortium Dataset[2] (NLCD 2006). **Table 1** contains a summary of land uses/land cover in the watershed, as well as the percentage of total area and areas located in Minnesota. Agriculture is the primary land use in the watershed, followed by pasture and grasslands. **Figure 1** maps the 2006 NLCD land use/land cover dataset for the watershed. It should be noted that **Table 1** and **Figure 1** provide the NLCD 2006 distribution instead of newer versions of the data (at this date of publication) since it is the basis for the development of the HSPF model and the HRUs used in the HSPF model. Much like most of rural Minnesota, land use/land has not seen significant changes in the last few generations of NLCDs (2001, 2006, and 2011), so it was determined for this source assessment, showing the 2006 NLCD data was appropriate to be consistent with the model results used to summaries the source assessment.

Table 1. NLCD Land Use/Land Cover (2006) for the UMRW.

NLCD ID	Description	Total Acres	% of Watershed	MN Acres	%MN Watershed
11	Open Water	63,558	4.66%	37,253	7.42%
21	Developed, Open Space	56,349	4.13%	22,143	4.41%
22	Developed, Low Intensity	5,757	0.42%	1,986	0.40%
23	Developed, Medium Intensity	1,838	0.13%	484	0.10%
24	Developed, High Intensity	380	0.03%	105	0.02%
31	Barren Land	1,718	0.13%	795	0.16%
41	Deciduous Forest	23,180	1.70%	4,663	0.93%
42	Evergreen Forest	4.9	0.0004%	1.1	0.0002%
52	Shrub/Scrub	166	0.01%	5	0.001%
71	Grassland	196,811	14.42%	10,479	2.09%
81	Pasture/Hay	169,242	12.40%	30,757	6.13%
82	Cultivated Crops	731,496	53.61%	328,395	65.43%
90	Woody Wetlands	4,603	0.34%	3,854	0.77%
95	Emergent Herbaceous Wetlands	109,275	8.01%	60,952	12.14%

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[2] http://www.mrlc.gov/

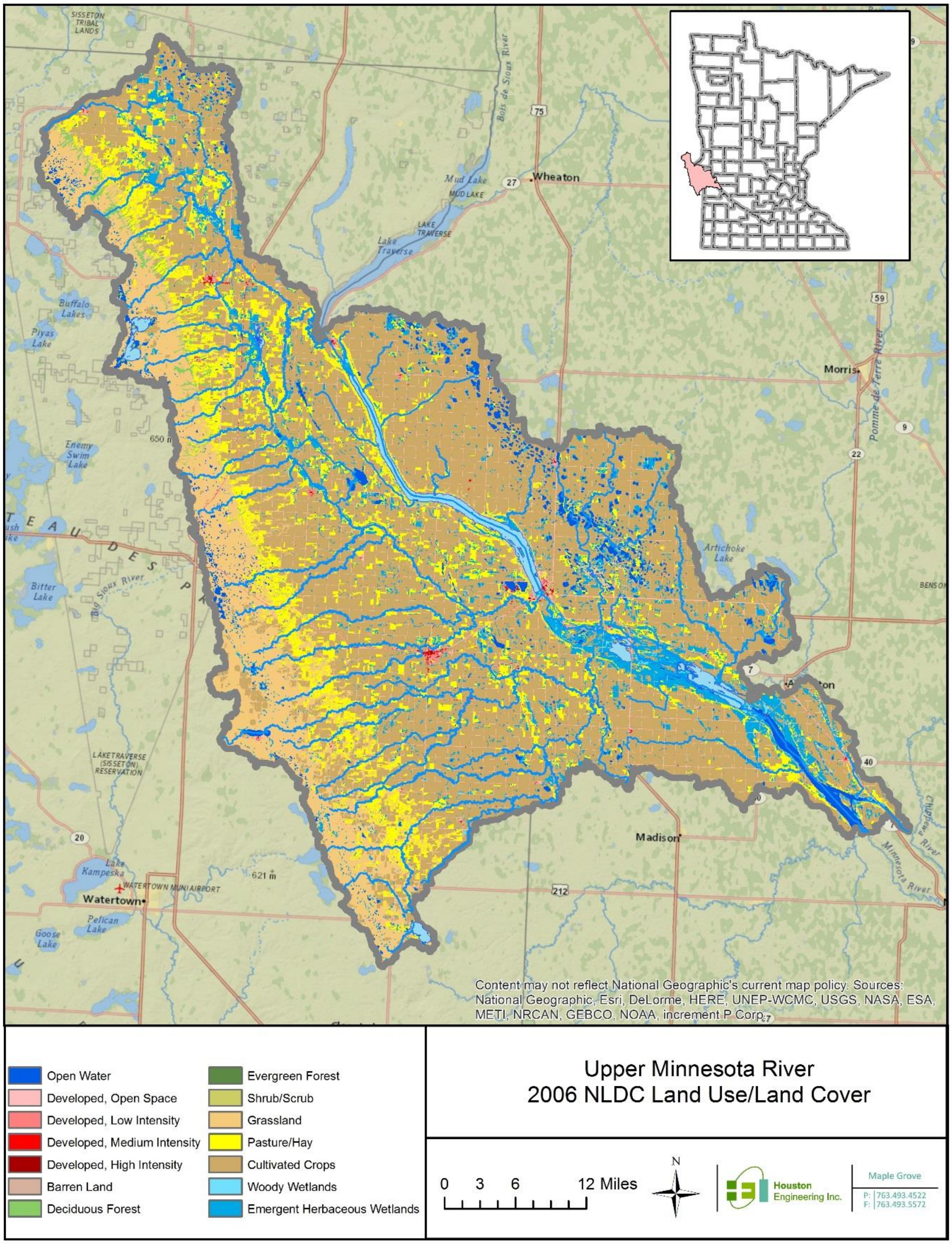


Figure 1. Land Use/Land Cover in the UMRW (NLCD 2006).

The Minnesota River-Headwaters and Lac qui Parle HSPF Model

Hydrology and water quality were simulated using the Hydrologic Simulation Program-FORTRAN (HSPF) watershed model. The Upper Minnesota River watershed was modeled as part of the Minnesota River-Headwaters and Lac qui Parle River HSPF model (referred to as the LqP/MRHW HSPF model for the remainder of the memorandum. The LqP/MRHW HSPF model was developed as part of the State's effort to support TMDLs, watershed restoration and protection strategies, and comprehensive watershed planning under Minnesota's Watershed Approach. The HSPF model were developed to simulate hydrology, sediment transport, and water quality, including simulation of dissolved oxygen, temperature, nitrogen and phosphorus at a 12-digit HUC scale.

The model set-up of the LqP/MRHW HSPF is shown in **Figure 2**. In HSPF, a watershed is divided into "model segments", called weather zone, based on the locations of the climate stations. Each model segment uses a unique set of climate data. Each model segment is further divided into subwatersheds with each subwatershed containing one hydrologic reach (lake, reservoir, or river) and roughly the size of a 12-digit HUC. Each modeling segment is composed of multiple HRU called PERLNDs (pervious areas) and IMPLNDs (impervious areas). These PERLNDs and IMPLNDs are typically based on land uses and soil types and a subwatershed can be composed of multiple PERLND/IMPLND types. RO and water quality loadings are simulated for each PERLND/IMPLND in a modeling segment, i.e. the same flows and loadings are used across all subwatersheds in a modeling segment for each individual PERLND/IMPLND type. The amount of RO and loading differ between subwatersheds based on differing acreage of each PERLND/IMPLND type.

Figure 2 shows the set-up of the LqP/MRHW HSPF model, including both the Minnesota River-Headwaters and Lac qui Parle watersheds. The LqP/MRHW HSPF model is composed of six modeling segments, or weather zones (**Figure 2**), and further divided into 145 subwatersheds, 90 in the Upper Minnesota River Watershed and 55 in the Lac qui Parle River Watershed. Each modeling segment, is divided by up to 23 pervious HRUs (PERLNDs) and three impervious HRUs (IMPLND) (see **Table 2**), for a total of 138 possible PERLNDs and 18 IMPLNDs in the HSPF model (see **Figure 3**). It should be noted, impervious areas (IMPLND) and tillage and drainage practices in croplands are taken as a percentage of area and not represented as separate HRUs in **Figure 3.**

The LqP/MRHW HSPF was developed to simulate hydrology, sediment transport, and water quality for the period 1993-2012. Unit RO, TP, total nitrogen (TN), and total sediment (TS) were extracted at the HRU scale and the subwatershed (reach) scale and used to develop this source assessment and priority rankings. For each water quality parameter, four maps were created to show the sources of each parameter. They include an annual average yield map at the HRU scale, an average annual yield at the subwatershed scale, a prioritization map developed for several stressors including altered hydrology (expressed as RO), excess nutrients (TP, TN) and turbidity and habitat alteration/geomorphology (TS), and a FSI map, which compares the water quality load delivered to the stream to the flux in the channel segment and highlights sources and sinks in the watershed.

The HRU and subwatershed yield maps can be used to complete pollutant sources assessments. They show which land segments and subwatersheds are the largest sources of RO, nutrients and sediment per area and time (annual average) delivered to the channel (edge of field) and maps the different stressors, which can lead to impairment. These maps were generated by extracting the flow and loadings from each PERLND and IMPLND, averaging the annual total flows and loads over the modeling period (1995 through 2012) for each PERLND/IMPLND, and using the areas of each PERLND/IMPLND in each subwatershed to get a subwatershed unit area, annual average yield. The HRU and subwatershed yields maps are provide below by parameter (RO, TP, TN, and TS).

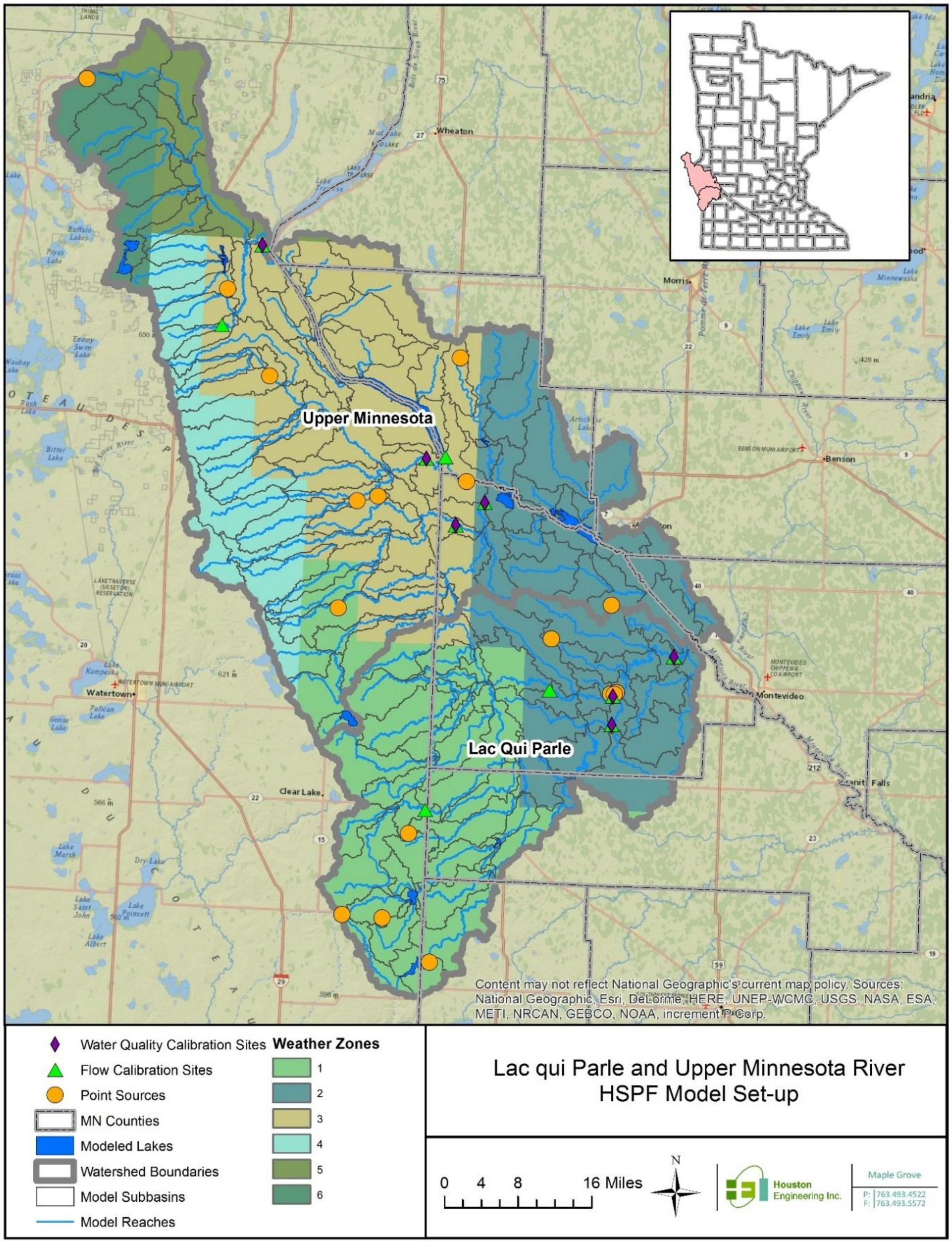


Figure 2. Model set-up for the LqP/UMRW HSPF model.

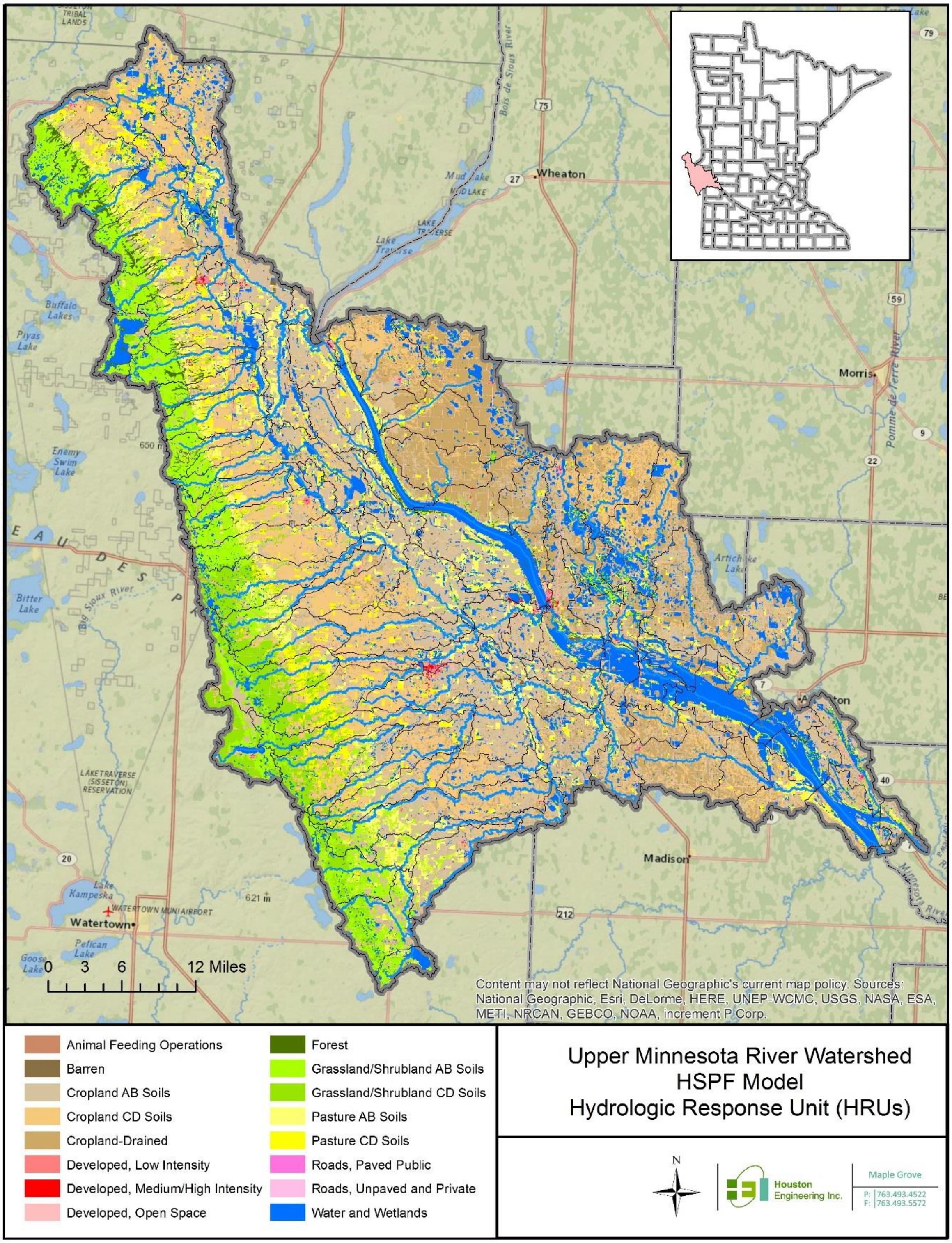


Figure 3. Hydrologic Response Units (HRUs) for the Upper Minnesota River Watershed HSPF model.

