September 2019

Watershed

Mississippi River-Grand Rapids Watershed Total Maximum Daily Load

A quantification of the total amount of phosphorus and bacteria that can be received by the lakes and streams in the Mississippi River-Grand Rapids Watershed and maintain their ability to support swimming, fishing, and healthy biological communities.

MINNESOTA POLLUTION CONTROL AGENCY

EOR water ecology community

CLEAN WATER LAND & LEGACY AMENDMENT

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Acronyms

ac-ft/yr	acre feet per year
AF	Anoxic factor
AFO	Animal Feeding Operation
AUID	Assessment Unit ID
BD-P	Bicarbonate Dithionite extractable Phosphorus
BMP	Best Management Practice
CAFO	Concentrated Animal Feeding Operation
cfu	colony-forming unit
Chl-*a*	Chlorophyll-*a*
DNR	Minnesota Department of Natural Resources
DO	Dissolved Oxygen
E. coli	*Escherichia coli*
EPA	United States Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
EQuIS	Environmental Quality Information System
FWMC	Flow weighted mean concentration
GIS	Geographic Information Systems
HUC	Hydrologic Unit Code
IBI	Index of Biological Integrity
ISTS	Individual Sewage Treatment System
ITPHS	Imminent Threat to Public Health and Safety
km^2	square kilometer
LA	Load Allocation
Lb	pound
lb/yr	pounds per year
LGU	Local Government Unit
m	meter
mg/m^2-day	milligram per square meter per day
mL	milliliter
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
NA	North American
NLCD	National Land Cover Dataset
NPDES	National Pollutant Discharge Elimination System
NRCS	National Resources Conservation Service
org.	organisms
P	Phosphorus
SDS	State Disposal System
SSTS	Subsurface Sewage Treatment Systems
SWCD	Soil and Water Conservation District
TMDL	Total Maximum Daily Load
TP	Total Phosphorus
USDA	United States Department of Agriculture
WLA	Wasteload Allocation
WRAPS	Watershed Restoration and Protection Strategies
WWTF	Wastewater Treatment Facility
WWTP	Wastewater Treatment Plant

Executive Summary

The Clean Water Act (1972) requires that each state develop a plan to identify and restore any waterbody that is deemed impaired by state regulations. As a result, a Total Maximum Daily Load (TMDL) Study is required by the United States Environmental Protection Agency (EPA) to be completed for an impaired water. A TMDL identifies the pollutant that is causing the impairment and how much of that pollutant can enter the waterbody and still meet water quality standards.

This TMDL study addresses phosphorus (P) and bacteria (in the form of *Escherichia coli, E. coli*) impairments in seven lakes and six streams located in the Mississippi River-Grand Rapids Watershed (MRGRW), Hydrologic Unit Code (HUC) 07010103, that are on the 2018 EPA's 303(d) list of impaired waters. The MRGRW (HUC-8 07010103) is located in north central Minnesota and includes the drainage areas of the Willow and Mississippi Rivers from the Cohasset Dam in Grand Rapids, Minnesota to the Willow River. The watershed is comprised largely of forested, rural areas. It contains approximately 1,908 miles of streams/river and 625 lakes greater than 10 acres. The MRGRW covers 5,398 square kilometers (km^2) (1,333,828 acres) in areas of Aitkin, Carlton, Cass, Itasca, and St. Louis counties in Minnesota.

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

- All available water quality data from the TMDL 10-year time period (2007 through 2016)
- MRGRW Hydrologic Simulation Program – FORTRAN (HSPF) model
- Geographic Information Systems (GIS) terrain analyses
- Sediment P concentrations
- Fisheries surveys
- Aquatic plant surveys
- Stream geomorphology and field surveys
- Stressor identification (SID) investigations
- Stakeholder input

The following pollutant sources were evaluated for each lake or stream: watershed runoff, loading from upstream waterbodies, atmospheric deposition, lake internal loading, point sources, feedlots, septic systems, and in-stream alterations. This TMDL study used an inventory of pollutant sources to develop a lake response model for each impaired lake and a load duration curve (LDCs) model for each impaired stream. These models were then used to determine the pollutant reductions needed for the impaired waterbodies to meet water quality standards. A summary of existing conditions, pollutant sources, and reductions needed to meet water quality standards for each impaired waterbody addressed in this TMDL is provided below.

Some of the lakes in this study (Eagle, North and South Island) appear at first glance to have total phosphorus (TP) levels that meet the standard, and shouldn't require a TMDL. However, in each of these cases, they were placed on the impaired waters list prior to the 2018 303(d) list, and the most current water quality data, although improving, was not sufficient to delist them. For these lakes, the TMDL provides a protective benefit.

Eagle Lake (09-0057-00) TP TMDL:

Eagle Lake was listed as impaired in 2002. The current 10-year (2007 through 2016) growing season average TP concentration is 28 µg/L with a WQS goal of <30 µg/L, however the standard error is large enough to suggest that the true mean still doesn't meet the standard. The TMDL reduction goal was based on achieving a 10-year growing season average TP concentration of 25.6 µg/L. Eagle Lake is 389 acres with a maximum depth of 35 feet and a shallow lake zone (<15 feet) that covers 30% of the lake surface area. The shoreline is well developed with seasonal conversion of cabins to year-round homes. There is a diverse and healthy fish and aquatic plant community. The lake watershed is 2,304 acres, or 6 times the lake surface area. Approximately 30% of the watershed is wetland. P reductions are needed from watershed runoff, converting failing shoreline septics to conforming, and internal load sources (from anoxic sediment P release).

Horseshoe Lake (01-0034-00) TP TMDL:

The current 10-year (2007 through 2016) growing season average TP concentration is 43 µg/L with a WQS goal of <30 µg/L. The TMDL reduction goal was based on achieving a 10-year growing season average TP concentration of 30.0 µg/L. Horseshoe Lake is 210 acres with a maximum depth of 12 feet and a shallow lake zone (<15 feet) that covers 100% of the lake surface area. Natural springs have been observed near the shoreline and in the lake bottom. There was a healthy aquatic plant community in the most recent DNR fish survey in 2015. There are occasional partial winterkills; the most recent observed was a partial kill in the winter of 2007-2008. Partial winterkills are likely due to the shallow, eutrophic nature of the lake. Mid-summer mixing events, combined with sediment P release under anoxic conditions at the lake bottom, may be contributing to internal loading in the lake. The lake watershed is 21,622 acres, or 90 times the lake surface area. Approximately 32% of the watershed is wetland, with beaver issues on Musselshell Creek. P reductions are needed from watershed runoff, converting failing shoreline septics to conforming, and near-shore sources (such as near-shore wetland export and shoreline erosion). Near-shore sources are not accounted for in the HSPF model or other P source assessment tools utilized by this TMDL. Additional field surveys are needed to target the source of these near-shore sources.

North Island Lake (09-0060-01) TP TMDL:

North Island Lake was listed as impaired for nutrients in 2010. The current 10-year (2007 through 2016) growing season average TP concentration is 27 µg/L with a WQS goal of <30 µg/L. However, the data set have a standard error large enough to suggest that the true mean may still exceed the standard. The TMDL reduction goal was based on achieving a 10-year growing season average TP concentration of 24.6 µg/L. North Island Lake is 114 acres with a maximum depth of 25 feet and a shallow lake zone (<15 feet) that covers 86% of the lake surface area. The shoreline is well developed and most residences are connected to the city of Cromwell sewer system. There is a healthy aquatic plant and fish community. The lake watershed is 4,798 acres, or 42 times the lake surface area. Eagle Lake and South Island Lakes are upstream of North Island Lake. North Island Lake receives some stormwater runoff from the city of Cromwell. A ditch drains a wetland on the north side of the lake, and could release P to North Island Lake under fluctuating water level conditions in the wetland. There are livestock to the northeast of the lake. P reductions are needed from watershed runoff, converting failing shoreline septics to conforming, and internal load sources (from anoxic sediment P release), and from Island Lake (South Basin) achieving its TMDL goals.

South Island Lake (09-0060-02) TP TMDL:

South Island Lake was listed as impaired for nutrients in 2008. The current 10-year (2007 through 2016) growing season average TP concentration is 29 µg/L with a WQS goal of <30 µg/L. The standard error of the current data set is inconclusive as to whether the lake is meeting standards. The TMDL reduction goal was based on achieving a 10-year growing season average TP concentration of 26.9 µg/L. South Island Lake is 324 acres with a maximum depth of 22 feet and a shallow lake zone (<15 feet) that covers 73% of the lake surface area. The shoreline is well developed with the northern half of residences connected to the city of Cromwell sewer system in 2007. There is a diverse aquatic plant community. The fish community is poor, with a fish-based index of biological integrity (FIBI) score of 26, or 12 points below the impairment threshold for similar lakes. The lake watershed is 4,028 acres, or 12 times the lake surface area. Eagle Lake is upstream of South Island Lake. South Island Lake receives some stormwater runoff from the city of Cromwell. P reductions are needed from watershed runoff, converting failing shoreline septics to conforming, and internal load sources (from anoxic sediment P release), and from Eagle Lake achieving its TMDL goals.

King Lake (31-0258-00) TP TMDL:

The current 10-year (2007-2016) growing season average TP concentration is 33 µg/L with a WQS goal of <30 µg/L. The TMDL reduction goal was based on achieving a 10-year growing season average TP concentration of 30.0 µg/L. King Lake is 311 acres with a maximum depth of just over 25 feet and a shallow lake zone (<15 feet) that covers 49% of the lake surface area. The lake weakly stratifies and has low oxygen at the thermocline. Mid-summer mixing events, combined with sediment P release under anoxic conditions at the lake bottom, may be contributing to internal loading in the lake. The western and southwest shorelines are heavily developed, and shoreline erosion has been noted on the lake. The lake watershed is 890 acres, or 3 times the lake surface area. Approximately 13% of the watershed is wetland and 48% woodland. There is forestry activity to the north and east of the lake, and an approximately 40 acre wetland complex on the northeast shore of the lake. P reductions are needed from watershed runoff, converting failing shoreline septics to conforming, and internal load sources (from anoxic sediment P release).

Little Cowhorn Lake (31-0098-00) TP TMDL:

The current 10-year (2007 through 2016) growing season average TP concentration is 46 µg/L with a WQS goal of <30 µg/L. The TMDL reduction goal was based on achieving a 10-year growing season average TP concentration of 30.0 µg/L. Little Cowhorn Lake is 181 acres with a maximum depth of 12 feet and a shallow lake zone (<15 feet) that covers 100% of the lake surface area. There was heavy submergent aquatic vegetation in the most recent DNR fish survey in 1992. There is a long history of low winter oxygen levels with many severe winterkills documented in Little Cowhorn Lake due to the shallow, eutrophic nature of the lake. Mid-summer mixing events, combined with sediment P release under anoxic conditions at the lake bottom, may be contributing to internal loading in the lake. There is only one residence on the lake. The lake watershed is 1,178 acres, or 6 times the lake surface area.

Approximately 23% of the watershed is wetland. P reductions are needed from watershed runoff and internal load sources (from anoxic sediment P release).

Split Hand Lake (31-0353-00) TP TMDL:

The current 10-year (2007 through 2016) growing season average TP concentration is 41 µg/L with a WQS goal of <30 µg/L. The TMDL reduction goal was based on achieving a 10-year growing season average TP concentration of 30.0 µg/L. Split Hand Lake is 1,369 acres with a maximum depth of just over 30 feet and a shallow lake zone (<15 feet) that covers 42% of the lake surface area. Lake water level fluctuations are an issue for Split Hand Lake. There is a history of high water levels, and even flooding of houses in recent years on the lake. In 2018, most docks were about one foot underwater. The eastern shoreline is well developed. Many of the residences have been converted from cabins to year-round homes. The lake watershed is 20,249 acres, or 15 times the lake surface area. Approximately 26% of the watershed is wetland. P reductions are needed from watershed runoff, converting failing shoreline septics to conforming, internal load sources (from anoxic sediment P release), and near-shore sources (such as near-shore wetland export and shoreline erosion). Near-shore sources are not accounted for in the HSPF model or other P source assessment tools utilized by this TMDL. Additional field surveys are needed to target the source of these near-shore sources.

***E. coli* TMDLs**:

The MRGRW is largely undeveloped. Approximately 90% of the watershed is comprised of forested areas, wetlands, or open water. There is evidence to support multiple potential sources of bacteria in each impaired stream, but overall, the most likely causes of bacteria impairments in the MRGRW are wildlife and livestock encroachment and failing septic systems. The Swan River (-753) is the only impaired stream with a significant number of permitted sources of *E. coli* (see Section 4.2.6.4). While the total WLA in the TMDL for the Swan River does not exceed the loading capacity, permitted sources may contribute stress to the Swan River system, especially under low and very low flow conditions. Additional bacteria and microbial DNA sampling is recommended to identify the specific source of bacteria in each impaired stream. These samples could be collected at multiple sites along each reach to spatially target these sources of bacteria. *E. coli* TMDLs were developed for:

- Split Hand Creek (07010103-574)
- Hasty Brook (07010103-603)
- Willow River (07010103-751)
- Swan River (07010103-753)
- Tamarack River (07010103-758)
- Prairie River (07010103-760)

The TMDL study's results aided in the selection of implementation activities during the Mississippi River-Grand Rapids Watershed Restoration and Protection Strategy (WRAPS) process, concurrent with this TMDL report. The purpose of the WRAPS process is to support local working groups in developing scientifically-supported restoration and protection strategies for subsequent implementation planning. The MRGR WRAPS Report is publically available on the Minnesota Pollution Control Agency (MPCA) MRGRW website: https://www.pca.state.mn.us/water/watersheds/mississippi-river-grand-rapids.

1 Project Overview

1.1 Purpose

The State of Minnesota has determined that the MRGRW lakes and streams listed in Table 1-1 and Table 1-2 are impaired because they exceed established state water quality standards. In accordance with the Clean Water Act, the State must conduct TMDL studies on the impaired waters. The goals of this TMDL are to provide wasteload allocations (WLA) and load allocations (LA) for pollutant sources within the MRGRW, and to quantify the pollutant reductions needed to meet Minnesota water quality standards. This TMDL study addresses the following impairments within the MRGRW that are included in the Minnesota 2018 303(d) list:

- Aquatic recreation use impairments due to eutrophication (TP) in seven lakes,
- Aquatic recreation use impairments due to *E. coli* in six stream reaches

Several lake and stream impairments within the watershed have already been addressed through previous TMDL studies. A TMDL Study was completed in 2011 to address impairments for aquatic recreation use due to eutrophication in Big Sandy Lake and Minnnewawa Lake (Barr 2011). Several impairments for aquatic consumption due to mercury were included in a statewide Mercury TMDL (MPCA 2007).

Other MRGRW studies referenced in the development of this TMDL include:

- Mississippi River-Grand Rapids SID Study (MPCA 2019)
- Mississippi River-Grand Rapids Monitoring and Assessment Report (MPCA 2018)

The TMDL study's results aided in the selection of implementation activities during the concurrent Mississippi River-Grand Rapids WRAPS process. The purpose of the WRAPS process is to support local working groups in developing scientifically-supported restoration and protection strategies for subsequent implementation planning. The Mississippi River-Grand Rapids WRAPS Report is publically available on the MPCA's MRGRW website:

https://www.pca.state.mn.us/water/watersheds/mississippi-river-grand-rapids

A future TMDL study will address the total suspended solids (TSS) impairment in the Mississippi River mainstem. That impairment crosses two major watersheds, so it will be addressed separately.

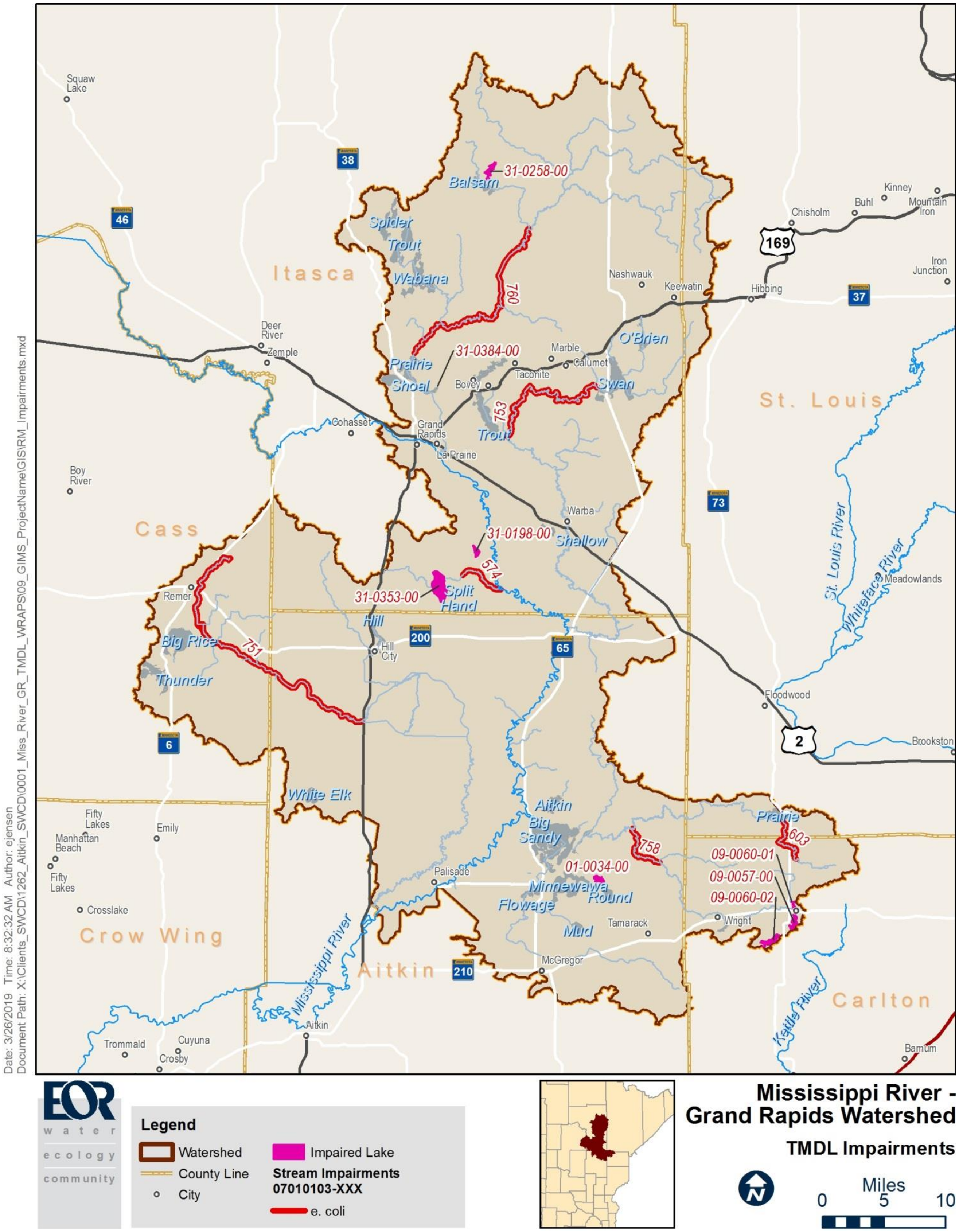

Figure 1-1. Impaired lakes and streams in the Mississippi River-Grand Rapids Watershed addressed in this TMDL

1.2 Identification of Waterbodies

Table 1-1. Mississippi River-Grand Rapids Watershed Impaired Lakes and Streams addressed in this TMDL

Affected Use: Pollutant/Stressor	Lake ID/Stream AUID	Name	Location/Reach Description	Designated Use Class	Listing Year	Target Completion Year
Aquatic Recreation: Nutrient/ Eutrophication Biological Indicators (Phosphorus)	09-0057-00	Eagle Lake	4 mi SW of Wright	2B, 3C	2002	2019
	01-0034-00	Horseshoe Lake	7 mi N of Tamarack	2B, 3C (s)	2010	2019
	09-0060-01	Upper Lake: North Island	At Cromwell	2B, 3C	2010	2019
	09-0060-02	Lower Lake: South Island	At Cromwell	2B, 3C	2008	2019
	31-0258-00	King Lake	16 mi N of Coleraine	2B, 3C	2018	2019
	31-0198-00	Little Cowhorn Lake	9 mi SE of Grand Rapids	2B, 3C (s)	2018	2019
	31-0353-00	Split Hand Lake	11 mi S of Grand Rapids	2B, 3C	2010	2019
Aquatic Recreation: Escherichia coli	07010103-574	Split Hand Creek	T53 R24W S18, W line to Miss R	2Bg, 3C	2018	2019
	07010103-603	Hasty Brook	Unnamed ditch to Prairie Lk	1B, 2Bg, 3B	2018	2019
	07010103-751	Willow River	S Fk Willow R to Willow R ditch	2Bg, 3C	2018	2019
	07010103-753	Swan River	Swan Lk to Trout Cr	2Bg, 3C	2018	2019
	07010103-758	Tamarack River	Little Tamarack R to Prairie R	2Be, 3C	2018	2019
	07010103-760	Prairie River	Balsam Cr to Prairie Lk	2Bg, 3C	2018	2019

Table 1-2. Impairments not addressed by this TMDL

Affected Use: Pollutant/Stressor	Lake ID/Stream AUID	Name	Location/Reach Description	Designated Use Class	Listing Year	Target Start/ Completion Year	Impairment addressed by:
Aquatic Recreation: Nutrient/ Eutrophication	01-0062-00	Big Sandy Lake	14 mi N of McGregor	2B, 3C	2002	2011	Completed TP TMDL[1]
	01-0033-00	Lake Minnewawa	7 mi NE of McGregor	2B, 3C (s)	2002	2011	
	09-0067-00	Tamarack Lake	5 mi W of Cromwell	2B, 3C	2010	2029	Future TMDL[2]

Affected Use: Pollutant/Stressor	Lake ID/Stream AUID	Name	Location/Reach Description	Designated Use Class	Listing Year	Target Start/ Completion Year	Impairment addressed by:
Biological Indicators (Phosphorus)	31-0384-00	Prairie Lake	6 mi N of Grand Rapids	2B, 3C	2010	2018	List correction
	01-0014-00	Savanna Lake	20 mi NE of McGregor	2B, 3C	2018	2018	Natural background
Aquatic Life: Dissolved oxygen	07010103-749	Moose River	HW to Moose-Willow R ditch	2Bg, 3C	2012	2018	Natural background
Aquatic Life: Macroinvertebrate Bioassessments	07010103-512	Sandy River	Headwaters to Big Sandy Lake	2Bg, 3C	2018	2029	Non-pollutant based stressor
	07010103-518	Minnewawa Creek	Unnamed ditch to Lk Minnewawa Outlet Cr	2Bm, 3C	2018	2029	
	07010103-590	Pickerel Creek	Headwaters to Swan Lk	1B, 2Ag, 3B	2018	2029	TBD
	07010103-719	Unnamed creek	Johnson Lk outlet to East R	2Bg, 3C	2018	2018	Natural background
	07010103-726	Unnamed creek	Blackberry Lk to Mississippi R	2Bg, 3C	2018	2029	Non-pollutant based stressor
	07010103-733	Pokegama Creek	Unnamed ditch to Mississippi R	2Bg, 3C	2018	2029	
	07010103-756	Unnamed ditch	Unnamed ditch to Mississippi R	2Bg, 3C	2018	2029	
Aquatic Life: Fish Bioassessments	09-0060-02	Lower (South) Island Lake	At Cromwell	2B, 3C	2018	2029	TBD
	07010103-512	Sandy River	Headwaters to Big Sandy Lk	2Bg, 3C	2018	2029	Non-pollutant based stressor
	07010103-518[4]	Minnewawa Creek[4]	Unnamed ditch to Lk Minnewawa Outlet Cr	2Bm, 3C	2018	2020	
	07010103-519	Minnewawa Creek	Lk Minnewawa Outlet Cr to Sandy R (Flowage Lk)	2Bg, 3C	2018	2029	
	07010103-590	Pickerel Creek	Headwaters to Swan Lk	1B, 2Ag, 3B	2018	2029	TBD
	07010103-717	Unnamed creek	Scooty Lk outlet to Prairie R	2Bg, 3C	2018	2018	Natural background
	07010103-726	Unnamed creek	Blackberry Lk to Mississippi R	2Bg, 3C	2018	2029	

Affected Use: Pollutant/Stressor	Lake ID/Stream AUID	Name	Location/Reach Description	Designated Use Class	Listing Year	Target Start/ Completion Year	Impairment addressed by:
Aquatic Life: Fish Bioassessments	07010103-727	Unnamed creek	Unnamed cr to Mississippi R	2Bg, 3C	2018	2029	Non-pollutant based stressor
	07010103-728[4]	Unnamed creek[4]	Unnamed cr to Swan R	2Bg, 3C	2018	2020	
	07010103-730	Unnamed creek	Unnamed cr to Mississippi R	2Bg, 3C	2018	2029	
	07010103-731	Unnamed creek	Unnamed cr to Unnamed cr	2Bg, 3C	2018	2029	TSS TMDL
	07010103-733[4]	Pokegama Creek[4]	Unnamed ditch to Mississippi River	2Bg, 3C	2018	2020	Non-pollutant based stressor
	07010103-739	Unnamed ditch	Headwaters to Hill R	2Bg, 3C	2018	2029	Non-pollutant based stressor
	07010103-741	White Elk Creek	Unnamed ditch to Willow R	2Bg, 3C	2018	2029	
	07010103-756[4]	Unnamed ditch[4]	Unnamed ditch to Miss R	2Bg, 3C	2018	2020	
Aquatic Life: Turbidity/TSS	07010103-708	Mississippi River	Swan River to Willow River	2Bg, 3C	2016	2020	TSS TMDL[3]

[1] Big Sandy Lake and Lake Minnewawa TMDL Report: https://www.pca.state.mn.us/sites/default/files/wq-iw8-24e.pdf

[2] Tamarack Lake is comprised of two distinct basins. Water quality monitoring has only been conducted in the southern basin. Additional monitoring is needed from the northern basin to determine impairment status of the entire lake and better inform lake water quality response modeling. The TMDL for Tamarack Lake has been deferred until the next 10-year assessment cycle.

[3] A separate TSS TMDL study is in progress for the Mississippi River mainstem in the Mississippi River-Grand Rapids and the Mississippi River-Brainerd Major Watersheds.

[4] Currently pending recategorization from category 5 (needs TMDL) to category 4C (impairment is not caused by a pollutant).

1.3 Priority Ranking

The MPCA's schedule for TMDL completion, as indicated on Minnesota's Section 303(d) impaired waters list, reflects Minnesota's priority ranking of this TMDL. The MPCA has aligned our TMDL priorities with the watershed approach and our WRAPS cycle. The schedule for TMDL completion corresponds to the WRAPS report completion on the 10-year cycle. The MPCA developed a state plan Minnesota's TMDL Priority Framework Report to meet the needs of EPA's national measure (WQ-27) under EPA's Long-Term Vision for Assessment, Restoration and Protection under the Clean Water Act Section 303(d) Program. As part of these efforts, the MPCA identified water quality impaired segments that will be addressed by TMDLs by 2022. The Mississippi River- Grand Rapids Watershed waters addressed by this TMDL are part of that MPCA prioritization plan to meet EPA's national measure.

2 Applicable Water Quality Standards and Numeric Water Quality Targets

All Waters of the State are assigned a Designated Use Classification which is defined by the MPCA and outlined in Minn. R. ch. 7050.0140. The Designated Use Classification defines the optimal purpose for that waterbody (see Table 1-1). The lakes and streams addressed by this TMDL study fall into one of the following two designated use classifications:

1B, 2Ag, 3B – a cold water aquatic life and habitat, also protected for drinking water

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

Class 1 waters are protected for domestic consumption. Class 2 waters are protected for aquatic life and aquatic recreation, and Class 3 waters are protected for industrial consumption. For additional details, see Minn. R. ch. 7050.0140 and Beneficial Use Designations for Stream Reaches: Mississippi River – Grand Rapids Watershed (07010103). Only one water body, Hasty Brook (Assessment Unit ID [AUID] 07010103-603), has a Class 1 designated use. The impairment for this stream reach, and other waterbodies addressed in this TMDL, is for Aquatic Recreation. Therefore, use classification 2B represents the most protective designated use classification for the impaired waterbodies. Water quality standards for Class 2B are provided below.

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

2.1 Lakes

2.1.1 Lake Eutrophication

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

The impaired lakes within the MRGRW were assessed against the Northern Lakes and Forest water quality standards (Table 2-1). To be listed as impaired (Minn. R. 7050.0150, subp. 5), the summer growing season (June through September) monitoring data must show that the standards for both TP (the causal factor) and either Chl-*a* or Secchi transparency (the response variables) were exceeded. If a lake is impaired with respect to only one of these criteria, it may be placed on a review list; a weight of evidence approach is then used to determine if it will be listed as impaired. For more details regarding the listing process, see the *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 303(b) Report and 303(d) List* (MPCA 2012).

Table 2-1. Lake Eutrophication Standards

Ecoregion	TP (µg/L)	Chl-a (µg/L)	Secchi (m)
Northern Lakes & Forest	< 30	< 9	> 2.0

2.2 Streams

2.2.1 Bacteria

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

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

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

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

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

Table 2-2. Past and current numeric water quality standards of bacteria (fecal coliform and *E. coli*) for the beneficial use of aquatic recreation (primary and secondary body contact)

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

3 Watershed and Waterbody Characterization

The MRGRW (HUC-8 07010103) is located in north central Minnesota and includes the drainage areas of the Willow and Mississippi Rivers from the Cohasset Dam in Grand Rapids, Minnesota to the Willow River. The watershed is comprised largely of forested, rural areas. It contains approximately 1,908 miles of streams/river and 552 lakes greater than 10 acres. The MRGRW covers 5,398 square kilometers (km^2) (1,333,828 acres) in areas of Aitkin, Carlton, Cass, Itasca, and St. Louis counties. Additional details regarding watershed characteristics can be found in the MRGR Monitoring and Assessment Report, Watershed Overview, and the MRGR WRAPS Report, Section 2, Watershed Conditions.

3.1 Lakes

The physical characteristics of the impaired lakes are listed in Table 3-1. Lake surface areas, lake volumes, mean depths, and littoral areas (less than 15 feet) were calculated using Minnesota Department of Natural Resources (DNR) bathymetry data; maximum depths were reported from the DNR Lake Finder website; and watershed areas and watershed to surface area ratios were calculated using MRGRW HSPF model subbasins (TetraTech 2018).

Table 3-1. Impaired lake physical characteristics

Impaired Lake or Upstream Lake/Lake ID	Surface area (ac)	Littoral area (% total area)	Volume (acre-feet)	Mean depth (feet)	Maximum depth (feet)	Watershed area* (incl. lake area) (ac)	Watershed area : Surface area
Eagle Lake 09-0057-00	389	30%	6,601	17	35	2,307	6:1
Horseshoe Lake 01-0034-00	240	100%	1,486	6	12	5,775	24:1
Upper Lake: North Island 09-0060-01	114	86%	1,001	9	25	8,835[1]	78:1
Lower Lake: South Island 09-0060-02	316	73%	2,825	9	22	4,028[2]	13:1
King Lake 31-0258-00	311	49%	4,141	13	25	890	3:1
Little Cowhorn Lake 31-0198-00	181	100%	1,076	6	12	1,178	6:1
Split Hand Lake 31-0353-00	1,374	42%	21,067	15	30	20,249	15:1

*Note that the watershed area includes the surface area of the lake
[1]Includes upstream drainage areas - Lower Lake: South Island and Eagle Lake
[2]Includes upstream drainage area - Eagle Lake

3.2 Streams

Table 3-2 lists the direct drainage and total watershed areas of the impaired stream reaches in the MRGRW. Total watershed and direct drainage areas were delineated from MRGRW HSPF model subbasins (RESPEC 2018). The direct drainage areas include only the area downstream of any impaired upstream reach impaired by the same pollutant.

Table 3-2. Impaired stream direct drainage and total watershed areas

Impaired Reach/AUID (07010103-XXX)	Upstream Impaired Reach	Direct Drainage Area (ac)	Total Drainage Area (ac)
Split Hand Creek, -574	*n/a*	6,925	**35,553**
Hasty Brook, -603	*n/a*	4,990	**17,895**
Willow River, -751	*n/a*	36,529	**112,000**
Swan River, -753	*n/a*	22,222	**94,618**
Tamarack River, -758	*n/a*	6,208	**58,112**
Prairie River, -760	*n/a*	58,286	**299,656**

3.3 Subwatersheds

The impaired lake and stream subwatersheds are illustrated in Figure 3-1 and Figure 3-2.