Table 2. Description of the base HRUs in the MRHW/LqP HSPF model (TetraTech 2016).

HRU Description	HSG	Base Number	Acres	Data Source(s)
Water and Wetlands	CD	101	236,910	Directly from NLCD (Merge Open Water & Wetlands)
Developed, Open Space	-	102	74,864	Directly from NLCD
Developed, Low Intensity	-	103	6,320	Directly from NLCD
Developed, Medium/High Intensity	-	104	2,505	Directly from NLCD (Merge Medium and High Density)
Barren	CD	105	2,090	Directly from NLCD
Forest	-	106	29,268	NLCD Forest Codes (Deciduous, evergreen, mixed)
Grassland/Shrubland AB Soils	AB	107	171,464	NLCD Herbaceous/Shrub + SSURGO HSG Overlay
Grassland/Shrubland CD Soils	CD	108	99,649	NLCD Herbaceous /Shrub + SSURGO HSG Overlay
Pasture AB Soils	AB	109	136,413	NLCD Pasture + SSURGO HSG Overlay
Pasture CD Soils	CD	110	96,471	NLCD Pasture + SSURGO HSG Overlay
Cropland AB Soils, Conventional Tillage, Nonmanured	AB	111	346,868	NLCD Cultivated Crops + HSG Overlay, TTS, USDA
Cropland CD Soils, Conventional Tillage, Nonmanured	CD	112	275,350	NLCD Cultivated Crops + HSG Overlay, TTS, USDA
Cropland-Drained, Conventional Tillage	-	113	182,202	NLCD Cultivated Crops + HSG Overlay, TTS, USDA
Roads, Paved Public	-	116	3,171	TIGER Primary, Secondary, and Local Streets (9m)
Roads, Unpaved and Private	-	117	20,273	TIGER Private Road and Vehicular Trail (9m)
Animal Feeding Operations	-	118	619	MPCA Feedlot layer, CAFO = No
Cropland AB Soils, Conservation Tillage, Nonmanured	AB	119	104,173	NLCD Cultivated Crops + HSG Overlay, TTS, USDA
Cropland CD Soils, Conservation Tillage, Nonmanured	CD	120	71,738	NLCD Cultivated Crops + HSG Overlay, TTS, USDA
Cropland-Drained, Conservation Tillage	-	121	149,905	NLCD Cultivated Crops + HSG Overlay, TTS, USDA
Cropland AB Soils, Conventional Tillage, Manured	AB	122	37,230	NLCD Cultivated Crops + HSG Overlay, TTS, USDA
Cropland-Drained, Conventional Tillage, Manured	-	123	18,587	NLCD Cultivated Crops + HSG Overlay, TTS, USDA

The priority rankings maps use the information in the yield maps to identify specific priority subwatersheds, which should be preferentially considered for targeting fields for practice implementation based solely on water quality. These maps were developed by taking the yields at the watershed and major tributary scales and ranking them smallest to largest and calculating their percentile rank. The ranks are summarized as the lowest implementation priority (lowest 10%), low priority (10% to 25%), moderate priority (25% to 75%), high priority (75% to 90%), and highest priority (highest 10%). The highest priority subwatersheds with the highest yields and most likely would benefit the most from implementation and protective strategy management.

The FSI maps highlights stream reaches that are sinks or sources of a pollutant combined with a ratio between in-channel sources to overland sources. The FSI also provides guidance, subject to field verification, about where field practices rather than in-stream implementation activities, provide the largest potential water quality benefit. These maps show the magnitude of field source loads relative to in-stream sources and are taken as the overland field load divided by the in-channel flux. Positive numbers represent a source of in-stream materials and a negative number represents a sink for in-stream materials. If the FSI is between -1 and 1, the dominate processes in the subwatershed are in-channel, meaning the in-channel flux is larger than the overland sources. If the FSI is less than -1 or greater than 1, field sources are larger than the in-stream sources. FSI maps where created for TP, TN, and TS.

Finally, in addition to the priority rankings maps, an overall water quality index (WQI) map was generated. The WQI (**Figure 19**) represents the combined importance of nutrients and sediment and is estimated using:

WQI = 0.5*Sediment Ranking + 0.25*TP Ranking + 0.25*TN Ranking

These maps should be used when the practitioner wishes to consider establishing priority based on both excess nutrients and sediment as stressors.

Unit Runoff

Unit RO is the depth of water running off the landscape that reaches the channel. Unit RO is used to show areas that contribute to the stressor “altered hydrology” and may benefit from practices and strategies that impact hydrology. In HSPF, RO from a land segment has three components: surface RO, interflow, and active groundwater flow. For PERLNDs, RO is taken as the sum of the three flow components and is outputted. RO from IMPLNDs only has a surface RO component. In-channel (RCHRES) streamflow was not used in this analysis. **Table 3** provides a list of the HSPF outs used to estimate unit RO.

Table 3. HSPF parameters used to describe unit runoff.

WQ Parameter	Description	Volume	Group	Variable	x1	x2	Factor
Unit Runoff	Total runoff from pervious areas	PERLND	PWATER	PERO	1	1	
	Surface water runoff for impervious areas	IMPLND	IWATER	SURO	1	1	

Figure 4 shows the annual average (1995 through 2012) RO depths by HRU. **Figure 5** shows the annual average (1995 through 2012) RO depths by subwatershed. **Figure 6** shows the subwatershed prioritization for the stressor “altered hydrology” based on annual average (1995 through 2012) RO depths by subwatershed. **Figure 6** shows the subwatersheds with the highest average RO depths.

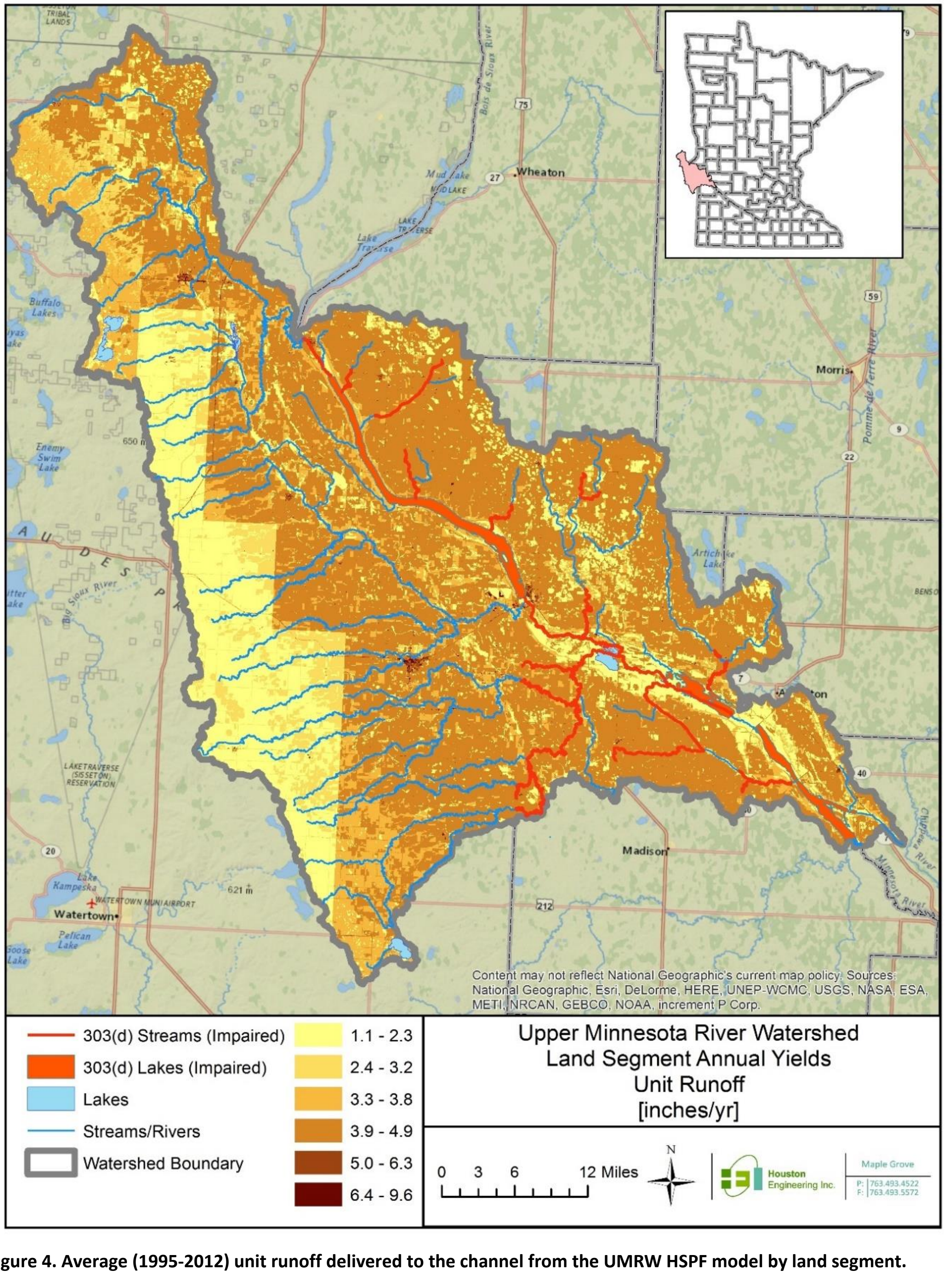


Figure 4. Average (1995-2012) unit runoff delivered to the channel from the UMRW HSPF model by land segment.

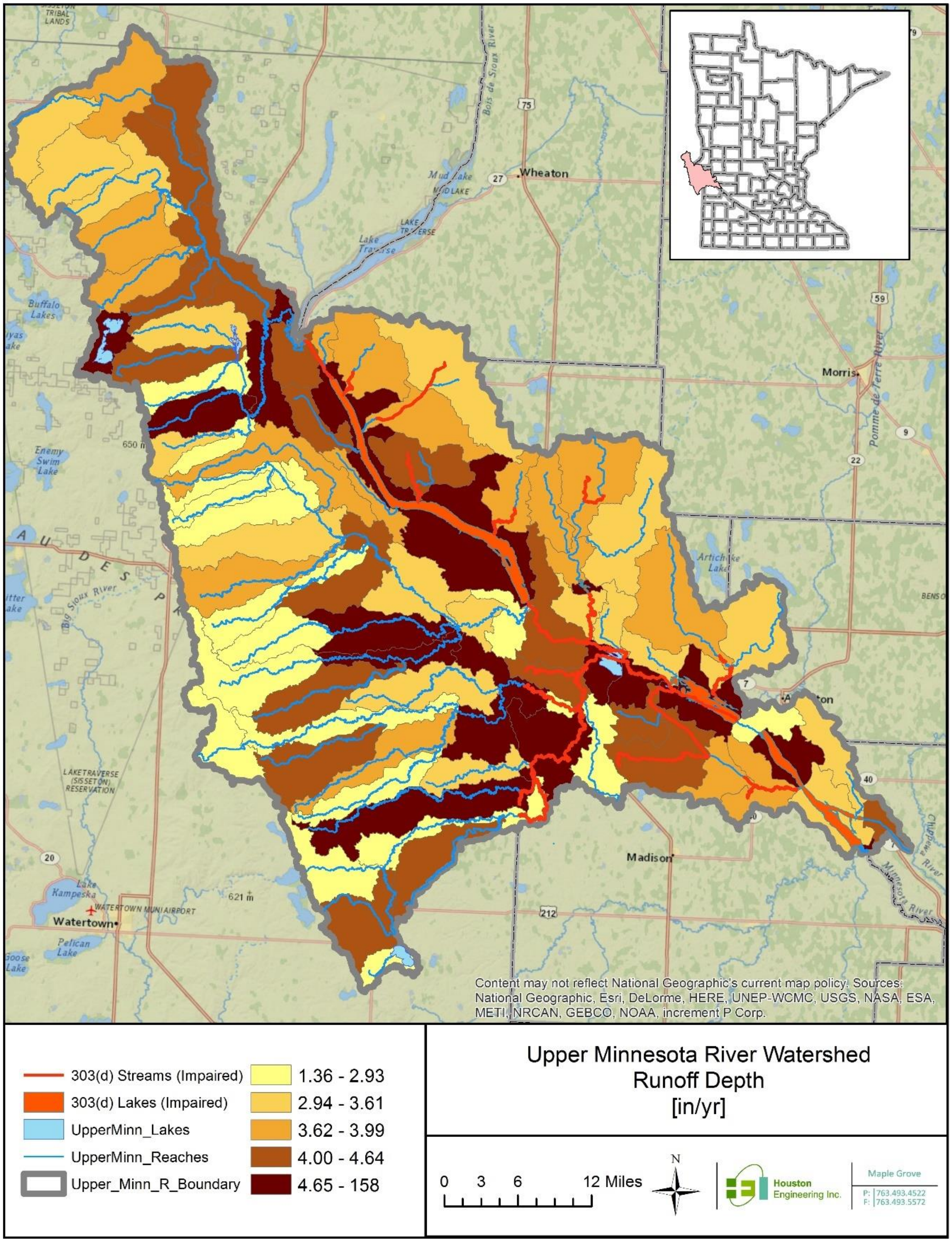


Figure 5. Average (1995-2012) unit runoff delivered to the channel from the UMRW HSPF model by subwatershed.

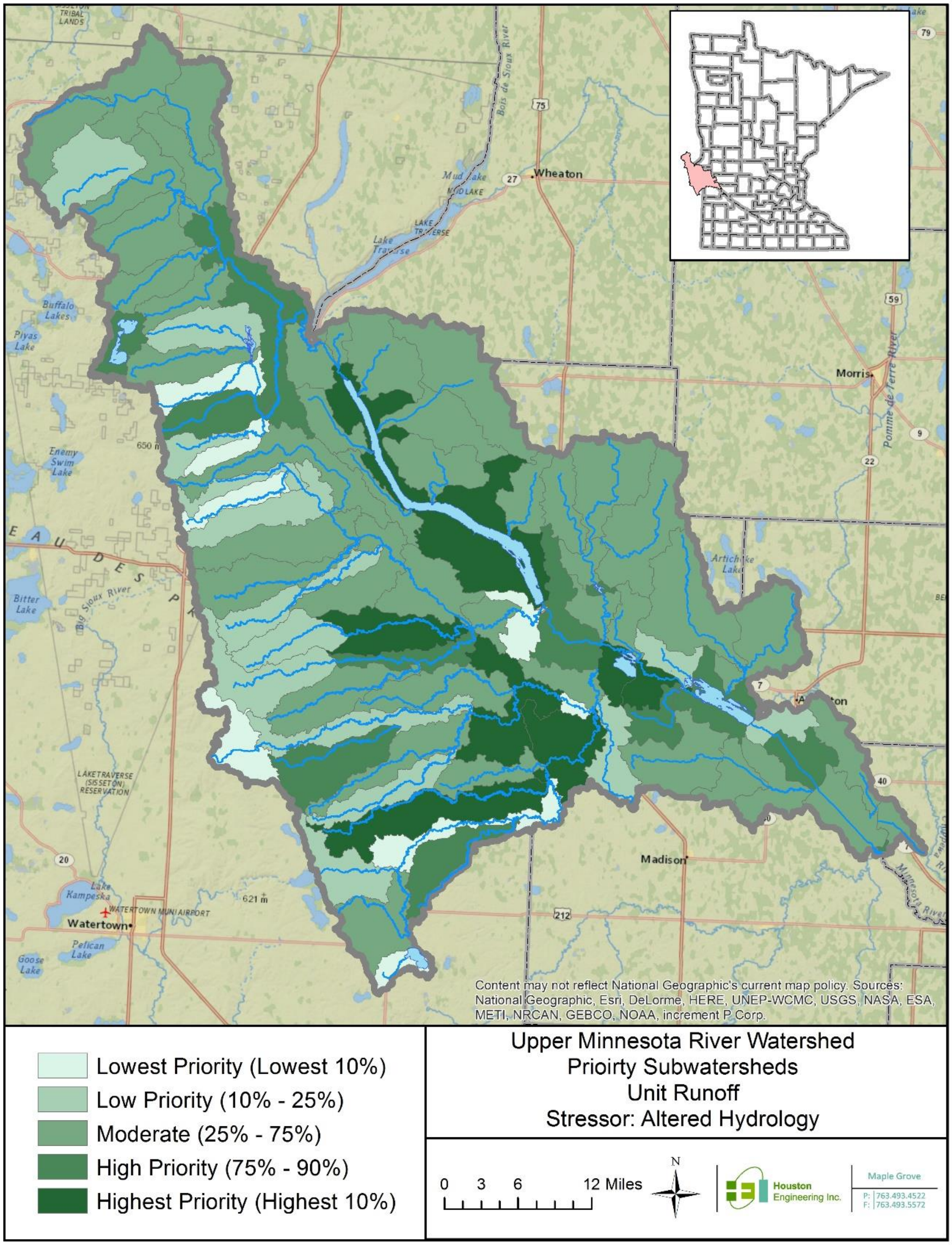


Figure 6: Watershed scale subwatershed priority for implementation for the stressor altered hydrology, using average (1995-2012) annual unit runoff.