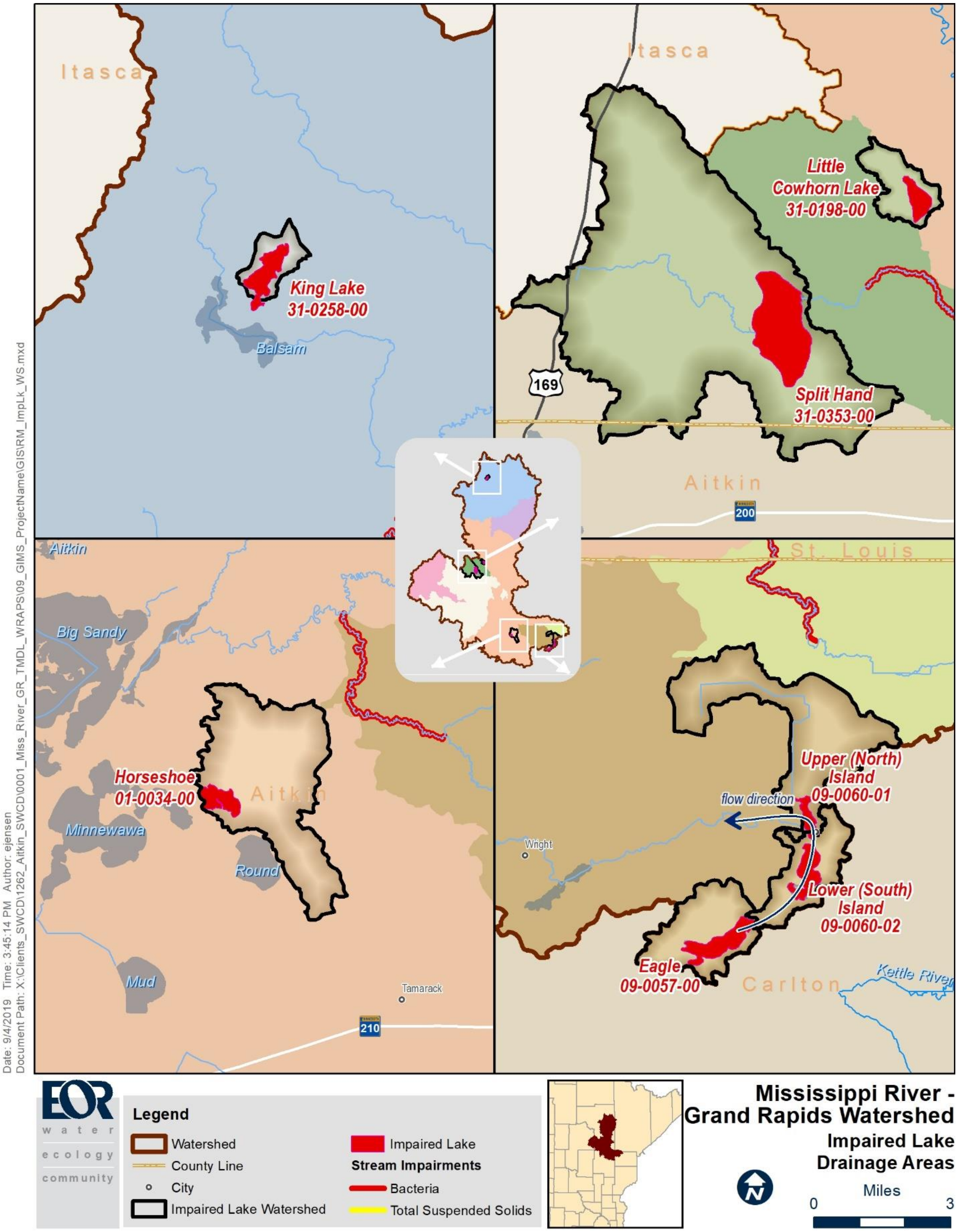

Figure 3-1. Impaired lake drainage areas

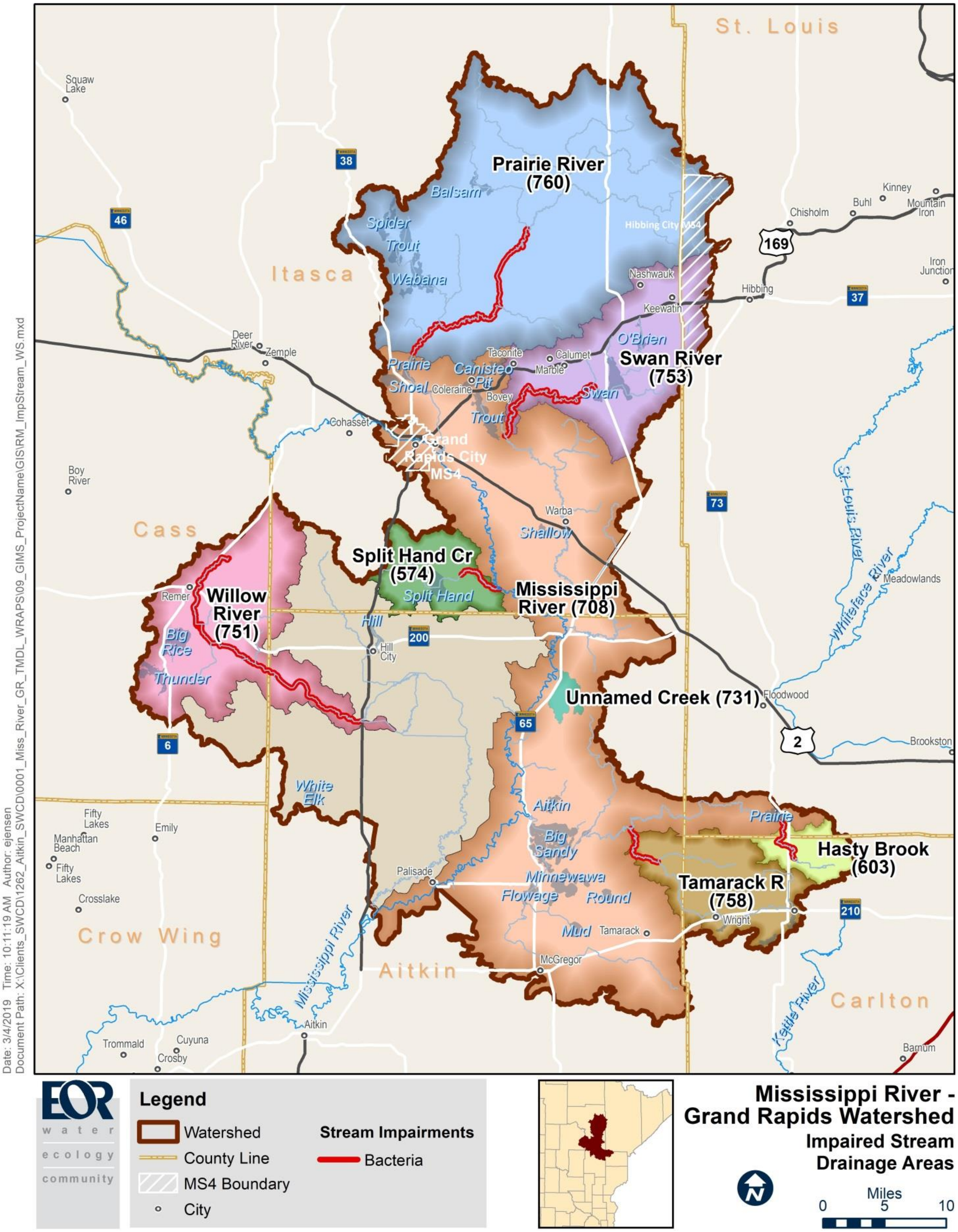

Figure 3-2. Impaired stream drainage areas

3.4 Land Use

Land cover in the MRGRW was assessed using the Multi-Resolution Land Characteristics Consortium 2011 National Land Cover Dataset (NLCD; https://www.mrlc.gov/). This information is necessary to draw conclusions about pollutant sources and best management practices (BMPs) that may be applicable within each subwatershed. The land cover distribution within impaired lake and stream watersheds is summarized in Table 3-3 and Figure 3-3. This data was simplified to reduce the overall number of categories. Forest includes evergreen forests, deciduous forests, mixed forests, and shrub/scrub. Developed includes developed open space, and low, medium, and high density developed areas. Grassland includes native grass stands, alfalfa, clover, long term hay, and pasture. Cropland includes all annually planted row crops (corn, soybeans, wheat, oats, barley, etc.), and fallow crop fields. Wetland includes wetlands and marshes. Open water includes all lakes and rivers. The primary land cover within MRGRW is woodland (41.5%; Table 3-3).

The location of Tribal Lands is included in Figure 3-3. Areas designated as Tribal Lands within the MRGRW total approximately 339 acres. No Tribal Lands are located within the watershed area of the impaired lakes and streams addressed in this TMDL study.

Table 3-3. Mississippi River-Grand Rapids Watershed and impaired lake and stream subwatershed land cover (NLCD 2011)

Lake ID/Stream AUID	Waterbody Name	Developed	Cropland	Grassland/ Pasture	Forest	Wetlands	Extraction	Open Water
09-0057-00	**Eagle Lake**	5.3%	0.5%	6.7%	40.7%	29.9%	0%	17.0%
01-0034-00	**Horseshoe Lake**	5.5%	1.2%	4.1%	48.1%	31.6%	0.01%	9.5%
09-0060-01	**Upper Lake: North Island**	11.2%	2.1%	14.2%	36.6%	21.0%	0%	14.9%
09-0060-02	**Lower Lake: South Island**	10.6%	2.4%	13.8%	27.8%	26.5%	0.4%	18.4%
31-0258-00	**King Lake**	4.0%	0%	0.9%	48.0%	12.6%	0%	34.5%
31-0198-00	**Little Cowhorn Lake**	3.1%	1.1%	10.1%	49.4%	23.2%	0%	13.1%
31-0353-00	**Split Hand Lake**	3.9%	1.1%	2.8%	57.2%	25.7%	0%	9.2%
07010103-574	**Split Hand Creek**	3.6%	1.9%	6.2%	53.0%	28.4%	0%	6.9%
07010103-603	**Hasty Brook**	1.4%	0.4%	2.8%	38.0%	55.5%	0%	1.9%
07010103-751	**Willow River**	3.4%	1.3%	4.2%	58.2%	27.4%	0%	5.5%
07010103-753	**Swan River**	4.1%	0.1%	3.9%	50.9%	16.5%	6.0%	18.6%
07010103-758	**Tamarack River**	3.0%	0.7%	6.5%	41.9%	45.2%	0.1%	2.6%
07010103-760	**Prairie River**	3.0%	0.1%	3.7%	58.9%	25.5%	0.2%	8.6%
Mississippi River-Grand Rapids Watershed		**3.9%**	**1.0%**	**6.1%**	**41.5%**	**29.9%**	**0.6%**	**7.8%**

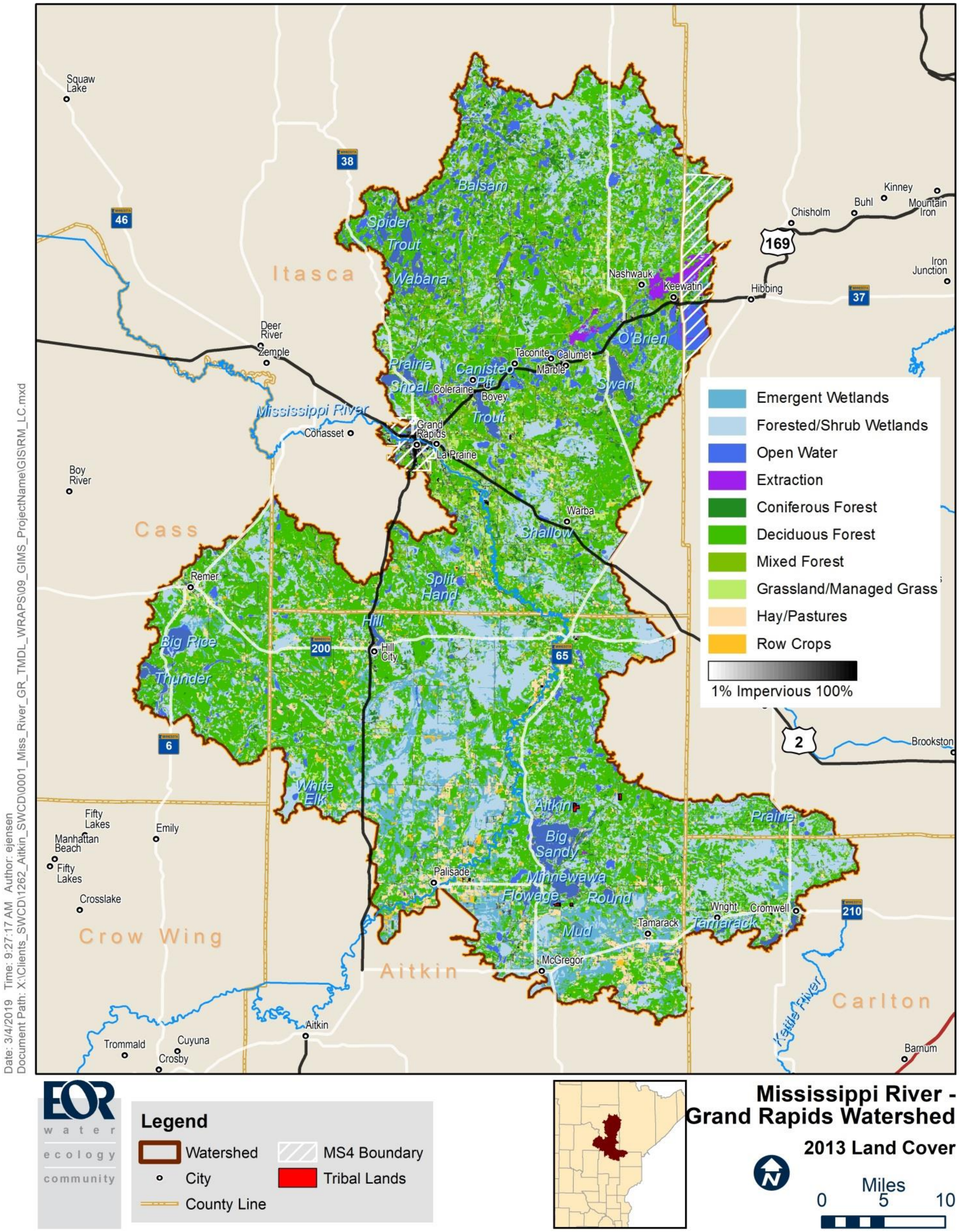

Figure 3-3. Mississippi River-Grand Rapids Watershed Land Cover (NLCD 2011)

3.5 Historic/Current Water Quality Conditions

3.5.1 Lake Eutrophication (Phosphorus)

The existing in-lake water quality conditions were quantified using data downloaded from the MPCA Environmental Quality Information System (EQuIS) database and available for the most recent 10-year time period (2007 through 2016). Growing season means of TP, Chl-*a*, and Secchi transparency depth were calculated using monitoring data from the growing season (June through September). Information on the species and abundance of aquatic plants and fish present in the lakes was compiled from DNR fisheries surveys. Year-to-year water quality trends and descriptions of the aquatic plant and fish communities for each impaired lake are included in Appendix B. The 10-year growing season mean TP, Chl-a, and Secchi data used to calibrate the lake water quality response models for each impaired lake are listed in Table 3-4 below.

Table 3-4. 10-year growing season mean TP, Chl-*a*, and Secchi by monitoring station (2007-2016)

Lake Name | Station ID		10-year (2007-2016) Growing Season Mean (June – September)					
		TP		Chl-*a*		Secchi	
		(µg/L)	CV	(µg/L)	CV	(m)	CV
Northern Lakes & Forest Ecoregion		**< 30**	**--**	**< 9**	**--**	**> 2.0**	**--**
Eagle Lake	09-0057-00-100	29	16%	7	27%	2.2	33%
	09-0057-00-201	27	9%	12	35%	2.3	4%
	ALL	**28**	**8%**	**11**	**30%**	**2.3**	**4%**
Horseshoe Lake	01-0034-00-201	43	6%	22	10%	0.9	3%
	01-0034-00-202	64	--	--	--	--	--
	ALL	**43**	**6%**	**22**	**10%**	**0.9**	**3%**
Upper Lake: North Island	09-0060-01-201	30	12%	10	25%	--	--
	09-0060-01-202	25	13%	5	30%	1.7	3%
	ALL	**27**	**9%**	**8**	**22%**	**1.7**	**3%**
Lower Lake: South Island	09-0060-02-100	26	13%	10	40%	--	--
	09-0060-02-201	31	8%	10	18%	1.8	8%
	ALL	**29**	**7%**	**10**	**16%**	**1.8**	**8%**
King Lake	31-0258-00-101	33	10%	17	25%	1.7	16%
	31-0258-00-201	--	--	--	--	1.8	8%
	ALL	**33**	**10%**	**17**	**25%**	**0.8**	**7%**

Lake Name | Station ID		10-year (2007-2016) Growing Season Mean (June – September)					
		TP		Chl-*a*		Secchi	
		(µg/L)	CV	(µg/L)	CV	(m)	CV
Northern Lakes & Forest Ecoregion		**< 30**	**--**	**< 9**	**--**	**> 2.0**	**--**
Little Cowhorn Lake	31-0198-00-101	59	11%	25	10%	0.7	11%
	31-0198-00-201	21	9%	16	22%	0.9	9%
	ALL	**46**	**15%**	**22**	**11%**	**0.8**	**7%**
Split Hand Lake	31-0353-00-203	41	12%	34	24%	1.2	7%
	31-0353-00-204	--	--	--	--	3.4	25%
	ALL	**41**	**12%**	**34**	**24%**	**1.5**	**11%**

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

3.5.2 Stream Monitoring Stations

Figure 3-4 displays the monitoring stations where water quality data, summarized in the following sections, was collected.

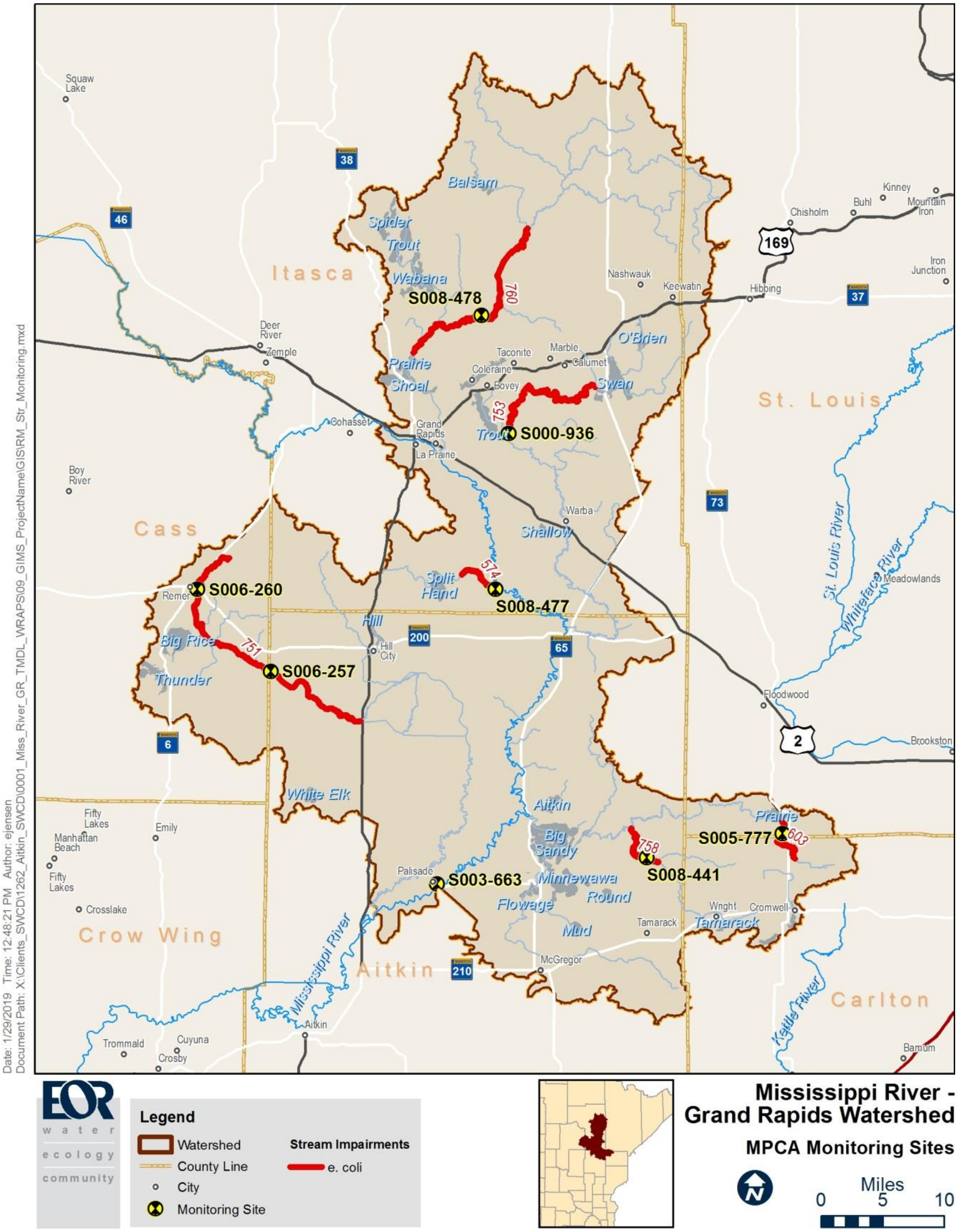

Figure 3-4. Monitoring stations on impaired reaches in the Mississippi River-Grand Rapids Watershed

3.5.3 Stream *E. coli*

Using data from the most recent 10-year period (2007 through 2016), geometric mean *E. coli* concentrations were calculated by month for the six stream reaches impaired by *E. coli*.

3.5.3.1 Split Hand Creek (07010103-574)

Table 3-5. 10-year geometric mean *E. coli* (org/100ml) concentrations by month in Split Hand Creek (07010103-574), 2007-2016.

Monitoring Station	Month	Number of Samples	Geometric Mean (org/100ml)	Min – Max (org/100ml)
S008-477	June	5	264	80 – 613
	July	6	311	28 – 1046
	August	5	135	67 - 548

Geometric means that exceed the water quality standard of 126 org/100ml for which there are at least 5 samples per calendar month collected over the 10-year time period are highlighted in bold.

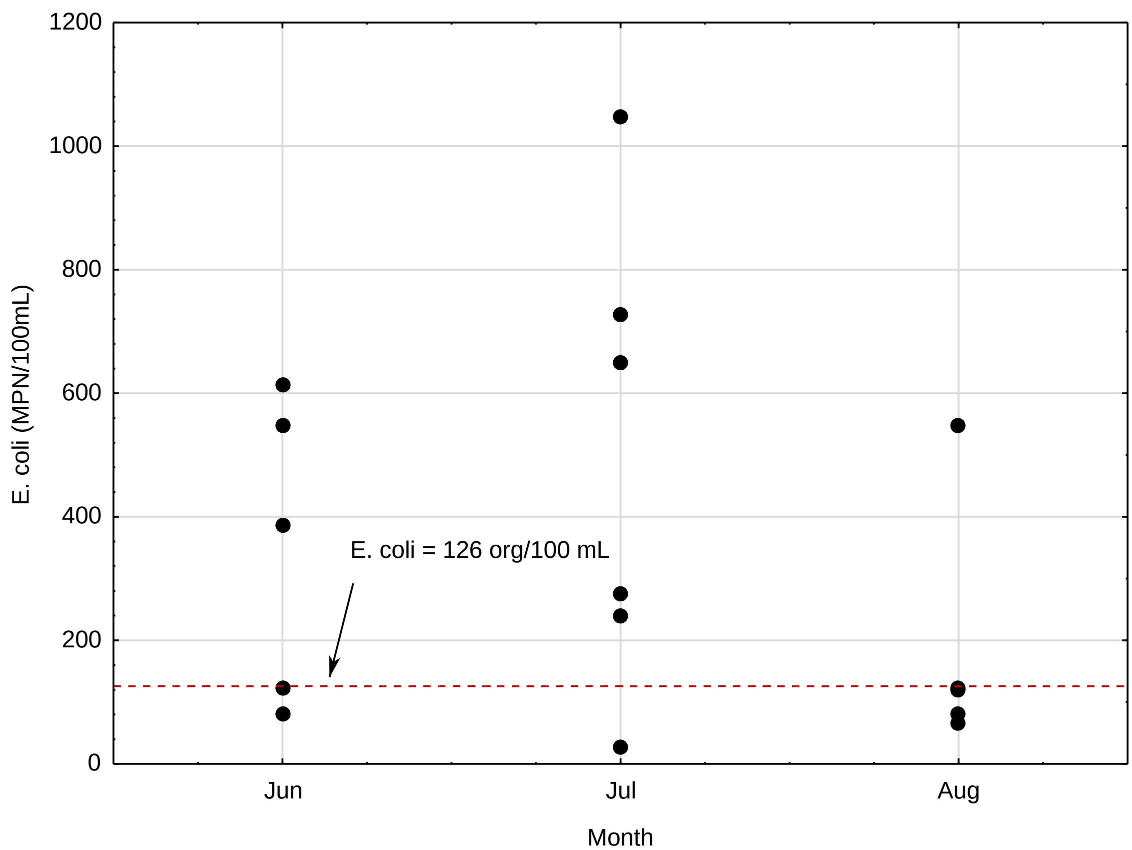

Figure 3-5. *E. coli* (MPN/100ml) by month in Split Hand Creek (07010103-574) at monitoring station S008-477, 2007-2016. The dashed line represents the stream water quality standard (126 org/100ml).

3.5.3.2 Hasty Brook (07010103-603)

Table 3-6. 10-year geometric mean *E. coli* (org/100ml) concentrations by month in Hasty Brook (07010103-603), 2007-2016.

Monitoring Station	Month	Number of Samples	Geometric Mean (org/100ml)	Min – Max (org/100ml)
S005-777	**June**	5	109	50 - 220
	July	**5**	**292**	**120 - 2400**
	August	**5**	**137**	**29 - 920**

Geometric means that exceed the water quality standard of 126 org/100ml for which there are at least 5 samples per calendar month collected over the 10-year time period are highlighted in bold.

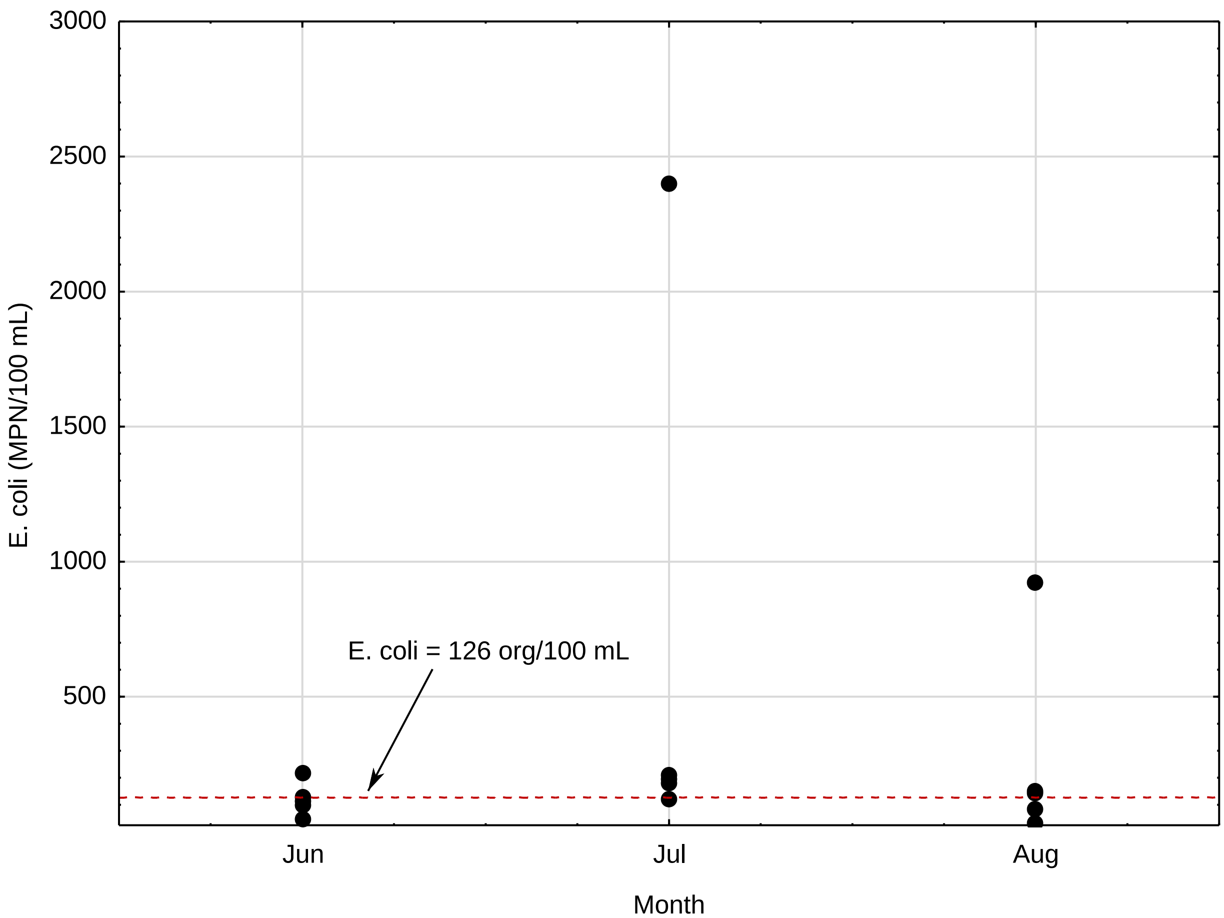

Figure 3-6. *E. coli* (MPN/100ml) by month in Hasty Brook (07010103-603) at monitoring station S005-777, 2007-2016. The dashed line represents the stream water quality standard (126 org/100ml).

3.5.3.3 Willow River (07010103-751)

Table 3-7. 10-year geometric mean *E. coli* (org/100ml) concentrations by month in Willow River (07010103-751), 2007-2016.

Geometric means that exceed the water quality standard of 126 org/100ml for which there are at least 5 samples per calendar month collected over the 10-year time period are highlighted in bold.

Monitoring Station	Month	Number of Samples	Geometric Mean (org/100ml)	Min – Max (org/100ml)
S006-257	June	6	86	20 – 308
	July	**5**	**155**	**56 – 1203**
	August	5	99	66 – 186
S006-260	June	5	77	26 - 1730
	July	**5**	**187**	**44 – 1414**
	August	5	73	37 - 107

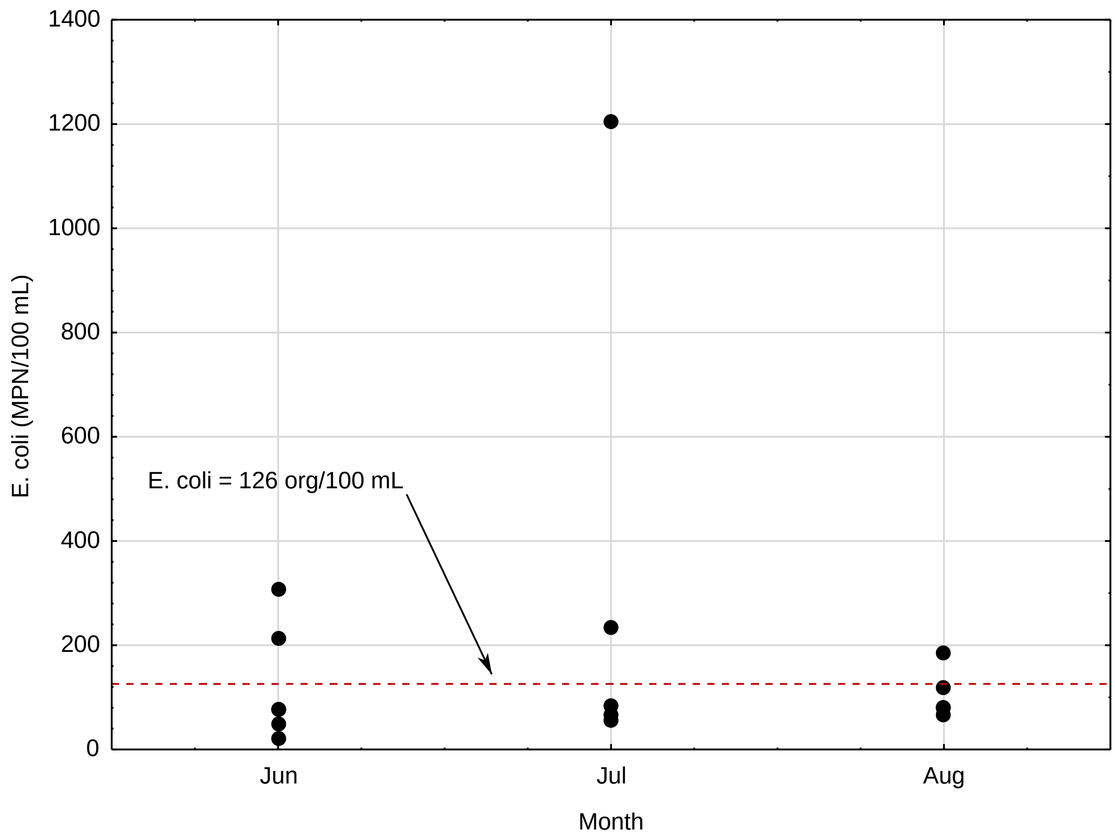

Figure 3-7. *E. coli* (MPN/100ml) by month in Willow River (07010103-751) at monitoring stations S006-257, 2007-2016. The dashed line represents the stream water quality standard (126 org/100ml).

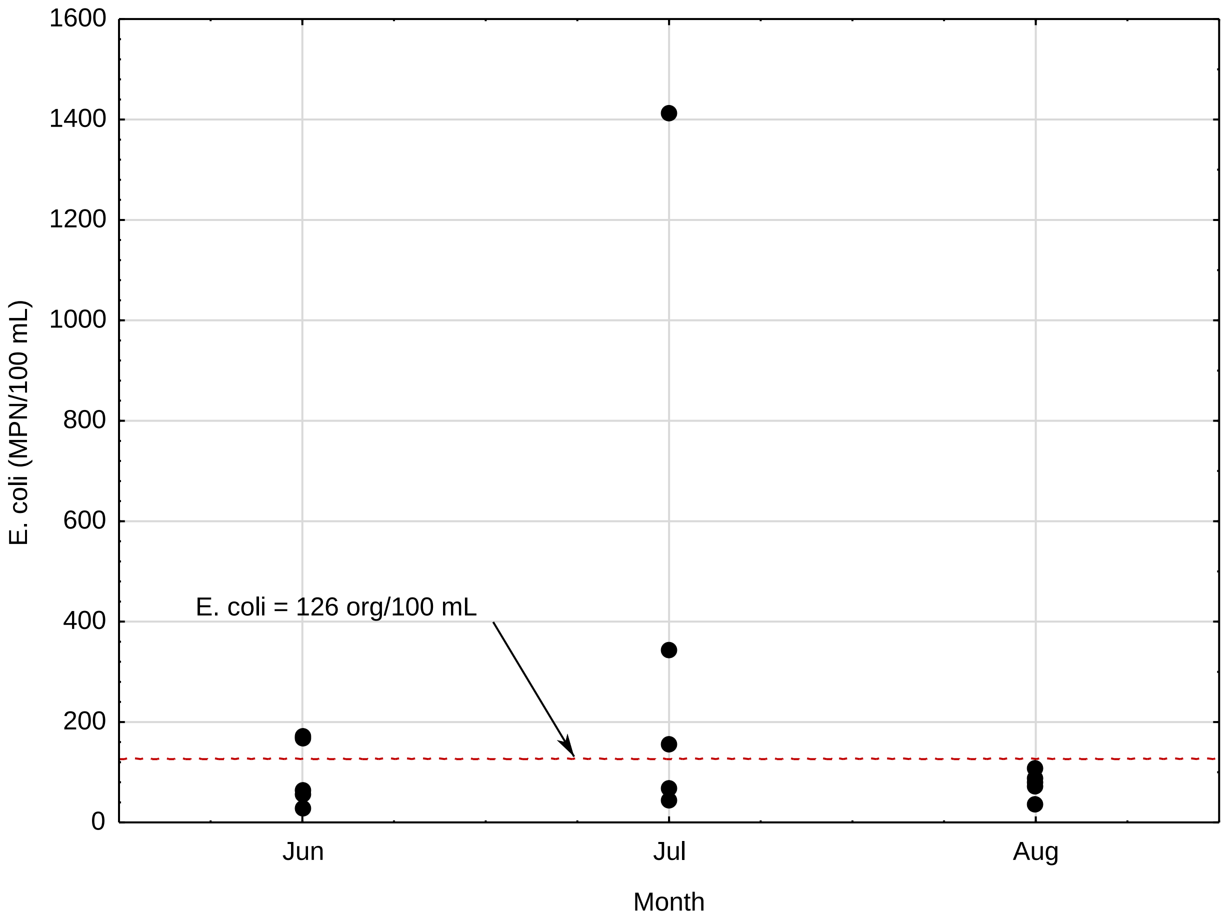

Figure 3-8. *E. coli* (MPN/100ml) by month in Willow River (07010103-751) at monitoring stations S006-260, 2007-2016. The dashed line represents the stream water quality standard (126 org/100ml).

3.5.3.4 Swan River (07010103-753)

Table 3-8. 10-year geometric mean *E. coli* (org/100ml) concentrations by month in Swan River (07010103-753), 2007-2016.

Geometric means that exceed the water quality standard of 126 org/100ml for which there are at least 5 samples per calendar month collected over the 10-year time period are highlighted in bold**.**

Monitoring Station	Month	Number of Samples	Geometric Mean (org/100ml)	Min – Max (org/100ml)
S000-936	**June**	5	40	26 – 84
	July	**6**	**175**	**39 – 378**
	August	5	61	50 - 81

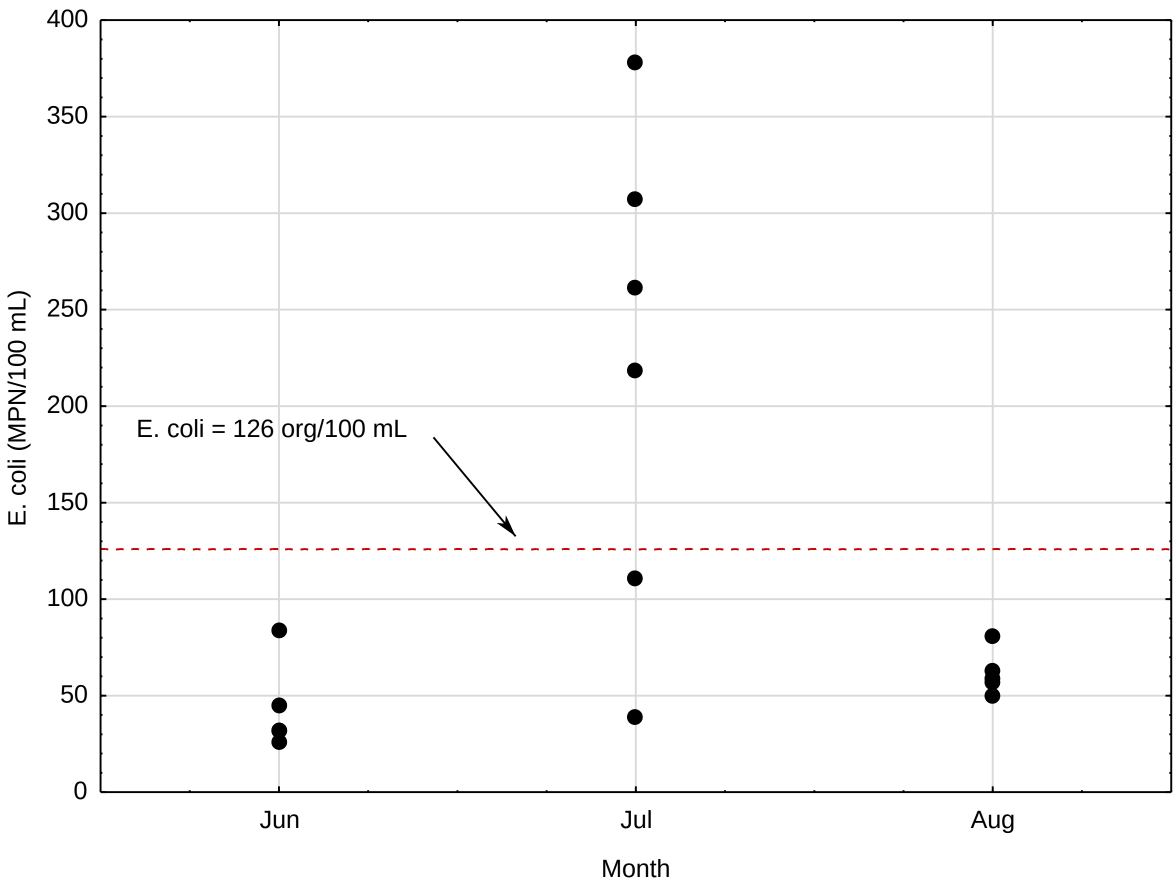

Figure 3-9. *E. coli* (MPN/100ml) by month in Swan River (07010103-753) at monitoring station S000-936, 2007-2016. The dashed line represents the stream water quality standard (126 org/100ml).

3.5.3.5 Tamarack River (07010103-758)

Table 3-9. 10-year geometric mean *E. coli* (org/100ml) concentrations by month in Tamarack River (07010103-758), 2007-2016.
Geometric means that exceed the water quality standard of 126 org/100ml for which there are at least 5 samples per calendar month collected over the 10-year time period are highlighted in bold**.**

Monitoring Station	Month	Number of Samples	Geometric Mean (org/100ml)	Min – Max (org/100ml)
S008-441	**June**	**5**	**163**	**82 – 435**
	July	6	98	22 – 816
	August	5	57	18 - 144

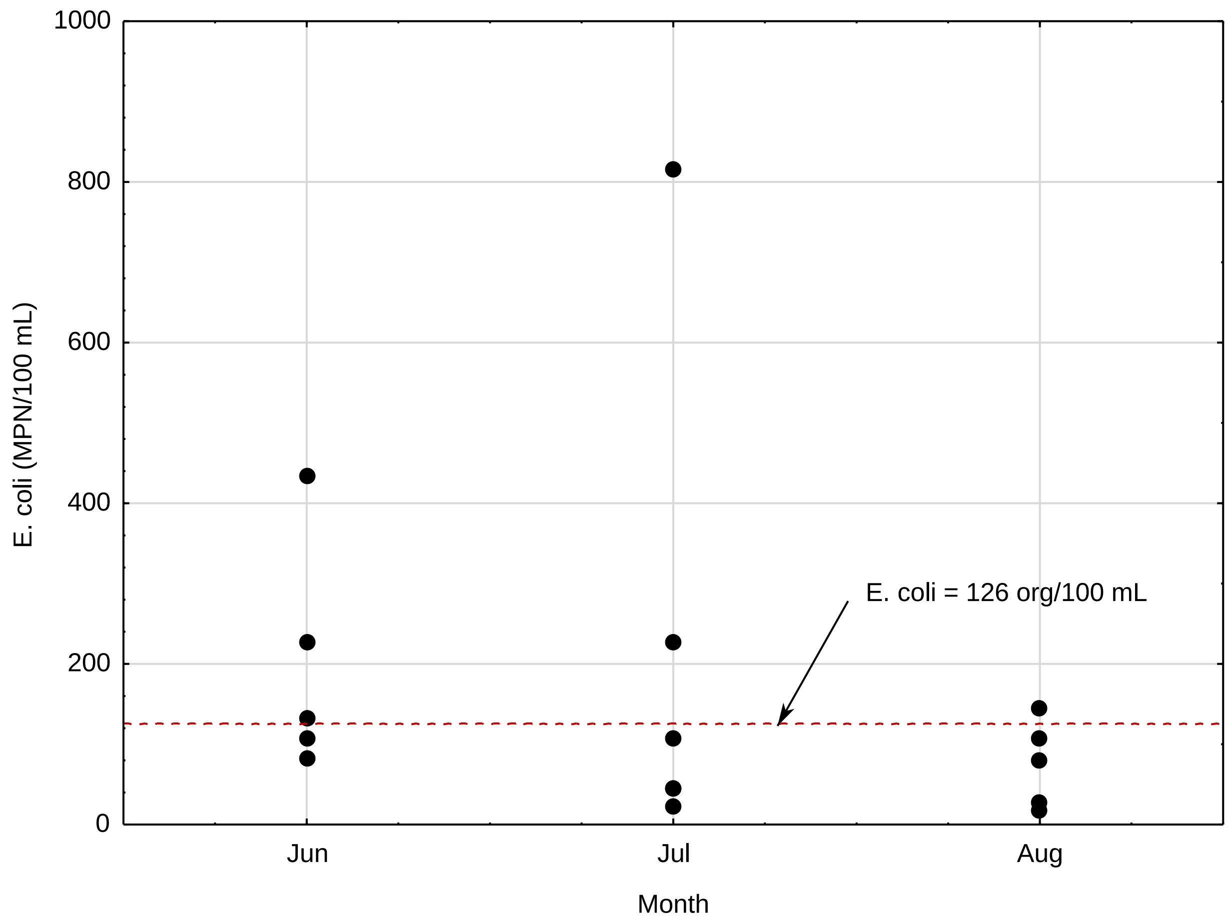

Figure 3-10. *E. coli* (MPN/100ml) by month in Tamarack River (07010103-758) at monitoring station S008-441, 2007-2016. The dashed line represents the stream water quality standard (126 org/100ml).

3.5.3.6 Prairie River (07010103-760)

Table 3-10. 10-year geometric mean *E. coli* (org/100ml) concentrations by month in Prairie River (07010103-760), 2007-2016.

Geometric means that exceed the water quality standard of 126 org/100ml for which there are at least 5 samples per calendar month collected over the 10-year time period are highlighted in bold.

Monitoring Station	Month	Number of Samples	Geometric Mean (org/100ml)	Min – Max (org/100ml)
S008-478	**June**	5	23	6 – 37
	July	6	46	20 – 175
	August	**5**	**187**	**33 - 2420**

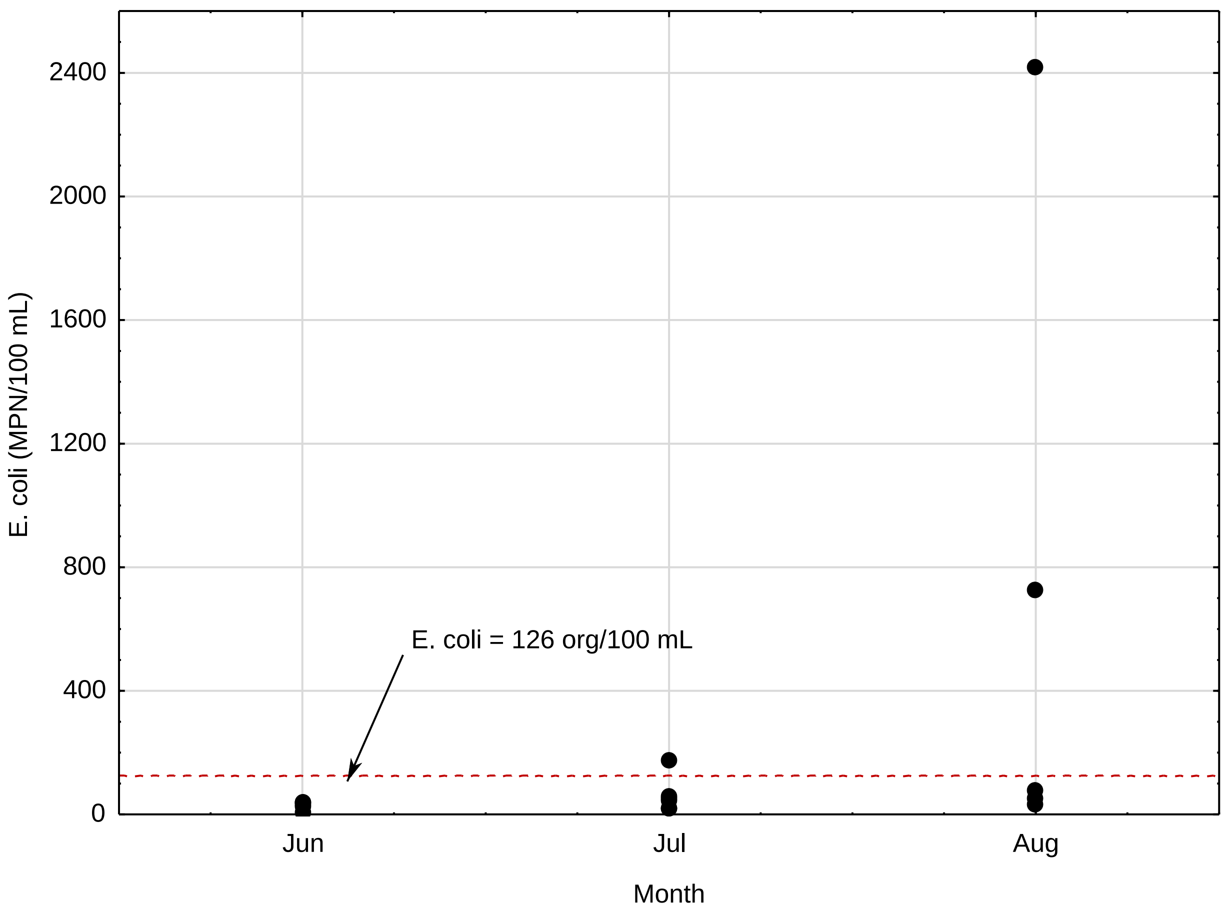

Figure 3-11. *E. coli* (MPN/100ml) by month in Prairie River (07010103-760) at monitoring station S008-478, 2007-2016. The dashed line represents the stream water quality standard (126 org/100ml).

3.6 Pollutant Source Summary

3.6.1 Lake Phosphorus

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

3.6.1.1 Permitted Sources

The regulated sources of P, within the subwatersheds of the eutrophication impairments addressed in this TMDL study, include WWTF effluent, construction stormwater, and industrial stormwater. P loads from National Pollutant Discharge Elimination System (NPDES) permitted wastewater and stormwater sources were accounted for using the methods described in Section 4.1.3 below. There is one WWTF located within the watershed of an impaired lake. The Cromwell Wastewater Treatment Plant (WWTP) is upstream of Flower Lake, but the lake was not assessed.

3.6.1.2 Non-permitted Sources

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

- Watershed runoff
- Loading from upstream waters including export from upstream wetlands
- Runoff from feedlots that do not require NPDES permit coverage
- Septic systems
- Atmospheric deposition
- Lake internal loading

Watershed runoff

A HSPF model (TetraTech 2018) was used to estimate watershed runoff volumes and TP loads from the direct drainage area of impaired lakes. The HSPF model generates overland runoff flows on a daily time step for 158 individual subwatersheds in the MRGRW based on land cover and soil type, and was calibrated using meteorological data from 1995 through 2015. A 10-year (2007 through 2016) average annual flow was calculated for lake BATHTUB models.

TP loads from specific sources within the watershed (upstream waters, feedlots not requiring NPDES permit coverage, subsurface sewage treatment systems (SSTS), and internal loading) were also independently estimated to determine their relative contributions, described below.

Table 3-11. HSPF 10-year (2007-2016) average annual flow volumes and TP loads for lake direct drainage areas

Impaired lake or Upstream Lake	Direct drainage area (ac)	Flow (ac-ft/yr)	TP Conc. (µg/L)	TP Load (lb/yr)
Eagle	1,918	1,268	19.6	67
Horseshoe	5,535	3,726	51.4	520
Upper Lake: North Island	4,693	3,055	32.1	266
Lower Lake: South Island	1,405	932	15.9	40
King Lake	580	250	27.8	19
Little Cowhorn	997	571	57.7	90
Split Hand	18,875	9,244	16.3	409

Wetland export

Minnesota's Intensive Watershed Monitoring program, and follow-up monitoring efforts such as SID, have found many examples of high TP concentrations in small, northern Minnesota streams with natural, forested subwatersheds. It is not uncommon to find TP concentrations of 0.080 to 0.300 µg/L or more in mid-summer samples. Other common findings in these streams are low dissolved oxygen (DO), cool water, significant groundwater seepage from the banks, extremely low nitrate concentrations, and often visual presence of iron. The common landscape feature among these streams is the large amounts of wetland acreage within their subwatersheds, often in the form of peatland bogs/fens, and often the immediate riparian landform.

P export from wetlands is a well-known phenomenon (O'Brien et al. 2013; Fristedt 2004; Dillon and Molot 1997; Banaszuk et al. 2005). Sediment release of P in lakes is known to be controlled by redox conditions and the interaction of P and iron. This is also true of P release from peatland soils (Carlyle and Hill 2001; Forsman and Kjaergaard 2014; Koerselman et al. 1993). Streams flowing through peatlands or with peatland riparian corridors have significant hydrological connection with the shallow groundwater of the peatlands, and particularly during anoxic periods, this groundwater can carry solubilized P into the stream channel, which then is exported downstream in the streamflow (Dillon, Molot, and Scheider 1991).

Sampling throughout the year in northern, peatland-dominated streams shows a very definite pattern of TP concentration. When applying polynomial regression to the data, the pattern is a bell-shaped curve, with its peak in mid-summer, typically late July, the warmest part of Minnesota summer. Samples of total iron show similar patterns, while DO usually shows an inverse bell curve with its trough occurring about the same time as the iron and TP peak, all of which suggest a redox controlled release of P from these peatlands. Thus, streams with abundant peatland in their subwatersheds may be a significant source of P to downstream waters, such as lakes. Examples of the discussion above, from Musselshell Creek, tributary to Horseshoe Lake, are shown in Figure 3-12 through Figure 3-14 below.

Three wetland-dominated tributaries discharging to the impaired Horseshoe, Split Hand, and Big Sandy Lakes were sampled in 2017 and 2018 as part of this TMDL study. Continuous flow and water quality grab samples were collected from snowmelt until the end of October/early November. These data were used to determine total load and flow-weighted mean P concentrations using the model FLUX. Note that Big Sandy Lake was addressed by a previous TMDL study and is not included in this study.

Higher concentrations of TP exported from wetlands were not accounted for in the HSPF watershed runoff model. Flow from the wetlands was estimated using an area-weight of the HSPF runoff flow for the drainage area based on the acres of wetland in the drainage area. This flow was multiplied by the difference in wetland tributary flow weighted mean concentration (FWMC) and the HSPF TP concentration (Table 3-12) for the lake drainage area, to estimate the portion of TP load to the lakes that could be attributed to wetland export (see Section 4.1.5 TMDL Summaries for Eagle, Horseshoe, and Split Hand Lakes).

Table 3-12. Wetland Tributary Monitoring Data for the Mississippi River-Grand Rapids Watershed (2017, 2018)

Tributary Monitoring Station	Year	Flow days	Water quality samples	Daily Flow (cfs)	Data Collection Range	Flow-weighted TP Load		
						Mass (kg)	FWMC (µg/L)	CV
Musselshell Cr. (S009-505)	2017	206	11	3.00	4/15/2017-11/6/2017	66.4	44	0.27
Tributary to Horseshoe Lake	2018	188	7	4.01	4/30/2018-11/3/2018	118.8	64	0.26
Splithand Cr. (S009-506)	2017	218	11	22.91	3/23/2017-10/31/2017	497.3	41	0.16
Tributary to Split Hand Lake	2018	208	6	44.23	4/24/2018-11/17/2018	943.0	42	0.04
Vanduse Cr. (S014-886)	2017	174	10	6.63	5/10/2017-10/30/2017	106.4	38	0.17
Tributary to Big Sandy Lake	2018	204	5	10.92	4/14/2018-11/3/2018	526.4	97	0.20

FWMC = flow weighted mean concentration

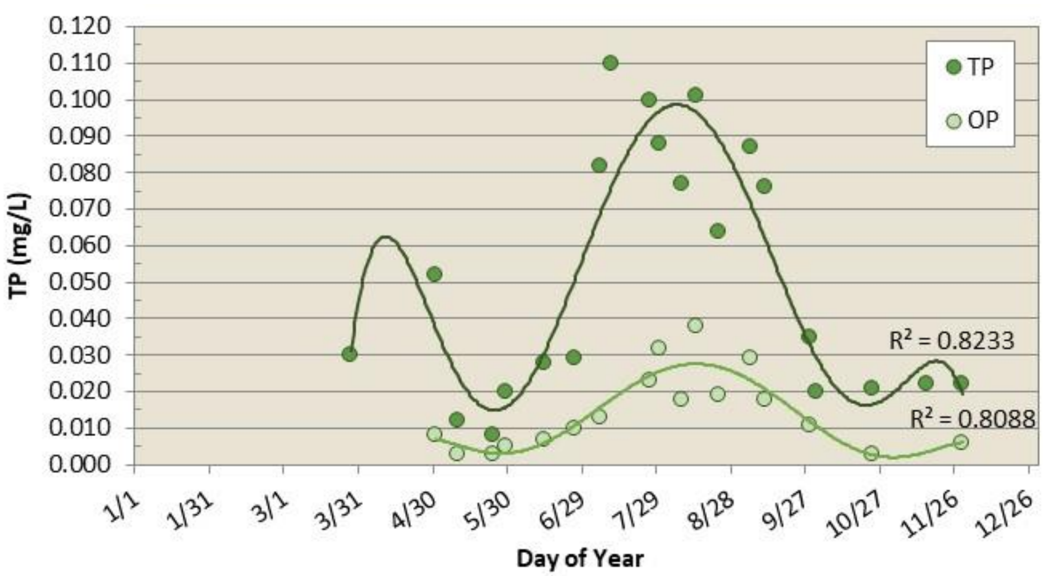

Figure 3-12. The strong seasonal pattern in phosphorus concentrations in Musselshell Creek, which peak in late July/early August.

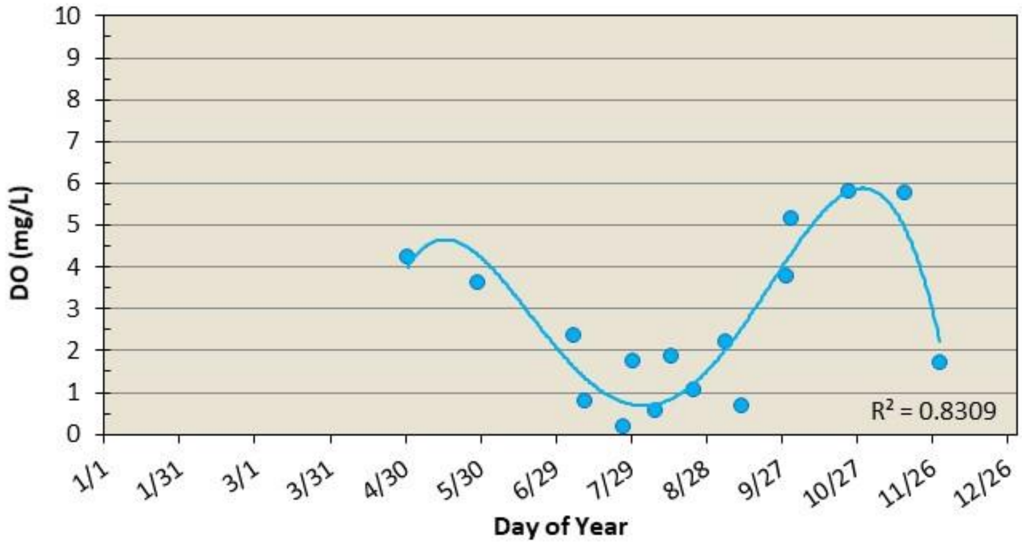

Figure 3-13. Seasonal pattern of DO in Musselshell Creek. Note that concentrations have an inverse pattern relative to phosphorus in Figure 1. The creek was frozen over at the 11/29 sampling, sealing off the stream from contact with atmospheric oxygen.

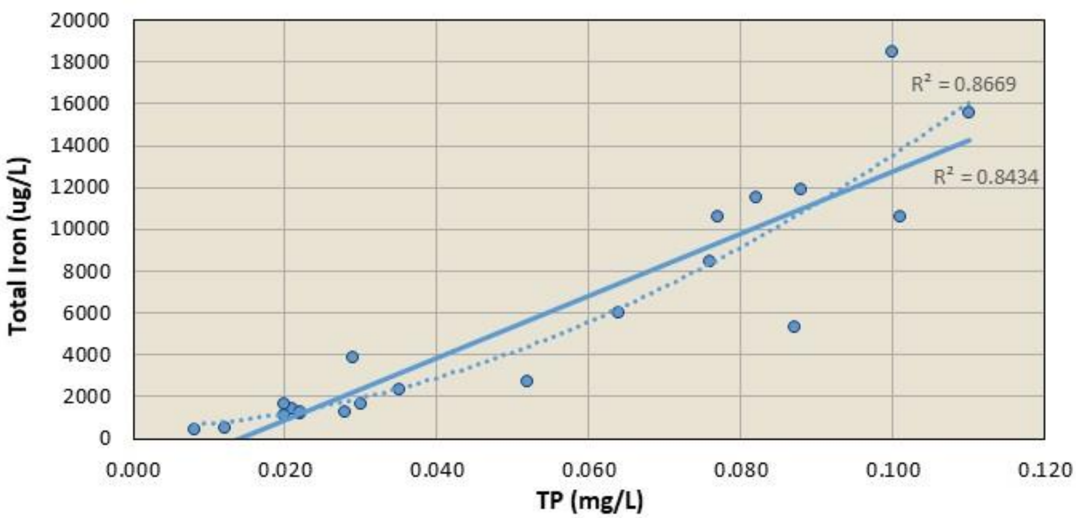

Figure 3-14. Musselshell Creek (S009-505) TP vs total iron. The very high correlation of these concentrations suggests their source being peatland soils. The dotted line is a 3rd order polynomial regression line, with a slightly better R^2 value than the linear model.

Upstream lakes and streams

Upstream lakes and streams can contribute significant P loads to downstream impaired lakes and streams. Water quality monitoring data and flow from upstream lakes and streams, summarized in Table 3-13, were used to estimate the P loads to downstream impaired waters.

Table 3-13. Existing upstream phosphorus loads to impaired lakes and streams

Impaired Lake	Upstream Lake (Lake ID)	TP (µg/L)	Flow (ac-ft/yr)	TP Load (lb/yr)
Upper Lake: North Island	Lower Lake (09-0060-02)	29	2,335	184
Lower Lake: South Island	Eagle Lake (09-0057-00)	28	1,342	102

Feedlots that do not require NPDES permits

For the purpose of this study, non-permitted feedlots are defined as being all registered feedlots without an NPDES/State Disposal System (SDS) permit that house under 1,000 AUs. Based on data from the MPCA county feedlot program and communication with county officers, there are no registered feedlots located within the drainage area of the impaired lakes.

Subsurface sewage treatment systems

Portions of Upper and Lower Island Lakes are served by the city of Cromwell sanitary sewer system, but a majority of residences located along the shoreline of impaired lakes rely on private SSTS, often referred to as septic systems. P loads from SSTS were estimated based on assumptions described in the *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds* (MPCA 2004), county specific estimates of failing septic systems rates from the MPCA 2012 SSTS Annual Report, and shoreline septic system counts from Aitkin County SWCD, Carlton County SWCD, and Itasca County Environmental Services. Estimated phosphorus loads from failing septic systems are likely conservative. Since 2011, the State of Minnesota has required local regulation of septic systems. Local governments with SSTS programs are required submit information to the MPCA annually on SSTS permitting and compliance trends. Statewide SSTS reports summarizing inspection rates and septic system counts are available for the years 2013 through 2017 through the MPCA, https://www.pca.state.mn.us/water/ssts-annual-report.

Table 3-14. SSTS assumptions and phosphorus loads to impaired lakes

Impaired Lake	Shoreline ISTS[a] #	Seasonal residence (4 mo/yr) [a] %	Permanent Residence[a] %	Conforming Systems %	Failing Systems[b] %	Capita per Residence #	P Production per Capita lb/yr	Conforming ISTS %P "passing" %	Failing ISTS %P "passing" %	Conforming Systems #	Failing Systems #	P Load Conforming ISTS lb/yr	P Load Failing ISTS lb/yr	Total Shoreline ISTS P Load lb/yr	Total Shoreline ISTS P Load due to Failing lb/yr
Eagle	184	68%	32%	86%	14%	2.52	1.95	20%	43%	158	26	86	30	116	**16.2**
Horseshoe	54	100%	0%	94%	6%	2.04	1.95	20%	43%	51	3	13	2	15	**0.9**
Upper Lake: North Island[b]	58	66%	34%	86%	14%	2.52	1.95	20%	43%	49	9	27	11	38	**4.3**
Lower Lake: South Island	76	46%	54%	86%	14%	2.52	1.95	20%	43%	65	11	45	16	43	**6.1**
King Lake	34	78%	22%	73%	27%	2.62	1.95	20%	43%	25	9	12	9	22	**5.0**
Little Cowhorn	1	0%	100%	73%	27%	2.62	1.95	20%	43%	1	0	1	0	1	**0**
Split Hand	45	71%	29%	73%	27%	2.62	1.95	20%	43%	33	12	18	14	32	**7.4**

[a]Based on counts of shoreline lots and review of property data from SWCDs.

[b]Loads are based on the estimated number of shoreline SSTS only. Based on reporting from Carlton County, 15% of shoreline residences are served by the City of Cromwell.

Atmospheric Deposition

Atmospheric deposition represents the P that is bound to particulates in the atmosphere and is deposited directly onto surface waters. Average P atmospheric deposition loading rates were approximately 0.17 kilograms per hectare of TP per year for an average rainfall year for the Upper Mississippi River Basin (Barr 2007 addendum to MPCA 2004). This rate was applied to the lake surface area to determine the total atmospheric deposition load per year to the impaired lakes and streams.

Table 3-15. Atmospheric deposition phosphorus loads to impaired lakes [MPCA 2004]

Impaired Lake or Upstream Lake	Atmospheric Deposition Phosphorus Load	
	(kg/yr)	(lb/yr)
Eagle	26.8	59.0
Horseshoe	16.5	36.4
North Island	7.8	17.2
South Island	22.3	49.1
King	21.4	47.1
Little Cowhorn	12.5	27.5
Split Hand	94.5	208.4

Internal Loading

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

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

Internal loading due to the anoxic release from the sediments of each lake was estimated, in this TMDL study, based on the expected release rate of P from the lakebed sediment, the lake anoxic factor (AF), and the lake area. Lake sediment samples were collected and tested for concentration of TP and bicarbonate dithionite extractable phosphorus (BD-P), which analyzes iron-bound P. P release rates were calculated using statistical regression equations, developed using measured release rates and sediment P concentrations from a large set of North American lakes (Nürnberg 1988; Nürnberg 1996). Internal loading due to physical disturbance is difficult to reliably estimate and was therefore not included in the lake P analyses. In lakes where internal loading is believed to be substantial, the internal load estimates derived from lake sediment data shown in Table 3-16 are likely an underestimate of the actual internal load.

Some amount of internal loading is implicit in the BATHTUB lake water quality model, therefore internal loading rates added to the BATHTUB model during calibration represents the excess sediment release rate beyond the average background release rate, accounted for by the model development lake dataset. The implicit amount of internal loading in BATHTUB is typically smaller than the calibrated BATHTUB rates for shallow lakes because the BATHTUB model development lake dataset is less representative of this lake type, and therefore accounts for less implicit internal loading in shallow lakes. Shallow lake sediments can easily be disturbed by wind-driven mixing of the water column, or physical disturbance from boats and carp. P release rates estimated from sediment core samples for impaired lakes (Table 3-16) were on the same order of magnitude, and generally somewhat greater than excess internal loading rates in calibrated BATHTUB models, validating the calibration.

Table 3-16. Internal phosphorus load assumptions and summary

Impaired Lake or Upstream Lake	Lake Type	Sediment P Concentration (mg/kg dry)		Anoxic Factor	Estimated Total Sediment P Release Rate NA Lakes Dataset (mg/m²-anoxic day)			Average Estimated Total Sediment P Release Rate NA Lakes Dataset	Average Estimated NA Lakes Dataset Internal Load	BATHTUB Calibrated Excess Release Rate	BATHTUB Calibrated Excess Internal Load	
		Iron P (BD-P)	Total P (TP)	(days)	BD-P	TP	Average	(mg/m²-calendar day)	(kg/yr)	(mg/m²-calendar day)	(kg/yr)	(lb/yr)
Eagle	Deep	230	2800	39	2.58	6.38	4.48	0.48	278.0	0.173	99.5	219.4
Horseshoe	Shallow	97.5	980	47	0.76	0.0	0.14	0.02	8.0	0.235	42.6	93.9
Upper Lake: North Island	Shallow	162	1400	39	1.64	1.10	1.37	0.14	24.3	0.08	13.4	29.5
Lower Lake: South Island	Deep	188	2200	39	2.00	4.11	3.06	0.33	152.3	0.164	78.4	172.8
King Lake	Deep	446	1300	43	5.54	0.72	3.13	0.37	167.5	0.196	90.0	198.4
Little Cowhorn	Shallow	455	1600	49	5.66	1.85	3.76	0.50	134.3	0.196	52.5	115.7
Split Hand	Deep	207	1400	46	2.26	1.10	1.68	0.21	430.1	0.657	1,334	2941.0

3.6.2 Stream *E. coli*

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

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

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

Bacteria production estimates are based on the bacteria content in feces and an average excretion rate (with units of colony forming units (cfu)/day-head; where *head* implies an individual animal). Bacteria content and excretion rates vary by animal type, as shown in Table 3-17. All production rates obtained from the literature are for fecal coliform rather than *E. coli* due to the lack of *E. coli* data. The fecal coliform production rates were converted to *E. coli* production rates based on 200 fecal coliforms to 126 *E. coli* per 100 milliliters (ml) (see discussion of *E. coli* water quality standard in Section 2.2).

However, recent research in Minnesota has shown that not all *E. coli* strains in streams originate from fecal matter and that many of these bacteria strains naturally occur in the sediments (https://www.mda.state.mn.us/growth-survival-and-genetic-structure-e-coli-found-ditch-sediments-and-water-seven-mile-creek). Therefore, the sources described here represent potential fecal sources of *E. coli* and should be field verified as part of the WRAPS process.

Table 3-17. Bacteria production by source

Source Category	Producer	*E. coli* Production Rate [cfu/day-head]	Literature Source
Humans & Pets	Humans	1.26×10^{9}	Metcalf and Eddy 1991
	Dogs	3.15×10^{9}	Horsley and Witten 1996
Livestock	Horses	2.65×10^{10}	Zeckoski et al. 2005
	Cattle	2.08×10^{10}	Zeckoski et al. 2005
	Dairy Cows	1.58×10^{10}	Zeckoski et al. 2005
	Sheep	7.56×10^{9}	Zeckoski et al. 2005
	Hogs	6.93×10^{9}	Zeckoski et al. 2005
	Turkeys	5.86×10^{7}	Zeckoski et al. 2005
	Chickens	5.61×10^{7}	Zeckoski et al. 2005
Wildlife	Beaver	1.26×10^{5}	Zeckoski et al. 2005
	Deer	2.21×10^{8}	Zeckoski et al. 2005
	Geese	5.04×10^{8}	Zeckoski et al. 2005
	Ducks	1.51×10^{9}	Zeckoski et al. 2005

3.6.2.1 Permitted

Wastewater Treatment Facilities

WWTFs are required to test fecal coliform bacteria levels in their effluent. Dischargers to Class 2 waters are required to disinfect their wastewater from April through October. Wastewater disinfection is required January through December for dischargers within 25 miles of a water intake for a potable water supply system (Minn. R. 7053.0215, subp. 1). The geometric mean for all samples collected in a month must not exceed 200 cfu/100 ml fecal coliform bacteria. The WWTFs located in the MRGRW, with a surface water discharge, are summarized in Table 3-18. Bacteria loads from NPDES/SDS permitted WWTFs are estimated based on the design flow and permitted bacteria effluent limit of 200 org/ 100 ml.

Table 3-18. WWTF design flows and permitted bacteria loads

Stream Reach	Facility Name, Permit #	Facility Type	Design Flow Rate (mgd)	Permitted Bacteria Load	
				as Fecal Coliform: 200 org/ 100 ml [billion org/day]	as *E. coli*: 126 org. / 100 ml[1] [billion org/day]
-753	Coleraine-Bovey-Taconite Joint WWTP MN0053341	Continuous Discharge	0.499	4.3	2.4
	Keewatin WWTP MN0022012		0.180	1.4	0.9
	Marble WWTP MN0020214		0.324	2.5	1.5
	Nashwauk WWTP MNG580184	Stabilization Pond[2]	0.106	23.4	14.8
-751	Remer WWTP MNG580210	Stabilization Pond[2]	0.353	3.3	2.1
-758	Cromwell WWTP MN0051101	Stabilization Pond[2]	0.595	4.7	2.8

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

[2]The permit for stabilization ponds allows discharge only during the period March 1 - June 30 and September 1 - December 31.

Land Application of Biosolids

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

Concentrated Animal Feeding Operations

Animal waste containing fecal bacteria can be transported in watershed runoff to surface waters. The MPCA regulates concentrated animal feeding operations (CAFOs) in Minnesota, though counties may be delegated by the MPCA to administer the program for feedlots that are not under federal regulation. The primary goal of the state program for animal feeding operations (AFO) is to ensure that surface waters are not contaminated by the runoff from feeding facilities, manure storage or stockpiles, and cropland with improperly applied manure. Livestock are also found on hobby farms small-scale farms that are not large enough to require registration but may have small-scale feeding operations and associated manure application or stockpiles. Based on input from SWCDs, there are several small-scale farms within the watershed. The National Resources Conservation Service (NRCS) and University of Minnesota Extension Service have worked with area producers to teach proper application rates of manure, and proper timing of manure application.