Total Phosphorus

TP is a nutrient that contributes to the eutrophication of lakes and streams. **Table 4** provides the HSPF parameters used to determine the TP yields. In HSPF, overland TP loading is the sum of inorganic phosphorus loading and organic phosphorus loading. Inorganic phosphorus is simulated directly using the PQUAL group. Inorganic phosphorus is taken as a fraction of the organic material simulated as biological oxygen demand (BOD). For pervious land segments (PERLNDs), differing factions of organic phosphorus is used for surface RO, interflow, and active groundwater flow (see **Table 4**). In channel TP loading has various forms but can be extracted from HSPF as TP using the PLANK group. In channel TP flux is taken as the difference between TP inflow and TP outflow for the hydrologic reach. Units for TP yields are in lbs/acre/year.

Table 4. HSPF parameters used to describe total phosphorus.

WQ Parameter	Description	Volume	Group	Variable	x1	x2	Factor
Total Phosphorus	Total flux of inorganic P (PO4)	PERLND	PQUAL	POQUAL	3	1	
	Portion of BOD composed of organic P in Surface runoff	PERLND	PQUAL	SOQUAL	4	1	0.003
	Portion of BOD composed of organic P in active groundwater	PERLND	PQUAL	AOQUAL	4	1	0.003
	Portion of BOD composed of organic P in interflow	PERLND	PQUAL	IOQUAL	4	1	0.003
	Total flux of inorganic P (PO4)	IMPLND	IQUAL	SOQUAL	3	1	
	Portion of BOD composed of organic P in Surface runoff	IMPLND	IQUAL	SOQUAL	4	1	0.003
	Total inflow of TP	RCHRES	PLANK	TPKIF	5	1	
	Total outflow of TP	RCHRES	PLANK	TPKCF1	5	1	

Figure 7 shows the annual average (1995 through 2012) TP yields delivered to the channel by HRU. **Figure 8** shows the annual average (1995 through 2012) TP yields delivered to the channel by subwatershed. **Figure 9** shows the subwatershed prioritization for the stressor “excessive nutrients” based on annual average (1995 through 2012) TP yields by subwatershed. **Figure 9** shows the subwatersheds with the highest average TP yields. **Figure 10** shows the Field Stream Index (FSI) for TP and indicates the stream reaches that are sources and sinks for TP and the subwatersheds where overland sources of TP dominate and where in-channel processes dominate. Overall, the stream reaches in the Upper Minnesota River are TP sinks.

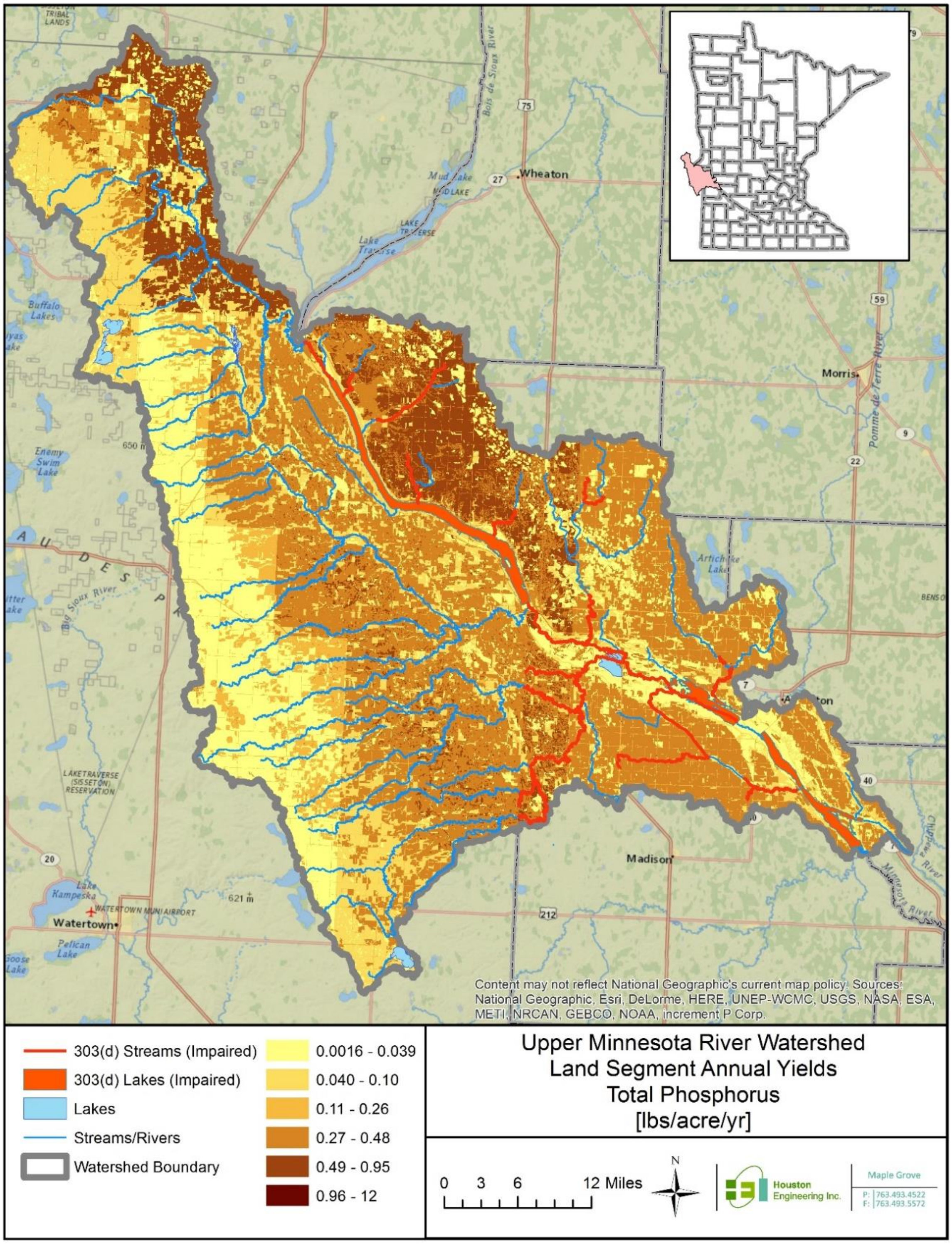


Figure 7. Average (1995-2012) total phosphorus yield (lbs/acre/yr) delivered to the channel from the HSPF model by land segment.

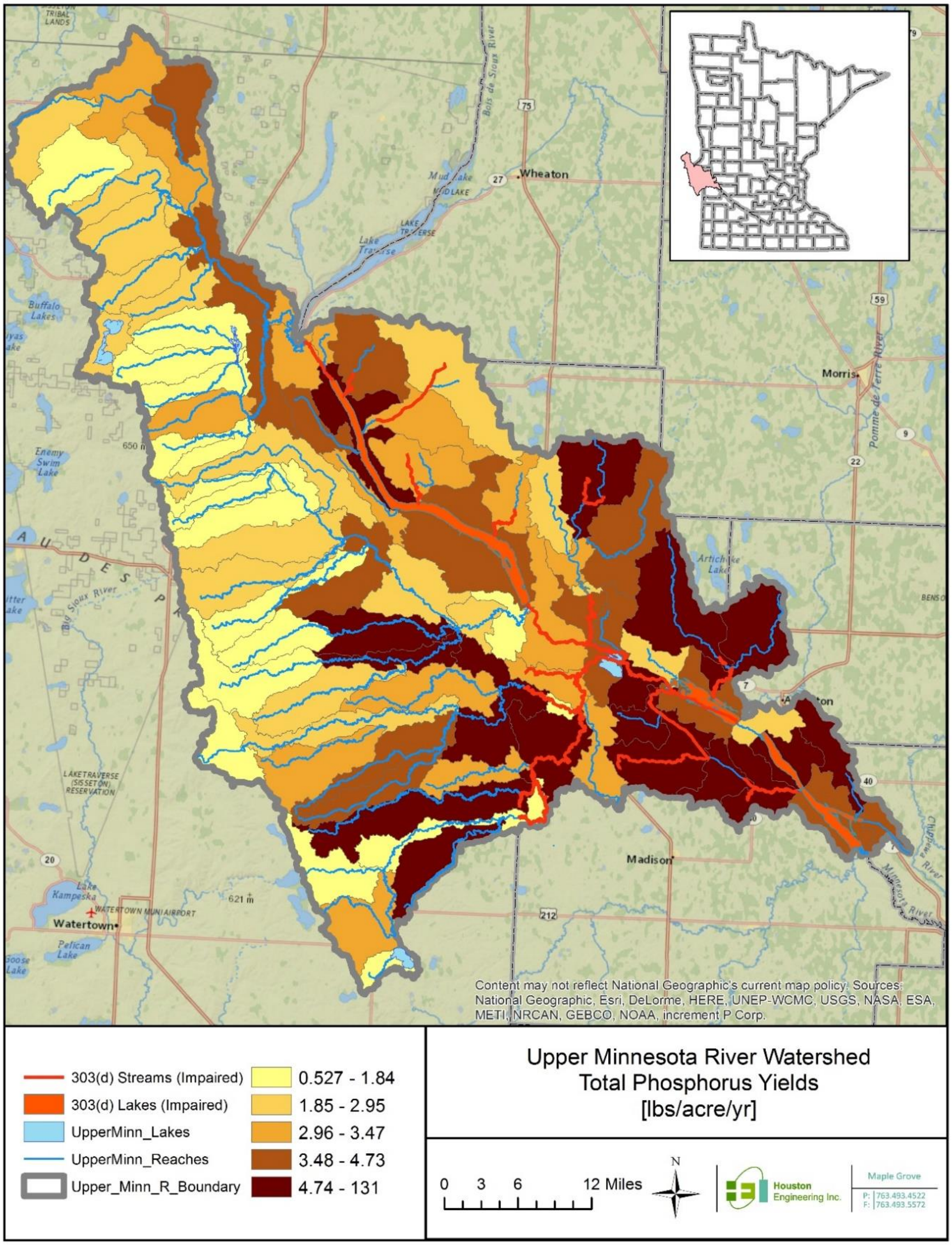


Figure 8. Average (1995-2012) total phosphorus yield (lbs/acre/yr) delivered to the channel from the HSPF model by subwatershed.

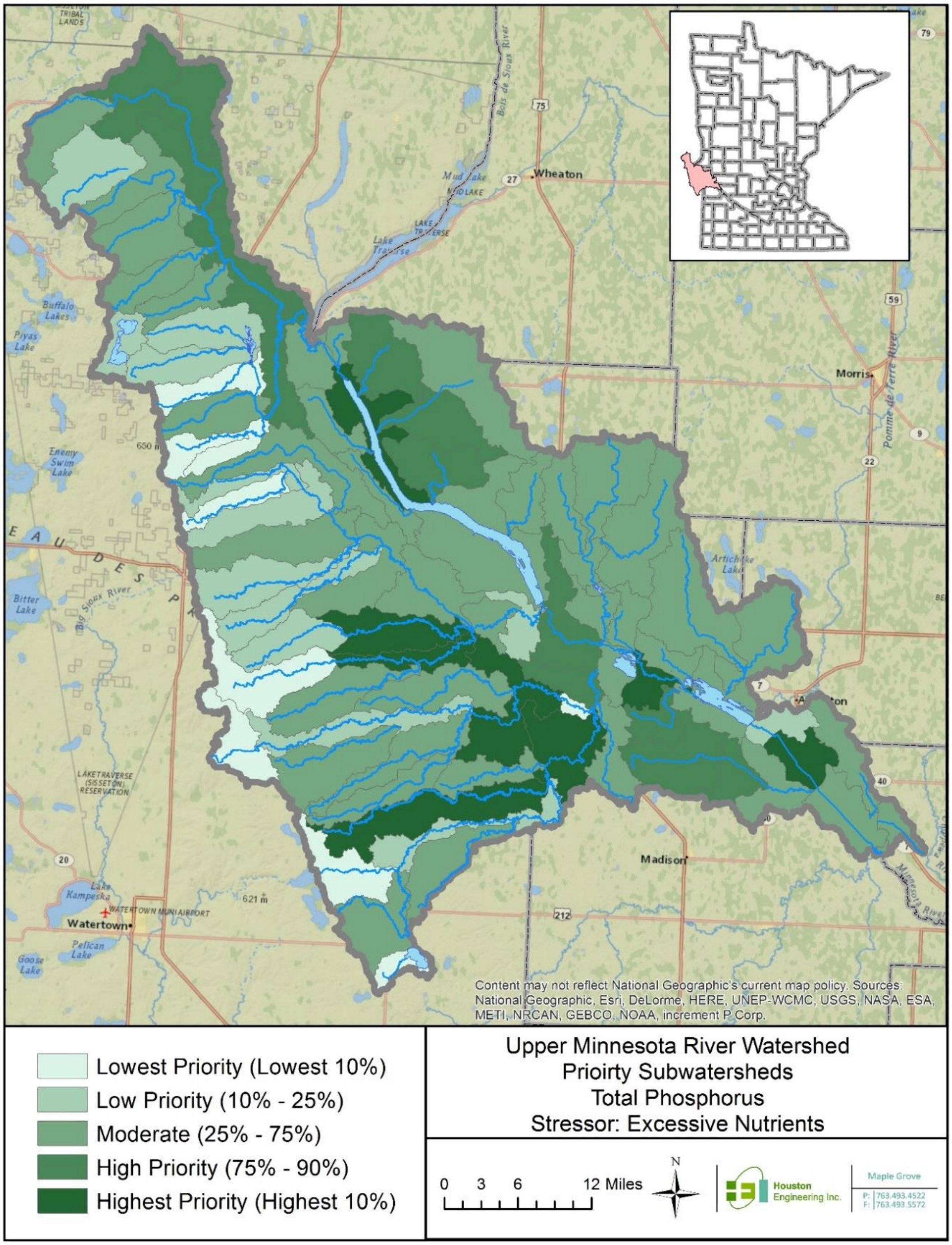


Figure 9: Watershed scale subwatershed priority for implementation for the stressor excessive nutrients, using average (1995-2012) total phosphorus yields.

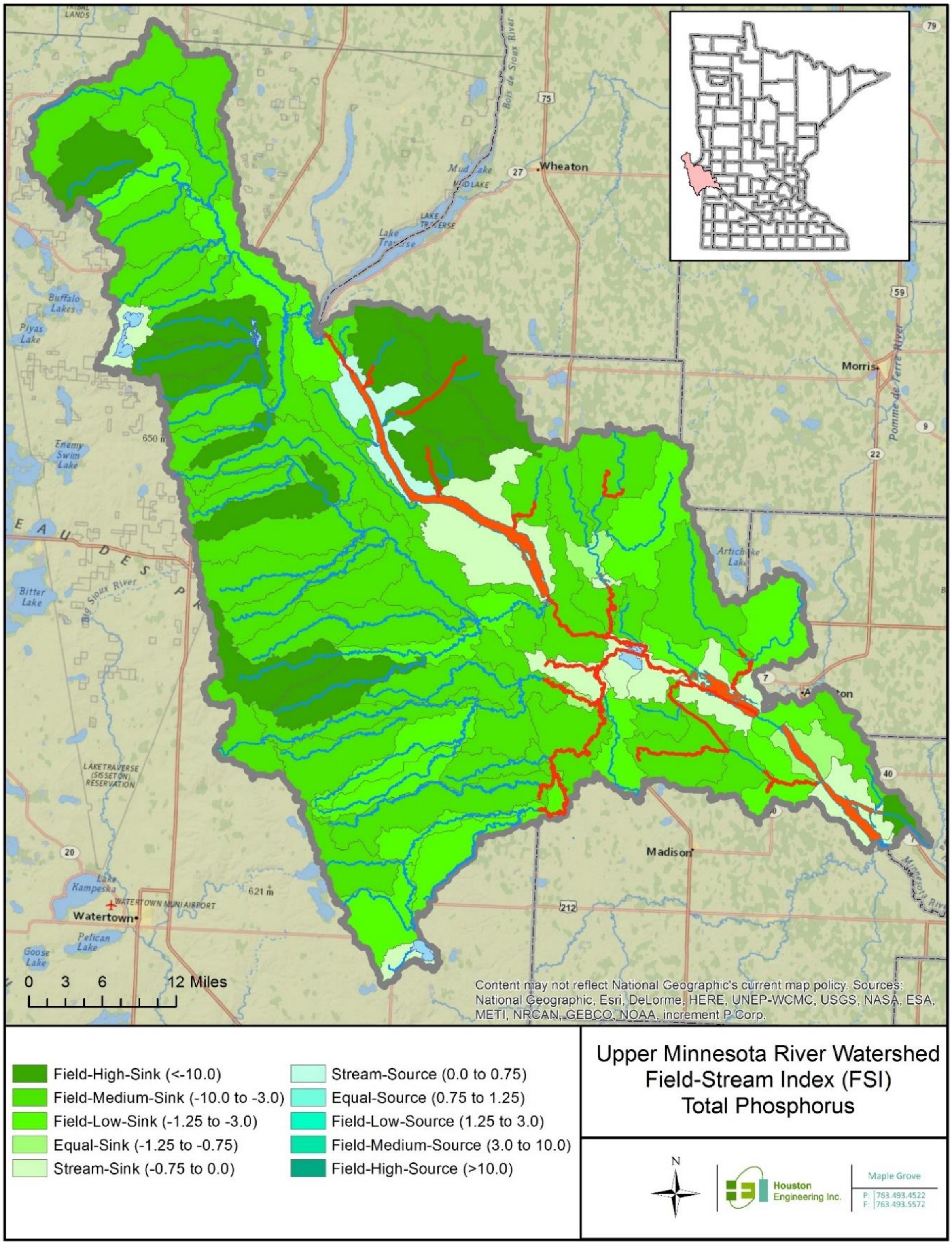


Figure 10: Watershed scale subwatershed priority for implementation of field and stream practices (Field Stream Index) for the stressor excess nutrients using total phosphorus (1996-2009) annual average load.