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

There are no active NPDES permitted CAFOs located within the watersheds of stream reaches impaired by *E. coli*.

3.6.2.2 Non-NPDES Permitted

Humans

Sewered and unsewered populations and number of households were determined using the 2010 Census data (U.S. Census Bureau 2011). Total population and the number of households were obtained for each subwatershed using block groups[1]; census block groups that overlap subwatershed boundaries were distributed between each applicable subwatershed on an area-weighted basis. Populations located in a sewered community were estimated from census block group data and boundaries of municipalities serviced by a WWTF (Table 3-18). A summary of the sewered and unsewered population and households by subwatershed are shown in Table 3-19.

Table 3-19. Sewered and unsewered population and households by subwatershed

Stream Reach	Population			Households		
	Sewered	Unsewered	Total	Sewered	Unsewered	Total
-574	0	2061	2061	0	1063	1063
-603	0	439	439	0	318	318
-751	403	2094	2497	397	2061	2358
-753	2,653	4360	7013	1494	2456	3950
-758	231	2704	2935	168	1967	2135
-760	0	8964	8964	0	7930	7930

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

Releases

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

Illicit Discharges from Unsewered Communities

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

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

ITPHS data are derived from surveys of County staff and County level SSTS status inventories. The MPCA's 2012 SSTS Annual Report provides the percentage of systems in unsewered communities that are ITPHS for each county in Minnesota (Table 3-20). Bacteria loads from ITPHS were estimated by subwatershed based on these percentages, the unsewered population (Table 3-19), and the bacteria production rate of humans (Table 3-17). Note that ITPHS data are derived from surveys of County staff and County level SSTS status inventories. The specific locations of ITPHS systems are not known. The table is not intended to suggest that ITPHS systems contribute excess bacteria to specific waterbodies addressed in this report; rather it suggests that, in general, ITPHS are believed to occur in the project area. Minnesota's SSTS rules and regulations are summarized on the MPCA website.

Table 3-20. Estimate of percent ITPHSS as reported by each county

County	%ITPHSS
Aitkin	1%
Cass	1%
Carlton	4%
Itasca	3%
St. Louis	3%

Figure 3-15. Estimated ITPHSS within each impaired stream drainage area

Estimated ITPHSS within each impaired stream drainage area:			
Stream Reach	2010 US Census Counts – Unsewered Communities		Estimated number of ITPHSS
	Population	Households	
-574	2061	1063	41
-603	439	318	10
-751	2094	2061	61
-753	4360	2456	74
-758	2704	1967	66
-760	8964	7930	96

Land Application of Septage

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

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

Pets

Human pets (dogs and cats) can contribute bacteria to a watershed when their waste is not properly managed. When this occurs, bacteria can be introduced to waterways from:

- Dog parks
- Residential yard runoff (spring runoff after winter accumulation)
- Rural areas where there are no pet cleanup ordinances
- Animal elimination of excrement directly into waterbodies

Dog waste can be a significant source of pathogen contamination of water resources (Geldreich 1996). Dog waste in the immediate vicinity of a waterway could be a significant local source with local water quality impacts. However, it is generally thought that these sources may be only minor contributors of fecal contamination on a watershed scale because the estimated magnitude of this source is very small compared to other sources. According to the American Veterinary Medical Association's (AVMA) 2006 data, 34.2% of Minnesota households own dogs with a mean number of 1.4 dogs in each of those households (AVMA 2007). In addition, it was assumed that only 38% of dog waste is not collected by owners and can contribute fecal pollution to surface waters (TBEP 2012). Bacteria load from dogs was estimated based on total households in each subwatershed (Table 3-19), the assumptions mentioned in this paragraph, and the bacteria production rate of dogs (Table 3-17).

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

Livestock

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

For the purpose of this study, non-permitted feedlots are defined as being all registered feedlots without a NPDES/SDS permit that house under 1,000 AUs. There are several registered feedlots located within the watershed areas of impaired streams which fall into this category. While these feedlots do not fall under NPDES regulation, other regulations still apply.

The number of feedlot animals registered with the MPCA was reviewed by an Environmental Services or Feedlot officer for the portion of each county located in the MRGRW in the spring of 2019 (Table 3-21). The bacteria load from grazing livestock was estimated based on the number of animals (Table 3-21) and the bacteria production rate of those animals (Table 3-17).

Table 3-21. MPCA registered feedlot animals by subwatershed (MPCA SDS Permit Database)

Stream Reach	County	Bovines	Horses	Hog	Sheep	Birds
-574	Itasca	50	0	0	0	0
-603	Carlton St. Louis	17	3	0	0	0
-751	Aitkin, Cass Itasca	0	0	0	0	0
-753	Itasca, St. Louis	12	0	0	0	25
-758	Carlton Aitkin	121	0	0	0	0
-760	Itasca, St. Louis	21	0	0	0	0

Wildlife

Bacteria can be contributed to surface water by wildlife (e.g., beaver, deer, geese, and ducks) dwelling in waterbodies, within conveyances to waterbodies, or when their waste is carried to stormwater inlets, creeks, and ditches during stormwater runoff events. Areas such as DNR designated wildlife management areas, State Parks, National Parks, National Wildlife Refuges, golf courses, and state forests provide wildlife habitat encouraging congregation and could be potential sources of higher fecal coliform due to the high densities of animals. There are likely many areas within the project area where wildlife congregates, especially in the wetland-dominated northeast portion of the watershed.

Wildlife populations were estimated based on DNR population data for permit areas and zones. Because permit areas or zones do not align with subwatershed boundaries, population data for any single permit area or zone was distributed among subwatersheds on an area-weighted basis (Table 3-22). Populations of wildlife (deer, ducks, and geese) were estimated from the data sources and assumptions listed in Table 3-23. Bacteria loads from wildlife were estimated based on the population and bacteria production rates of wildlife (Table 3-17).

Table 3-22. Wildlife population estimates and bacteria production by subwatershed

Stream reach	Estimated Population				*E. Coli* Production (cfu/head/day)			
	Beaver	Deer	Ducks	Geese	Beaver	Deer	Ducks	Geese
-574	26	838	150	48	3.22E+06	1.85E+11	4.22E+11	1.27E+12
-603	20	431	21	24	2.55E+06	9.53E+10	2.17E+11	6.51E+11
-751	73	3,416	376	150	9.22E+06	7.55E+11	1.72E+12	5.16E+12
-753	76	2,110	1074	126	9.51E+06	4.66E+11	1.06E+12	3.19E+12
-758	46	1,243	92	78	5.84E+06	2.75E+11	6.26E+11	1.88E+12
-760	251	3,416	1572	400	3.16E+07	7.55E+11	1.72E+12	5.16E+12

Table 3-23. Population Estimate Data Sources and Habitat Assumptions for Wildlife

Wildlife	Population Estimate Data Sources and Habitat Assumptions
Beaver	Population estimates for beaver were not reported in wildlife status reports published by the DNR in 2009, and 2017. However, according to the species fact sheet published on the DNR website, in its range, there are 0.6 beaver colonies per river mile. To estimate beaver populations by impaired stream watershed, the total number of river miles within the each impaired stream watershed was multiplied by the population density reported on the DNR species information page (https://www.dnr.state.mn.us/mammals/beaver.html).
Ducks	According to a presentation by Steve Cordts of the Minnesota DNR Wetland Wildlife Population and Research Group at the 2010 Minnesota DNR Roundtable, Minnesota's annual breeding duck population averaged 550,000 between the years 2005 through 2009. While the breeding range of the canvasback and lesser scaup is typically outside of the project area, the majority of the breeding duck population (including blue-winged teal, mallards, ring-necked ducks, and wood ducks) has a state-wide breeding range. Statewide there is approximately 90,555,611 acres of suitable open water NWI habitat, equivalent to 0.061 ducks per acre of open water. This duck population density was distributed over all suitable open water NWI land covers plus a 100 foot buffer within each subwatershed on an area-weighted basis.
Deer	The DNR report Status of Wildlife Populations, Fall 2017, includes a collection of studies that estimate wildlife populations of various species (Dexter 2009). Pre-fawn deer densities were reported by DNR deer permit area. Permit area deer population densities over all 2006 NLCD land covers except open water within each subwatershed on an area-weighted basis.
Geese	The DNR report Status of Wildlife Populations, Fall 2009, also includes a collection of studies that estimate wildlife populations of various species by Minnesota ecoregion (Dexter 2009). Geese population data were distributed over and within a 100 foot buffer of all open water areas (PWI basins, streams, ditches and rivers, and 2006 NLCD *Open Water*) on an area-weighted basis within each subwatershed.

3.6.2.3 Strengths and Limitations

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

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

3.6.2.4 Summary

The MRGRW is largely undeveloped. Approximately 90% of the watershed is comprised of forested areas, wetlands, or open water. There is evidence to support multiple potential sources of bacteria in each impaired stream, but overall, the most likely causes of bacteria impairments in the MRGRW are wildlife, livestock encroachment, and failing septic systems. The Swan River (-753) is the only impaired stream with a significant number of permitted sources of *E. coli* (see Section 4.2.5.4). While the total WLA in the TMDL for the Swan River does not exceed the loading capacity, permitted sources may contribute stress to the Swan River system, especially under low and very low flow conditions.

Additional bacteria and microbial DNA sampling is recommended to identify the specific source of bacteria in each impaired stream. These samples could be collected at multiple sites along each reach to spatially target these sources of bacteria.

4 TMDL Development

4.1 Phosphorus

4.1.1 Loading Capacity

4.1.1.1 Lake Response Model

The modeling software BATHTUB (Version 6.1) was selected to link P loads with in-lake water quality. A publicly available model, BATHTUB was developed by William W. Walker for the U.S. Army Corps of

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

System Representation in Model

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

Model Inputs

The input required to run the BATHTUB model includes lake geometry, climate data, and water quality and flow data for runoff contributing to the lake. Observed lake water quality data are also entered into the BATHTUB program in order to facilitate model verification and calibration. Lake segment inputs are listed in Table 4-1 and tributary inputs are listed in Table 4-2. Average annual precipitation rates are based on the Minnesota Climatology Working Group Gridded Precipitation Database of annual average precipitation for 2007 through 2016 at the centroid of each impaired lake, and average annual evaporation rates are based on the Minnesota DNR St. Paul Campus Pan Evaporation measurements for 2007 through 2016, multiplied by a pan evaporation coefficient of 0.795. Precipitation and evaporation rates apply only to the lake surface areas. Average P atmospheric deposition loading rates were estimated to be 0.17 kilograms per hectare per year (kg/ha-yr) for the Upper Mississippi River Basin (Barr 2007), applied over each lake's surface area. See discussion titled *Atmospheric Deposition* in *Section 3.6.1* for more details.

Table 4-1. BATHTUB segment input data for impaired lakes

Impaired Lake	Average Annual Precipitation (m/yr)	Average Annual Evaporation (m/yr)	Surface area (sq km)	Lake fetch (km)	Mean depth (m)	Total Phosphorus	
						(µg/L)	CV (%)
Eagle	0.784	0.726	1.5742	2.5298	5.17	28	8%
Horseshoe	0.770		0.9715	1.5850	1.89	43	6%
North Island	0.784		0.4596	1.2192	2.69	27	9%
South Island	0.784		1.2804	1.5850	2.72	29	7%
King Lake	0.715		1.2571	2.0422	4.06	33	10%
Little Cowhorn	0.732		0.7337	1.2192	1.81	46	15%
Split Hand	0.732		5.5593	4.1758	4.67	41	12%

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

Table 4-2. BATHTUB tributary input data for impaired lakes

Impaired Lake	Tributary	Drainage area (km^2)	TP Conc. (µg/L)	Flow (hm3/yr)
Eagle	Direct Drainage	7.7621	53.19	1.5631
Horseshoe	Direct Drainage	22.3980	52.86	4.5945
North Island	Direct Drainage	18.9917	36.09	3.7667
North Island	South Island Lake	16.3020	29.00	2.8792
South Island	Direct Drainage	5.6853	32.85	1.1488
South Island	Eagle Lake	9.3363	28.00	1.6544
King Lake	Direct Drainage	2.3459	59.60	0.3083
Little Cowhorn	Direct Drainage	4.0344	58.35	0.7046
Split Hand	Direct Drainage	76.3859	17.52	11.3977

* TP concentration includes phosphorus load from HSPF runoff and septic systems

Model Equations

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

Model Calibration

The BATHTUB model initially under predicted the in-lake P concentration of all the impaired lakes. When the predicted in-lake TP concentration was *lower* than the average observed (monitored) concentration, an explicit additional load was added to calibrate the model. The models were calibrated to existing water quality data, found in Table 4-3, and then were used to determine the P loading capacity (TMDL) of each lake.

Table 4-3. Model calibration summary for the impaired lakes

Impaired Lake	Added Excess Internal/ Load (mg/m2-day)
Eagle	0.173
Horseshoe	0.235
North Island	0.080
South Island	0.164
King Lake	0.196
Little Cowhorn	0.191
Split Hand	0.657

Determination of Lake Loading Capacity

Using the calibrated existing conditions model as a starting point, the P concentrations associated with tributaries and excess internal loading rates were reduced until the model indicated that the TP state standard was met, to the nearest tenth of a whole number. First, upstream lake P concentrations were assumed to meet eutrophication water quality standards. Next, any added internal loads were reduced until in-lake P concentration met the lake water quality standard. If further reductions were needed, the direct drainage flow-weighted mean TP concentration was reduced until the in-lake P concentration met the lake water quality standard. Minnesota lake water quality standards assume that once the TP goals are met, the Chl-*a* and Secchi transparency standards will likewise be met (see *Section 2.1.1 Applicable Water Quality Standards*). With this process, a series of models were developed that included a level of P loading consistent with lake water quality state standards, or the TMDL goal. Actual load values are calculated within the BATHTUB software, so loads from the TMDL goal models could be compared to the loads from the existing conditions models to determine the amount of load reduction required.

4.1.2 Load Allocation Methodology

The LA includes all sources of P that do not require NPDES/SDS permit coverage: watershed runoff, internal loading, atmospheric deposition, and any other identified loads described in Section 3.6.1. The remainder of the loading capacity (TMDL), after subtraction of the MOS and calculation of the WLA, was used to determine the LA for each impaired lake. The remainder of the LA, after subtraction of atmospheric deposition LA and internal loading LA, was used to determine the watershed runoff LA for each impaired lake on an areal basis. Note that the MOS was distributed proportionately among internal loading and watershed runoff based on the proportion of existing loads relative to the loading capacity. The MOS cannot be accounted for in the atmospheric deposition and upstream impaired lake out-flow allocations, as no further reductions can be achieved from these sources beyond what is needed to achieve the loading capacity (i.e., atmospheric loads cannot be reduced and upstream impaired lakes are not required to improve in-lake water quality beyond the state eutrophication standards).

4.1.3 Wasteload Allocation Methodology

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

4.1.3.1 MS4 Regulated Stormwater

There are no Municipal Separate Storm Sewer Systems (MS4s) located within the drainage area of the impaired lakes.

4.1.3.2 Regulated Construction Stormwater

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

A categorical WLA was assigned to all construction activity in each impaired lake subwatershed. First, the average annual fraction of the impaired subwatershed area, under construction activity over the most recent 10 years, was calculated based on MPCA Construction Stormwater Permit data from January 1, 2008 to December 31, 2017 (Table 4-4), area-weighted based on the fraction of the subwatershed located in each county. This percentage was multiplied by the watershed runoff load component to determine the construction stormwater WLA. The watershed runoff load component is equal to the total TMDL (loading capacity) minus the sum of the non-watershed runoff load components (atmospheric load, upstream lake loads, internal loads, and MOS).

Table 4-4. Average Annual NPDES/SDS Construction Stormwater Permit Activity by County (1/1/2007-10/6/2012)

County	Total Area (ac)	Average Annual Construction Activity (% Total Area)
Aitkin	1,275,804	0.017%
Carlton	559,725	0.014%
Itasca	1,872,384	0.053%

4.1.3.3 Regulated Industrial Stormwater

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

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

4.1.3.4 Feedlots Requiring NPDES/SDS Permit Coverage

The primary goal of the state feedlot program is to ensure that surface waters are not contaminated by runoff from feedlots, manure storage or stockpiles, and cropland with improperly applied manure. AFOs that either: (a) have a capacity of 1,000 animal units (AUs) or more, or (b) meet or exceed the EPA's CAFO threshold and discharge to Waters of the United States, are required to apply for permit coverage through the MPCA. These permits require that the feedlots have zero discharge to surface water. There are no active NPDES/SDS permitted feedlots located within the MRGRW.

4.1.3.5 Municipal and Industrial Wastewater Treatment Systems

No NPDES/SDS permitted WWTFs fall within an impaired lake subwatershed.

4.1.3.6 Margin of Safety

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

- BATHTUB model calibration using added internal load with values typical for eutrophic lakes. (see Section 3.6.1.2: Internal Loading).
- Generally good agreement between BATHTUB model predicted and observed values indicating that the models reasonably reflect the conditions in the lakes and their subwatersheds, and
- Three or more years of in-lake water quality data used to calibrate the BATHTUB model.

4.1.4 Seasonal Variation

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

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

4.1.5 TMDL Summary

4.1.5.1 Eagle Lake (09-0057-00) TP TMDL

Table 4-5. Eagle Lake (09-0057-00) TP TMDL and Allocations

Eagle Lake Load Component		Existing	Goal		Reduction	
		(kg/yr)	(kg/yr)	(kg/day)	(kg/yr)	(%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.010	0.010	0.000027	0.0	0%
	Industrial stormwater (MNR500000)	0.010	0.010	0.000027	0.0	0%
	Total WLA	**0.020**	**0.020**	**0.000054**	**0.0**	
Load Allocations*	*Watershed runoff*	*75.8*	*69.0*	*0.189*	*6.8*	*9%*
	Failing septics	*7.4*	*0.0*	*0.000*	*7.4*	*100%*
	Internal load	*99.5*	*68.5*	*0.188*	*31.0*	*31%*
	Total Watershed/In-lake	182.7	137.5	0.377	45.2	25%
	Atmospheric	26.8	26.8	0.073	0.0	0%
	Total LA	**209.5**	**164.3**	**0.45**	**45.2**	**22%**
MOS			**18.3**	**0.050**		
TOTAL		**209.5**	**182.6**	**0.50**		

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

Phosphorus Reductions Needed to Meet Water Quality Goal

- 6.8 kg/yr from watershed runoff
- 7.4 kg/yr from converting ~26 failing shoreline septic systems to conforming
- 31.0 kg/yr from internal load

Phosphorus Source Summary

- Eagle Lake is 389 acres with a maximum depth of 35 feet and a shallow lake zone (<15 feet) that covers 30% of the lake surface area.
- Sediment P release rates based on sediment core sampling were greater than the release rates in the calibrated BATHTUB model, indicating that all of the added load to the BATHTUB model was likely due to internal loading from anoxic sediment P release (Table 3-16).

- There is a diverse and healthy fish and aquatic plant community.
- Water levels have been collected since 1993. The recorded range is 3.91 feet, with a minimum recorded in August 2010 (1307.65 ft) and a maximum recorded in June 2012 (1311.56 ft). Except for the very high water levels in 2012, recent water levels have been at or below the ordinary high water level (OHW) of 1309.2 ft.
- The lake watershed is 2,304 acres, or 6 times the lake surface area.
- The shoreline is well developed with seasonal conversion of cabins to year-round homes.
- Approximately 30% of the watershed is wetland.
- Assuming the watershed wetlands are contributing P at the flow-weighted mean concentration of 44-64 µg/L (average of 54.2 µg/L) measured from Musselshell Creek (tributary to Horseshoe Lake), compared to the HSPF predicted runoff P concentration of 19.6 µg/L, the additional load from the Eagle Lake wetlands beyond what was accounted for by HSPF is approximately 20 kg/yr of the 100 kg/yr of internal load.

4.1.5.2 Horseshoe Lake (01-0034-00) TP TMDL

Table 4-6. Horseshoe Lake (01-0034-00) TP TMDL and Allocations

Horseshoe Lake Load Component		Existing (kg/yr)	Goal (kg/yr)	Goal (kg/day)	Reduction (kg/yr)	Reduction (%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.024	0.024	0.000066	0.0	0%
	Industrial stormwater (MNR500000)	0.024	0.024	0.000066	0.0	0%
	Total WLA	**0.048**	**0.048**	**0.000132**	**0.0**	
Load Allocations*	*Watershed runoff*	*242.4*	*143.8*	*0.394*	*98.6*	*41%*
	Failing septics	*0.4*	*0.0*	*0.000*	*0.4*	*100%*
	Wetland anoxic release	*4.3*	*4.3*	*0.012*	*0.0*	*0%*
	Near-shore runoff	*79.1*	*33.7*	*0.092*	*45.4*	*57%*
	Total Watershed/In-lake	326.2	181.8	0.498	144.4	44%
	Atmospheric	16.5	16.5	0.045	0.0	0%
	Total LA	**342.7**	**198.3**	**0.543**	**144.4**	**42%**
MOS			**22.0**	**0.060**		
TOTAL		**342.7**	**220.3**	**0.603**		

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

Phosphorus Reductions Needed to Meet Water Quality Goal

- 98.6 kg/yr from watershed runoff
- 0.4 kg/yr from converting ~3 failing shoreline septic systems to conforming
- 45.4 kg/yr from near-shore runoff

Phosphorus Source Summary

- Horseshoe Lake is 210 acres with a maximum depth of 12 feet and a shallow lake zone (<15 feet) that covers 100% of the lake surface area.
- Natural springs have been observed near the shoreline and in the lake bottom.
- Sediment P release rates based on sediment core sampling were much less than the release rates in the calibrated BATHTUB model, indicating that the added load in the BATHTUB model was likely not due to internal loading from anoxic sediment P release (Table 3-16).
- There are occasional partial winterkills; the most recent observed was a partial kill in the winter of 2007-2008. Partial winterkills are likely due to the shallow, eutrophic nature of the lake.
- There was a healthy aquatic plant community in the most recent DNR fish survey in 2015.
- Water levels have been collected since 1970. The recorded range is 1.79 feet, with a minimum recorded in October 2006 (1223.7 ft) and a maximum recorded in April 2001 (1225.49 ft).
- Mid-summer mixing events, combined with sediment P release under anoxic conditions at the lake bottom, may be contributing to internal loading in the lake.
- The lake watershed is 21,622 acres, or 90 times the lake surface area.
- Approximately 32% of the watershed is wetland, with beaver issues on Musselshell Creek.
- Pollutant load monitoring on Musselshell Creek (Flow gage: H09077002, Water quality monitoring site: S009-505) in 2017 and 2018 by MPCA measured a flow-weighted mean concentration entering the lake of 44-64 µg/L (average 54.2 µg/L), compared to the HSPF predicted runoff P concentration of 51.4 µg/L. The estimated additional load from the wetland dominated drainage area of Musselshell Creek beyond what was accounted for by HSPF is approximately 4 kg/yr of the 83 kg/yr of the total added load. The remainder of the added load in the BATHUB model is likely coming from the near shore area, such as shoreline wetland and erosion sources. Near-shore sources are not accounted for in the HSPF model or other P source assessment tools utilized by this TMDL. Additional field surveys are needed to target the source of these near-shore sources.

4.1.5.3 North Island Lake (09-0060-01) TP TMDL

Table 4-7. North Island Lake (09-0060-01) TMDL and Allocations

Island Lake (North Basin) Load Component		Existing	Goal		Reduction	
		(kg/yr)	(kg/yr)	(kg/day)	(kg/yr)	(%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.016	0.016	0.000044	0.0	0%
	Industrial stormwater (MNR500000)	0.016	0.016	0.000044	0.0	0%
	Total WLA	**0.032**	**0.032**	**0.000088**	**0.0**	
Load Allocations*	*Watershed runoff*	*133.7*	*110.1*	*0.301*	*23.6*	*18%*
	Failing septics	*2.2*	*0.0*	*0.000*	*2.2*	*100%*
	Internal load	*13.4*	*0.0*	*0.000*	*13.4*	*100%*
	Total Watershed/In-lake	149.3	110.1	0.301	39.2	26%
	Island Lake (South Basin)	83.5	77.5	0.212	6.0	7%
	Atmospheric	7.8	7.8	0.021	0.0	0%
	Total LA	**240.6**	**195.4**	**0.534**	**45.2**	**19%**
MOS			**21.7**	**0.059**		
TOTAL		**240.6**	**217.1**	**0.593**		

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

Phosphorus Reductions Needed to Meet Water Quality Goal

- 23.6 kg/yr from watershed runoff
- 2.2 kg/yr from converting ~10 failing shoreline septic systems to conforming
- 13.4 kg/yr from internal load
- 6.0 kg/yr from Island Lake (South Basin) achieving its TMDL goals

Phosphorus Source Summary

- North Island Lake is 114 acres with a maximum depth of 25 feet and a shallow lake zone (<15 feet) that covers 86% of the lake surface area.
- Sediment P release rates based on sediment core sampling were greater than the release rates in the calibrated BATHTUB model, indicating that all of the added load to the BATHTUB model was likely due to internal loading from anoxic sediment P release (Table 3-16).
- There is a healthy aquatic plant and fish community.
- Water levels have been collected since 1997. The recorded range was 4.11 feet, with a minimum recorded in September 2007 (1299.82 ft) and a maximum recorded in May 2005 (1303.93 ft).
- The lake watershed is 4,798 acres, or 42 times the lake surface area. Eagle Lake and South Island Lakes are upstream of North Island Lake.

- The shoreline is well developed and most residences are connected to the city of Cromwell sewer system.
- North Island Lake receives some stormwater runoff from the city of Cromwell.
- A ditch drains a wetland on the north side of the lake, and could release P to North Island Lake under fluctuating water level conditions in the wetland.
- There are livestock to the northeast of the lake.

4.1.5.4 South Island Lake (09-0060-02) TP TMDL

Table 4-8. South Island Lake (09-0060-02) TP TMDL and Allocations

Island Lake (South Basin) Load Component		Existing	Goal		Reduction	
		(kg/yr)	(kg/yr)	(kg/day)	(kg/yr)	(%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.004	0.004	0.000011	0.0	0%
	Industrial stormwater (MNR500000)	0.004	0.004	0.000011	0.0	0%
	Total WLA	**0.008**	**0.008**	**0.000022**	**0.0**	
Load Allocations*	*Watershed runoff*	*34.9*	*31.6*	*0.086*	*3.3*	*10%*
	Failing septics	*2.8*	*0.0*	*0.000*	*2.8*	*100%*
	Internal load	*78.4*	*54.0*	*0.148*	*24.4*	*31%*
	Total Watershed/In-lake	116.1	85.6	0.234	30.5	26%
	Eagle Lake	46.3	42.4	0.116	3.9	9%
	Atmospheric	22.3	22.3	0.061	0.0	0%
	Total LA	**184.7**	**150.3**	**0.411**	**34.4**	**19%**
MOS			**16.6**	**0.046**		
TOTAL		**184.7**	**166.9**	**0.457**		

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

Phosphorus Reductions Needed to Meet Water Quality Goal

- 3.3 kg/yr from watershed runoff
- 2.8 kg/yr from converting ~11 failing shoreline septic systems to conforming
- 24.4 kg/yr from internal load
- 3.9 kg/yr from Eagle Lake reaching its TMDL goals

Phosphorus Source Summary

- South Island Lake is 324 acres with a maximum depth of 22 feet and a shallow lake zone (<15 feet) that covers 73% of the lake surface area.

- Sediment P release rates based on sediment core sampling were greater than the release rates in the calibrated BATHTUB model, indicating that all of the added load to the BATHTUB model was likely due to internal loading from anoxic sediment P release (Table 3-16).
- There is a diverse aquatic plant community.
- The fish community is poor, with a FIBI score of 26, or 12 points below the impairment threshold for similar lakes (See Appendix B.4).
- Water levels were collected between 1997 and 2007. The recorded range was 2.75 feet, with a minimum recorded in July 2006 (1299.96 ft) and a maximum recorded in June 2005 (1302.71 ft).
- The lake watershed is 4,028 acres, or 12 times the lake surface area. Eagle Lake is upstream of South Island Lake.
- The shoreline is well developed with the northern half of residences connected to the city of Cromwell sewer system in 2007.
- South Island Lake receives some stormwater runoff from the city of Cromwell.

4.1.5.5 King Lake (31-0258-00) TP TMDL

Table 4-9. King Lake (31-0258-00) TP TMDL and Allocations

King Lake Load Component		Existing	Goal		Reduction	
		(kg/yr)	(kg/yr)	(kg/day)	(kg/yr)	(%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.007	0.007	0.000019	0.0	0%
	Industrial stormwater (MNR500000)	0.007	0.007	0.000019	0.0	0%
	Total WLA	**0.014**	**0.014**	**0.000038**	**0.0**	
Load Allocations*	*Watershed runoff*	*16.1*	*14.1*	*0.039*	*2.0*	*12%*
	Failing septics	*2.3*	*0.0*	*0.000*	*2.3*	*100%*
	Internal load	*90.0*	*63.5*	*0.174*	*26.5*	*29%*
	Total Watershed/In-lake	108.4	77.6	0.213	30.8	28%
	Atmospheric	21.4	21.4	0.059	0.0	0%
	Total LA	**129.8**	**99.0**	**0.272**	**30.8**	**24%**
MOS			**11.0**	**0.030**		
TOTAL		**129.8**	**110.0**	**0.302**		

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

Phosphorus Reductions Needed to Meet Water Quality Goal

- 2.0 kg/yr from watershed runoff
- 2.3 kg/yr from converting ~9 failing shoreline septic systems to conforming
- 26.5 kg/yr from internal load.

Phosphorus Source Summary

- King Lake is 311 acres with a maximum depth of just over 25 feet and a shallow lake zone (<15 feet) that covers 49% of the lake surface area.
- Sediment P release rates based on sediment core sampling were greater than the release rates in the calibrated BATHTUB model, indicating that all of the added load to the BATHTUB model was likely due to internal loading from anoxic sediment P release (Table 3-16).
- The lake weakly stratifies and has low oxygen at the thermocline. Mid-summer mixing events, combined with sediment P release under anoxic conditions at the lake bottom, may be contributing to internal loading in the lake.
- Lake water levels have been noted as an issue on King Lake due to beaver dam issues at the lake outlet. However, no lake level data has been collected within the last 10 years. A hydrological and/or paleolimnological core study are needed to understand the impacts of water level on the in-lake nutrient dynamics of King Lake.
- The lake watershed is 890 acres, or 3 times the lake surface area.
- There is forestry activity to the north and east of the lake.
- Approximately 13% of the watershed is wetland and 48% woodland.
- The western and southwest shorelines are heavily developed, and shoreline erosion has been noted on the lake.
- There is an approximately 40 acre wetland complex on the northeast shore of King Lake.

4.1.5.6 Little Cowhorn Lake (31-0098-00) TP TMDL

Table 4-10. Little Cowhorn Lake (31-0098-00) TP TMDL and Allocations

Little Cowhorn Lake Load Component		Existing	Goal		Reduction	
		(kg/yr)	(kg/yr)	(kg/day)	(kg/yr)	(%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.016	0.016	0.000044	0.0	0%
	Industrial stormwater (MNR500000)	0.016	0.016	0.000044	0.0	0%
	Total WLA	**0.032**	**0.032**	**0.000088**	**0.0**	
Load Allocations*	*Watershed runoff*	*41.1*	*30.7*	*0.084*	*10.4*	*25%*
	Failing septics	*0.0*	*0.0*	*0.000*	*0.0*	*0%*
	Internal load	*52.5*	*8.6*	*0.024*	*43.9*	*84%*
	Total Watershed/In-lake	93.6	39.3	0.108	54.3	58%
	Atmospheric	12.5	12.5	0.034	0.0	0%
	Total LA	**106.1**	**51.8**	**0.142**	**54.3**	**51%**
MOS			**5.8**	**0.016**		
TOTAL		**106.1**	**57.6**	**0.158**		

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

Phosphorus Reductions Needed to Meet Water Quality Goal

- 10.4 kg/yr from watershed runoff

- 43.9 kg/yr from internal load

Phosphorus Source Summary

- Little Cowhorn Lake is 181 acres with a maximum depth of 12 feet and a shallow lake zone (<15 feet) that covers 100% of the lake surface area.
- Sediment P release rates based on sediment core sampling were greater than the release rates in the calibrated BATHTUB model, indicating that all of the added load to the BATHTUB model was likely due to internal loading from anoxic sediment P release (Table 3-16).
- There is a long history of low winter oxygen levels with many severe winterkills documented in Little Cowhorn Lake due to the shallow, eutrophic nature of the lake.
- There was heavy submergent aquatic vegetation in the most recent DNR fish survey in 1992.
- No lake level data has been collected within the last 10 years.
- Mid-summer mixing events, combined with sediment P release under anoxic conditions at the lake bottom, may be contributing to internal loading in the lake.
- The lake watershed is 1,178 acres, or 6 times the lake surface area.
- There is only one residence on the lake.
- Approximately 23% of the watershed is wetland.

4.1.5.7 Split Hand Lake (31-0353-00) TP TMDL

Table 4-11. Split Hand Lake (31-0353-00) TP TMDL and Allocations

Split Hand Lake Load Component		Existing (kg/yr)	Goal (kg/yr)	Goal (kg/day)	Reduction (kg/yr)	Reduction (%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.094	0.094	0.00026	0.0	0%
	Industrial stormwater (MNR500000)	0.094	0.094	0.00026	0.0	0%
	Total WLA	**0.188**	**0.188**	**0.00052**	**0.0**	
Load Allocations*	*Watershed runoff*	*196.1*	*177.5*	*0.486*	*18.6*	*9%*
	Failing septics	*3.4*	*0.0*	*0.000*	*3.4*	*100%*
	Wetland anoxic release	*78.7*	*78.7*	*0.216*	*0.0*	*0%*
	Internal load	*430.1*	*197.8*	*0.541*	*232.3*	*54%*
	Near-shore runoff	*825.2*	*379.4*	*1.039*	*445.8*	*54%*
	Total Watershed/In-lake	1,533.5	833.4	2.282	700.1	46%
	Atmospheric	94.5	94.5	0.259	0.0	0%
	Total LA	**1,628.0**	**927.9**	**2.541**	**700.1**	**43%**
MOS			**103.1**	**0.282**		
TOTAL		**1,628.2**	**1,031.2**	**2.823**		

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

Phosphorus Reductions Needed to Meet Water Quality Goal

- 18.6 kg/yr from watershed runoff
- 3.4 kg/yr from converting ~12 failing shoreline septic systems to conforming
- 232.3 kg/yr from internal load
- 445.8 kg/yr from near-shore runoff

Phosphorus Source Summary

- Split Hand Lake is 1,369 acres with a maximum depth of just over 30 feet and a shallow lake zone (<15 feet) that covers 42% of the lake surface area.
- Sediment P release rates based on sediment core sampling were less than the release rates in the calibrated BATHTUB model, indicating that only some of the added load in the BATHTUB model is likely due to internal loading from anoxic sediment P release (Table 3-16).
- Lake water level fluctuations are an issue for Split Hand Lake. There is a history of high water levels, and even flooding of houses in recent years on the lake. In 2018, most docks were about one foot underwater.
- The lake watershed is 20,249 acres, or 15 times the lake surface area.

- Approximately 26% of the watershed is wetland.
- The Split Hand Creek drainage area is dominated by wetlands and enters Split Hand Lake on the western shore. Pollutant load monitoring on Split Hand Creek (Flow gage: H09053002, Water quality monitoring site: S009-506) in 2017 and 2018 measured a flow-weighted mean concentration entering the lake of 41-42 µg/L, compared to the HSPF predicted runoff P concentration of 16 µg/L. The estimated additional load from Split Hand Creek beyond what was accounted for by HSPF is approximately 80 kg/yr of the 1,334 kg/yr of the total added load. The remainder of the added load in the BATHUB model is likely coming from the near shore area, such as shoreline wetland and erosion sources. Near-shore sources are not accounted for in the HSPF model or other P source assessment tools utilized by this TMDL. Additional field surveys are needed to target the source of these near-shore sources.
- The eastern shoreline is well developed. Many of the residences have been converted from cabins to year-round homes.

4.1.6 TMDL Baseline

The lake P TMDLs are based on modeling results for the period 2006 through 2015 (see *HSPF modeling*). Any activities implemented during or after 2015 that lead to a reduction in loads or an improvement in an impaired stream water quality may be considered as progress towards meeting a WLA or LA.

4.2 *E. coli*

4.2.1 Loading Capacity Methodology

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

For the stream TMDL derivation, loading capacities were derived using HSPF modeled flows for the period 2006 through 2017. The loading capacities were determined by applying the *E. coli* water quality standard (126 org/ 100 mL) to the flow duration curve to produce a bacteria standard curve. Loading capacities presented in the allocation tables represent the median *E. coli* load (in billion org/day) along the bacteria standard curve within each flow regime. A bacteria LDC and a TMDL allocation table are provided for each stream in Section 4.2.5. Limited observations and estimates of existing bacteria loads are plotted along with the bacteria standard curve for each impaired stream. Existing loads were estimated by pairing observed *E. coli* concentrations with flow records for each impaired reach. Existing

E. coli loads were estimated using the median daily flow within each defined flow regime multiplied by the geometric mean of all paired *E. coli* concentration observations.

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

4.2.2 Load Allocation Methodology

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

4.2.3 Wasteload Allocation Methodology

4.2.3.1 MS4 Regulated Stormwater

Portions of the Hibbing MS4 area intersect both the Swan River and the Prairie River watersheds (Figure 3-2). Under Permit MNR040000 (MS4 General Permit), MS4 communities must take steps to address TMDLs for waterbodies that receive runoff from the MS4 permit area. An *E. coli* WLA, calculated as an area-weighted fraction of the watershed LA, was assigned to the Hibbing MS4 in the TMDL for each of these streams.

Table 4-12. *E. coli* Wasteload Allocation for MS4s located within the watershed area of an impaired stream.

Impaired Reach AUID 07010103-XXX	MS4 Community	Impaired Stream Watershed Area (ac)	MS4 Area within Watershed (ac)	Area Weight Applied in WLA Calcuation[1]
-753	Hibbing, MN	94,618	11,780	12.4%
-760		299,656	11,835	3.9%

[1]See Section 4.2.5.4 and Section 4.2.5.6 for WLAs at each flow regime.

4.2.3.2 Regulated Construction Stormwater

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

4.2.3.3 Regulated Industrial Stormwater

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

4.2.3.4 Feedlots Requiring NPDES/SDS Permit Coverage

There are no active NPDES permitted feedlot operations (CAFO) within an *E. coli* impaired stream reach drainage area, in the MRGRW.

4.2.3.5 Municipal and Industrial Wastewater Treatment Systems

An individual WLA was provided for all NPDES/SDS permitted WWTF that have fecal coliform discharge limits (200 org/100ml, March 1 through October 31) and whose surface discharge stations fall within an impaired stream subwatershed. There are six NPDES/SDS permitted WWTFs whose surface discharge stations fall within an *E. coli* impaired stream subwatershed. These WWTFs include continuous and intermittent discharge facilities and stabilization pond systems (controlled discharge) (Table 4-13).

E. coli WLAs were calculated by multiplying the facility design flow and the permitted fecal coliform effluent limit of 200 org/ 100 ml (Table 4-13). For continuous discharge facilities (Coleraine-Bovey-Taconite Joint WWTP, Keewatin WWTP, and Marble WWTP), WLAs were calculated based on the average wet weather design flow, equivalent to the wettest 30-days of influent flow expected over the course of a year. For stabilization pond systems (Nashwauk WWTP and Remer WWTP), the NPDES/SDS permits allow for two discharge windows between March 1 and June 30, and between September 1 and December 31, annually. The pond WWTFs are only allowed to discharge six inches of volume from the secondary pond system in a 24-hour period. WLAs were calculated by using the volume of wastewater permitted to be discharged within a given 24-hour period.

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

Table 4-13. WWTF design flows and permitted bacteria loads

Stream Reach	Facility Name, Permit #	Facility Type	Design Flow Rate (mgd)	Permitted Bacteria Load	
				as Fecal Coliform[1]: 200 org/ 100 ml [billion org/day]	as *E. coli*: 126 org. / 100 ml[1] [billion org/day]
-753	Coleraine-Bovey-Taconite Joint WWTP MN0053341	Continuous Discharge	0.499	4.3	2.4
	Keewatin WWTP MN0022012		0.180	1.4	0.9
	Marble WWTP MN0020214		0.324	2.5	1.5
	Nashwauk WWTP MNG580184	Stabilization Pond[2]	0.353	23.4	14.8
-751	Remer WWTP MNG580210	Stabilization Pond[2]	0.1063	3.3	2.1
-758	Cromwell WWTP MN0051101	Continuous Discharge	0.052	4.5	2.8

[1] WWTF permits are regulated for fecal coliform, not *E. coli*. The MPCA surface water quality standard for *E. coli* (126 org. / 100 ml) was used in place of the fecal coliform permitted limit of 200 org. / 100 ml, which was also the MPCA surface water quality standard prior to the March 2008 revisions to Minn. R. ch. 7050.
[2]The permit for stabilization ponds allows discharge only during the period March 1 - Jun 30 and September 1 - December 31.

Margin of Safety

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

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

4.2.4 Seasonal Variation

Use of these water bodies for aquatic recreation occurs from April through October, which includes all or portions of the spring, summer, and fall seasons. *E. coli* loading varies with the flow regime and season. Spring is associated with large flows from snowmelt, the summer is associated with the growing season as well as periodic storm events and receding stream flows, and the fall brings increasing precipitation and rapidly changing agricultural landscapes.

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

4.2.5 TMDL Summary

4.2.5.1 Split Hand Creek (07010103-574) *E. coli* TMDL

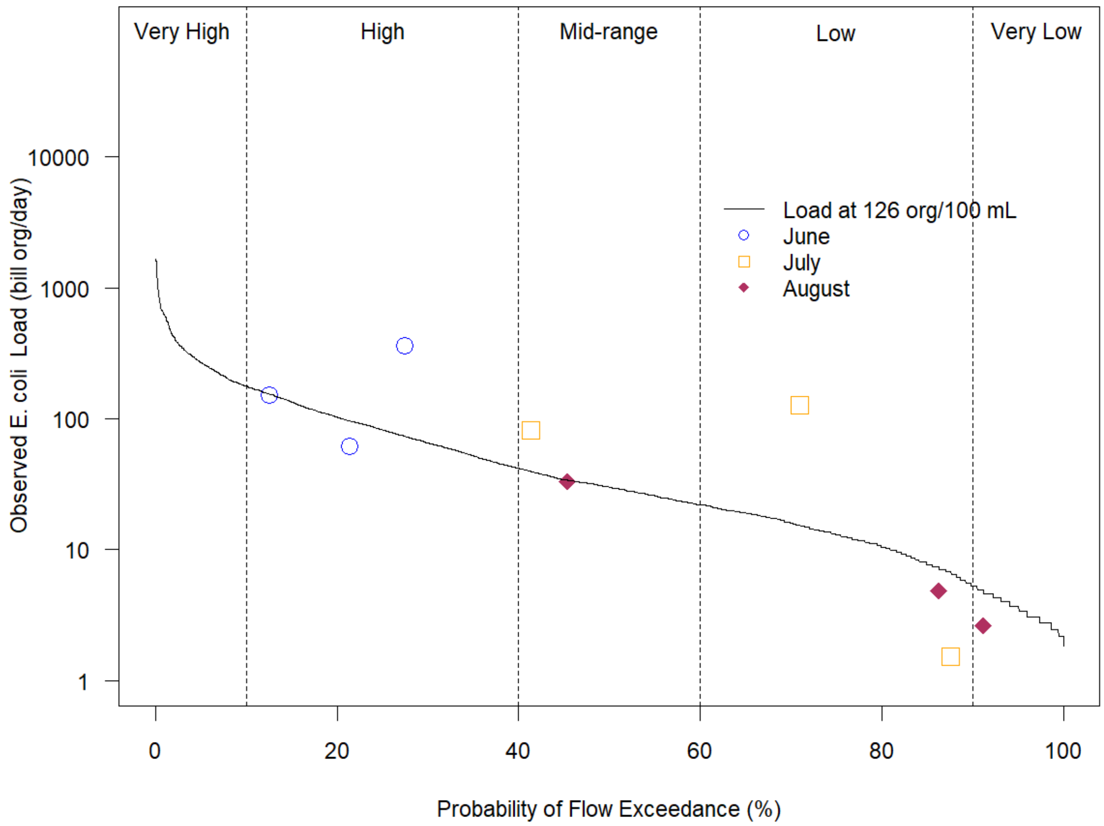

Figure 4-1. Split Hand Creek (07010103-574) *E. coli* Load Duration Curve

The LDC is the *E. coli* standard load at 126 org/100 ml. Plotted sample loads are based on monitored *E. coli* concentrations from station S008-477 collected 2006-2015.

Table 4-14. Split Hand Creek (07010103-574) *E. coli* TMDL and allocations

Split Hand Creek 07010103-574 Load Component		Flow Regime				
		Very High	High	Mid	Low	Very Low
		E. coli (billion organisms per day)				
Existing Load		***NA***	***151.5***	***57.1***	***4.8***	***2.6***
Wasteload Allocations	*NPDES Permitted Facilities*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
	Total WLA	**0**	**0**	**0**	**0**	**0**
Load Allocations	*Watershed Runoff*	*242.5*	*74.1*	*26.9*	*11.7*	*3.3*
	Total LA	**242.5**	**74.1**	**26.9**	**11.7**	**3.3**
10% MOS		**26.9**	**8.2**	**3.0**	**1.3**	**0.4**
Total Loading Capacity		**269.4**	**82.3**	**29.9**	**13.0**	**3.7**
Estimated Load Reduction		*NA*	*69.2*	*27.2*	*NA*	*NA*
		NA	*46%*	*48%*	*NA*	*NA*

4.2.5.2 Hasty Brook (07010103-603) *E. coli* TMDL

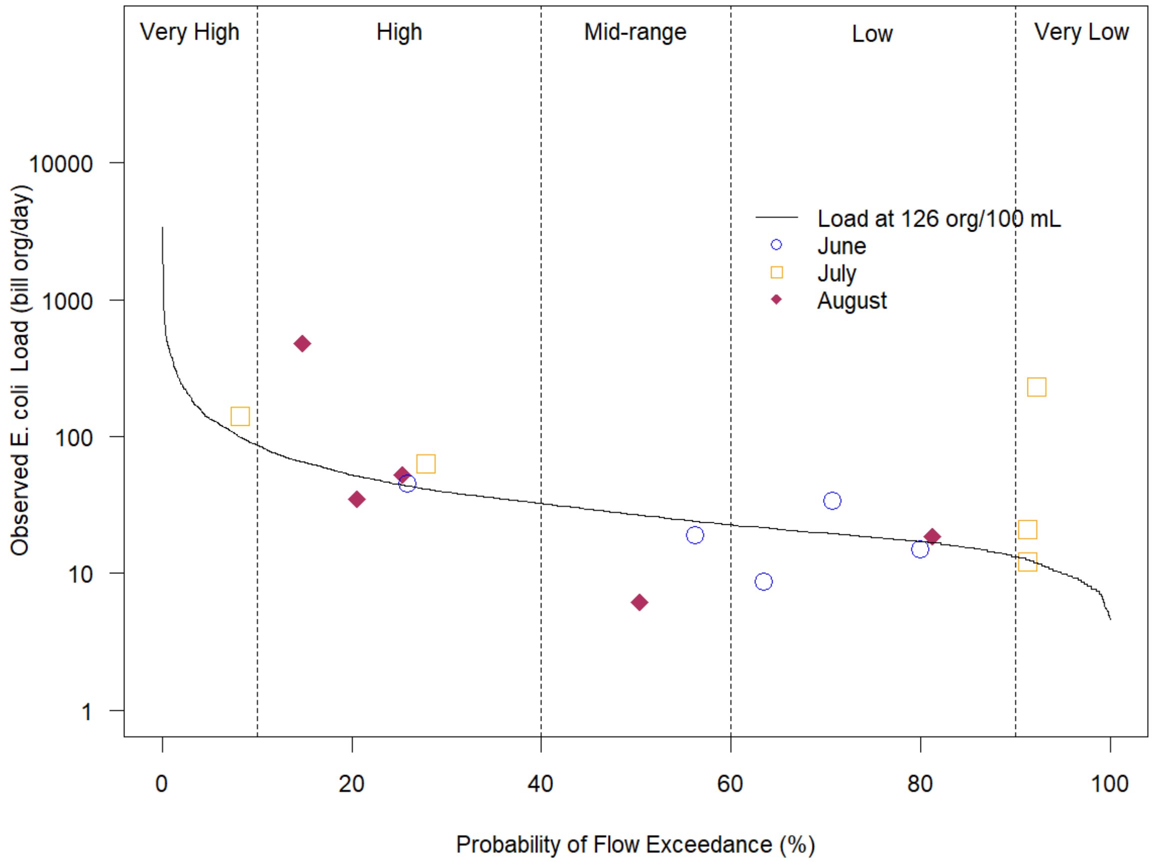

Figure 4-2. Hasty Brook (07010103-603) *E. coli* Load Duration Curve

The LDC is the *E. coli* standard load at 126 org/100 ml. Plotted sample loads are based on monitored *E. coli* concentrations from station S005-777 collected 2006-2015.

Table 4-15. Hasty Brook (07010103-603) *E. coli* TMDL and allocations

Hasty Brook 07010103-603 Load Component		Flow Regime				
		Very High	High	Mid	Low	Very Low
		E. coli (billion organisms per day)				
Existing Load		***140***	***52***	***12***	***17***	***21***
Wasteload Allocations	*NPDES Permitted Facilities*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
	Total WLA	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Load Allocations	*Watershed Runoff*	*121.2*	*40.2*	*24.1*	*16.4*	*8.9*
	Total LA	**121.2**	**40.2**	**24.1**	**16.4**	**8.9**
10% MOS		**13.5**	**4.5**	**2.7**	**1.8**	**1.0**
Total Loading Capacity		**134.7**	**44.7**	**26.8**	**18.2**	**9.9**
Estimated Load Reduction		*5.3*	*7.3*	*NA*	*NA*	*11.1*
		4%	*14%*	*NA*	*NA*	*53%*

4.2.5.3 Willow River (07010103-751) *E. coli* TMDL

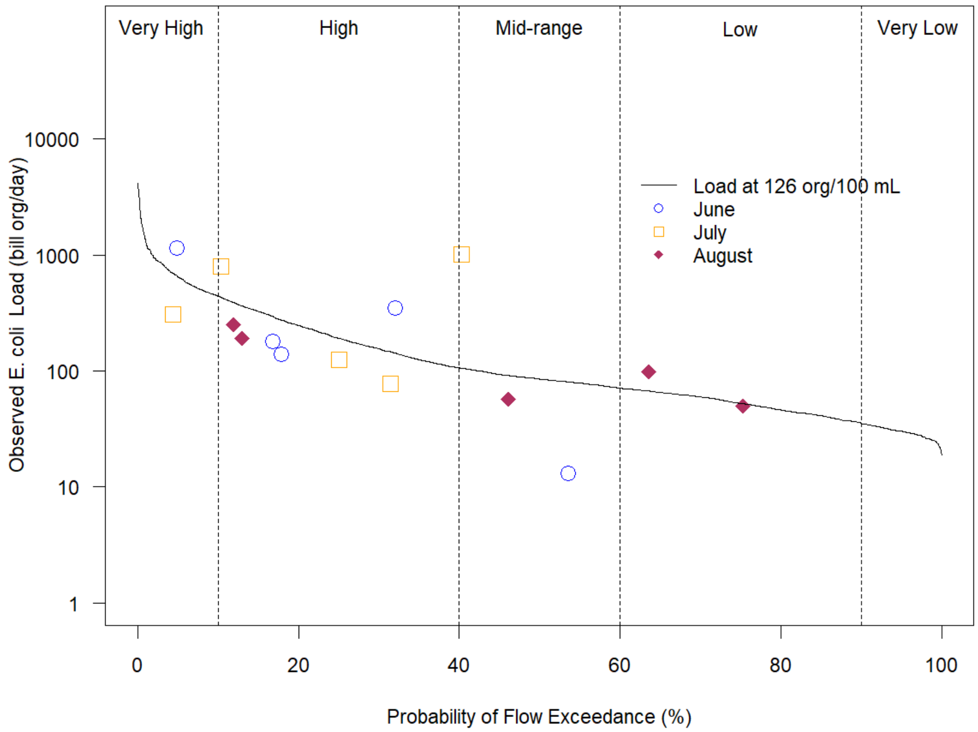

Figure 4-3. Willow river (07010103-751) *E. coli* Load Duration Curve

The LDC is the *E. coli* standard load at 126 org/100 ml. Plotted sample loads are based on monitored *E. coli* concentrations from station S006-257 collected 2006-2015.

Table 4-16. Willow River (07010103-751) *E. coli* TMDL and allocations

Willow River 007010103-751 Load Component		Flow Regime				
		Very High	High	Mid	Low	Very Low
		Billion organisms per day				
Existing Load[1]		***245.0***	***101.5***	***23.7***	***8.4***	***NA***
Wasteload Allocations	*Remer WWTP (MNG580210)*	*1.7*	*1.7*	*1.7*	*1.7*	*1.7*
	Total WLA	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**
Load Allocations	*Watershed Runoff*	*244.4*	*72.1*	*33.6*	*20.0*	*12.7*
	Total LA	**244.4**	**72.1**	**33.6**	**20.0**	**12.7**
10% MOS		**27.3**	**8.2**	**3.9**	**2.4**	**1.6**
Total Loading Capacity[1]		**273.4**	**82.0**	**39.2**	**24.1**	**16.0**
Estimated Load Reduction		*NA*	*19.5*	*NA*	*NA*	*NA*
		NA	*19%*	*NA*	*NA*	*NA*

[1]The TMDL for Willow River reach -751 was calculated using data from the HSPF model area weighted to WQ station S006-257. Existing loads were estimated using observed E.coli data from WQ station S006-257 (Appendix C).

4.2.5.4 Swan River (07010103-753) *E. coli* TMDL

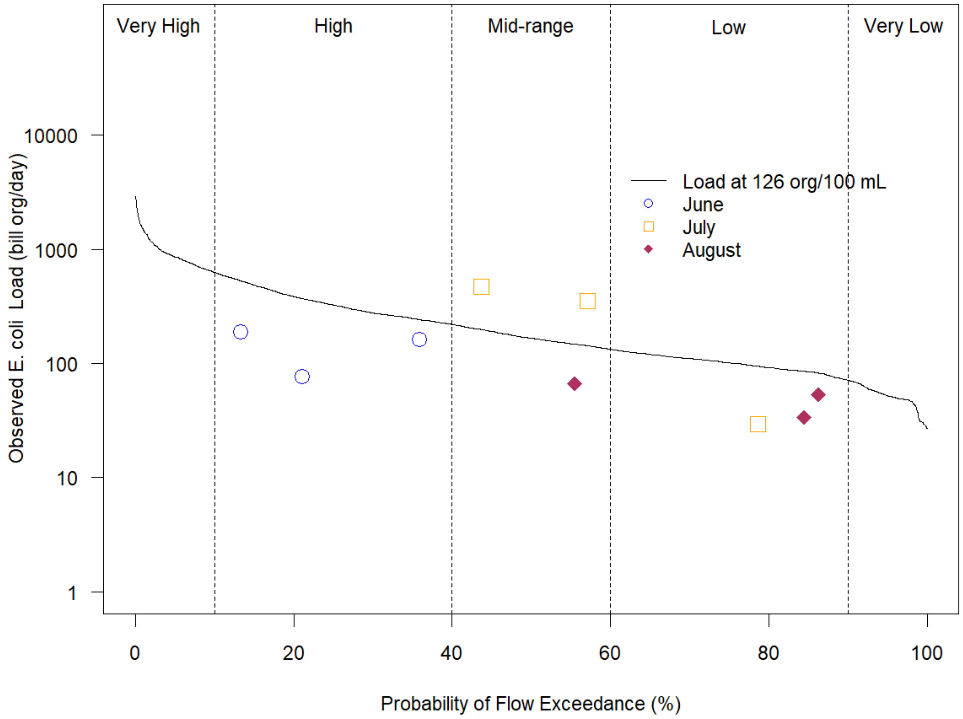

Figure 4-4. Swan River (07010103-753) *E. coli* Load Duration Curve

The LDC is the *E. coli* standard load at 126 org/100 ml. Plotted sample loads are based on monitored *E. coli* concentrations from station S000-936 collected 2006-2015.

Table 4-17. Swan River (07010103-753) *E. coli* TMDL and allocations

Swan River 07010103-753 Load Component		Flow Regime				
		Very High	High	Mid	Low	Very Low
		E. coli (billion organisms per day)				
Existing Load		*NA*	*160.8*	*349.9*	*33.7*	*NA*
Wasteload Allocations	*Coleraine-Bovey WWTP (MN0053341)*	*2.4*	*2.4*	*2.4*	*2.4*	*2.4*
	Keewatin WWTP (MN0022012)	*1.5*	*1.5*	*1.5*	*1.5*	*1.5*
	Marble WWTP (MN0020214)	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*
	Nashwauk WWTP(MNG580184)	*14.8*	*14.8*	*14.8*	*14.8*	*14.8*
	Hibbing, MN MS4 (MS400270)	*93.7*	*34.1*	*16.3*	*9.0*	*3.5*
	Total WLA	**112.9**	**53.3**	**35.5**	**28.2**	**22.7**
Load Allocations	*Watershed Runoff*	*658.4*	*239.9*	*114.3*	*62.8*	*24.1*
	Total LA	**658.4**	**239.9**	**114.3**	**62.8**	**24.1**
10% MOS		**85.7**	**32.6**	**16.6**	**10.1**	**5.2**
Total Loading Capacity		**857.0**	**325.8**	**166.4**	**101.1**	**52**
Estimated Load Reduction		*NA*	*NA*	*183.5*	*NA*	*NA*
		NA	*NA*	*52%*	*NA*	*NA*

4.2.5.5 Tamarack River (07010103-758) *E. coli* TMDL

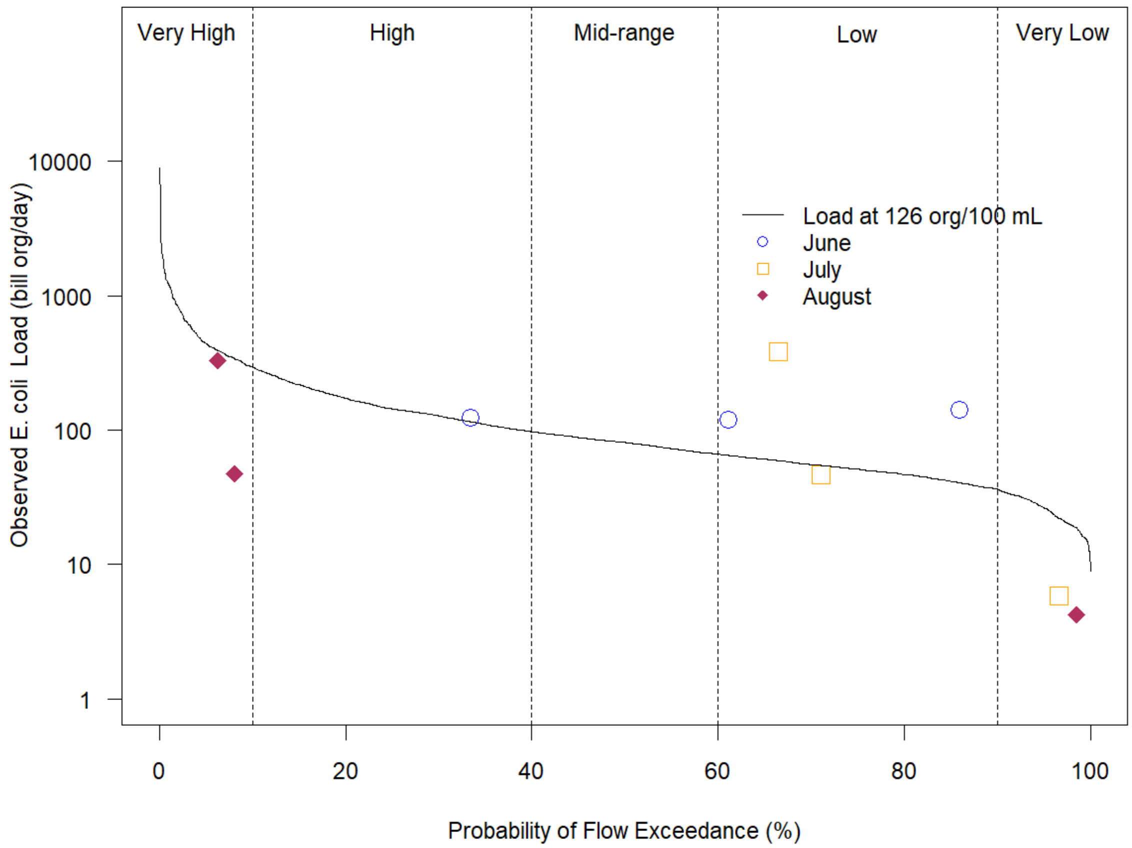

Figure 4-5. Tamarack River (07010103-758) *E. coli* Load Duration Curve

The LDC is the *E. coli* standard load at 126 org/100 ml. Plotted sample loads are based on monitored *E. coli* concentrations from station S008-441 collected 2006-2015.

Table 4-18. Tamarack River (07010103-758) *E. coli* TMDL and allocations

Tamarack River 07010103-758 Load Component		Flow Regime				
		Very High	High	Mid	Low	Very Low
		E. coli (billion organisms per day)				
Existing Load		*189.1*	*122.3*	*NA*	*129.2*	*5.0*
Wasteload Allocations	*Cromwell WWTP (MN0051101)*	*2.8*	*2.8*	*2.8*	*2.8*	*2.8*
	Total WLA	**2.8**	**2.8**	**2.8**	**2.8**	**2.8**
Load Allocations	*Watershed Runoff*	*395.6*	*127.1*	*70.2*	*43.3*	*20.8*
	Total LA	**395.6**	**127.1**	**70.2**	**43.3**	**20.8**
10% MOS		**44.3**	**14.4**	**8.1**	**5.1**	**2.6**
Total Loading Capacity		**442.7**	**144.3**	**81.1**	**51.2**	**26.2**
Estimated Load Reduction		*NA*	*NA*	*NA*	*78*	*NA*
		NA	*NA*	*NA*	*60%*	*NA*

4.2.5.6 Prairie River (07010103-760) *E. coli* TMDL

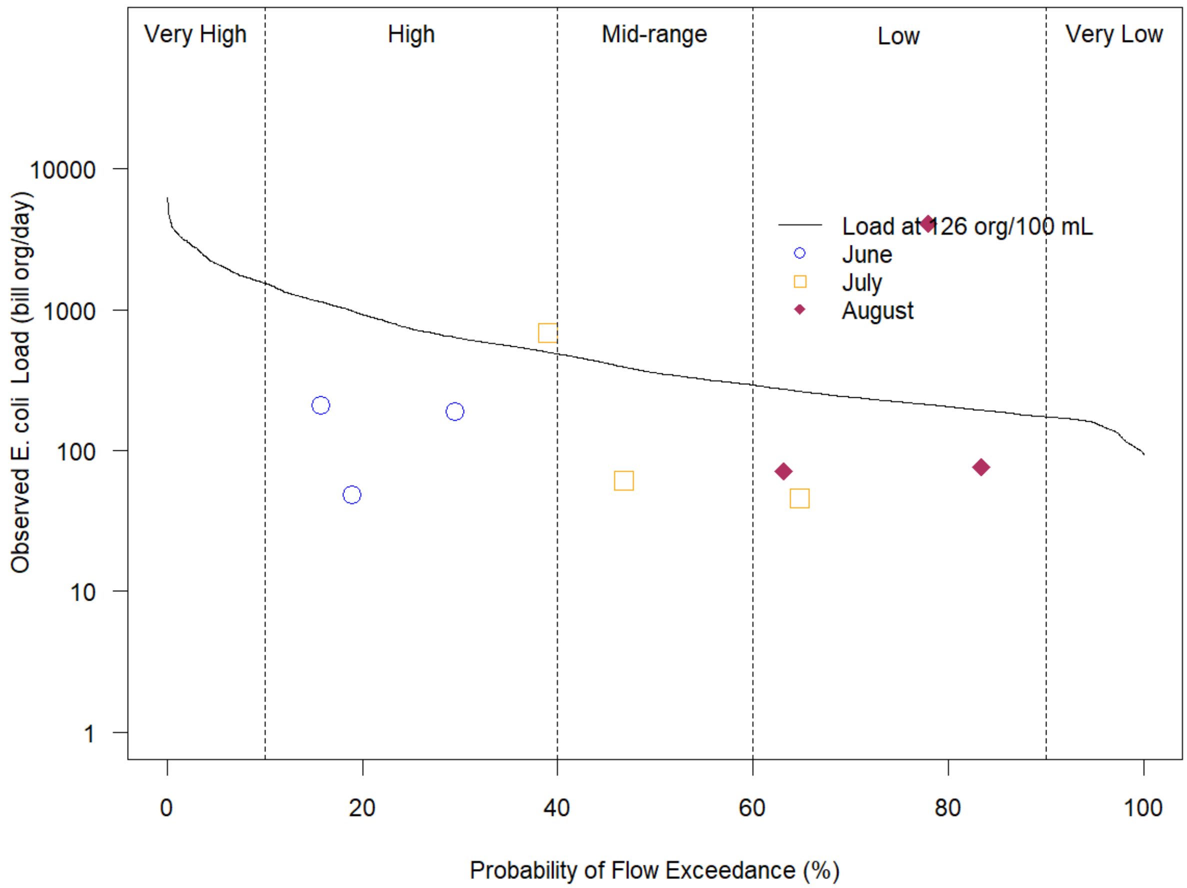

Figure 4-6. Prairie River (07010103-760) *E. coli* Load Duration Curve

The LDC is the *E. coli* standard load at 126 org/100 ml. Plotted sample loads are based on monitored *E. coli* concentrations from station S008-478, 2006-2015.

Table 4-19. Prairie River (07010103-760) *E. coli* TMDL and allocations

Prairie River 07010103-760 Load Component		Flow Regime				
		Very High	High	Mid	Low	Very Low
		E. coli (billion organisms per day)				
Existing Load		***NA***	***198.7***	***61.2***	***73.3***	***NA***
Wasteload Allocations	*Hibbing, MN MS4 (MS400270)*	*76.0*	*26.0*	*12.7*	*7.9*	*5.6*
	Total WLA	**76.0**	**26.0**	**12.7**	**7.9**	**5.6**
Load Allocations	*Watershed Runoff*	*1,850.0*	*631.0*	*308.9*	*191.9*	*136.4*
	Total LA	**1,850.0**	**631.0**	**308.9**	**191.9**	**136.4**
10% MOS		**214.0**	**73.0**	**35.7**	**22.2**	**15.8**
Total Loading Capacity		**2,140.0**	**730.0**	**357.3**	**222.0**	**157.8**
Estimated Load Reduction		*NA*	*NA*	*NA*	*NA*	*NA*
		NA	*NA*	*NA*	*NA*	*NA*

4.2.6 TMDL Baseline

The stream *E. coli* TMDLs are based on modeling results for the period 2006 through 2015 (see *HSPF modeling*). Any activities implemented during or after 2015 that lead to a reduction in loads or an improvement in an impaired stream water quality may be considered as progress towards meeting a WLA or LA.

5 Future Growth/Reserve Capacity

The MRGRW is mostly undeveloped, with the majority of land cover in woodland and wetland. Land use and population are not expected to change much in the future. Based on information obtained from the United States Census Bureau, population in the MRGRW has changed very little from 2010 to 2017 (Itasca County: +0.2%, Aitkin County: -2.3%, Carlton County: +0.3%).

How changing sources of pollutants may or may not impact TMDL allocations are discussed below, in the event that population and land use in the MRGRW do change over time.

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 non-regulated MS4s become regulated. If this has not been accounted for in the WLA, then a transfer must occur from the LA.
4. Expansion of a U.S. Census Bureau Urban Area encompasses new regulated areas for existing permittees. An example is existing state highways that were outside an Urban Area at the time the TMDL 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/SDS 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 (see Section 4.2.3). One transfer rate was defined for each impaired stream as the total WLA (in kg/day or billion org/day) divided by the watershed area downstream of any upstream impaired waterbody (acres). In the case of a load transfer, the amount transferred from LA to WLA will be based on the area (acres) of land coming under permit coverage multiplied by the transfer rate (in kg/ac-day or billion org/ac-day). The MPCA will make these allocation shifts. In cases where WLA is transferred from or to a regulated MS4, the permittees will be notified of the transfer and have an opportunity to comment.

5.2 New or Expanding Wastewater

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

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

6 Reasonable Assurance

6.1 Non-regulatory

Moderate watershed and internal nonpoint source load reductions were identified for all P impaired lakes, and minor watershed reductions were identified for the bacteria impaired streams addressed in this TMDL. Internal load reductions will be achieved through management of lake levels, in-lake plant and fish communities, and/or sediment P release. The Mississippi River-Grand Rapids WRAPS Report outlines strategies for achieving the watershed and internal load reductions by impaired lake and stream. Watershed load reductions will be achieved through management of septic systems, shoreline erosion, and stormwater runoff. Some of the watershed loads are from wetland sources due to wetland water level changes. In some cases these loads can be managed through lake or wetland water level management, but some of the load is due to increased frequency and intensity of rainfall events that cause fluctuations in wetland water levels.

Key watershed-wide strategies that will improve the water quality of impaired and unimpaired lakes and streams include Public and Private Land Protection, Forest Protection programs, Non-functioning Ditch Decommissioning, and Shoreland Ordinance Enforcement, Education, and Updating.

At the local level, the Aitkin, Carlton, and Itasca County Soil and Water Conservation Districts (SWCD) currently implement programs that target improving water quality and have been actively involved in projects to improve water quality in the past. The United States Department of Agriculture (USDA)-NRCS administers several programs in Minnesota which provide guidance and financial incentives to agricultural producers and private landowners for implementation of conservation practices. Willing landowners, within this watershed, have implemented many practices in the past including, agricultural producer education and BMP initiatives (water quality certification, livestock exclusion), shoreline revegetation and buffer establishment, stormwater management (rain gardens), shoreline stabilization, conservation easements, and Sustainable Forest Incentive Act participation (Forest Stewardship Planning). It is assumed that these activities will continue. In addition, the MPCA maintains an online database of BMPs implemented by Major Watershed since 2004:

https://www.pca.state.mn.us/water/best-management-practices-implemented-watershed. A summary of BMPs implemented in the MRGRW since 2004 is shown in Figure 6-1 below.