Total Nitrogen

Like phosphorus, TN is a nutrient that contributes to eutrophication. The HSPF parameters used to estimate TN are provided in **Table 5**. Overland TN has multiple forms and is taken as the summation of ammonia (NH3), nitrate-nitrite (NO2NO3), and organic nitrogen loadings. NH3 and NO2NO3 are simulated directly using the PQUAL group. Organic nitrogen is taken as a fraction of the organic material simulated as BOD with varying fractions for different flow types (surface RO, interflow, and active groundwater) (see **Table 4**). In channel TN loading has various forms but can be extracted from HSPF as TN using the PLANK group. In channel TN flux is taken as the difference between TN inflow and TN outflow for the hydrologic reach. Units for TN yields are in lbs/acre/year.

Table 5. HSPF parameters used to describe total nitrogen.

WQ Parameter	Description	Volume	Group	Variable	x1	x2	Factor
Total Nitrogen	Total flux of Ammonia (NH3)	PERLND	PQUAL	POQUAL	1	1	
	Total flux of Nitrate-Nitrite (NO2NO3)	PERLND	PQUAL	POQUAL	2	1	
	Portion of BOD composed of organic N in Surface runoff	PERLND	PQUAL	SOQUAL	4	1	0.053
	Portion of BOD composed of organic N in active groundwater	PERLND	PQUAL	AOQUAL	4	1	0.057
	Portion of BOD composed of organic N in interflow	PERLND	PQUAL	IOQUAL	4	1	0.053
	Total flux of Ammonia (NH3)	IMPLND	IQUAL	SOQUAL	1		
	Total flux of Nitrate-Nitrite (NO2NO3)	IMPLND	IQUAL	SOQUAL	2		
	Portion of BOD composed of organic N in Surface runoff	IMPLND	IQUAL	SOQUAL	4	1	0.053
	Total inflow of TN	RCHRES	PLANK	TPKIF	4	1	
	Total outflow of TN	RCHRES	PLANK	TPKCF1	4	1	

Figure 11 shows the annual average (1995 through 2012) TN yields delivered to the channel by HRU. **Figure 12** shows the annual average (1995 through 2012) TN yields delivered to the channel by subwatershed. **Figure 13** shows the subwatershed prioritization for the stressor “excessive nutrients” based on annual average (1995 through 2012) TN yields by subwatershed. **Figure 13** shows the subwatersheds with the highest average TN yields. **Figure 14** shows the FSI for TN and indicates the stream reaches that are sources and sinks for TN and the subwatersheds where overland sources of TN dominate and where in-channel processes dominate. Overall, the stream reaches in the Upper Minnesota River are TN sinks.

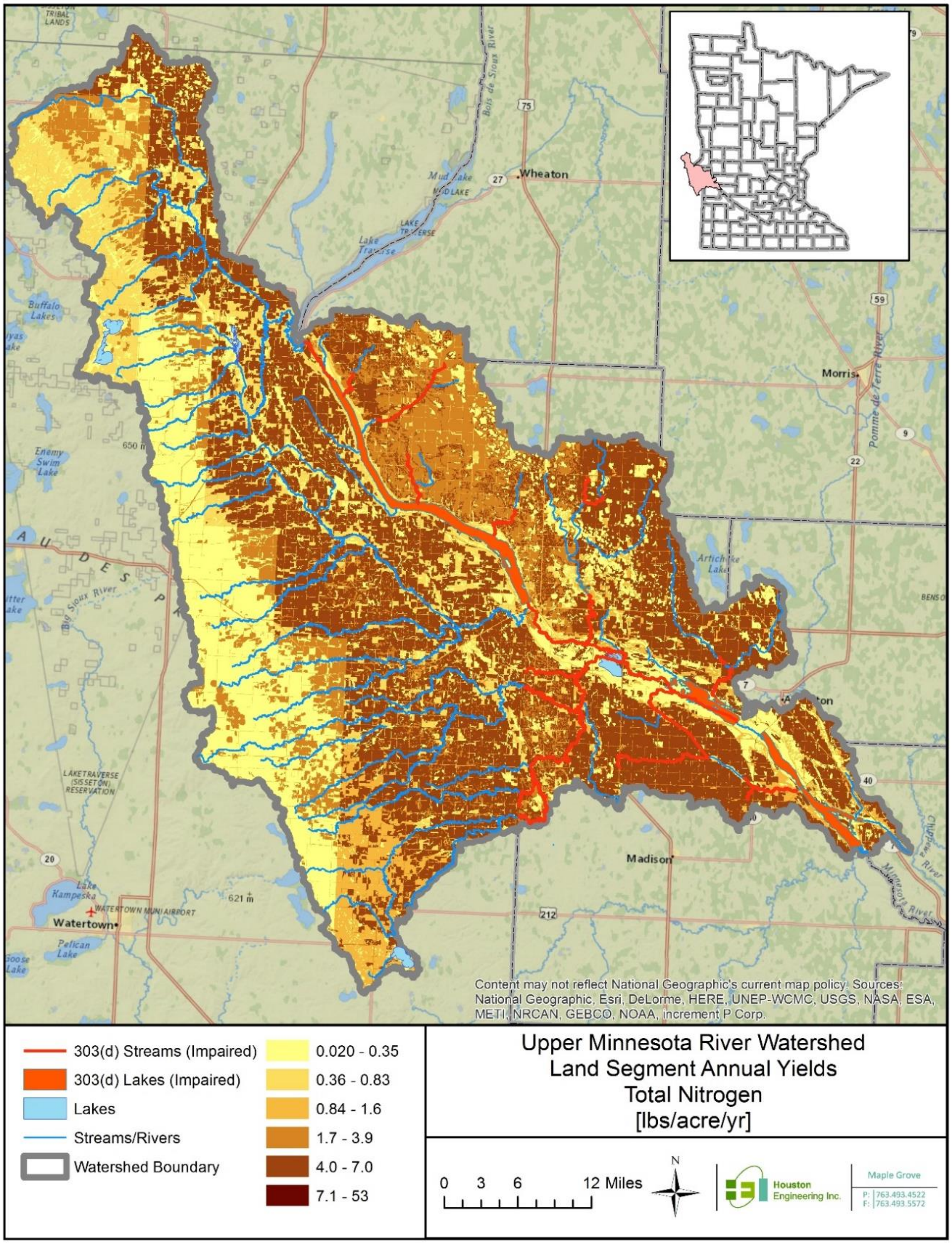


Figure 11. Average (1995-2012) total nitrogen yield (lbs/acre/yr) delivered to the channel from HSPF model by HRU.

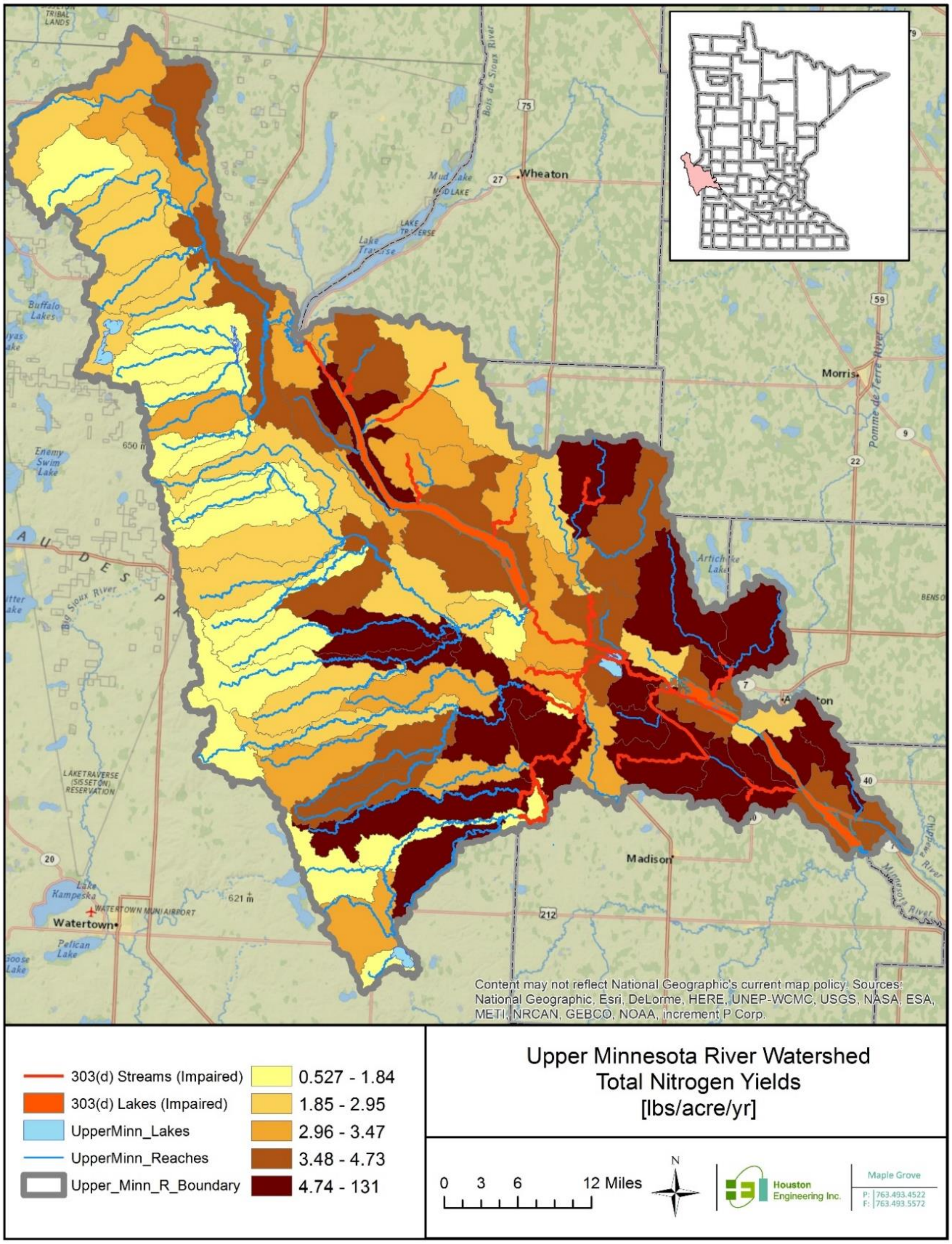


Figure 12. Average (1995-2012) total nitrogen yield (lbs/acre/yr) delivered to the channel from the HSPF model by subwatershed.

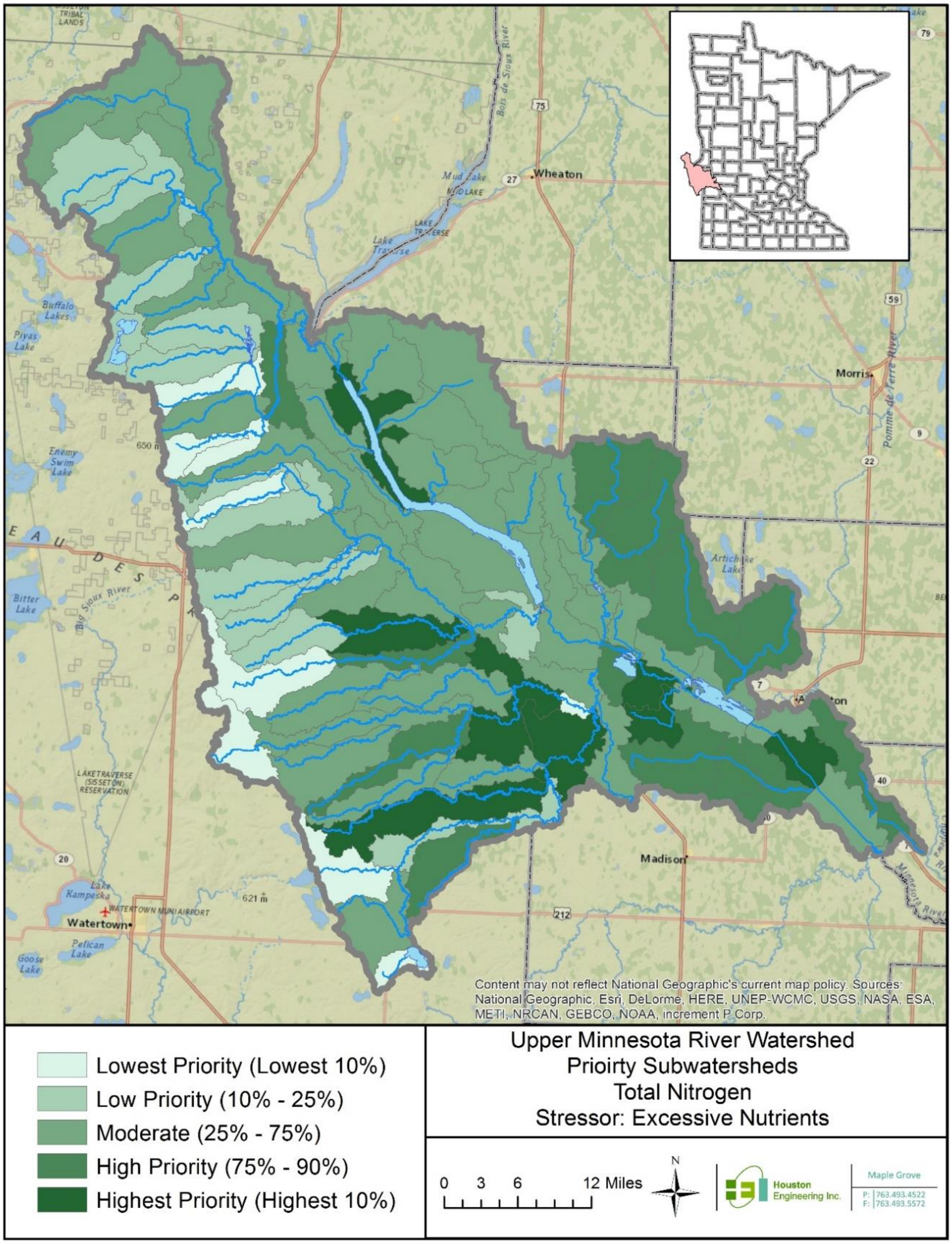
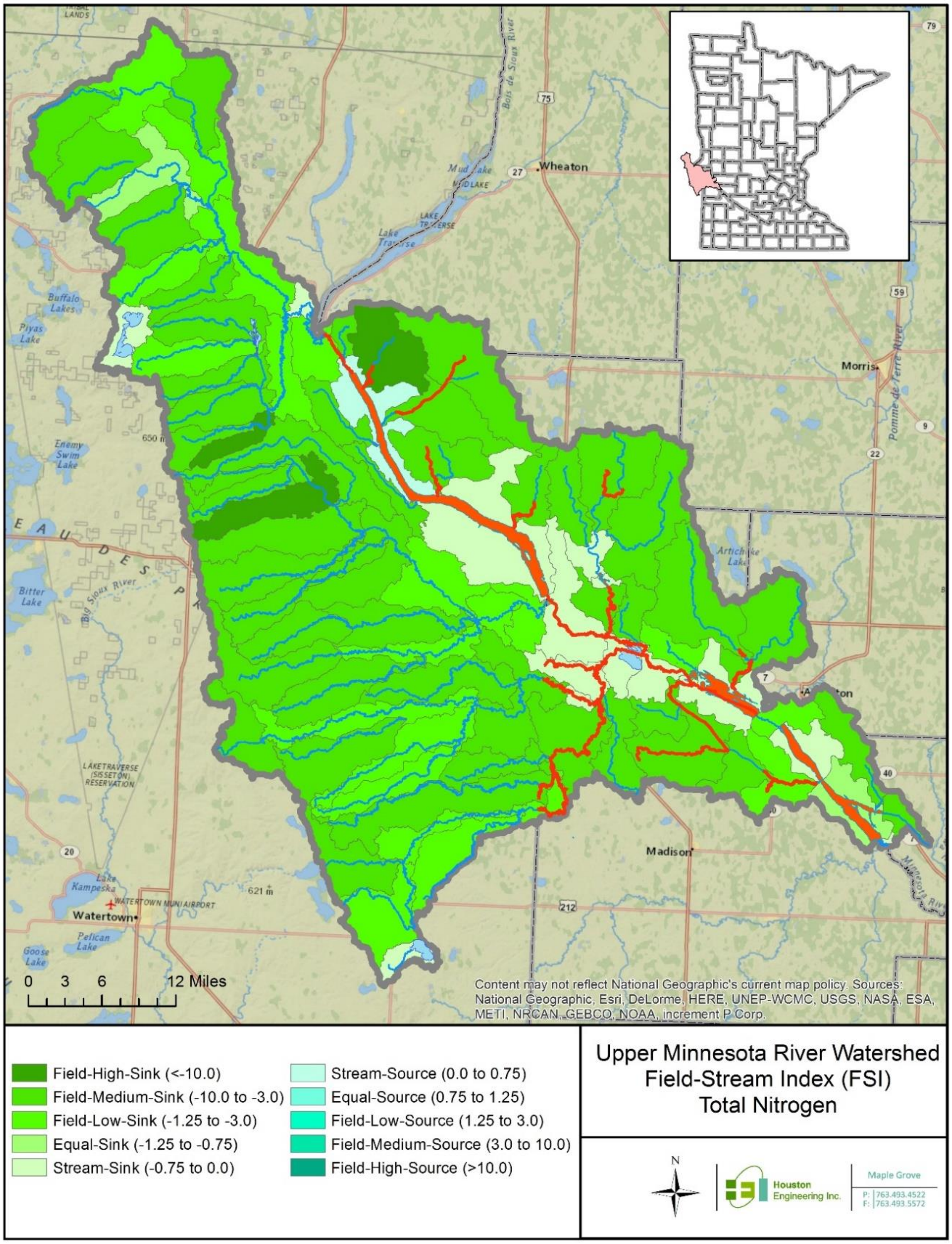


Figure 13: Watershed scale subwatershed priority for implementation for the stressor excessive nutrients, using average (1995-2012) total nitrogen yields.