Potential state funding of Restoration and Protection projects include Clean Water Fund grants and Clean Water Partnership 0% interest loans. At the federal level, funding can be provided through the federal Clean Water Act Section 319 grants that provide cost-share dollars to implement activities in small watersheds. Various other local funding and cost-share sources exist, which are listed in the Mississippi River-Grand Rapids WRAPS Report. The implementation strategies described in this plan have demonstrated to be effective in reducing nutrient loading to lakes and streams. There are programs in place within the watershed to continue implementing the recommended activities. Monitoring will continue and adaptive management will be in place to evaluate the progress made towards achieving water quality goals.

Strategy	Total BMPs	Number of BMPs (by unit)	Installed Amount (by unit)	Units
Habitat & stream connectivity	119	119	700	ac
Septic System Improvements	55	55	55	count
Stream banks, bluffs & ravines	27	27	37,229	ft
Converting land to perennials	14	14	34	ac
Buffers and filters - field edge	9	9	1,870	ac
Urban Stormwater Runoff Control	8	8	8	count
Nutrient management (cropland)	2	2	2	count
Pasture management	2	2	0	ac
Lliving cover to crops in fall/spri..	1	1	112	ac
Designed erosion control	1	1	0	ac
Feedlot runoff controls	1	1	1	ac
Other	183	8	8	count
		22	42,390	ft
		153	1,922	ac

Figure 6-1. BMPs implemented in the MRGRW since 2004 (MPCA)

6.2 Regulatory

6.2.1 Regulated Construction Stormwater

State implementation of the TMDL will be through action on NPDES/SDS permits for regulated construction stormwater. To meet the WLA for construction stormwater, construction stormwater activities are required to meet the conditions of the Construction Stormwater General Permit (MNR100001), and properly select, install, and maintain all BMPs required under the permit, including any applicable additional BMPs required in Appendix A of the Construction Stormwater General Permit for discharges to impaired waters, or meet local construction stormwater requirements if they are more restrictive than requirements of the General Permit.

6.2.2 Regulated Industrial Stormwater

To meet the WLA for industrial stormwater, industrial stormwater activities are required to meet the conditions of the Industrial Stormwater Multi-Sector General Permit (MNR05) or Nonmetallic Mining &

Associated Activities General Permit (MNG49), and properly select, install and maintain all BMPs required under the General Permit.

6.2.3 Wastewater & National Pollutant Discharge Elimination System/State Disposal System Permits

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

6.2.4 Subsurface Sewage Treatment Systems Program

Many residences located within the watershed areas of the impaired lakes and streams rely on SSTS, commonly known as septic systems, which are regulated by Minn. Stat. §§ 115.55 and 115.56. A Certificate of Compliance is required for new residences or at point of sale for structures located within 1,000 feet of a classified lake or 300 feet of a classified river or stream. A Certificate of Compliance is also required if adding bedrooms. Current estimated rates of compliance for shoreline SSTS are outlined in (Table 3-14).

These regulations detail:

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

6.2.5 Feedlot Rules

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

There are two primary concerns about feedlots in protecting water:

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

6.2.6 State of Minnesota Buffer Law Rule

Minnesota's buffer law requires perennial vegetative buffers along public ditches, lakes, rivers, and streams. Buffers along lakes, rivers, and streams are to be 50 feet in width, and buffers along public ditches are to be 16.5 feet wide or more. These buffers help filter out P, nitrogen, and sediment. Buffers are critical to protecting and restoring water quality and healthy aquatic life, natural stream functions and aquatic habitat due to their immediate proximity to the water.

The law provides some flexibility for landowners to install alternative practices if they provide equal or better water quality benefits. An example of an alternative practice could be a narrower buffer if the land slopes away from the water body. This is not uncommon with some ditches, rivers, and streams. Alternative practices must be approved by the local governmental unit that implements the buffer law.

In the Upper Mississippi Grand Rapids Watershed, most of the private lands are well vegetated with forests, grasslands, and wetlands. Most of the privately owned lands are managed for wildlife habitat, forest management, or recreational purposes. These lands are almost always covered by permanent vegetation. The buffer requirement sometimes is not met on agricultural lands, depending on the current crop or tillage methods. The majority of lands where buffers are not in place are being used for agricultural purposes, either livestock, or crop production. Reported rates of compliance on private lands for counties in the MRGR Watershed include Aitkin County at 99%, and St. Louis and Carlton Counties at 100%. The Board of Water and Soil Resources (BWSR) reports that statewide 95.5% of parcels adjacent to Minnesota waters meet preliminary compliance with the law. More information on compliance with the state buffer law on a County by County basis is available through MN.GOV.

7 Monitoring Plan

7.1 Lake and Stream Monitoring

7.1.1 Citizen Lake Monitoring Program

Volunteers throughout the watershed conduct stream and lake condition monitoring through the MPCA Citizen's Volunteer Monitoring Program (CVMP). Currently, 76 volunteers are monitoring six stream and 93 lakes sites across the MRGRW. Citizen-led data collection is anticipated to continue into the future through the efforts of lake associations and local sources like the Water Planning Task Force.

7.1.2 DNR Aquatic Life Monitoring

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

7.1.3 Lake and Stream Monitoring

As part of the MPCA Intensive Watershed Monitoring (IWM) strategy, 73 stream sites were monitored for biology (fish and macroinvertebrates) and water chemistry. A selection of these sites and a representative set of lakes across a range of conditions and lake type (size and depth) will be monitored in the next monitoring cycle beginning in 2025. Details about the MPCA IWM strategy can be found in the Mississippi River-Grand Rapids Watershed Monitoring and Assessment Report.

The MPCA requires a record of pre-9 a.m. DO readings in order to declare that the waterway contains enough DO to fully support aquatic life. The collection of continuous DO data is essential, at most sites, for the collection of DO measurements prior to 9:00 am. Moreover, the new MPCA river eutrophication assessment (DO flux) now requires a minimum of two DO logger deployments over separate years within the assessment window. DO logging equipment can collect regular DO measurements (e.g. every 30 minutes) while deployed in a waterway. Equipment is deployed for a maximum of two weeks at a time before it is retrieved for data retrieval, cleaning, and re-calibration. Prior to the next formal water quality assessment of the MRGRW, continuous DO monitoring should be conducted to fully assess the capacity of key reaches in the watershed to support aquatic life. Priority should be given to reaches and sites that are too remotely located from Local Government Unit (LGU) offices for pre-9 a.m. measurements.

7.1.4 Watershed Pollutant Load Monitoring

The Watershed Pollutant Load Monitoring Network (WPLMN), which includes state and federal agencies, Metropolitan Council Environmental Services, state universities, and local partners, collects data on water quality and flow in Minnesota to calculate pollutant loads in rivers and streams. Pollutant loads are the amount of a pollutant that passes a monitoring station over a period of time. Data is collected at 199 sites around the state. There are four sites within the MRGRW.

Table 7-1. WPLMN stream monitoring sites for the Mississippi River-Grand Rapids Watershed.

Site Type	Stream Name	EQuIS ID
Basin	Mississippi River at Grand Rapids, MN	S003-656
Subwatershed	Prairie River near Taconite	S007-944
Subwatershed	Swan River near Jacobson, CR 431	S001-922
Subwatershed	Willow River near Pallisade, CSAH 5	S004-407

Pollutant loads are calculated for five substances:

- Total suspended solids
- TP
- Nitrate plus nitrite nitrogen
- Total Kjeldahl nitrogen
- Dissolved orthophosphate

WPLMN data assist in watershed modeling, determining pollutant source contributions, developing reports, and measuring water quality restoration efforts.

Each year, approximately 25 to 35 water quality samples are collected at each monitoring site, either year-round or seasonally depending on the site. Water quality samples are collected near gaging stations, at or near the center of the channel. Samples are collected more frequently when water flow is moderate and high, when pollutant levels are typically elevated and most changeable. Pollutant concentrations are generally more stable when water flows are low, and fewer samples are taken in those conditions. This staggered approach generally results in samples collected over the entire range of flows.

7.2 BMP Monitoring

Limited on-site monitoring of implementation practices could also take place in order to better assess BMP effectiveness. All BMPs installed utilizing financial assistance from the State of Minnesota will follow the Operation, Maintenance, and Inspection Procedures adopted by BWSR. Qualified technical staff will prepare an Operation and Maintenance Plan specific to the BMP and site. All practices will be inspected by the landowner on a regular basis. Technical staff will confirm that the project is functioning as designed through completion of site inspections during the effective life of the project. For BMPs installed through other sources, a variety of criteria such as land use, soil type, and other watershed characteristics, as well as monitoring feasibility, will be used to determine which BMPs to monitor. Monitoring of a specific type of implementation practice can be accomplished at one site but can be applied to similar practices under similar criteria and scenarios. Effectiveness of other BMPs can be extrapolated based on monitoring results.

8 Implementation Strategy Summary

This TMDL study's results aided in the selection of implementation strategies during the Mississippi River-Grand Rapids WRAPS process. The purpose of the WRAPS process is to support local working groups in developing scientifically-supported restoration and protection strategies for subsequent implementation planning. The Mississippi River-Grand Rapids WRAPS Report is publically available on the MPCA MRGRW website concurrently with this TMDL report:

https://www.pca.state.mn.us/water/watersheds/mississippi-river-grand-rapids.

8.1 Permitted Sources

8.1.1 Construction Stormwater

The WLA for stormwater discharges from sites where there is construction activity reflects the number of construction sites greater than one acre in size, that are expected to be active in the watershed at any one time, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in the State's NPDES/SDS Construction Stormwater General Permit (MNR100001). If a construction site owner/operator obtains coverage under the Construction Stormwater General 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 Stormwater General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local construction stormwater requirements must also be met.

8.1.2 Industrial Stormwater

The WLA for stormwater discharges from sites where there is industrial activity reflects the number of sites in the watershed for which NPDES/SDS Industrial Stormwater Permit coverage is required, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at the industrial sites are defined in the State's NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000) or the 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 all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local stormwater management requirements must also be met.

8.1.3 Wastewater

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

8.2 Non-Permitted Sources

8.2.1 Adaptive Management

This list of implementation elements and the more detailed WRAPS report prepared concurrently with this TMDL assessment focuses on adaptive management (Figure 8-1). Continued monitoring and "course corrections" responding to monitoring results are the most appropriate strategy for attaining the water quality goals established in this TMDL. Management activities will be changed or refined to efficiently meet the TMDL and lay the groundwork for de-listing the impaired water bodies.

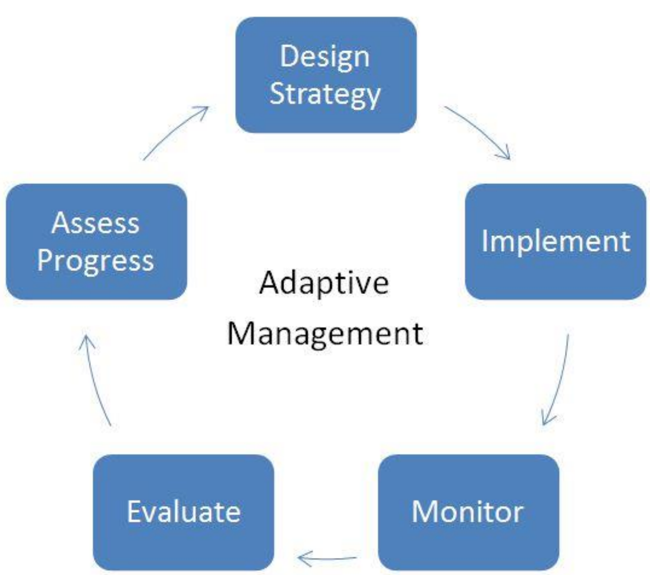

Figure 8-1. Adaptive Management

The response of the lakes and streams will be evaluated as management practices are implemented. Evaluation will follow the approach laid out in the Monitoring Section above. Data will be evaluated and decisions will be made as to how to proceed for the ensuing years. The management approach to achieving the goals should be adapted as new information is collected and evaluated.

8.2.2 Best Management Practices

A variety of BMPs to restore and protect the lakes and streams within the MRGRW have been outlined and prioritized in the WRAPS report. In-lake BMPs include management of lake levels, in-lake plant and fish communities, and/or sediment P release. Watershed BMPs include management of septic systems, shoreline erosion, and stormwater runoff. Key watershed-wide strategies that will improve the water quality of impaired and unimpaired lakes and streams include Public and Private Land Protection, Non-functioning Ditch Decommissioning, and Shoreland Ordinance Enforcement, Education, and Updating.

8.2.3 Education and Outreach

A crucial part in the success of the WRAPS implementation strategies designed to clean up the impaired lakes and streams and protect the non-impaired water bodies will be participation from local citizens. In order to gain support from these citizens, education and civic engagement opportunities will be necessary. A variety of educational avenues have been and will continue to be used throughout the MRGRW. These include (but are not limited to): press releases, meetings, workshops, focus groups, trainings, websites, etc. Local staff (conservation district, county, etc.) and board members work to educate the residents of the watersheds about ways to clean up their lakes and streams on a regular basis. A summary of public outreach efforts conducted during the development of the TMDL is provided in the MRGRW WRAPs report.

The SWCDs and other LGUs will continue conducting the public outreach efforts that were initiated during the development of the TMDL. Goals for future civic engagement efforts in the MRGRW include:

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

If the solutions in the TMDL/WRAPS plan are developed with input from local land managers, the likelihood of implementation may increase. In addition, implementation activities will be streamlined due to the collaboration between landowners, local agencies, and funding sources. More detailed information on current and future civic engagement efforts for the watershed are found in the WRAPS report.

8.2.4 Technical Assistance

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

Programs such as state cost share, SWCD sponsored Agricultural BMP Loan programs, Forestry Stewardship Plans, SWCD sponsored shoreline and pollinator habitat grants, and Clean Water Legacy funding are available to help implement the best conservation practices that each parcel of land is eligible for in order to target the best conservation practices per site. Conservation practices may include, but are not limited to: stormwater bioretention, septic system upgrades, feedlot improvements, invasive species control, wastewater treatment practices, rural BMPs, internal loading reduction, forest stewardship planning, and shoreline stabilization and revegetation. More information about types of practices and implementation of BMPs will be discussed in the Mississippi River-Grand Rapids WRAPS Report.

8.2.5 Partnerships

Partnerships with counties, cities, townships, citizens, businesses, Mille Lacs Band of Ojibwe, Natural Resources Conservation Service (NRCS), and lake associations are one mechanism through which the Aitkin, Carlton, and Itasca County SWCDs will protect and improve water quality. Strong partnerships with state and local government to protect and improve water resources and to bring waters within the MRGRW into compliance with state standards will continue. A partnership with LGUs and regulatory agencies such as cities, townships and counties may be formed to develop and update ordinances to protect the area’s water resources.

8.3 Cost

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

8.3.1 Phosphorus

For all seven impaired lakes, a total of 2,373 pounds of P needs to be reduced each year to meet state water quality standards. Assuming an average life-cycle cost of $1,500 per pound of P per year, the total cost to achieve all of the lake P load reductions is approximately $3.6 million.

8.3.2 Bacteria

The cost estimate for bacteria load reduction is based on unit costs for the two major sources of bacteria: livestock and ITPHSS. The unit cost for bringing AUs under manure management plans and feedlot lot runoff controls is $350/AU. This value is based on USDA Environmental Quality Incentives Program (EQIP) payment history and includes buffers, livestock access control, manure management plans, waste storage structures, and clean water diversions. Repair or replacement of ITPHSS was estimated at $7,500/system (EPA 2011). Multiplying those unit costs by an estimated 348 ITPHSS and 373 AU in the impaired reach subwatersheds provides a total cost of approximately $2.6 million.

9 Public Participation

9.1 Core Team Meetings

Quarterly working meetings were held with Core Team to discuss civic engagement and development of the WRAPS plan (Table 9-1). The Core Team was comprised of representatives from the SWCDs and state agencies.

Table 9-1. Mississippi River-Grand Rapids Watershed Core Team Meetings

Date	Location	Meeting Focus
3/26/2014	Grand Rapids DNR	Preliminary Organizational Meeting
9/11/2015	Forest History Center, Grand Rapids	Civic Engagement Strategic Planning
10/20/2015	Forest History Center, Grand Rapids	Civic Engagement Strategic Planning
12/16/2015	Forest History Center	Phase II Contract Development
2/4/2016	Sawmill Inn, Grand Rapids	Civic Engagement Communication Network Development
2/17/2016	Conference Call	Civic Engagement Plan Implementation Check In
3/23/2016	Grand Rapids DNR	Biological Monitoring, Stressor ID, Zonation
5/24/2016	Conference Call	Civic Engagement Plan Implementation Check In
9/27/2016	Grand Rapids DNR	Zonation, Groundwater, Tech Update, C&E
10/5/2016	Conference Call	Zonation Survey planning
11/16/2016	Conference Call	Zonation Survey planning
12/1/2016	Brainerd MPCA	Stressor ID needs
1/10/2017	Grand Rapids DNR	Tech Team Zonation Survey
1/20/2017	Conference Call	Zonation Survey Planning
2/16/2017	Brainerd MPCA	Standard Deliverables-Miss- Brainerd and GR
3/22/2017	Brainerd MPCA	Watershed Assessment Team-Stream assessment
3/28/2017	Long Lake Conservation Center	Zonation Results, Planning
4/3/2017	Brainerd MPCA	WAT for Lakes
5/2/2017	Long Lake Conservation Center	Professional Judgement Group Meeting
6/16/2017	Long Lake Conservation Center	Zonation Synthesis
6/26/2017	Conference Call	Civic Engagement planning
6/29/2017	Aitkin SWCD	Zonation Synthesis
7/6/2017	Brainerd MPCA	Cass County Update/Zonation
8/1/2017	BWSR	1W1P & WRAPS integration
8/28/2017	Conference Call	WRAPS Ambassador Meeting Planning
9/14/2017	Hill City	Lakes Protection, Land Use Management and Shoreland Ordinance Strategies, EOR involvement

Date	Location	Meeting Focus
1/11/2018	Webex	Core- Project Status Update 2018 Planning, Lake Prioritization
2/27/2018	Long Lake Conservation Center	Stream and Lake Prioritization, WRAPS content and strategy
4/16/2018	WebEx	Reports Update, Stream Protection, Subwatershed forested/protection map, Lakes list-data check
6/4/2018	WebEx	Subwatershed Source Assessment/Characterization
6/11/2018	WebEx	Subwatershed Source Assessment/Characterization
7/24/2018	DNR Grand Rapids	Subwatershed Prioritization
9/17/2018	Long Lake Conservation Center	Review HUC 12 and Lakes Priorities, strategy table intro
11/13/2018	Big Sandy Army Corps of Engineers	USACE, Review lake and stream TMDL results, plan public meetings
12/12/2018	Carlton SWCD	Storymap creation
1/9/2019	WebEx	WRAPS preview and assignments
2/5/2019	Skype	WRAPS check in, Mining in the watershed, Hydroelectric
3/5/2019	Skype	WRAPS check, Hydroelectric

9.2 Civic Engagement

The MRGRW Core Team engaged with various stakeholders to guide the informing and development of the WRAPS. A team of 'Ambassadors" was developed as part of the process. The intention was for Ambassadors to represent their group (lake association, community, etc.) at a series of round table meetings throughout the WRAPS process. They were able to provide input on their group's water quality concerns, important lakes and streams, and implementation ideas. We also wanted the Ambassadors to serve as a two-way communication route, so that they would share updates with their group during the WRAPS process. These Ambassadors gained a greater understanding of water quality in the watershed, networking water resource connections with other groups, new implementation ideas as well as a stake in the development of the WRAPS report and strategies that will guide future grant funding applications.

Core team members partnered with staff from the University of Minnesota Extension Service to learn civic engagement tools and strategies that could be used to fully engage with citizen partners on this effort. Several training sessions were held, resulting in the development of a Civic Engagement Plan for this watershed. Two sessions of "Convening Community Conservation That Engage" were held in Grand Rapids. This workshop offered information on hosting conversations the encourage participation, and develop meaningful dialogue. Community members and core team members attended the meetings and worked to build the relationships that would carry this project forward.

A summary of public meetings hosted by the Core Team is listed in (Table 9-2).

Table 9-2. Mississippi River-Grand Rapids Watershed Public Meetings and Communication

Date	Location	Meeting Focus
5/29/2015	Sawmill Inn, Grand Rapids	Kick – Off Meeting
2/4/2016	Sawmill Inn, Grand Rapids	Convening Community Conversations That Engage
2/5/2016	Sawmill Inn, Grant Rapids	Convening Community Conversations That Engage

Date	Location	Meeting Focus
2/29/2016	Long Lake Conservation Center, Palisade	Zonation Overview
6/18/2016	Aitkin High School	Rivers & Lakes Fair – WRAPS Information Sharing
7/16/2016	Tamarack Sno-Flyers Clubhouse	Big Sandy Area Lakes Watershed Management Project – WRAPS Overview
11/18/2016	KKIN Radio Station	WRAPS discussion
12/15/2016	Itasca County Courthouse	Zonation survey
2/8/2017	Cromwell Park Pavilion	Big Sandy Area Lakes Watershed Management Project-WRAPS overview and zonation survey administration
4/21/2017	Red Rock Radio Station	Radio
6/17/2017	Aitkin High School	Rivers & Lakes Fair – WRAPS / Monitoring Information Sharing
7/19/2017	Mille Lacs Energy Cooperative, Aitkin	Aitkin Water Planning-WRAPS Ambassador Solicitation
9/14/2017	Hill City	WRAPS Ambassador Kickoff
10/11/2017	Cromwell Park Pavilion	Big Sandy Area Lakes Watershed Management Project – Tour of Tamarack River Watershed, Monitoring, Stressor ID, Impairments
11/9/2017	Grand Rapids Blandin	303d 2018 List Public meeting
12/7/2017	Itasca County Courthouse	WRAPS Ambassador- Zonation overview/Lakes Prioritization
1/24/2018	Carlton SWCD	Carlton County Planning and Zoning
2/12/2018	Aitkin SWCD	Aitkin County Planning and Zoning
2/15/2018	Itasca County Courthouse	Itasca County Planning and Zoning
3/6/2018	Long Lake Conservation Center-Palisade	Ambassador-Lake prioritization finalization
6/16/2018	Aitkin High School	Rivers & Lakes Fair – WRAPS Information Sharing
6/26/2018	Long Lake Conservation Center-Palisade	Ambassador-WRAPS Overview, Connection between Forests and Water Quality, Impairment Source Assessment, Common Stream Stressors
9/26/2018	Blandin Foundation-Grand Rapids	WRAPS Overview, HUC 12 map comments
12/6/2018	Cromwell Pavilion	TMDL overview
12/6/2018	Blandin Foundation-Grand Rapids	TMDL overview
3/13/2019	Cromwell Pavilion	Ditch abandonment education sessions
5/8/2019	Cromwell Pavilion	WRAPS overview
7/10/2019	Tamarac Sno-Flyers Clubhouse	TMDL and WRAPS Open House
7/10/2019	Blandin Foundation- Grand Rapids	TMDL and WRAPS Open House

Public notice for comments

An opportunity for public comment on the draft TMDL report was provided via a public notice in the State Register from July 15, 2019 through August 14, 2019. There were no comment letters received as a result of the public comment period.

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APPENDIX A. BATHTUB SUPPORTING INFORMATION

A.1 Eagle Lake

Table A-1. Calibrated Model Predicted and Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 Eagle Lake

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	28.0	0.36	27.5%	28.0	0.08	27.5%

Table A-2. Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

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

Trb	**Type**	**Seg**	**Name**	**Area km²**	**Flow hm³/yr**	**Variance (hm3/yr)²**	**CV -**	**Runoff m/yr**
1	1	1	Direct Dra	7.8	1.6	2.44E-02	0.10	0.20
PRECIPITATION				1.6	1.2	1.52E-02	0.10	0.78
TRIBUTARY INFLOW				7.8	1.6	2.44E-02	0.10	0.20
***TOTAL INFLOW				9.3	2.8	3.97E-02	0.07	0.30
ADVECTIVE OUTFLOW				9.3	1.7	3.66E-01	0.37	0.18
***TOTAL OUTFLOW				9.3	1.7	3.66E-01	0.37	0.18
***EVAPORATION					1.1	3.27E-01	0.50	

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

Trb	**Type**	**Seg**	**Name**	**Load kg/yr**	**%Total**	**Load Variance (kg/yr)²**	**%Total**	**CV**	**Conc mg/m³**	**Export kg/km²/yr**
1	1	1	Direct Dra	83.1	39.7%	3.46E+02	65.9%	0.22	53.2	10.7
PRECIPITATION				26.8	12.8%	1.79E+02	34.1%	0.50	21.7	17.0
INTERNAL LOAD				99.5	47.5%	0.00E+00		0.00		
TRIBUTARY INFLOW				83.1	39.7%	3.46E+02	65.9%	0.22	53.2	10.7
***TOTAL INFLOW				209.4	100.0%	5.25E+02	100.0%	0.11	74.8	22.4
ADVECTIVE OUTFLOW				46.3	22.1%	4.45E+02		0.46	28.0	5.0
***TOTAL OUTFLOW				46.3	22.1%	4.45E+02		0.46	28.0	5.0
***RETENTION				163.1	77.9%	7.64E+02		0.17		

Overflow Rate (m/yr)	1.1	Nutrient Resid. Time (yrs)	1.0867
Hydraulic Resid. Time (yrs)	4.9194	Turnover Ratio	0.9
Reservoir Conc (mg/m3)	28	Retention Coef.	0.779

Table A-3. TMDL Goal Scenario Model Predicted and Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1	Eagle Lake				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P	25.6	0.36	24.3%	28.0	0.08	27.5%

Table A-4. TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance					Averaging Period =		1.00	years
				Area	Flow	Variance	CV	Runoff
Trb	Type	Seg	Name	km^2	hm^3/yr	$(hm3/yr)^2$	-	m/yr
1	1	1	Direct Dra	7.8	1.6	2.44E-02	0.10	0.20
PRECIPITATION				1.6	1.2	1.52E-02	0.10	0.78
TRIBUTARY INFLOW				7.8	1.6	2.44E-02	0.10	0.20
***TOTAL INFLOW				9.3	2.8	3.97E-02	0.07	0.30
ADVECTIVE OUTFLOW				9.3	1.7	3.66E-01	0.37	0.18
***TOTAL OUTFLOW				9.3	1.7	3.66E-01	0.37	0.18
***EVAPORATION					1.1	3.27E-01	0.50	

Overall Mass Balance Based Upon				Predicted	Outflow & Reservoir Concentrations					
Component:				TOTAL P						
				Load		Load Variance			Conc	Export
Trb	Type	Seg	Name	kg/yr	%Total	$(kg/yr)^2$	%Total	CV	mg/m^3	$kg/km^2/yr$
1	1	1	Direct Dra	78.2	42.8%	3.05E+02	63.0%	0.22	50.0	10.1
PRECIPITATION				26.8	14.7%	1.79E+02	37.0%	0.50	21.7	17.0
INTERNAL LOAD				77.6	42.5%	0.00E+00		0.00		
TRIBUTARY INFLOW				78.2	42.8%	3.05E+02	63.0%	0.22	50.0	10.1
***TOTAL INFLOW				182.5	100.0%	4.84E+02	100.0%	0.12	65.3	19.6
ADVECTIVE OUTFLOW				42.3	23.2%	3.65E+02		0.45	25.6	4.5
***TOTAL OUTFLOW				42.3	23.2%	3.65E+02		0.45	25.6	4.5
***RETENTION				140.2	76.8%	6.56E+02		0.18		

Overflow Rate (m/yr)	1.1	Nutrient Resid. Time (yrs)	1.1409
Hydraulic Resid. Time (yrs)	4.9194	Turnover Ratio	0.9
Reservoir Conc (mg/m3)	26	Retention Coef.	0.768

A.2 Horseshoe Lake

Table A-5. Calibrated Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1	Horseshoe				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P	43.0	0.22	45.3%	43.0	0.06	45.2%

Table A-6. Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance					Averaging Period =		1.00	years
				Area	Flow	Variance	CV	Runoff
Trb	Type	Seg	Name	km^2	hm^3/yr	$(hm3/yr)^2$	-	m/yr
1	1	1	Direct Dra	22.4	4.6	8.44E-01	0.20	0.21
PRECIPITATION				1.0	0.7	5.60E-03	0.10	0.77
TRIBUTARY INFLOW				22.4	4.6	8.44E-01	0.20	0.21
***TOTAL INFLOW				23.4	5.3	8.50E-01	0.17	0.23
ADVECTIVE OUTFLOW				23.4	4.6	9.74E-01	0.21	0.20
***TOTAL OUTFLOW				23.4	4.6	9.74E-01	0.21	0.20
***EVAPORATION					0.7	1.24E-01	0.50	

Overall Mass Balance Based Upon				Predicted	Outflow & Reservoir Concentrations					
Component:				TOTAL P						
				Load		Load Variance			Conc	Export
Trb	Type	Seg	Name	kg/yr	%Total	$(kg/yr)^2$	%Total	CV	mg/m^3	$kg/km^2/yr$
1	1	1	Direct Dra	242.9	70.9%	4.72E+03	98.6%	0.28	52.9	10.8
PRECIPITATION				16.5	4.8%	6.82E+01	1.4%	0.50	22.1	17.0
INTERNAL LOAD				83.4	24.3%	0.00E+00		0.00		
TRIBUTARY INFLOW				242.9	70.9%	4.72E+03	98.6%	0.28	52.9	10.8
***TOTAL INFLOW				342.8	100.0%	4.79E+03	100.0%	0.20	64.2	14.7
ADVECTIVE OUTFLOW				199.6	58.2%	3.50E+03		0.30	43.0	8.5
***TOTAL OUTFLOW				199.6	58.2%	3.50E+03		0.30	43.0	8.5
***RETENTION				143.2	41.8%	2.18E+03		0.33		

Overflow Rate (m/yr)	4.8	Nutrient Resid. Time (yrs)	0.2391
Hydraulic Resid. Time (yrs)	0.4106	Turnover Ratio	4.2
Reservoir Conc (mg/m3)	43	Retention Coef.	0.418

Table A-7. TMDL Goal Scenario Model Predicted and Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	**1**	**Horseshoe**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	30.0	0.21	30.1%	43.0	0.06	45.2%

Table A-8. TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance					**Averaging Period =**		**1.00**	**years**
				Area	**Flow**	**Variance**	**CV**	**Runoff**
Trb	**Type**	**Seg**	**Name**	**km^2**	**hm^3/yr**	**$(hm3/yr)^2$**	**-**	**m/yr**
1	1	1	Direct Dra	22.4	4.6	8.44E-01	0.20	0.21
PRECIPITATION				1.0	0.7	5.60E-03	0.10	0.77
TRIBUTARY INFLOW				22.4	4.6	8.44E-01	0.20	0.21
***TOTAL INFLOW				23.4	5.3	8.50E-01	0.17	0.23
ADVECTIVE OUTFLOW				23.4	4.6	9.74E-01	0.21	0.20
***TOTAL OUTFLOW				23.4	4.6	9.74E-01	0.21	0.20
***EVAPORATION					0.7	1.24E-01	0.50	

Overall Mass Balance Based Upon				**Predicted**		**Outflow & Reservoir Concentrations**				
Component:				**TOTAL P**						
				Load		**Load Variance**			**Conc**	**Export**
Trb	**Type**	**Seg**	**Name**	**kg/yr**	**%Total**	**$(kg/yr)^2$**	**%Total**	**CV**	**mg/m^3**	**$kg/km^2/yr$**
1	1	1	Direct Dra	161.3	73.2%	2.08E+03	96.8%	0.28	35.1	7.2
PRECIPITATION				16.5	7.5%	6.82E+01	3.2%	0.50	22.1	17.0
INTERNAL LOAD				42.6	19.3%	0.00E+00		0.00		
TRIBUTARY INFLOW				161.3	73.2%	2.08E+03	96.8%	0.28	35.1	7.2
***TOTAL INFLOW				220.4	100.0%	2.15E+03	100.0%	0.21	41.2	9.4
ADVECTIVE OUTFLOW				138.9	63.0%	1.57E+03		0.29	30.0	5.9
***TOTAL OUTFLOW				138.9	63.0%	1.57E+03		0.29	30.0	5.9
***RETENTION				81.4	37.0%	8.18E+02		0.35		

Overflow Rate (m/yr)	4.8	Nutrient Resid. Time (yrs)	0.2589
Hydraulic Resid. Time (yrs)	0.4106	Turnover Ratio	3.9
Reservoir Conc (mg/m3)	30	Retention Coef.	0.370

A.3 North Island Lake

Table A-9. Calibrated Model Predicted and Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1	North Island				
	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	27.0	0.15	26.2%	27.0	0.09	26.2%

Table A-10. Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	South Islan	16.3	2.9	6.04E-01	0.27	0.18
2	1	1	Direct Drai	1.5	3.8	1.42E-01	0.10	2.52
PRECIPITATION				0.5	0.4	1.30E-03	0.10	0.78
TRIBUTARY INFLOW				17.8	6.6	7.46E-01	0.13	0.37
***TOTAL INFLOW				18.3	7.0	7.48E-01	0.12	0.38
ADVECTIVE OUTFLOW				18.3	6.7	7.75E-01	0.13	0.37
***TOTAL OUTFLOW				18.3	6.7	7.75E-01	0.13	0.37
***EVAPORATION					0.3	2.78E-02	0.50	

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

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	South Islan	77.5	34.3%	8.75E+02	70.7%	0.38	26.9	4.8
2	1	1	Direct Drai	131.8	58.3%	3.48E+02	28.1%	0.14	35.0	88.2
PRECIPITATION				7.8	3.5%	1.53E+01	1.2%	0.50	21.7	17.0
INTERNAL LOAD				8.9	3.9%	0.00E+00		0.00		
TRIBUTARY INFLOW				209.3	92.6%	1.22E+03	98.8%	0.17	31.5	11.8
***TOTAL INFLOW				226.0	100.0%	1.24E+03	100.0%	0.16	32.3	12.4
ADVECTIVE OUTFLOW				170.4	75.4%	1.11E+03		0.20	25.5	9.3
***TOTAL OUTFLOW				170.4	75.4%	1.11E+03		0.20	25.5	9.3
***RETENTION				55.6	24.6%	4.28E+02		0.37		

Overflow Rate (m/yr)	14.5	Nutrient Resid. Time (yrs)	0.1397
Hydraulic Resid. Time (yrs)	0.1853	Turnover Ratio	7.2
Reservoir Conc (mg/m3)	26	Retention Coef.	0.246

Table A-11. TMDL Goal Scenario Model Predicted and Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1	North Island				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P	24.6	0.15	23.0%	27.0	0.09	26.2%

Table A-12. TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance					Averaging Period =		1.00	years
				Area	Flow	Variance	CV	Runoff
Trb	Type	Seg	Name	km^2	hm^3/yr	$(hm3/yr)^2$	-	m/yr
1	1	1	South Islaı	16.3	2.9	6.04E-01	0.27	0.18
2	1	1	Direct Dra	1.5	3.8	1.42E-01	0.10	2.52
PRECIPITATION				0.5	0.4	1.30E-03	0.10	0.78
TRIBUTARY INFLOW				17.8	6.6	7.46E-01	0.13	0.37
***TOTAL INFLOW				18.3	7.0	7.48E-01	0.12	0.38
ADVECTIVE OUTFLOW				18.3	6.7	7.75E-01	0.13	0.37
***TOTAL OUTFLOW				18.3	6.7	7.75E-01	0.13	0.37
***EVAPORATION					0.3	2.78E-02	0.50	

Overall Mass Balance Based Upon				Predicted	Outflow & Reservoir Concentrations					
Component:				TOTAL P						
				Load		Load Variance			Conc	Export
Trb	Type	Seg	Name	kg/yr	%Total	$(kg/yr)^2$	%Total	CV	mg/m^3	$kg/km^2/yr$
1	1	1	South Islaı	77.5	35.7%	8.75E+02	70.7%	0.38	26.9	4.8
2	1	1	Direct Dra	131.8	60.7%	3.48E+02	28.1%	0.14	35.0	88.2
PRECIPITATION				7.8	3.6%	1.53E+01	1.2%	0.50	21.7	17.0
TRIBUTARY INFLOW				209.3	96.4%	1.22E+03	98.8%	0.17	31.5	11.8
***TOTAL INFLOW				217.1	100.0%	1.24E+03	100.0%	0.16	31.0	11.9
ADVECTIVE OUTFLOW				164.5	75.7%	1.08E+03		0.20	24.6	9.0
***TOTAL OUTFLOW				164.5	75.7%	1.08E+03		0.20	24.6	9.0
***RETENTION				52.6	24.3%	3.95E+02		0.38		

Overflow Rate (m/yr)	14.5	Nutrient Resid. Time (yrs)	0.1404
Hydraulic Resid. Time (yrs)	0.1853	Turnover Ratio	7.1
Reservoir Conc (mg/m3)	25	Retention Coef.	0.244

A.4 South Island Lake

Table A-13. Calibrated Model Predicted and Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 South Island

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	29.0	0.27	28.9%	29.0	0.07	28.9%

Table A-14. Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

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

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Eagle Lake	9.3	1.7	3.75E-01	0.37	0.18
2	1	1	Direct Dra	5.7	1.1	1.32E-02	0.10	0.20
PRECIPITATION				1.3	1.0	1.05E-02	0.10	0.78
TRIBUTARY INFLOW				15.0	2.8	3.88E-01	0.22	0.19
***TOTAL INFLOW				16.3	3.8	3.98E-01	0.16	0.23
ADVECTIVE OUTFLOW				16.3	2.9	6.24E-01	0.27	0.18
***TOTAL OUTFLOW				16.3	2.9	6.24E-01	0.27	0.18
***EVAPORATION					1.0	2.26E-01	0.50	

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

Component: TOTAL P

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Eagle Lake	46.3	25.1%	5.88E+02	79.4%	0.52	28.0	5.0
2	1	1	Direct Dra	37.7	20.4%	2.85E+01	3.8%	0.14	32.8	6.7
PRECIPITATION				22.3	12.0%	1.24E+02	16.7%	0.50	21.7	17.0
INTERNAL LOAD				78.4	42.5%	0.00E+00		0.00		
TRIBUTARY INFLOW				84.1	45.5%	6.16E+02	83.3%	0.30	30.0	5.6
***TOTAL INFLOW				184.8	100.0%	7.40E+02	100.0%	0.15	48.2	11.3
ADVECTIVE OUTFLOW				83.5	45.2%	7.71E+02		0.33	29.0	5.1
***TOTAL OUTFLOW				83.5	45.2%	7.71E+02		0.33	29.0	5.1
***RETENTION				101.3	54.8%	6.63E+02		0.25		

Overflow Rate (m/yr)	2.2	Nutrient Resid. Time (yrs)	0.5508
Hydraulic Resid. Time (yrs)	1.2190	Turnover Ratio	1.8
Reservoir Conc (mg/m3)	29	Retention Coef.	0.548

Table A-15. TMDL Goal Scenario Model Predicted and Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 South Island

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	26.9	0.27	26.0%	29.0	0.07	28.9%

Table A-16. TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

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

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Eagle Lake	9.3	1.7	3.75E-01	0.37	0.18
2	1	1	Direct Dra	5.7	1.1	1.32E-02	0.10	0.20
PRECIPITATION				1.3	1.0	1.05E-02	0.10	0.78
TRIBUTARY INFLOW				15.0	2.8	3.88E-01	0.22	0.19
***TOTAL INFLOW				16.3	3.8	3.98E-01	0.16	0.23
ADVECTIVE OUTFLOW				16.3	2.9	6.24E-01	0.27	0.18
***TOTAL OUTFLOW				16.3	2.9	6.24E-01	0.27	0.18
***EVAPORATION					1.0	2.26E-01	0.50	

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

Component: TOTAL P

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Eagle Lake	42.4	25.4%	4.91E+02	76.3%	0.52	25.6	4.5
2	1	1	Direct Dra	37.7	22.6%	2.85E+01	4.4%	0.14	32.8	6.7
PRECIPITATION				22.3	13.3%	1.24E+02	19.3%	0.50	21.7	17.0
INTERNAL LOAD				64.6	38.7%	0.00E+00		0.00		
TRIBUTARY INFLOW				80.1	48.0%	5.20E+02	80.7%	0.28	28.6	5.3
***TOTAL INFLOW				166.9	100.0%	6.44E+02	100.0%	0.15	43.6	10.2
ADVECTIVE OUTFLOW				77.4	46.3%	6.47E+02		0.33	26.9	4.7
***TOTAL OUTFLOW				77.4	46.3%	6.47E+02		0.33	26.9	4.7
***RETENTION				89.6	53.7%	5.53E+02		0.26		

Overflow Rate (m/yr)	2.2	Nutrient Resid. Time (yrs)	0.5649
Hydraulic Resid. Time (yrs)	1.2190	Turnover Ratio	1.8
Reservoir Conc (mg/m3)	27	Retention Coef.	0.537

A.5 King Lake

Table A-17. Calibrated Model Predicted and Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1	King				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P	33.0	0.43	33.9%	33.0	0.10	33.9%

Table A-18. Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance					Averaging Period =		1.00	years
				Area	Flow	Variance	CV	Runoff
Trb	Type	Seg	Name	km^2	hm^3/yr	$(hm3/yr)^2$	-	m/yr
1	1	1	Direct Dra	2.3	0.3	3.80E-03	0.20	0.13
PRECIPITATION				1.3	0.9	8.08E-03	0.10	0.71
TRIBUTARY INFLOW				2.3	0.3	3.80E-03	0.20	0.13
***TOTAL INFLOW				3.6	1.2	1.19E-02	0.09	0.34
ADVECTIVE OUTFLOW				3.6	0.0	2.20E-01	9.99	0.00
***TOTAL OUTFLOW				3.6	0.0	2.20E-01	9.99	0.00
***EVAPORATION					0.9	2.08E-01	0.50	
***STORAGE INCREASE					0.3	0.00E+00	0.00	

Overall Mass Balance Based Upon				Predicted		Outflow & Reservoir Concentrations				
Component:				TOTAL P						
				Load		Load Variance			Conc	Export
Trb	Type	Seg	Name	kg/yr	%Total	$(kg/yr)^2$	%Total	CV	mg/m^3	$kg/km^2/yr$
1	1	1	Direct Dra	18.4	14.2%	2.70E+01	19.1%	0.28	59.6	7.8
PRECIPITATION				21.4	16.5%	1.14E+02	80.9%	0.50	23.8	17.0
INTERNAL LOAD				90.0	69.4%	0.00E+00		0.00		
TRIBUTARY INFLOW				18.4	14.2%	2.70E+01	19.1%	0.28	59.6	7.8
***TOTAL INFLOW				129.7	100.0%	1.41E+02	100.0%	0.09	107.5	36.0
ADVECTIVE OUTFLOW				0.2	0.1%	2.42E+02		10.00	33.0	0.0
***TOTAL OUTFLOW				0.2	0.1%	2.42E+02		10.00	33.0	0.0
***STORAGE INCREASE				9.5	7.4%	9.10E-01		0.10	33.0	
***RETENTION				120.0	92.5%	3.69E+02		0.16		

Overflow Rate (m/yr)	0.2	Nutrient Resid. Time (yrs)	1.2975
Hydraulic Resid. Time (yrs)	17.3321	Turnover Ratio	0.8
Reservoir Conc (mg/m3)	33	Retention Coef.	0.925

Table A-19. TMDL Goal Scenario Model Predicted and Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1	King				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P	30.0	0.43	30.1%	33.0	0.10	33.9%

Table A-20. TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct Dra	2.3	0.3	3.80E-03	0.20	0.13
PRECIPITATION				1.3	0.9	8.08E-03	0.10	0.71
TRIBUTARY INFLOW				2.3	0.3	3.80E-03	0.20	0.13
***TOTAL INFLOW				3.6	1.2	1.19E-02	0.09	0.34
ADVECTIVE OUTFLOW				3.6	0.3	2.20E-01	1.59	0.08
***TOTAL OUTFLOW				3.6	0.3	2.20E-01	1.59	0.08
***EVAPORATION					0.9	2.08E-01	0.50	

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

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct Dra	16.1	14.6%	2.07E+01	15.4%	0.28	52.2	6.9
PRECIPITATION				21.4	19.4%	1.14E+02	84.6%	0.50	23.8	17.0
INTERNAL LOAD				72.5	65.9%	0.00E+00		0.00		
TRIBUTARY INFLOW				16.1	14.6%	2.07E+01	15.4%	0.28	52.2	6.9
***TOTAL INFLOW				110.0	100.0%	1.35E+02	100.0%	0.11	91.1	30.5
ADVECTIVE OUTFLOW				8.8	8.0%	1.83E+02		1.53	30.0	2.5
***TOTAL OUTFLOW				8.8	8.0%	1.83E+02		1.53	30.0	2.5
***RETENTION				101.2	92.0%	2.95E+02		0.17		

Overflow Rate (m/yr)	0.2	Nutrient Resid. Time (yrs)	1.3912
Hydraulic Resid. Time (yrs)	17.3321	Turnover Ratio	0.7
Reservoir Conc (mg/m3)	30	Retention Coef.	0.920

A.6 Little Cowhorn Lake

Table A-21. Calibrated Model Predicted and Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1	Little Cowhorn				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P	46.0	0.33	48.2%	46.0	0.15	48.2%

Table A-22. Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance					Averaging Period =		1.00	years
				Area	Flow	Variance	CV	Runoff
Trb	Type	Seg	Name	km^2	hm^3/yr	$(hm3/yr)^2$	-	m/yr
1	1	1	Direct Dra	4.0	0.7	1.99E-02	0.20	0.17
PRECIPITATION				0.7	0.5	2.88E-03	0.10	0.73
TRIBUTARY INFLOW				4.0	0.7	1.99E-02	0.20	0.17
***TOTAL INFLOW				4.8	1.2	2.27E-02	0.12	0.26
ADVECTIVE OUTFLOW				4.8	0.7	9.37E-02	0.43	0.15
***TOTAL OUTFLOW				4.8	0.7	9.37E-02	0.43	0.15
***EVAPORATION					0.5	7.09E-02	0.50	

Overall Mass Balance Based Upon				Predicted		Outflow & Reservoir Concentrations				
Component:				TOTAL P						
				Load		Load Variance			Conc	Export
Trb	Type	Seg	Name	kg/yr	%Total	$(kg/yr)^2$	%Total	CV	mg/m^3	$kg/km^2/yr$
1	1	1	Direct Dra	41.1	38.7%	1.35E+02	77.7%	0.28	58.3	10.2
PRECIPITATION				12.5	11.8%	3.89E+01	22.3%	0.50	23.2	17.0
INTERNAL LOAD				52.5	49.5%	0.00E+00		0.00		
TRIBUTARY INFLOW				41.1	38.7%	1.35E+02	77.7%	0.28	58.3	10.2
***TOTAL INFLOW				106.1	100.0%	1.74E+02	100.0%	0.12	85.5	22.3
ADVECTIVE OUTFLOW				32.6	30.7%	2.18E+02		0.45	46.0	6.8
***TOTAL OUTFLOW				32.6	30.7%	2.18E+02		0.45	46.0	6.8
***RETENTION				73.5	69.3%	2.46E+02		0.21		

Overflow Rate (m/yr)	1.0	Nutrient Resid. Time (yrs)	0.5752
Hydraulic Resid. Time (yrs)	1.8731	Turnover Ratio	1.7
Reservoir Conc (mg/m3)	46	Retention Coef.	0.693

Table A-23. TMDL Goal Scenario Model Predicted and Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1	Little Cowhorn				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P	30.0	0.33	30.2%	46.0	0.15	48.2%

Table A-24. TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance					Averaging Period =		1.00	years
				Area	Flow	Variance	CV	Runoff
Trb	Type	Seg	Name	km^2	hm^3/yr	$(hm3/yr)^2$	-	m/yr
1	1	1	Direct Dra	4.0	0.7	1.99E-02	0.20	0.17
PRECIPITATION				0.7	0.5	2.88E-03	0.10	0.73
TRIBUTARY INFLOW				4.0	0.7	1.99E-02	0.20	0.17
***TOTAL INFLOW				4.8	1.2	2.27E-02	0.12	0.26
ADVECTIVE OUTFLOW				4.8	0.7	9.37E-02	0.43	0.15
***TOTAL OUTFLOW				4.8	0.7	9.37E-02	0.43	0.15
***EVAPORATION					0.5	7.09E-02	0.50	

Overall Mass Balance Based Upon Component:				Predicted TOTAL P		Outflow & Reservoir Concentrations				
				Load		Load Variance			Conc	Export
Trb	Type	Seg	Name	kg/yr	%Total	$(kg/yr)^2$	%Total	CV	mg/m^3	$kg/km^2/yr$
1	1	1	Direct Dra	35.2	61.1%	9.93E+01	71.9%	0.28	50.0	8.7
PRECIPITATION				12.5	21.6%	3.89E+01	28.1%	0.50	23.2	17.0
INTERNAL LOAD				9.9	17.2%	0.00E+00		0.00		
TRIBUTARY INFLOW				35.2	61.1%	9.93E+01	71.9%	0.28	50.0	8.7
***TOTAL INFLOW				57.6	100.0%	1.38E+02	100.0%	0.20	46.4	12.1
ADVECTIVE OUTFLOW				21.3	37.0%	8.86E+01		0.44	30.0	4.5
***TOTAL OUTFLOW				21.3	37.0%	8.86E+01		0.44	30.0	4.5
***RETENTION				36.3	63.0%	1.17E+02		0.30		

Overflow Rate (m/yr)	1.0	Nutrient Resid. Time (yrs)	0.6922
Hydraulic Resid. Time (yrs)	1.8731	Turnover Ratio	1.4
Reservoir Conc (mg/m3)	30	Retention Coef.	0.630

A.7 Split Hand Lake

Table A-25. Calibrated Model Predicted and Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1	Split Hand				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P	41.0	0.32	43.1%	41.0	0.12	43.1%

Table A-26. Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km²	Flow hm³/yr	Variance (hm3/yr)²	CV -	Runoff m/yr
1	1	1	Direct Dra	76.4	11.4	5.20E+00	0.20	0.15
PRECIPITATION				5.6	4.1	1.66E-01	0.10	0.73
TRIBUTARY INFLOW				76.4	11.4	5.20E+00	0.20	0.15
***TOTAL INFLOW				81.9	15.5	5.36E+00	0.15	0.19
ADVECTIVE OUTFLOW				81.9	11.4	9.43E+00	0.27	0.14
***TOTAL OUTFLOW				81.9	11.4	9.43E+00	0.27	0.14
***EVAPORATION					4.0	4.07E+00	0.50	

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

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)²	%Total	CV	Conc mg/m³	Export kg/km²/yr
1	1	1	Direct Dra	199.7	12.3%	3.19E+03	58.8%	0.28	17.5	2.6
PRECIPITATION				94.5	5.8%	2.23E+03	41.2%	0.50	23.2	17.0
INTERNAL LOAD				1334.1	81.9%	0.00E+00		0.00		
TRIBUTARY INFLOW				199.7	12.3%	3.19E+03	58.8%	0.28	17.5	2.6
***TOTAL INFLOW				1628.3	100.0%	5.42E+03	100.0%	0.05	105.3	19.9
ADVECTIVE OUTFLOW				468.3	28.8%	3.08E+04		0.37	41.0	5.7
***TOTAL OUTFLOW				468.3	28.8%	3.08E+04		0.37	41.0	5.7
***RETENTION				1160.0	71.2%	2.89E+04		0.15		

Overflow Rate (m/yr)	2.1	Nutrient Resid. Time (yrs)	0.6672
Hydraulic Resid. Time (yrs)	2.3198	Turnover Ratio	1.5
Reservoir Conc (mg/m3)	41	Retention Coef.	0.712

Table A-27. TMDL Goal Scenario Model Predicted and Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 Split Hand

Variable	Predicted Values---> Mean	CV	Rank	Observed Values---> Mean	CV	Rank
TOTAL P	30.0	0.31	30.1%	41.0	0.12	43.1%

Table A-28. TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

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

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct Dra	76.4	11.4	5.20E+00	0.20	0.15
PRECIPITATION				5.6	4.1	1.66E-01	0.10	0.73
TRIBUTARY INFLOW				76.4	11.4	5.20E+00	0.20	0.15
***TOTAL INFLOW				81.9	15.5	5.36E+00	0.15	0.19
ADVECTIVE OUTFLOW				81.9	11.4	9.43E+00	0.27	0.14
***TOTAL OUTFLOW				81.9	11.4	9.43E+00	0.27	0.14
***EVAPORATION					4.0	4.07E+00	0.50	

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

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct Dra	199.7	19.4%	3.19E+03	58.8%	0.28	17.5	2.6
PRECIPITATION				94.5	9.2%	2.23E+03	41.2%	0.50	23.2	17.0
INTERNAL LOAD				737.1	71.5%	0.00E+00		0.00		
TRIBUTARY INFLOW				199.7	19.4%	3.19E+03	58.8%	0.28	17.5	2.6
***TOTAL INFLOW				1031.3	100.0%	5.42E+03	100.0%	0.07	66.7	12.6
ADVECTIVE OUTFLOW				342.7	33.2%	1.51E+04		0.36	30.0	4.2
***TOTAL OUTFLOW				342.7	33.2%	1.51E+04		0.36	30.0	4.2
***RETENTION				688.6	66.8%	1.44E+04		0.17		

Overflow Rate (m/yr)	2.1	Nutrient Resid. Time (yrs)	0.7708
Hydraulic Resid. Time (yrs)	2.3198	Turnover Ratio	1.3
Reservoir Conc (mg/m3)	30	Retention Coef.	0.668

APPENDIX B. LAKE SUMMARIES

B.1 Eagle Lake

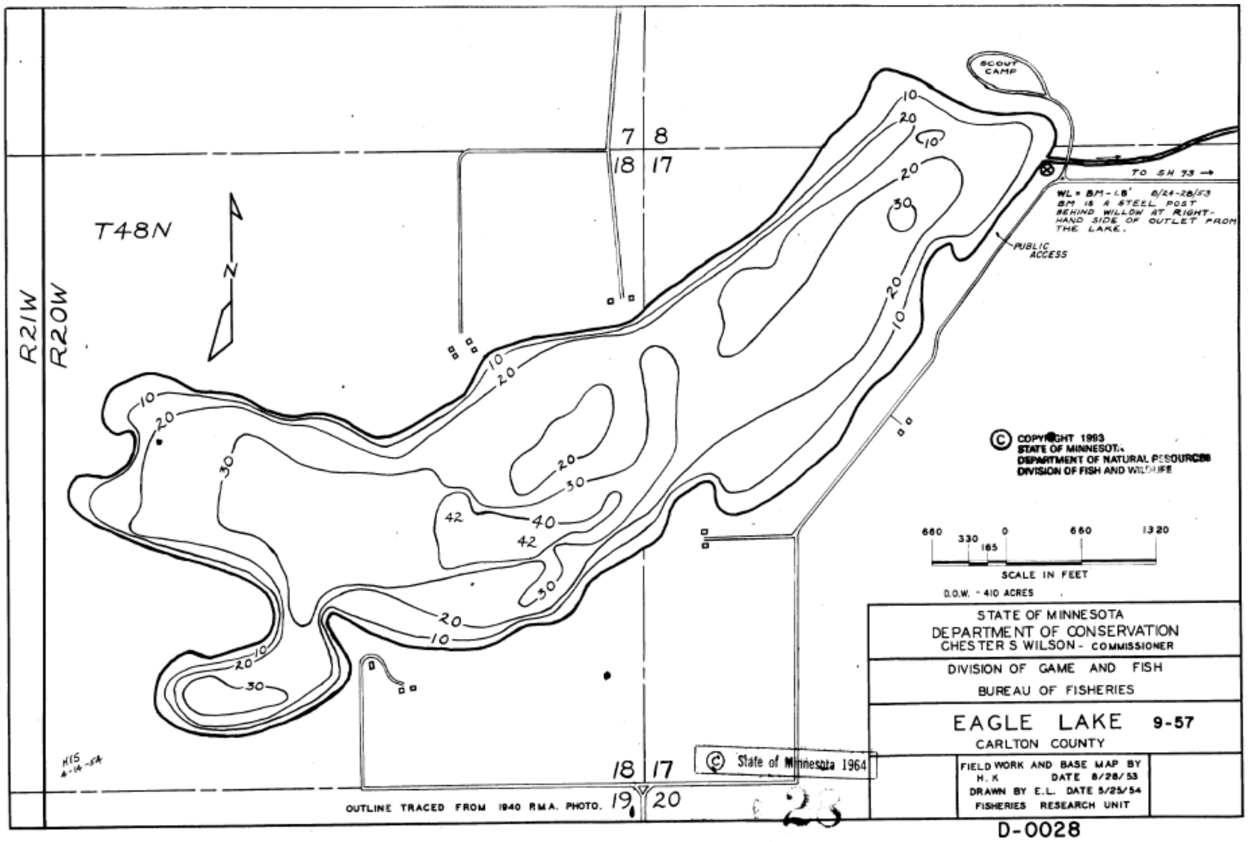

Figure A-1. Eagle Lake Bathymetric Map (DNR, August 1953)

Aquatic Plant and Fish Community

DNR completed a Minnesota Biological Survey of Eagle Lake on July 10, 1997. At the time of the survey, the aquatic plant community was diverse with submersed, floating, emergent and shoreline species. No invasive species were observed.

The most recent DNR fish survey was completed on August 8, 2016. This survey noted:

- Walleye are self-sustaining and have not been stocked since 1989. The walleye abundance was above average.
- Black Crappie and Yellow Perch are also very abundant.

Growing Season Annual Average Water Quality Figures

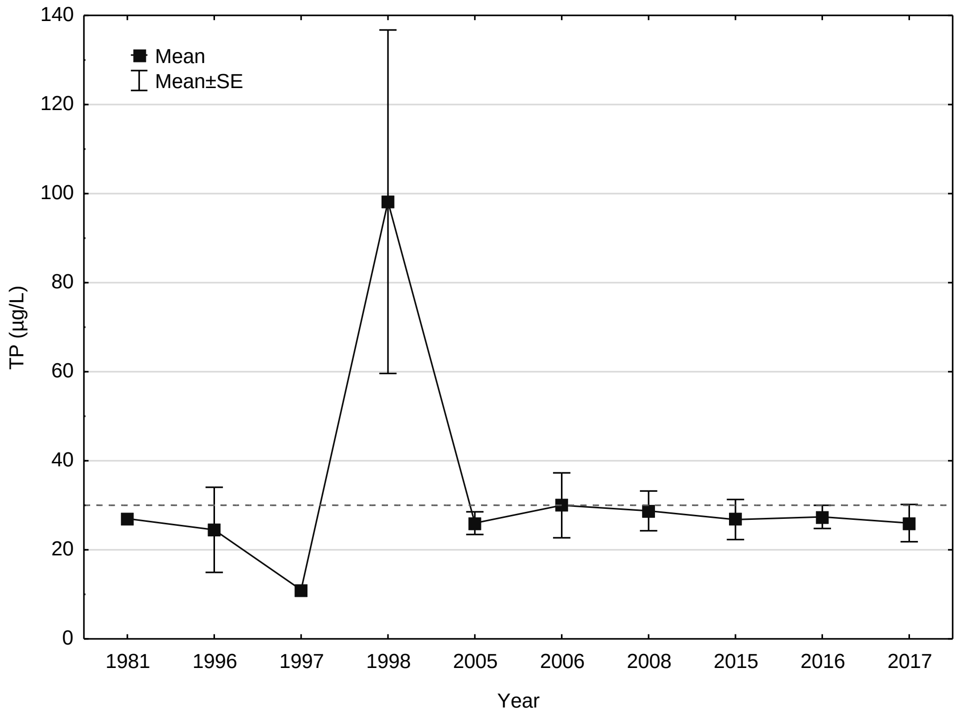

Figure A-2. Growing Season Means ± SE of Total Phosphorus for Eagle Lake by Year
The dashed line represents the water quality standard for TP (30 µg/L)

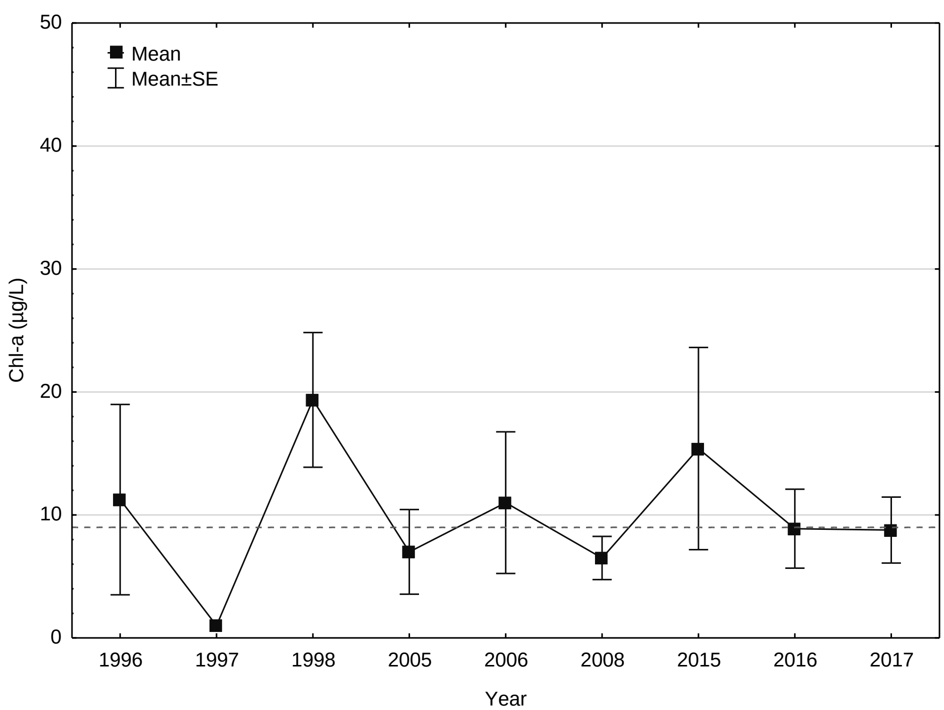

Figure A-3. Growing Season Means ± SE of Chlorophyll-a for Eagle Lake by Year
The dashed line represents the water quality standard for Chl-a (9 µg/L)

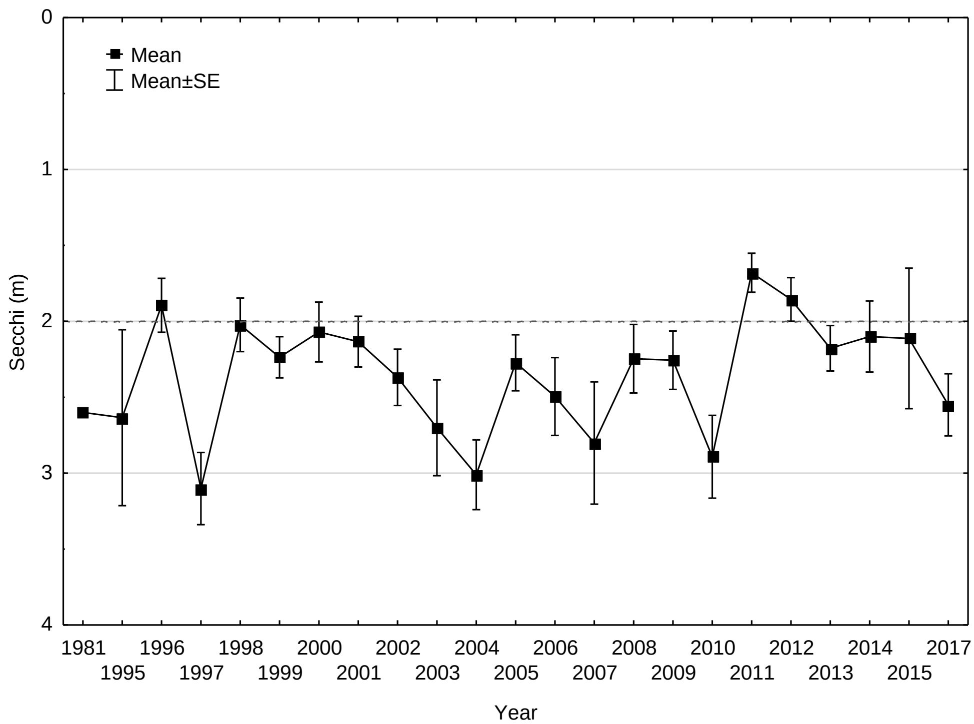

Figure A-4. Growing Season Means ± SE of Secchi transparency for Eagle Lake by Year
The dashed line represents the water quality standard for transparency (2.0 m)

B.2 Horseshoe Lake

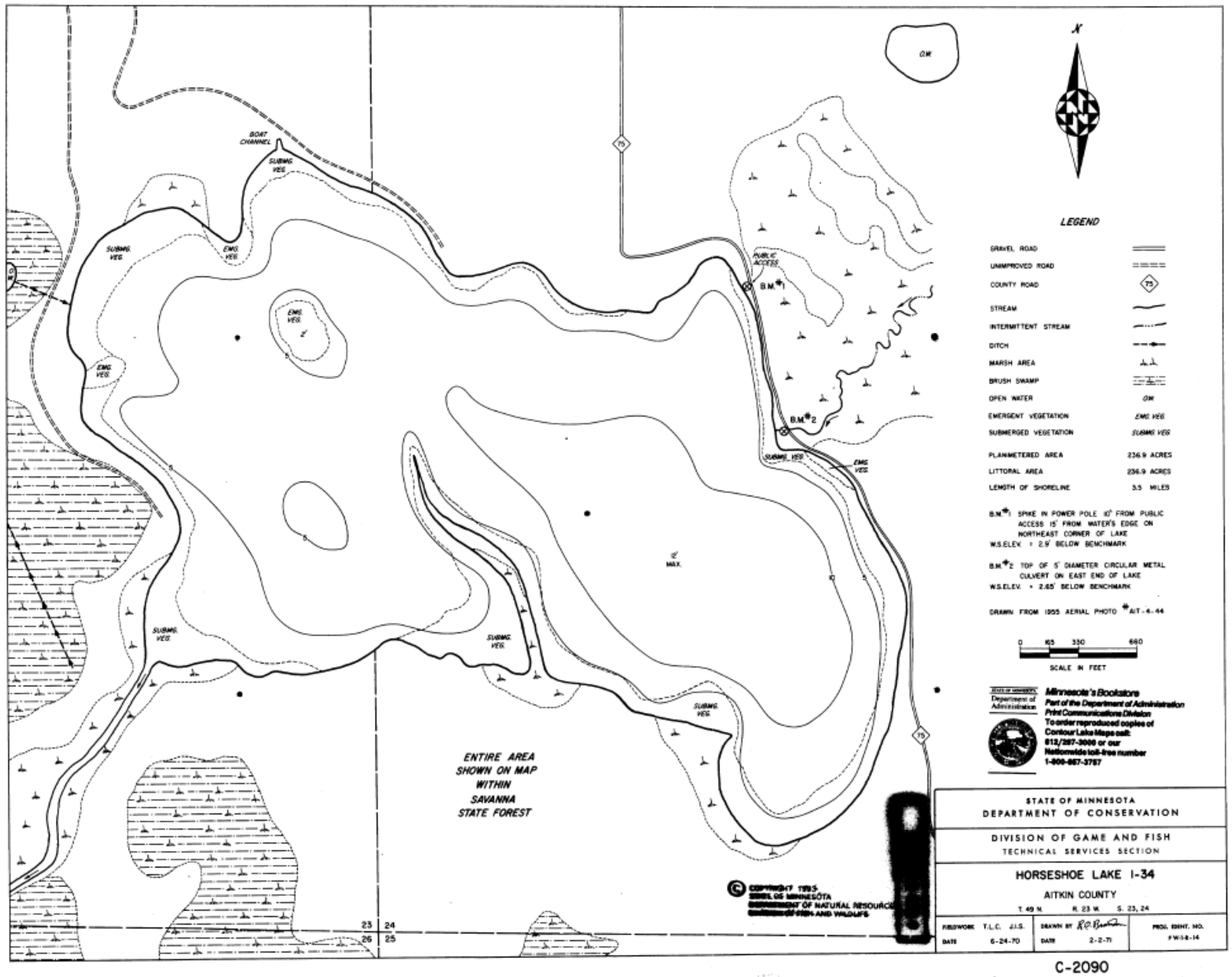

Figure A-5. Horseshoe Lake Bathymetric Map (DNR, June 1970)

Aquatic Plant and Fish Community

DNR completed a Minnesota Biological Survey of Horseshoe Lake on July 15, 1996. At the time of the survey, the aquatic plant community was diverse with submersed, floating, emergent and shoreline species. The invasive species Purple loosestrife was observed.

The most recent DNR fish survey was completed on August 24, 2015. This survey noted:

- The lake is shallow with a maximum depth of 12 feet and relatively common summer algal blooms.
- The water is tannin stained dark brown in color.
- Most of the shoreline is ringed with wild rice.
- Shallow water areas are comprised primarily of sand, silt, and muck with occasional areas of gravel and rubble.
- There are occasional partial winterkills, the most recent observed was a partial kill in the winter of 2007-2008.

- Access to the lake is either through the channel from Lake Minnewawa or through a private access on the northeast corner of the lake.
- Walleye are naturally occurring, but declining.
- Bluegill, black crappie, and yellow perch catches have decreased from the last survey.
- The Score-the-Shore rating was 69.8 out of a possible score of 100, which is equivalent to a “Poor” rating but only 0.2 points away from the “Fair” rating at 70.
- Horseshoe Lake maintains a health aquatic plant community with much of the shoreline rimmed with emergent and floating plants.