Content may not reflect National Geographic's current map policy. Sources: National Geographic, Esri, DeLorme, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.

Figure 14: Watershed scale subwatershed priority for implementation of field and stream practices (Field Stream Index) for the stressor excess nutrients using total nitrogen (1996-2009) annual average load.

Total Sediment

TS contributes to the stressors "elevated turbidity" and "loss of habitat" and contributes to turbidity and total suspended sediment impairments. The HSPF parameters used to estimate TS are provided in **Table 6**. Overland sediment can be extracted directly from the HSPF model as TS from overland sources using the SEDMNT group for PERLNDs and SOLIDS group for IMPLNDs. In channel sediment loading and sediment flux can be extracted directly using the SEDTRN group. In channel sediment flux can be taken as the change in bed storage.

Table 6. HSPF parameters used to describe total sediment.

WQ Parameter	Description	Volume	Group	Variable	x1	x2	Factor
Total Sediment	Total Sediment	PERLND	SEDMNT	SOSED	1	1	
	Total Solids	IMPLND	SOLIDS	SOSLD	1	1	
	Inflow of Sediment	RCHRES	SEDTRN	ISED	4	1	
	Outflow Sediment	RCHRES	SEDTRN	ROSED	4	1	
	Sediment Flux/Change in Storage	RCHRES	SEDTRN	DEPSCR	4	1	

Figure 15 shows the annual average (1995 through 2012) TS yields delivered to the channel by HRU. **Figure 16** shows the annual average (1995 through 2012) TS yields delivered to the channel by subwatershed. **Figure 17** shows the subwatershed prioritization for the stressor "elevated turbidity" and "loss of habitat" based on annual average (1995 through 2012) TS yields by subwatershed. **Figure 17** shows the subwatersheds with the highest average TS yields. **Figure 18** shows the FSI for TS and indicates the stream reaches that are sources and sinks for TS and the subwatersheds where overland sources of TS are dominate and where in-channel processes are dominate. Overall, the stream reaches in the Upper Minnesota River are sinks TS.

Water Quality Index

In addition to the priority rankings maps, an overall WQI map was generated. The WQI (**Figure 19**) represents the combined importance of nutrients and sediment and is estimated using:

$$WQI = 0.5*Sediment\ Ranking + 0.25*TP\ Ranking + 0.25*TN\ Ranking$$

These maps should be used when the practitioner wishes to consider establishing priority based on both excess nutrients and sediment as stressors.

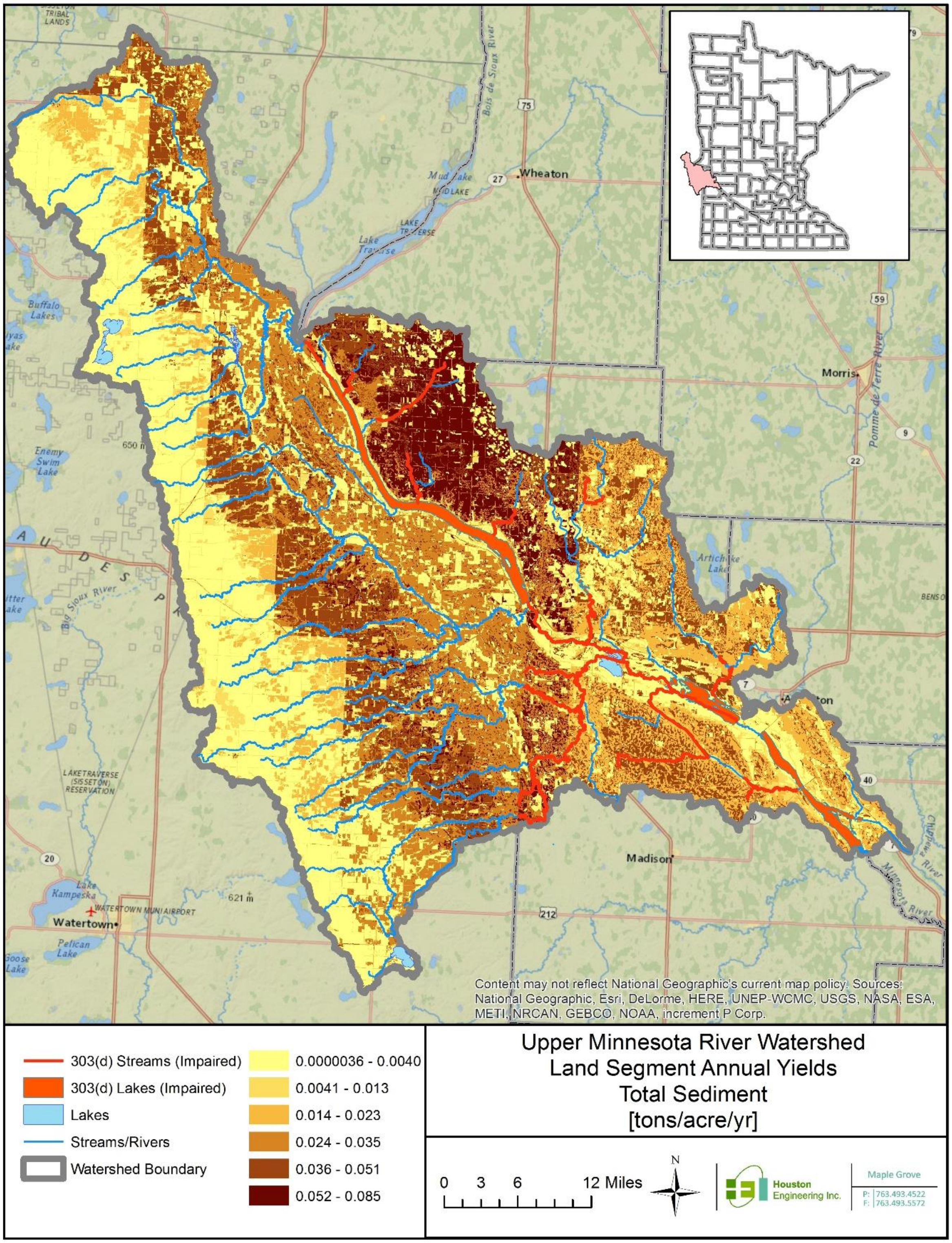


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Figure 15: Average (1995-2012) total sediment yield delivered to the channel from the HSPF model by land segment.

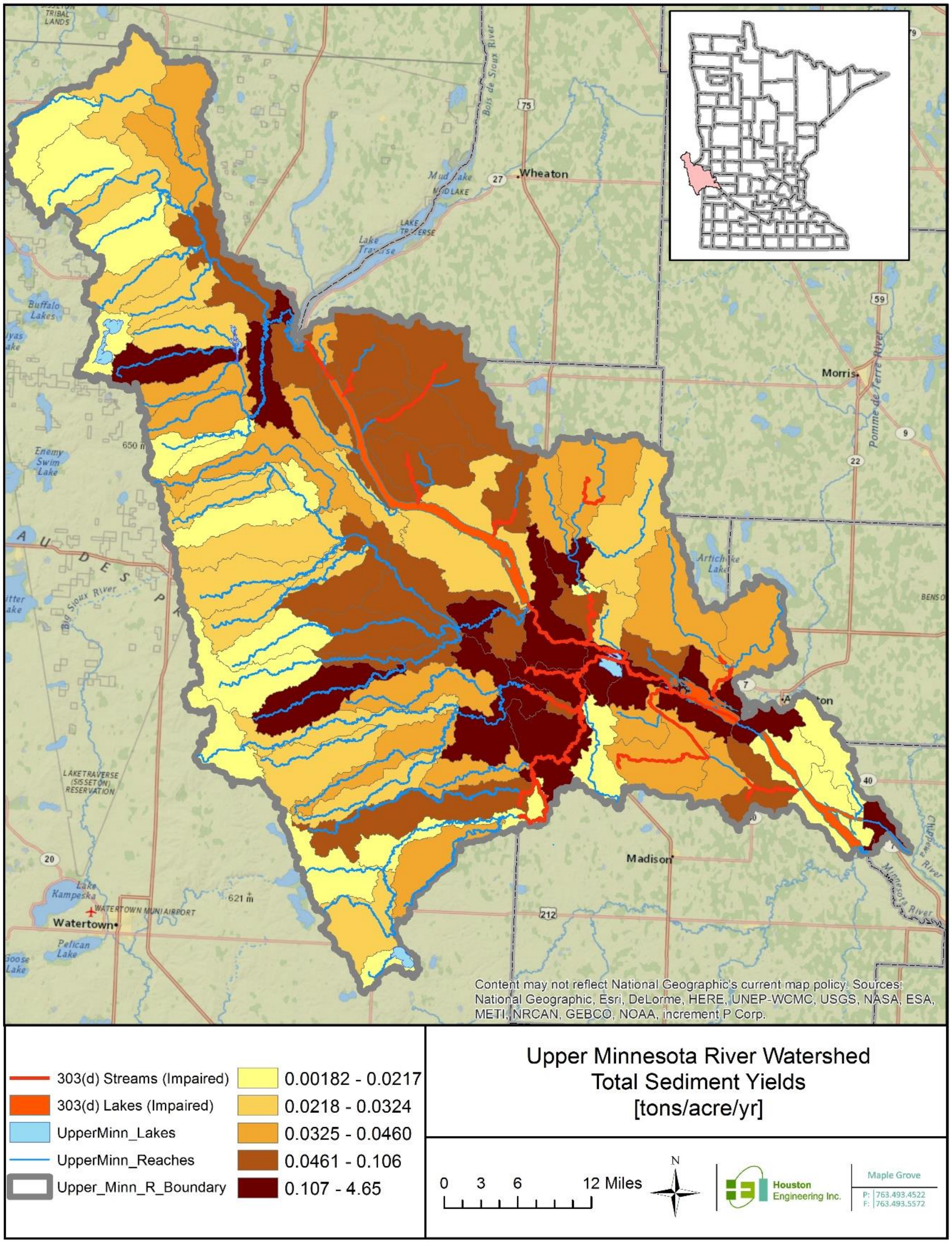

Figure 16: Average (1995-2012) total sediment yield delivered to the channel from the HSPF model by subwatershed.

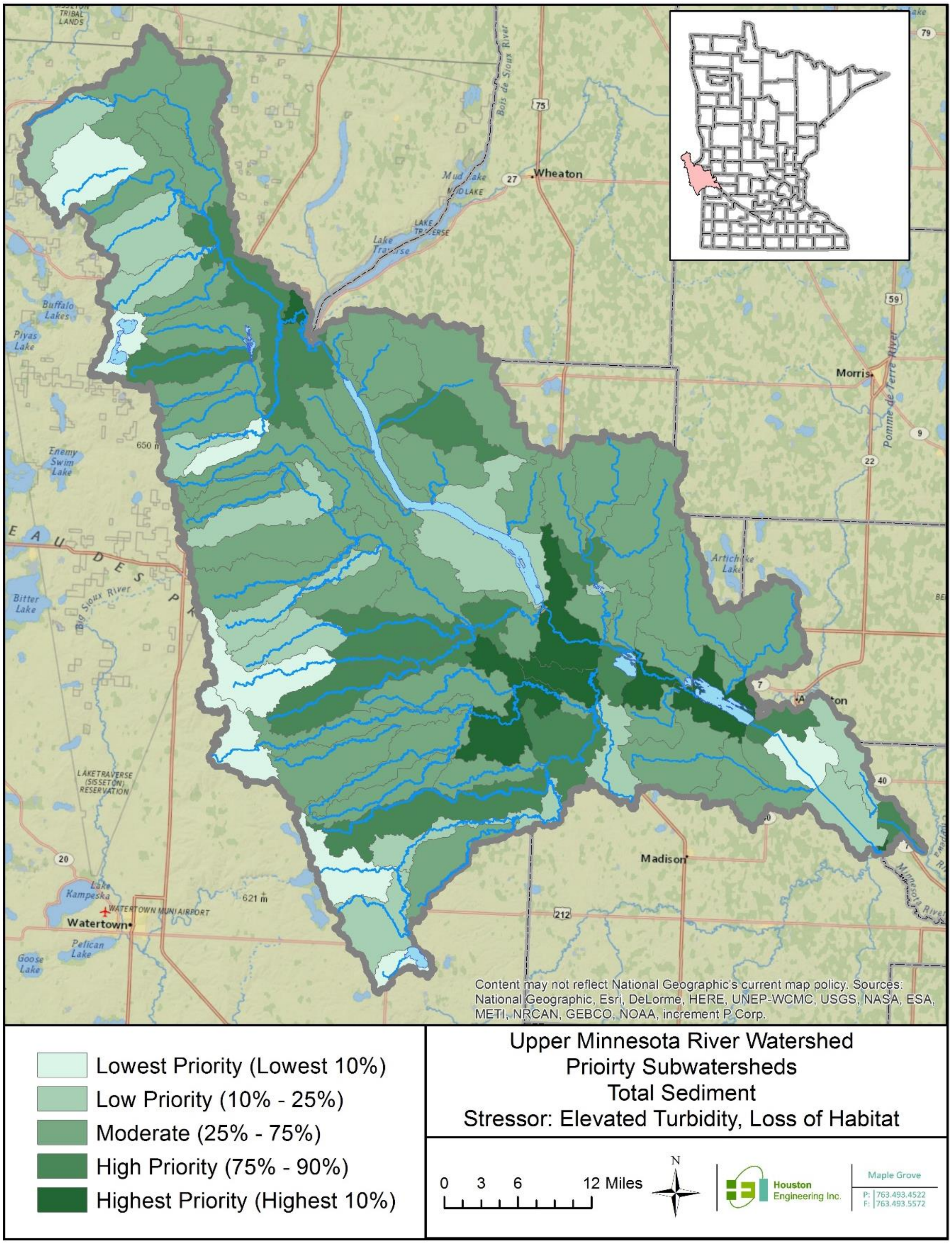

Figure 17: Watershed scale subwatershed priority for implementation for the stressors elevated turbidity and loss of habitat, using average (1995-2012) total sediment yields.

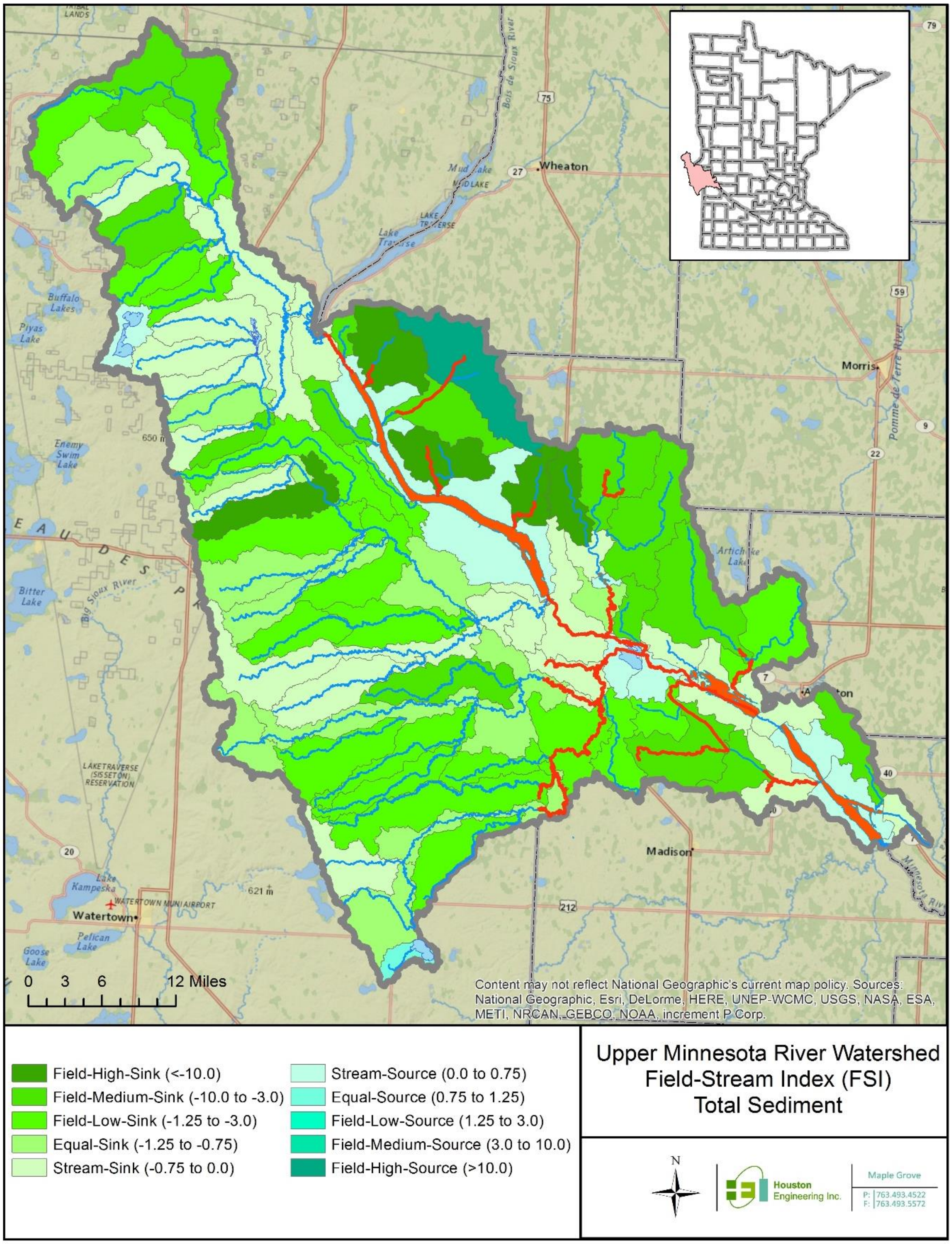

Figure 18: Watershed scale subwatershed priority for implementation of field and stream practices (Field Stream Index) for the stressor elevated turbidity using total sediment (1995-2012) annual average load.

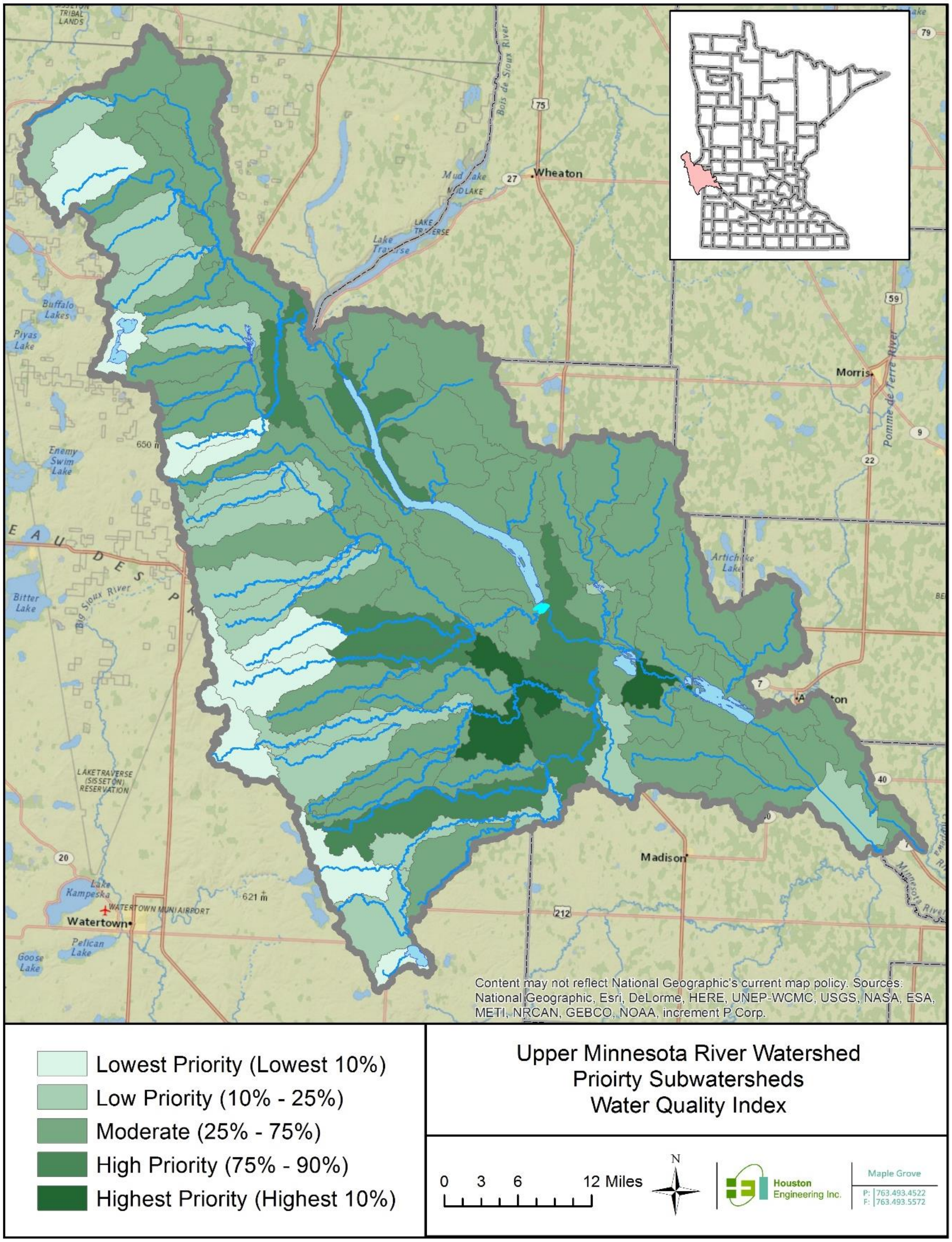

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Figure 19: Watershed scale subwatershed priority for implementation, using the average (1995-2012) water quality index.

Escherichia coli

The relationship between bacterial sources and bacterial concentrations found in streams is complex, driven in part by the amount of precipitation and RO, surface water temperature, the type of livestock management practices, wildlife population abundance and spatial distribution, bacterial survival rates, land use practices, and other environmental factors. These relationships were evaluated to determine the sources of bacteria. To evaluate the potential sources of bacteria delivered to waterbodies, a qualitative bacteria source investigation was conducted based on source population estimates and delivery mechanics.

Sources of Bacteria

Permitted Sources

Wastewater Treatment Facilities

Permitted WWTFs in the State of Minnesota are required to monitor their effluent to ensure that concentrations of specific pollutants remain within levels specified in their National Pollutant Discharge Elimination System (NPDES) discharge permit. In Minnesota, WWTFs are permitted based on fecal coliform, not *E. coli*. Effluent limits require that fecal coliform concentrations remain below 200 organisms/100 mL (MPCA 2002). Based on the previous fecal standard and the current *E. coli* standard, a ratio of 200:126 (0.63) is used to convert fecal coliform to *E. coli*. Therefore, the effluent limit for *E. coli* concentrations remains below 126 organisms/100 mL.

The UMRW contains 11 "minor" (as defined by the MPCA) wastewater treatment plants (WWTPs) and 2 industrial dischargers. Six of the WWTPs are located in Minnesota and five in South Dakota. **Table 7** identifies the NPDES permit dischargers in the UMRW, and their permitted daily discharge flow and permitted daily bacteria load.

Table 7. NPDES permit facilities, permitted flows, and bacteria loads for minor facilities in the UMRW.

NPDES Permit Number	Location Name	State	Permit Type	Avg. Flow (MGD)	Equivalent Bacteria Load as *E. coli*: 126 org/100mL [billion org/day]
SD0026662	Labolt	SD	WWTP	0.07	0.334
SD0020371 SDL020371	Milbank	SD	WWTP	0.59	2.814
SD0022756	Peever	SD	WWTP	0.36	1.717
SD0027987	Valley	SD	Industrial	0.37	NA
SD0020001	Veblen	SD	WWTP	0.68	3.243
SD0021024	Wilmot	SD	WWTP	1.14	5.437
MNG580152	Bellingham	MN	WWTP	0.3	1.431
MNG580193	Clinton	MN	WWTP	0.93	4.435
MNG580091	LacQui	MN	WWTP	0.22	1.049
MN0068764	LGEverist	MN	Noncontact cooling	0.22	NA
MNG580141	Milan	MN	WWTP	0.32	1.526
MNG580099	Odessa	MN	WWTP	0.26	1.240
MNG580151	Ortonville	MN	WWTP	2.31	11.017

NPDES Permitted Concentrated Animal Feeding Operation

The MPCA regulates the collection, transportation, storage, processing, and disposal of animal manure and other livestock operation wastes (MPCA 2011). The MPCA currently uses the federal definition of a CAFO in its regulation of animal facilities. In Minnesota, the following types of livestock facilities are issued, and must operate under, a NPDES Permit: (a) all federally defined (CAFOs); and (b) all CAFOs and non-CAFOs, which have 1,000 or more AUs (MPCA 2010). As required by the permit, NPDES permitted feedlots are required to have no direct discharge to surface waterbodies. Bacteria for manure from any NPDES permitted feedlot is accounted for in the field application of manure.

Nonpermitted

Humans

Subsurface Sewage Treatment Systems

Malfunctioning SSTSs can be an important source of fecal contamination to surface waters, especially during dry periods when these sources continue to discharge and surface water RO is minimal. Malfunctioning SSTSs are commonly placed in two categories: Imminent Public Health Threat (IPHTs) or failing to protect groundwater (i.e., failing). IPHT indicates the system has a sewage discharge to surface water; sewage discharge to ground surface; sewage backup; or any other situation with the potential to immediately and adversely affect or threaten public health or safety. Failing to protect groundwater indicates the bottom of the system does not have the required separation to groundwater or bedrock.

Based on an area-weighted average, the rural population in the UMRW has an estimated 959 systems with inadequate treatment of household wastewater. This includes individual residences and any un-sewered communities. An MPCA document (MPCA 2011) reports numbers from 2000 through 2009 on the total number of SSTSs by county, along with the average estimated percent of SSTSs that are failing versus the percent that are considered IPHTs. The total numbers of SSTSs per county were multiplied by the estimated percent IPHT and percent failing within each area (MPCA 2011) to compute the number of potential IPHTs and potentially failing SSTSs per county. **Table 8** provides the county totals for failing SSTSs and IPHT systems for counties in the UMRW.

Table 8. 2009 SSTS compliance status in the watershed (MPCA 2011).

County	%Area with the watershed	Identified # of SSTSs	2009 Average Estimate of %Failing	# of potentially failing SSTSs	2009 Average Estimate of %IPHT	# of potential IPHTs
Big Stone	85.5%	1,661	24%	399	7%	116
Chippewa	7.3%	2,227	7%	156	51%	1,136
Lac qui Parle	29.2%	1,792	35%	627	0%	0
Stevens	0.6%	1,182	2%	24	30%	355
Swift	7.4%	3,969	50%	1,985	27%	1,072
Traverse	6.7%	846	18%	152	5%	42

Companion Animals

Companion animals, such as dogs and cats, can contribute bacteria to a watershed when their waste is not disposed of properly. Dog waste can be a significant source of bacteria to water resources (Geldreich 1996) at a local level when in the immediate vicinity of a waterbody. It was estimated that 34.3% of households own dogs and each dog owning households has 1.4 dogs (AVMA 2007). Waste from domestic cats is usually collected by owners in the form of litter boxes. Therefore, it is assumed that domestic cats do not supply significant amounts of bacteria on the watershed scale. Feral cats may supply a significant source of bacteria and are accounted for under wildlife. Population estimates of domestic dogs were taken from the 2010 Census as a function of number of households per census block. Distribution of bacteria from companion animals is applied to the developed categories in the NLCD land cover layer (**Figure 1**). The bacteria sources, assumptions, and distribution used to estimate the potential source of bacteria related to humans are listed in **Table 9**.

Table 9: Data sources, assumptions, and distribution of bacteria attributed to humans.

Bacteria Source	Distribution
Un-sewered Communities-Failing and IPHT SSTS Population in un-sewered communities based on 2010 Census Block information. Number of failing and IPHT SSTS from County estimates (MPCA 2011).	The population of un-sewered communities were estimated, based on 2010 Census Block data. Production rates of 1.3 x 10^9 cfu/day/person was used. Total bacteria were applied to Developed land use classes in the NLCD 2006 dataset.
Companion Animals (Dogs only) 34.3% of households own dogs, 1.4 dogs in households with dogs. Populations of dogs was based on the 2010 Census Block data.	An estimated 38% of dog owners do not dispose of waste properly (TBEP 2011). Population distributions are based on 2010 Census Blocks. Production rates of 3.2 x 10^9 cfu/day/dog was used. Total bacteria were distributed among Developed land use classes in the NLCD 2006 dataset.

Livestock

Populations

The USDA National Agricultural Statistics Service (NASS) provides livestock numbers, by county. Estimated numbers are available for cattle, hogs, horses, sheep, goats, and poultry (chicken and turkey) through the U.S. Census of Agriculture. County livestock populations were distributed across the watershed in an area-weighted basis. Livestock waste is distributed throughout the UMRW in four main categories: grazing animals, animal feedlot operations (AFOs), land application of manure, and small operations. Discussion of each of these categories follows.

Livestock - Grazing

Grazing occurs on pastured areas where concentrations of animals allow grasses or other vegetative cover to be maintained during the growing season. The state of Minnesota does not require permitting or registration of grazing pastures. Grazing cattle were assumed to be the total cattle population from the Census of Agriculture (see *Livestock Populations*) minus the cattle of feed.

Livestock - Animal Feedlot Operations

AFOs with less than 1,000, but more than 50, AUs (and are outside of shoreland areas) are regulated by MPCA under a registration program. AFOs with more than 10 AUs and inside shoreland areas are also regulated under this program. Shoreland is defined in Minn. Stat. § 103F.205 to include: land within 1,000 feet of the normal high-watermark of lakes, ponds, or flowages; land within 300 feet of a river or stream; and designated floodplains (MPCA 2010). These smaller facilities are subject to state feedlot rules, which include provisions for registration, inspection, permitting, and upgrading.

Livestock - Land Application of Manure

Manure is often surface applied or incorporated into fields as a fertilizer and soil amendment. The land application of manure has the potential to be a substantial source of fecal bacteria, transported to waterbodies from surface RO and drain tile intakes. Minn. R. ch. 7020 contains manure application setbacks based on research related to nutrient transport, but the effectiveness of these setbacks on bacteria transport to surface waters is unknown. A portion of the livestock population was assumed to supply manure for land application (see **Table 10**).

Livestock – Small Operations

Small-scale animal operations do not require registration and are not included in the MPCA's geographic feedlots (AFOs) database, but should be included in the Census of Agriculture (see *Livestock Populations*). All cattle, goats, horses, sheep, and poultry were treated as partially housed or open lot operations, and literature estimates were used to identify the number of AFOs without RO controls (see **Table 10**). The geographic areas for stockpiling or spreading of manure from these small, partially housed or open lot operations is based on NLCD 2006 *Pasture/Hay* land cover.

Table 10: Data sources, assumptions, and watershed distribution of bacteria from livestock.

Bacteria Sources		Distribution
Grazing Grazing populations estimates for cattle, horses, goats, and sheep were based on NASS Quick Stats (http://www.nass.usda.gov/Quick_Stats/).		Bacteria from grazing animals was applied to pasture classes in the NLCD 2006 dataset.
Animal Feeding Operation (AFO) AFO populations for cattle, goats, hogs, horses, poultry, and sheep are based on NASS Quick Stats (http://www.nass.usda.gov/Quick_Stats/)	Partially Housed or Open Lot without Runoff Controls[3] The proportion of AFO animals that are partially housed or in open lots without runoff controls: - Cattle 50% - Poultry 8% - Goats 42% - Sheep 42% - Hogs 15%	Bacteria from Open Lot AFOs was applied to barren, scrub/shrub, grassland, and pasture classes of the NLCD 2011 dataset.
	Land Application of Manure1 - Cattle 50% - Poultry 92% - Goats 58% - Sheep 58% - Hogs 85%	Land application of manure was distributed across the cropland class of the NLCD 2011 dataset.

Livestock populations were estimated for cattle, chickens, goats, horses, sheep, and turkeys for each county and are provided in **Table 11**. **Figure 20** shows the distribution of animal units (livestock) in the Minnesota portion of the watershed based the MPCA's feedlot dataset.

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[3] Estimates based on Mulla et al. 2001.

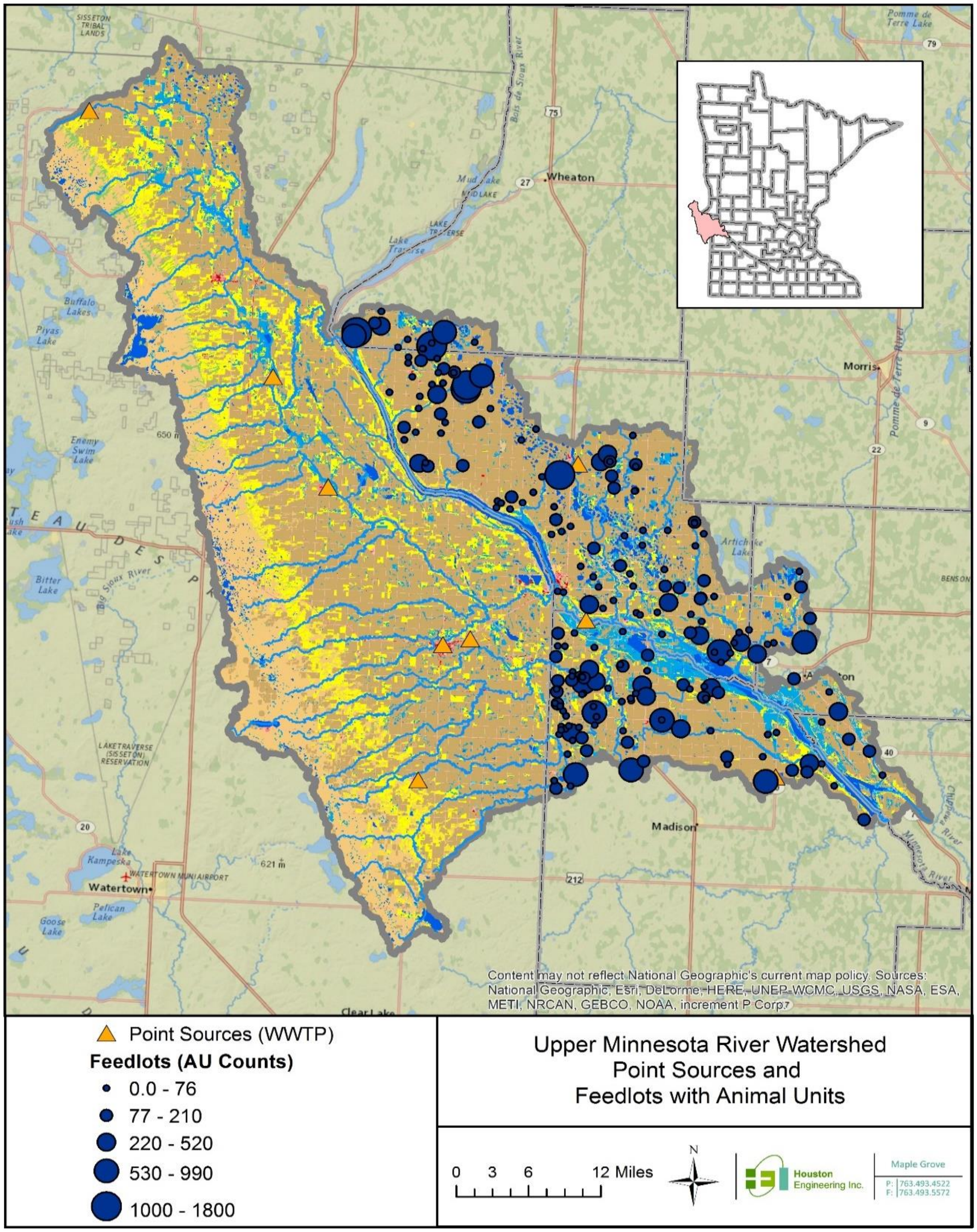


Figure 20. Animal unit counts by feedlot in the UMRW.

Table 11. Livestock population estimates (numbers) in the watershed.

Animal	Type	Big Stone	Chippewa	Lac qui Parle	Stevens	Swift	Traverse
Cattle	Beef	4,632	26,239	14,478	58,455	15,905	5,825
	Cattle on Feed	937	3,710	4,507	11,844	3,871	1,612
Other	Pigs	41,005	50,200	97,508	186,865	13,116	16,966
	Sheep and Goats	646	2,511	2,061	1,162	931	260
	Horses	253	220	435	198	301	121
Poultry	Layers	293	491	251	555	821	522
	Boilers	265	(D)[1]	1,674	880	333	300
	Turkey	(D)[1]	(D)[1]	(D)[1]	(D)[1]	1,942,920	(D)[1]
	Ducks and other	155	(D)[1]	(D)[1]	(D)[1]	465	(D)[1]

[1] Population from single farm, not reported.

Wildlife

Wildlife, especially waterfowl, contribute bacteria to the watershed by directly defecating into waterbodies and through RO from wetlands and fields adjacent to waterbodies, which are used as feeding grounds. In the watershed, land cover which could potentially attract wildlife includes: herbaceous wetlands and row crops adjacent to streams and lakes, wildlife management areas (WMA), and open water. Wildlife contribute bacteria to surface waters by living in waterbodies, living near conveyances to waterbodies, or when their waste is delivered to waterbodies during storm RO events. Areas such as WMAs, state parks, national parks, national wildlife refuges, golf courses, state forest, and other conservation areas provide habitat for wildlife and are potential sources of bacteria due to high densities of animals. Additionally, private land managed for wildlife with practices such as food-plotting or supplemental feeding can concentrate wildlife and have the potential to be a source of bacteria from wildlife sources.

Fate and transport mechanisms differ between wildlife that live in surface waters (e.g., ducks, geese, cliff swallows, shorebirds, and beavers) where bacteria are directly delivered to waters and wildlife that live in upland areas (e.g., deer) where bacteria delivery is primarily driven by washoff and surface RO. The wildlife considered as potential sources of bacteria include deer, ducks, geese, and others. Data sources and assumptions for wildlife populations are shown in **Table 12**. In addition, a category called “other wildlife” was added to the source summary. These other animals include all other wildlife that may dwell in the watershed, such as beaver, raccoons, coyote, foxes, squirrels, etc. It is possible that the “other wildlife” category may at times be a significant source of bacteria, which lacks the data needed to account for it in this assessment. An example might be cliff swallows nesting under bridges, which may be in close proximity to sampling sites. The lack of data needed for this source assessment is a limitation of this technique.

Table 12. Data sources and assumption for wildlife population and bacteria delivery.

Bacteria Source	Delivery
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 (in deer per square mile) were reported by DNR deer permit area.	Bacteria from deer were applied to all land use classes in the NLCD 2006 dataset except for open water and developed land use classes.
Ducks Populations of breeding ducks was taken from the U.S. Fish and Wildlife "Thunderstorm" Maps for the Prairie Pothole Region of Minnesota and Iowa	The USFW "Thunder Maps" are spatially distributed and were used once a bacteria production rate was applied.
Geese Population estimates were taken from the state-wide DNR's Minnesota Spring Canada Goose Survey, 2009 (Rave 2009). Counts were reported by Level I Ecoregion. An area-weighted estimate was taken from the state-wide data, resulting in an estimate of 9,145 geese in the UMRW.	Bacteria from geese were distributed to areas within a 100 ft buffer of and including wetlands and open water classes in the NLCD 2006 dataset.
Other Wildlife Other wildlife in the watershed includes such animals as swallows, beaver, raccoons, coyote, foxes, and squirrels. Instead of estimating individual populations of each type of wildlife within the watershed. The bacteria production was assumed to be the same as the bacteria production from deer. Therefore, the bacteria production from deer was doubled to account for all other wildlife in the watershed that are not accounted for explicitly.	Same as deer.

Natural/Background Sources

Two Minnesota studies described the potential for the presence of "naturalized" or "indigenous" *E. coli* in watershed soils (Ishii et al. 2006) and ditch sediment and water (Sadowsky et al. 2010; Chandrasekaran et al. 2015). Sadowsky et al. (2010) conducted DNA fingerprinting of *E. coli* in sediment and water samples from Seven Mile Creek, located in south-central Minnesota. They concluded that roughly 63.5% of the bacteria were represented by a single isolate, suggesting new or transient sources of *E. coli*. The remaining 36.5% of strains were represented by multiple isolates, suggesting persistence of specific *E. coli*. The authors suggested that 36% might be used as a rough indicator of "background" levels of bacteria at this site during the study period but results might not be transferable to other locations without further study. Although the result may not be transferable to other locations, they do suggest the presence of natural background *E. coli* and a fraction of *E. coli* may be present regardless of the control measures taken by traditional implementation strategies.

Fate and Delivery of Bacteria

A delivery factor was developed to account for the fate and transport of bacteria from the landscape to the impaired waterbody. The delivery factor accounts for factors such as proximity to surface waters, landscape slope, imperviousness, and the probable bacteria die-off rate (bacteria cannot survive outside of a warm-blooded host). Therefore, the die-off rate is known to follow an exponential (first-order) loss rate. The bacteria delivery factor assumed delivery to the waterbody is dependent on water travel time and a bacteria die-off rate.

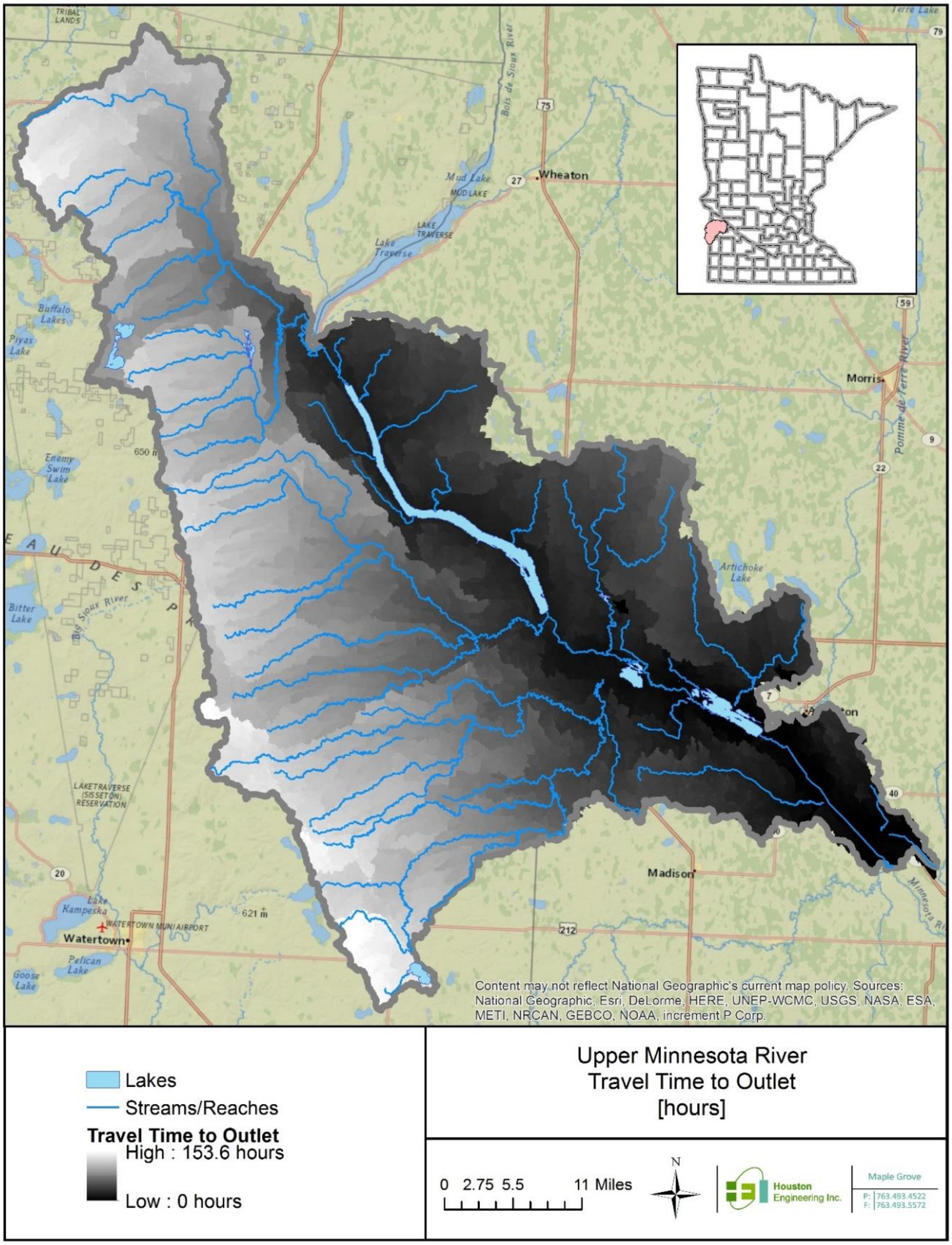
The EPA's *Protocols for Developing Pathogen TMDLs* provides a methodology for estimating bacteria die-off and lists coefficients for die-off calculations (EPA 2001). The die-off equation was given as:

$$C = C_0 exp(-KT_t)$$

Where C is the concentration of bacteria (cfu/day), C_0 is the initial concentration of bacteria (cfu/day), K is the decay (die-off) coefficient (1/day), and T_t is travel time (days). The die-off coefficient for natural surface water used in the watershed was 0.202 days^{-1} (essentially meaning about 20% per day). The die-off equation was applied to a water travel-time grid for the watershed as a whole and each impaired reach to estimate the delivery factor. An assumption is that the time of travel through the watershed by bacteria is the same as water. The travel time in the watershed is provide in **Figure 21**.

The magnitudes of the bacteria sources were placed into one of three categories: low, medium, and high. The rankings are based on the percentage of total bacteria load for each potential source. The sources were categorized into 10 groups. If all 10 potential sources contributed equally, they should each contribute 10% of the total load. As such, we ranked potential sources contributing 5% to 20% of the total load as a medium risk, or half to twice the expected value. If the source of bacteria was less than 5% of the total load, a rank of low was assigned and if greater than 20% a rank of high was assigned. The rankings for the watershed were all relative to the delivery of *E. coli* to the outlet.

The magnitude of bacterial source delivery was summarized for the watershed and drainage areas for any bacteria impaired waterbody within the watershed. The bacterial source loading to the outlet of the drainage areas were calculated for each drainage area. Some of the data sources only covered Minnesota's portion of the watershed. In these cases, the areal average bacteria yield was computed by land use/land cover and extrapolated to drainage areas in other states (e.g. South Dakota). The bacterial sources were aggregated to Human (STSS; Pets), Livestock (Grazing; Manure; AFOs), and Wildlife (Deer; Ducks; Gees; Other). The magnitudes of the three sources were then ranked using a linear normalization relative to the total magnitude of all sources.



Upper Minnesota River
Travel Time to Outlet
[hours]

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Figure 21. Travel time to the outlet of the watershed (in hours).

Appendix E. CAFOs

CAFOs

Name	Registration Number	County	WID
Diekmann Farms Inc - Site 3	011-50002	Big Stone	-571, 06-0152-00, 37-0046-01, 37-0046-02
Prairie Pride of Big Stone	011-88782	Big Stone	-531, -536, 06-0060-00, 06-0029-00, 37-0046-01, 37-0046-02
Lismore Hutterian Brethren Inc	011-94084	Big Stone	06-0152-00, 37-0046-01, 37-0046-02
Bellingham Farm	073-96574	Lac qui Parle	-570, 37-0046-01, 37-0046-02
Brian Boehnke Farm Site F065	073-100833	Lac qui Parle	37-0046-01, 37-0046-02
Robert Toelle Farm	155-84965	Traverse	-508, 06-0152-00, 37-0046-01, 37-0046-02
Zych Feedlot Inc	155-100997	Traverse	-541, 06-0152-00, 37-0046-01, 37-0046-02

Additional CAFOs in Lac qui Parle Lake – NW Bay and Lac qui Parle Lake – SE Bay watersheds

Name	Registration Number	County	Watershed	WID
New Horizon Dairy LLP	051-62611	Grant	Pomme de Terre River	37-0046-01, 37-0046-02
Mark & David Starner Farm - Sec 16	051-98302	Grant	Pomme de Terre River	37-0046-01, 37-0046-02
Loren Schmidgall Farm - Site 1	149-50001	Stevens	Pomme de Terre River	37-0046-01, 37-0046-02
Farmco Supply LLP - Sec 5	149-50003	Stevens	Pomme de Terre River	37-0046-01, 37-0046-02
Leonard Wulf & Sons Inc	149-50005	Stevens	Pomme de Terre River	37-0046-01, 37-0046-02
Koehl Beef Inc	149-50006	Stevens	Pomme de Terre River	37-0046-01, 37-0046-02
Riverview LLP - RVD Parlor	149-50007	Stevens	Pomme de Terre River	37-0046-01, 37-0046-02
Martys Swine Systems Inc - East Site	149-70172	Stevens	Pomme de Terre River	37-0046-01, 37-0046-02
Fairfield Genetics Inc	149-70183	Stevens	Pomme de Terre River	37-0046-01, 37-0046-02
Mike Koehl Farm	149-70189	Stevens	Pomme de Terre River	37-0046-01, 37-0046-02
DeTerre Farms Inc	149-70213	Stevens	Pomme de Terre River	37-0046-01, 37-0046-02
Taffe Pork, LLC	149-70249	Stevens	Pomme de Terre River	37-0046-01, 37-0046-02
Riverview LLP - West River Dairy	149-98140	Stevens	Pomme de Terre River	37-0046-01, 37-0046-02
Martys Swine Systems Inc - West Site	149-100020	Stevens	Pomme de Terre River	37-0046-01, 37-0046-02

Name	Registration Number	County	Watershed	WID
District 45 Dairy	149-104720	Stevens	Pomme de Terre River	37-0046-01, 37-0046-02
Horton Hog Farm	149-107200	Stevens	Pomme de Terre River	37-0046-01, 37-0046-02
Moore Lean Sow Unit	149-107240	Stevens	Pomme de Terre River	37-0046-01, 37-0046-02
Loren Schmidgall Farms - Site 2	149-112049	Stevens	Pomme de Terre River	37-0046-01, 37-0046-02
West Line Pork	149-113298	Stevens	Pomme de Terre River	37-0046-01, 37-0046-02
Outback Five Inc	151-50001	Swift	Pomme de Terre River	37-0046-01, 37-0046-02
Multi-Site - Jennie-O Turkey Store - AJ/Jennings/Pederson	151-50004	Swift	Pomme de Terre River	37-0046-01, 37-0046-02
David Gades Farm	151-84027	Swift	Pomme de Terre River	37-0046-01, 37-0046-02
Fairfield Hog Farm	151-113258	Swift	Pomme de Terre River	37-0046-01, 37-0046-02
Spring Valley Farms	151-124608	Swift	Pomme de Terre River	37-0046-01, 37-0046-02
Christensen Farms Site F146	073-50001	Lac qui Parle	Lac qui Parle River	37-0046-01
Kuhlmann Farms Inc	073-50003	Lac qui Parle	Lac qui Parle River	37-0046-01
Stratmoen Hog Finishing Inc	073-50004	Lac qui Parle	Lac qui Parle River	37-0046-01
Mortenson Hog Farms	073-50005	Lac qui Parle	Lac qui Parle River	37-0046-01
Lee Johnson Farm	073-62843	Lac qui Parle	Lac qui Parle River	37-0046-01
David Dahl Farm	073-80100	Lac qui Parle	Lac qui Parle River	37-0046-01
Wayne Dahl Hog Farm	073-80101	Lac qui Parle	Lac qui Parle River	37-0046-01
Greg Bothun Farm Baxter Section 6	073-83860	Lac qui Parle	Lac qui Parle River	37-0046-01
Mike & Jared Anhalt Turkey Farm	073-96591	Lac qui Parle	Lac qui Parle River	37-0046-01
Jeffrey Abraham Farm - Sec 21	073-96784	Lac qui Parle	Lac qui Parle River	37-0046-01
Jason and Andrea Hastad	073-96789	Lac qui Parle	Lac qui Parle River	37-0046-01
Joe Bothun	073-100040	Lac qui Parle	Lac qui Parle River	37-0046-01
Greg Bothun Section 12	073-100041	Lac qui Parle	Lac qui Parle River	37-0046-01
Cori Bothun Farm - Sec 28	073-100829	Lac qui Parle	Lac qui Parle River	37-0046-01
Dave DeJong Farm - Sec 1	073-102740	Lac qui Parle	Lac qui Parle River	37-0046-01
SFLLC-Dawson Prairie Pork Site	073-105620	Lac qui Parle	Lac qui Parle River	37-0046-01
Dane Prestholdt Farm	073-107300	Lac qui Parle	Lac qui Parle River	37-0046-01

Name	Registration Number	County	Watershed	WID
Brent Dahl Farm	073-110480	Lac qui Parle	Lac qui Parle River	37-0046-01
Bothun Hog Site LLC	073-125560	Lac qui Parle	Lac qui Parle River	37-0046-01
Todd Bach Farm - Maxwell 24	073-125734	Lac qui Parle	Lac qui Parle River	37-0046-01
Robertson Finisher	073-127134	Lac qui Parle	Lac qui Parle River	37-0046-01
B-C-H Enterprises LLP - Site I	173-50372	Yellow Medicine	Lac qui Parle River	37-0046-01
Alfred Jessen Farm	173-100141	Yellow Medicine	Lac qui Parle River	37-0046-01
Farmco Supply LLP - Sec 34	151-84043	Swift	Chippewa River	37-0046-01
Multi-Site - Jennie-O Turkey Store - AJ/Jennings/Pederson	151-50005	Swift	Chippewa River	37-0046-01
Multi-Site - Jennie-O Turkey Store - AJ/Jennings/Pederson	151-93689	Swift	Chippewa River	37-0046-01
Riverview LLP - Chippewa Calves	023-112618	Chippewa	Chippewa River	37-0046-01
Jacob Tofte	151-84128	Swift	Chippewa River	37-0046-01
Joe Wagner Farm	041-66885	Douglas	Chippewa River	37-0046-01
Jennie-O Turkey Store - Riverside Farm	151-93687	Swift	Chippewa River	37-0046-01
Michael O'Leary Farms Inc - East & West Barn	151-84119	Swift	Chippewa River	37-0046-01
Erick Meyer Farm	023-112869	Chippewa	Chippewa River	37-0046-01
Multi-Site - Jennie-O Turkey Store - Commerford Brood & Grower/Swenson	151-50002	Swift	Chippewa River	37-0046-01
Multi-Site - Jennie-O Turkey Store - Commerford Brood & Grower/Swenson	151-50003	Swift	Chippewa River	37-0046-01
Multi-Site - Jennie-O Turkey Store - Commerford Brood & Grower/Swenson	151-93688	Swift	Chippewa River	37-0046-01
Swenoda Dairy	151-125982	Swift	Chippewa River	37-0046-01
Hancock Pro Pork Inc	149-50002	Stevens	Chippewa River	37-0046-01
Stan Schaefer Inc	149-70146	Stevens	Chippewa River	37-0046-01
Riverview LLP - Moore Calves	149-70206	Stevens	Chippewa River	37-0046-01
Hancock Pro Pork Inc - Sec 14	149-109360	Stevens	Chippewa River	37-0046-01

Name	Registration Number	County	Watershed	WID
Canadian Connection - Sec 14	149-50009	Stevens	Chippewa River	37-0046-01
Jennie-O Turkey Store - Camp Lake Farm	151-93692	Swift	Chippewa River	37-0046-01
Multi-Site - Select Genetics - Starbuck Hills and Hargin Sites	121-82380	Pope	Chippewa River	37-0046-01
Multi-Site - Select Genetics - Starbuck Hills and Hargin Sites	121-82391	Pope	Chippewa River	37-0046-01
Blair West Site	121-62454	Pope	Chippewa River	37-0046-01
Nadgwick Dairy	051-62585	Grant	Chippewa River	37-0046-01
Riverview LLP - West Dublin	151-84835	Swift	Chippewa River	37-0046-01
East Dublin Dairy LLP	151-105420	Swift	Chippewa River	37-0046-01
Carlson Dairy LLP - Sec 28	067-101111	Kandiyohi	Chippewa River	37-0046-01
Johnson Dairy Inc	151-65178	Swift	Chippewa River	37-0046-01
Willmar Poultry Farms Inc - Kerkhoven	151-84097	Swift	Chippewa River	37-0046-01
Louriston Dairy	023-125653	Swift	Chippewa River	37-0046-01
Broberg Farms	151-118599	Swift	Chippewa River	37-0046-01

Feedlot Summary by Impaired Reach

Scale	**Watershed -wide**	**Impaired Reaches**										
Description	**Minnesota River Headwaters (HUC-08 07020001)**	**Unnamed Creek (West Salmonsen Creek); Unnamed Creek to Big Stone Lk (AUID 07020001-504)**	**Little Minnesota River; MN/SD border to Big Stone Lk (AUID 07020001-508)**	**Unnamed Creek (Five Mile Creek); Unnamed Cr to Marsh Lk (AUID 07020001-521)**	**Stony Run Creek; Unnamed Cr to MN River (AUID 07020001-531)**	**Stony Run Creek; Long Tom Lk to Unnamed Cr (AUID 07020001-536)**	**Unnamed Creek; Unnamed Creek to Big Stone Lk (AUID 07020001-541**	**Emily Creek; Unnamed Cr to Lac qui Parle Lk (AUID 07020001-547)**	**Unnamed Creek; Headwaters to S Fk Yellow Riv (AUID 07020001-551)**	**Unnamed Creek (Meadowbrook Creek); 340th St to Big Stone Lk (AUID 07020001-568)**	**Unnamed Creek; CSAH 38 to Marsh Lk (07020001-570)**	**Fish Creek; Headwaters to CSAH 33 (AUID 07020001-571)**
Total Feedlots	115	3	2	14	15	14	6	8	0	1	7	10
Total CAFOs[2]	7	0	1	0	1	1	1	0	0	0	1	1
Total AUs	33,522	730	1,819	2,467	3,660	3,588	3,346	1,462	0	285	1,958	5,011
Primary Animal Type(s)[3]	Cattle (49%)	Cattle (99%)	Swine (100%)	Cattle (67%)	Swine (61%)	Swine (63%)	Cattle (56%)	Cattle (88%)	NA	Cattle (95%)	Swine (42%)	Swine (74%)
	Swine (46%)	Horses (<1%)	NA	Swine (33%)	Cattle (24%)	Cattle (37%)	Swine (44%)	Swine (10%)	NA	Goat/Sheep (5%)	Goat/Sheep (30%)	Cattle (25%)
Open Lot Feedlots	95	3	0	12	12	11	2	7	0	1	6	6
Feedlots in Shoreland	14	0	0	0	9	4	2	1	0	0	0	2
Open Lot Feedlots in Shoreland	12	0	0	0	2	3	1	1	0	0	0	2

[1] Data from "Feedlots in Minnesota" data layer. Downloaded March 2020 from https://gisdata.mn.gov/dataset/env-feedlots

[2] Permitted Large CAFOs as identified in the feedlots GIS layer ("Feedlots in Minnesota").

[3] Percentages based on AUs. Top 2 provided as primary animal type.

Appendix F. TMDL Accounting

Water body name	AUID	Use Class	Year Listed	Proposed Category	Impaired Waters Listing	Pollutant or Stressor	TMDL Developed in this Report
Unnamed creek (West Salmonsen Creek), Unnamed cr to Big Stone Lk	07020001-504	2Bg, 3C	2018	4A	*Escherichia coli (E.coli)*	*E.coli*	**Yes**
Little Minnesota River, MN/SD border to Big Stone Lk	07020001-508	2Bg, 3C	2018	5	Benthic macroinvertebrates bioassessments		No - deferred to collected additional data
			2018	4A	*Escherichia coli (E.coli)*	*E.coli*	**Yes**
Yellow Bank River, North Fork, MN/SD border to Yellow Bank R	07020001-510	2Bg, 3C	2006	4A	Fecal coliform	Fecal coliform	No - TMDL completed in 2013 (PRJ06876-001)
			2018	5	Fish bioassessments		No - deferred to collected additional data
Unnamed creek (Five Mile Creek), Unnamed cr to Marsh Lk	07020001-521	2Bg, 3C	2018	4A	*Escherichia coli (E.coli)*	*E.coli*	**Yes**
			2018	5	Fish bioassessments		No - deferred to collected additional data
Yellow Bank River, N Fk Yellow Bank R to Minnesota R	07020001-525	2Bg, 3C	2018	5	Benthic macroinvertebrates bioassessments		No - deferred to collected additional data
Yellow Bank River, N Fk Yellow Bank R to Minnesota R	07020001-525	2Bg, 3C	2006	4A	Fecal coliform	Fecal coliform	No - TMDL completed in 2013 (PRJ06876-001)
			2018	5	Fish bioassessments		No - deferred to collected additional data
			2010	4A	Turbidity	TSS	No - TMDL completed in 2013 (PRJ06876-001)
Yellow Bank River, South Fork, MN/SD border to N Fk Yellow Bank R	07020001-526	2Bg, 3C	2006	4A	Fecal coliform	Fecal coliform	No - TMDL completed in 2013 (PRJ06876-001)

Water body name	AUID	Use Class	Year Listed	Proposed Category	Impaired Waters Listing	Pollutant or Stressor	TMDL Developed in this Report
			2018	5	Fish bioassessments		No - deferred to collected additional data
Stony Run Creek, Unnamed cr to Minnesota R	07020001-531	2Bg, 3C	2018	5	Benthic macroinvertebrates bioassessments		No - deferred to collected additional data
			2018	4A	*Escherichia coli (E.coli)*	*E.coli*	**Yes**
			2004	5	Fish bioassessments		No - deferred to collected additional data
Stony Run Creek, Long Tom Lk to Unnamed cr	07020001-536	2Bg, 3C	2018	4A	*Escherichia coli (E.coli)*	*E.coli*	**Yes**
Unnamed creek, Unnamed cr to Big Stone Lk	07020001-541	2Bg, 3C	2018	4A	*Escherichia coli (E.coli)*	*E.coli*	**Yes**
			2018	5	Fish bioassessments		No - deferred to collected additional data

Water body name	AUID	Use Class	Year Listed	Proposed Category	Impaired Waters Listing	Pollutant or Stressor	TMDL Developed in this Report
Emily Creek, Unnamed cr to Lac qui Parle Lk	07020001-547	2Bg, 3C	2018	5	Benthic macroinvertebrates bioassessments		No - deferred to collected additional data
			2018	4A	*Escherichia coli (E.coli)*	*E.coli*	**Yes**
			2018	5	Fish bioassessments		No - deferred to collected additional data
Unnamed creek, Unnamed cr to Emily Cr	07020001-548	2Bg, 3C	2004	5	Fish bioassessments		No - deferred to collected additional data
Unnamed creek, Headwaters to S Fk Yellow R	07020001-551	2Bg, 3C	2018	5	Benthic macroinvertebrates bioassessments		No - deferred to collected additional data
			2018	4A	*Escherichia coli (E.coli)*	*E.coli*	**Yes**
			2018	5	Fish bioassessments		No - deferred to collected additional data
Minnesota River, Big Stone Lk to Marsh Lk Dam	07020001-552	1C, 2Bdg, 3C	2018	5	Benthic macroinvertebrates bioassessments		No - deferred to collected additional data
			2018	4A	*Escherichia coli (E.coli)*	*E.coli*	No - TMDL completed in 2019 (PRJ07706-002)
Unnamed creek, Unnamed cr to Unnamed cr	07020001-559	2Bg, 3C	2018	5	Fish bioassessments		No - deferred to collected additional data
Unnamed creek, Unnamed cr to Unnamed cr	07020001-560	2Bg, 3C	2018	5	Fish bioassessments		No - deferred to collected additional data
Unnamed creek, MN/SD border to Yellow Bank R	07020001-561	2Bg, 3C	2018	5	Fish bioassessments		No - deferred to collected additional data
Unnamed creek (Meadowbrook Creek), 340th St to Big Stone Lk	07020001-568	2Bg, 3C	2018	5	Benthic macroinvertebrates bioassessments		No - deferred to collected additional data

			2018	4A	*Escherichia coli (E.coli)*	*E.coli*	**Yes**
			2018	5	Fish bioassessments		No - deferred to collected additional data
Unnamed creek, Headwaters to CSAH 38	07020001-569	2Bg, 3C	2018	5	Fish bioassessments		No - deferred to collected additional data
Unnamed creek, CSAH 38 to Marsh Lk	07020001-570	2Bg, 3C	2018	5	Benthic macroinvertebrates bioassessments		No - deferred to collected additional data
			2018	4A	*Escherichia coli (E.coli)*	*E.coli*	**Yes**
			2018	5	Fish bioassessments		No - deferred to collected additional data
Fish Creek, Headwaters to CSAH 33	07020001-571	2Bg, 3C	2018	5	Benthic macroinvertebrates bioassessments		No - deferred to collected additional data
			2018	4A	*Escherichia coli (E.coli)*	*E.coli*	**Yes**
			2018	5	Fish bioassessments		No - deferred to collected additional data
County Ditch 2 (Five Mile Creek), -96.1283, 45.2472 to T121 R43W S31, south line	07020001-574	2Bg, 3C	2018	5	Fish bioassessments		No - deferred to collected additional data
Emily Creek, 290th St to Unnamed cr	07020001-576	2Bg, 3C	2018	5	Benthic macroinvertebrates bioassessments		No - deferred to collected additional data
			2018	5	Fish bioassessments		No - deferred to collected additional data
Long Tom	06-0029-00	2B, 3C	2018	4A	Nutrients	Phosphorus	**Yes**
Unnamed	06-0060-00	2B, 3C	2018	4A	Nutrients	Phosphorus	**Yes**
Big Stone	06-0152-00	2B, 3C	2018	4A	Nutrients	Phosphorus	**Yes**
Lac qui Parle (SE Bay)	37-0046-01	2B, 3C	1992	5	Ammonia, un-ionized		No - need additional data to determine if impairment still exists

			2018	4A	Nutrients	Phosphorus	**Yes**
Lac qui Parle (NW Bay)	37-0046-02	2B, 3C	2018	4A	Nutrients	Phosphorus	**Yes**