Growing Season Annual Average Water Quality Figures

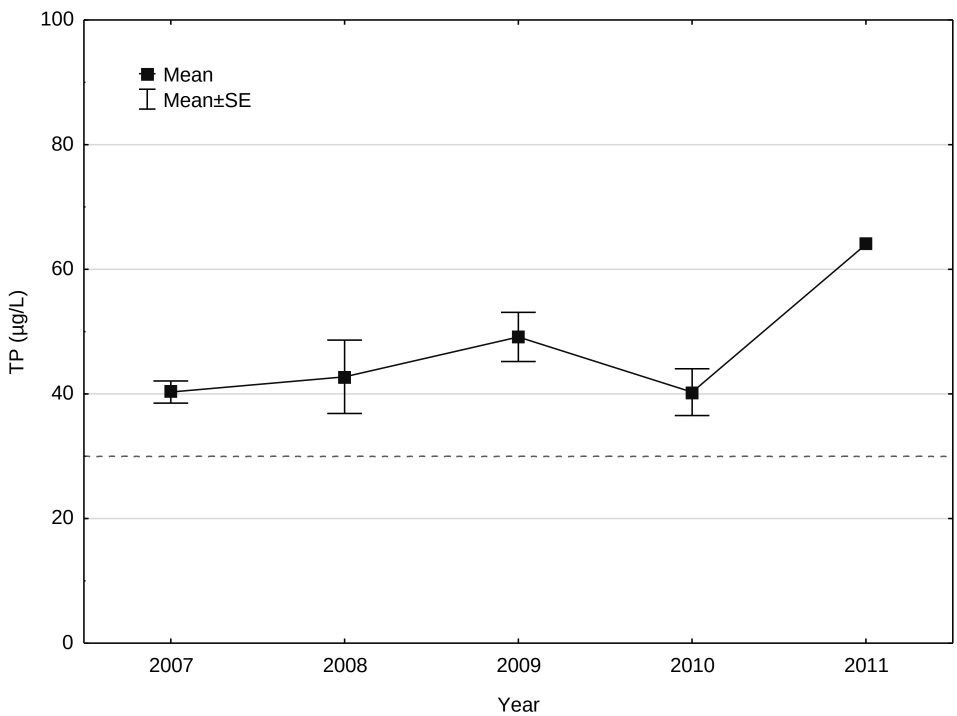

Figure A-6. Growing Season Means ± SE of Total Phosphorus for Horseshoe Lake by Year
The dashed line represents the water quality standard for TP (30 µg/L)

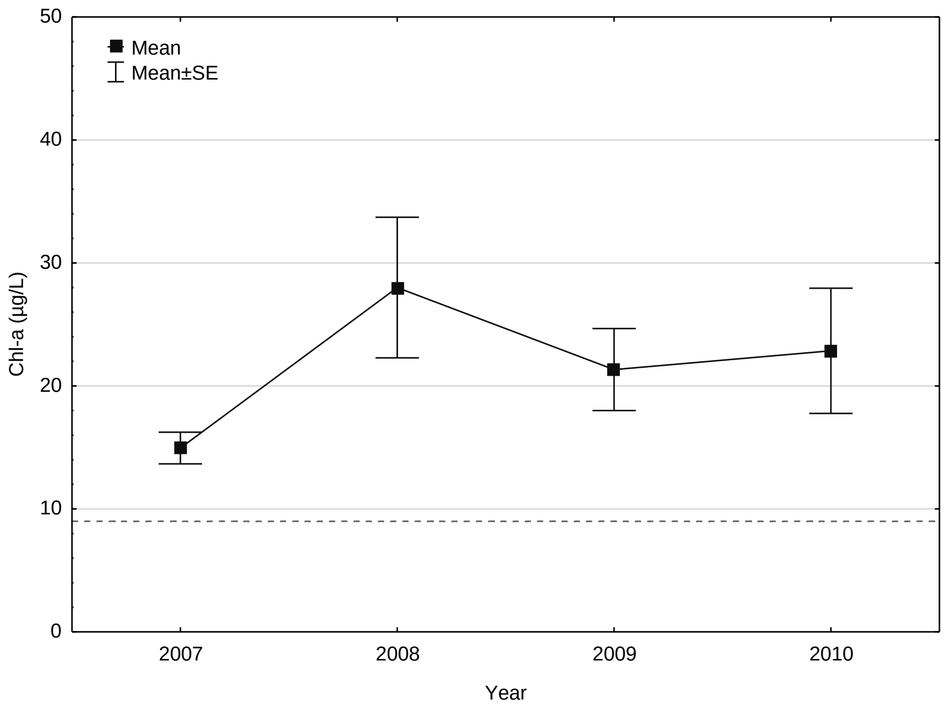

Figure A-7. Growing Season Means ± SE of Chlorophyll-a for Horseshoe Lake by Year
The dashed line represents the water quality standard for Chl-a (9 µg/L)

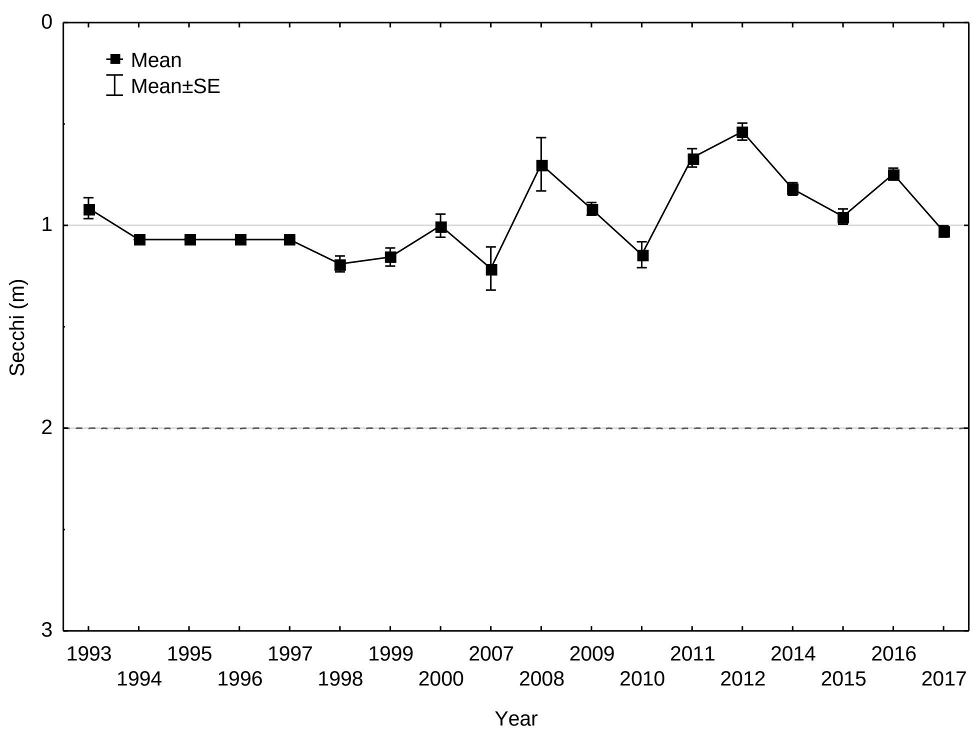

Figure A-8. Growing Season Means ± SE of Secchi transparency for Horseshoe Lake by Year
The dashed line represents the water quality standard for transparency (2.0 m)

B.3 North Island Lake

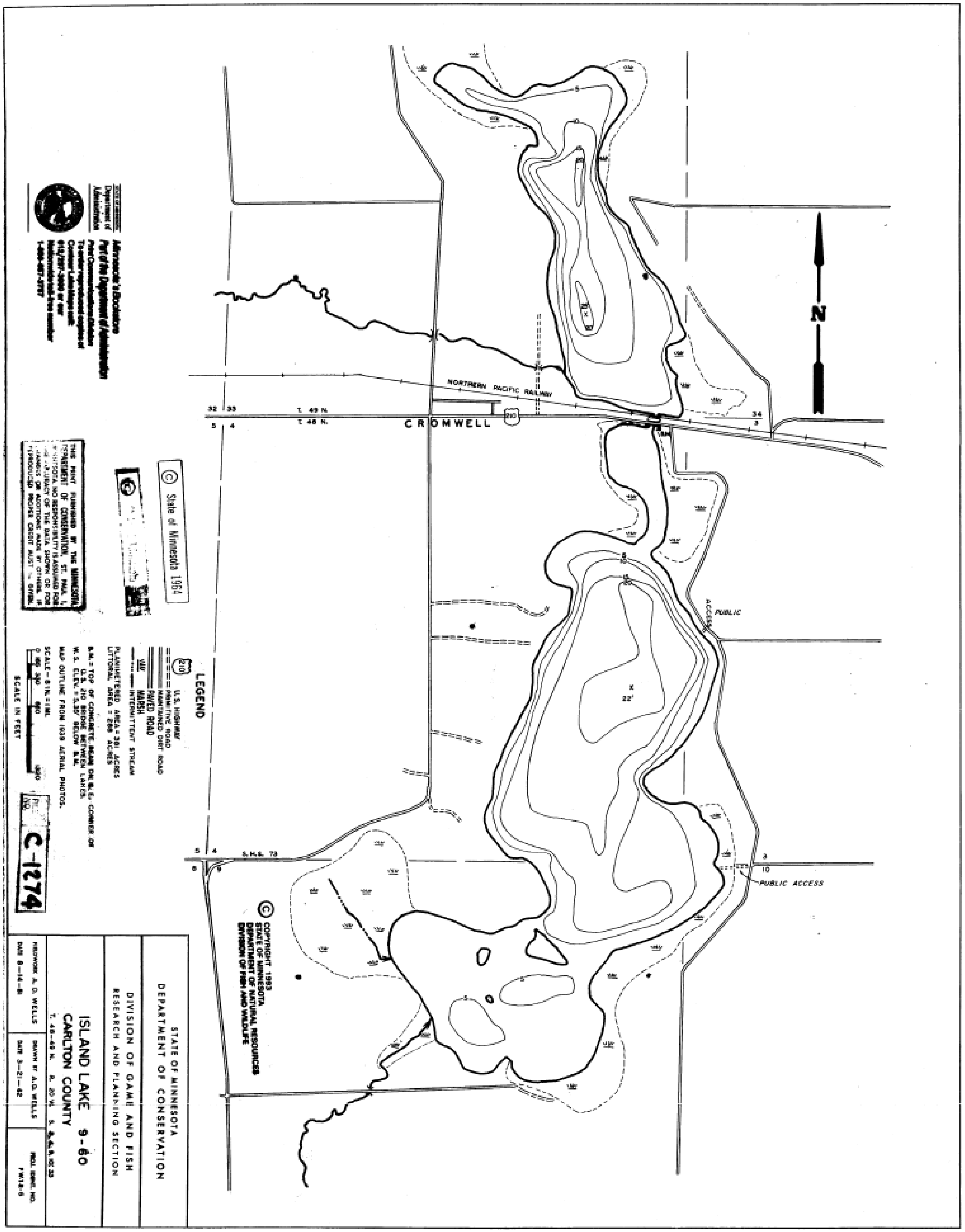

Figure A-9. Island Lake Bathymetric Map (DNR, August 1961)

Aquatic Plant and Fish Community

DNR completed a Minnesota Biological Survey of South Island Lake on August 20, 1997. At the time of the survey, the aquatic plant community was diverse with submersed, floating, emergent and shoreline species. No invasive species were observed.

The most recent DNR fish survey was completed on July 26, 2010. This survey noted:

- Thirty three aquatic plant species or species groups were identified along transects.
- Yellow water lily, coontail, and flat-stem pondweed were the most frequently found plant species (90% of transects) followed by northern milfoil (80% of transects).
- Results of laboratory water analysis indicated Upper Island is an alkaline, moderately hard water lake with low fertility.
- An index of biotic integrity (IBI) assessment was completed in 2010 and the fish community was above the impairment threshold for similar lakes.

Growing Season Annual Average Water Quality Figures

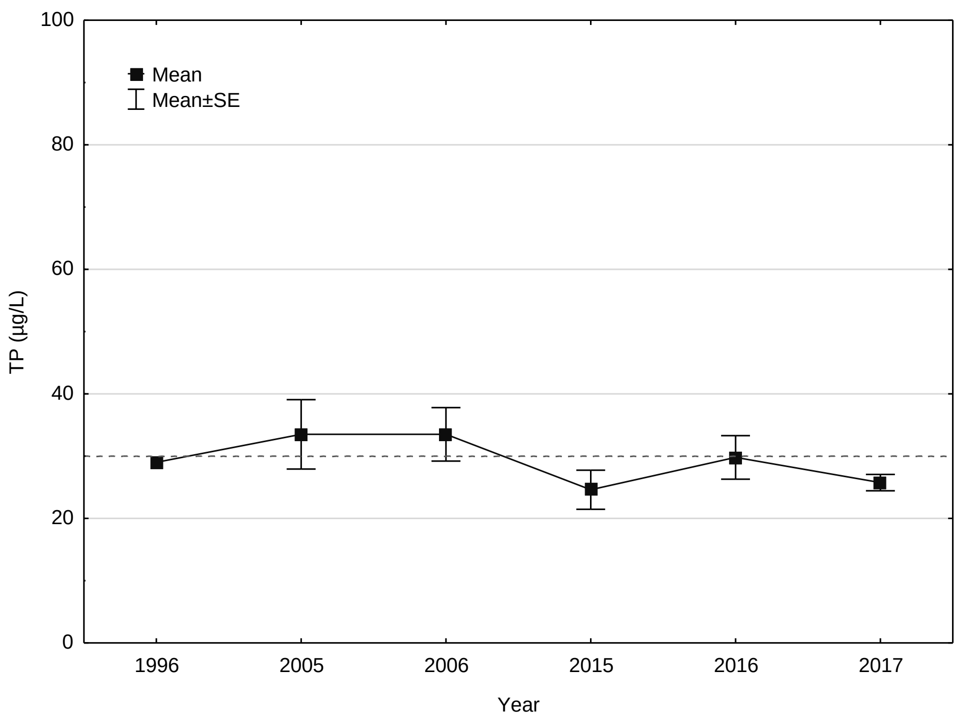

Figure A-10. Growing Season Means ± SE of Total Phosphorus for Upper Lake: North Island Lake by Year
The dashed line represents the water quality standard for TP (30 µg/L)

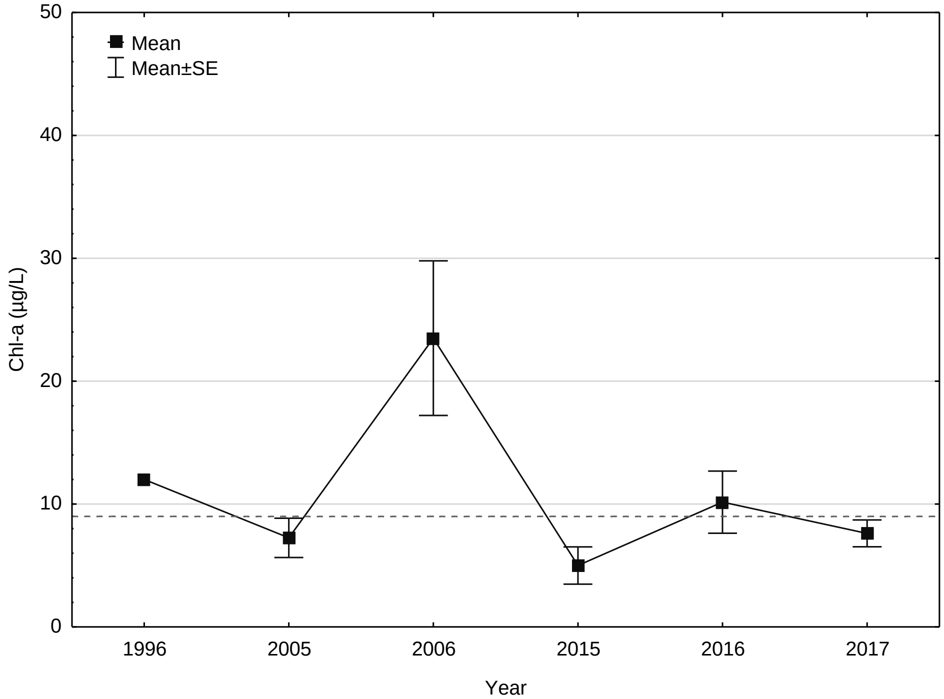

Figure A-11. Growing Season Means ± SE of Chlorophyll-a for Upper Lake: North Island Lake by Year
The dashed line represents the water quality standard for Chl-a (9 µg/L)

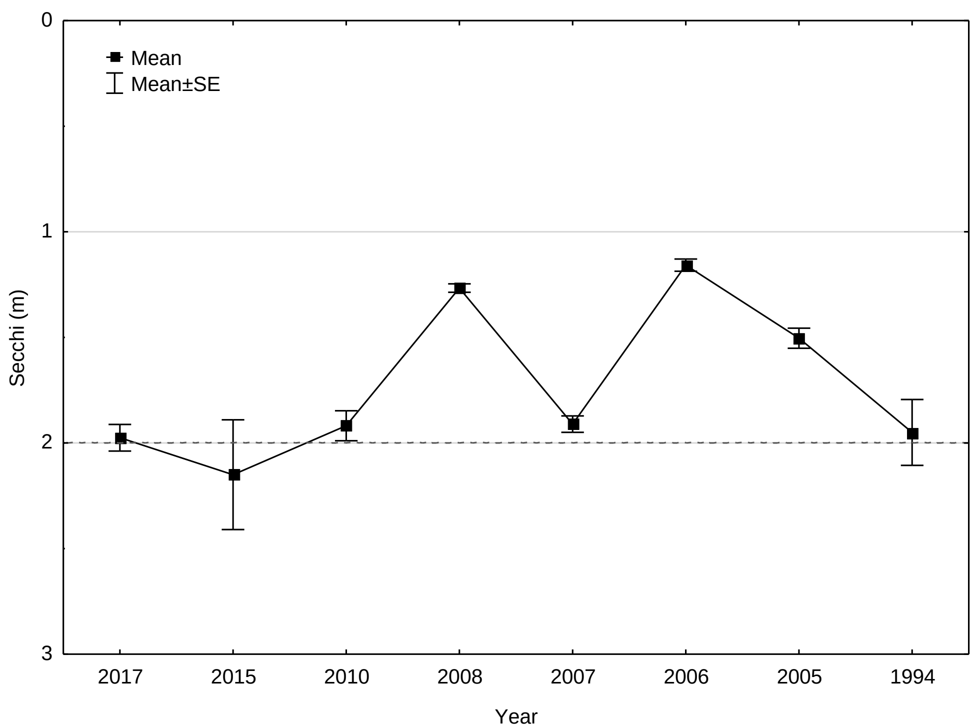

Figure A-12. Growing Season Means ± SE of Secchi transparency for Upper Lake: North Island Lake by Year
The dashed line represents the water quality standard for transparency (2.0 m)

B.4 South Island Lake

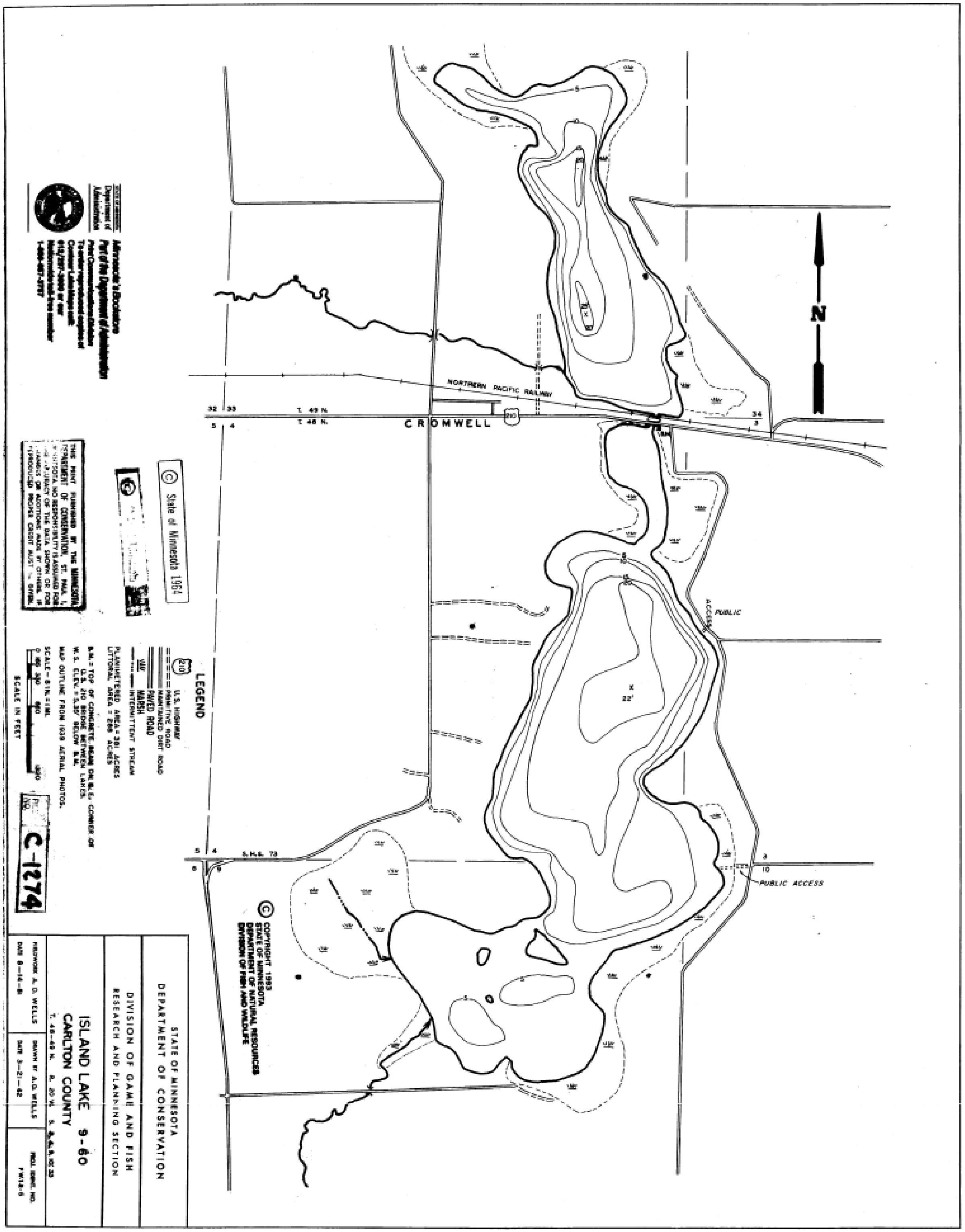

Figure A-13. Island Lake Bathymetric Map (DNR, August 1961)

Aquatic Plant and Fish Community

DNR completed a Minnesota Biological Survey of South Island Lake on July 17, 1997. At the time of the survey, the aquatic plant community was diverse with submersed, floating, emergent and shoreline species. No invasive species were observed.

The most recent DNR fish survey was completed on July 22, 2013. This survey noted:

- Lower Island has been actively managed with stocking of fry, fingerling, and yearling walleye from 1948 through 2012.
- Yellow perch and black crappie are below average abundance.

South Island Lake Fish Community and Stressors

A SID study was completed in coordination between DNR and MPCA to identify potential stressors to the fish community in South Island Lake. The FIBI score in 2010 was 26, or 12 points below the impairment threshold for similar lakes. The species sampled that negatively affected the FIBI score were Bigmouth buffalo, Black bullhead, White sucker, and Yellow bullhead. The species sampled that positively affected the FIBI score were Black crappie, Bowfin, Bluegill, Central mudminnow, Hybrid sunfish, Largemouth bass, Northern pike, Pumpkinseed, Rock bass, Walleye, and Yellow perch.

Inconclusive stressors were:

- Physical Habitat Alteration: moderate dock density of 10 docks per mile of shoreline, moderate lakewide Score the Shore habitat score of 93, and documented cases of aquatic plant removal.
- Altered Interspecific Competition: only documented non-native species is Chinese Mystery Snail.
- Temperature Regime Changes: estimated 1.6 degree Fahrenheit increase in mean annual air temperature over the last century.
- Decreased DO: adequate DO to 14 feet (thermocline) during summer months.

Candidate stressor:

- Eutrophication (excess nutrients)

Recommendations:

- Follow TMDL recommendations
- Inspect individual sewage treatment systems for compliance
- Limit fertilizer application on lawns and in agricultural areas
- Promote and maintain riparian buffer areas around shoreline
- Limit removal of emergent and floating-leaf aquatic vegetation

Growing Season Annual Average Water Quality Figures

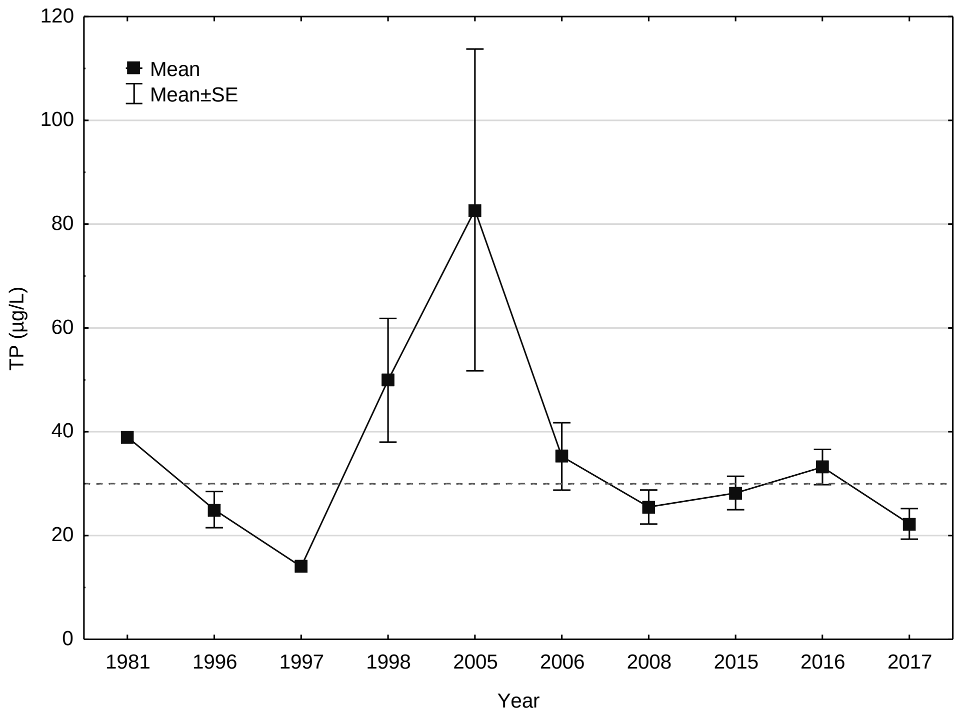

Figure A-14. Growing Season Means ± SE of Total Phosphorus for Lower Lake: South Island Lake by Year
The dashed line represents the water quality standard for TP (30 µg/L)

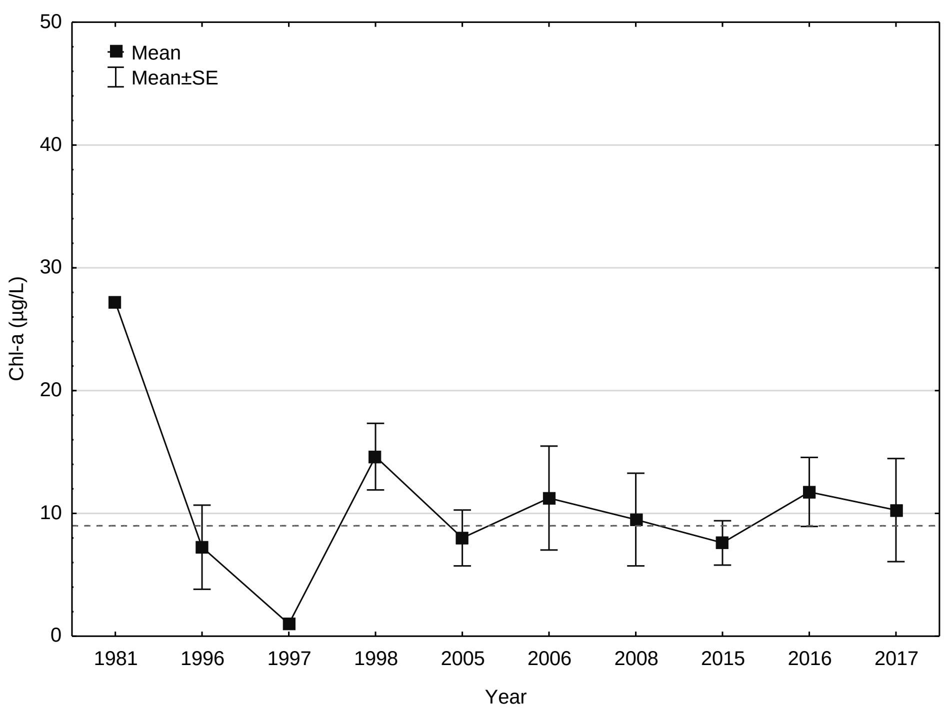

Figure A-15. Growing Season Means ± SE of Chlorophyll-a for Lower Lake: South Island Lake by Year
The dashed line represents the water quality standard for Chl-a (9 µg/L)

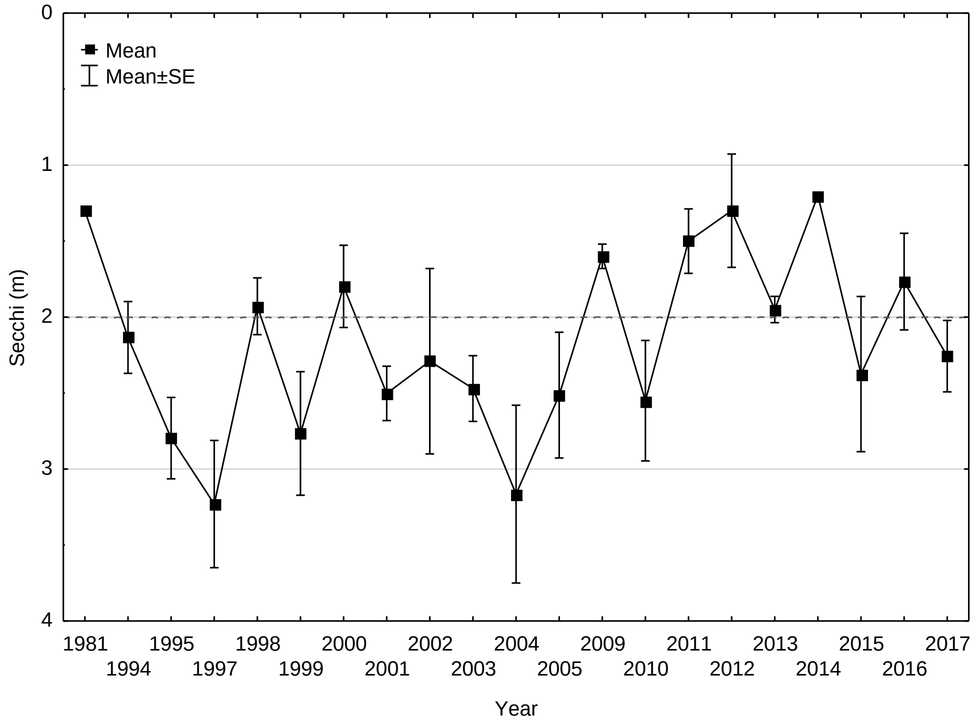

Figure A-16. Growing Season Means ± SE of Secchi transparency for Lower Lake: South Island Lake by Year
The dashed line represents the water quality standard for transparency (2.0 m)

B.5 King Lake

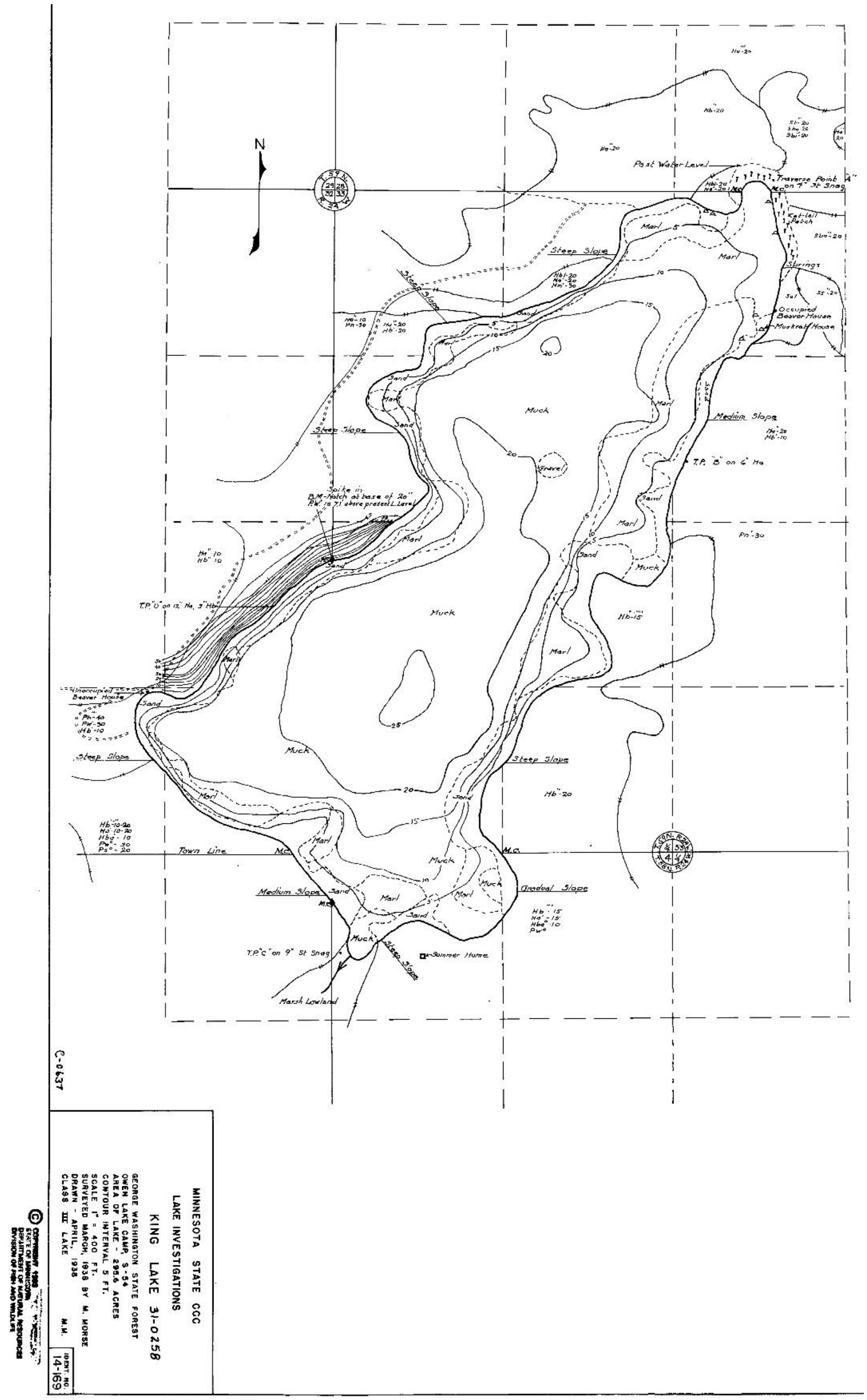

Figure A-17. King Lake Bathymetric Map (DNR, March 1938)

Aquatic Plant and Fish Community

DNR completed a Minnesota Biological Survey of King Lake on July 3, 2002. At the time of the survey, the aquatic plant community was diverse with submersed, floating, emergent and shoreline species.

The most recent DNR fish survey was completed on August 17, 2009. This survey noted:

- Small outlet to Balsam Lake on the south shore
- Water levels are controlled by a small control structure on the outlet and is a migration barrier for fish moving upstream
- DO was less than 2.0 ppm below 11.0 feet
- Lakeshore is almost entirely privately owned, with a carry down access with a steep trail to the lake on the west shore
- Walleye are maintained in the lake entirely through stocking. Walleye were stocked under permit by a private party in 1992, 1998, and 2000.
- DNR noted that it is important to leave a 30 to 50 ft buffer strip of native vegetation along the shoreline to prevent erosion and provide habitat for fish and wildlife. Nonfunctioning septic systems can also lead to water quality problems.

Growing Season Annual Average Water Quality Figures

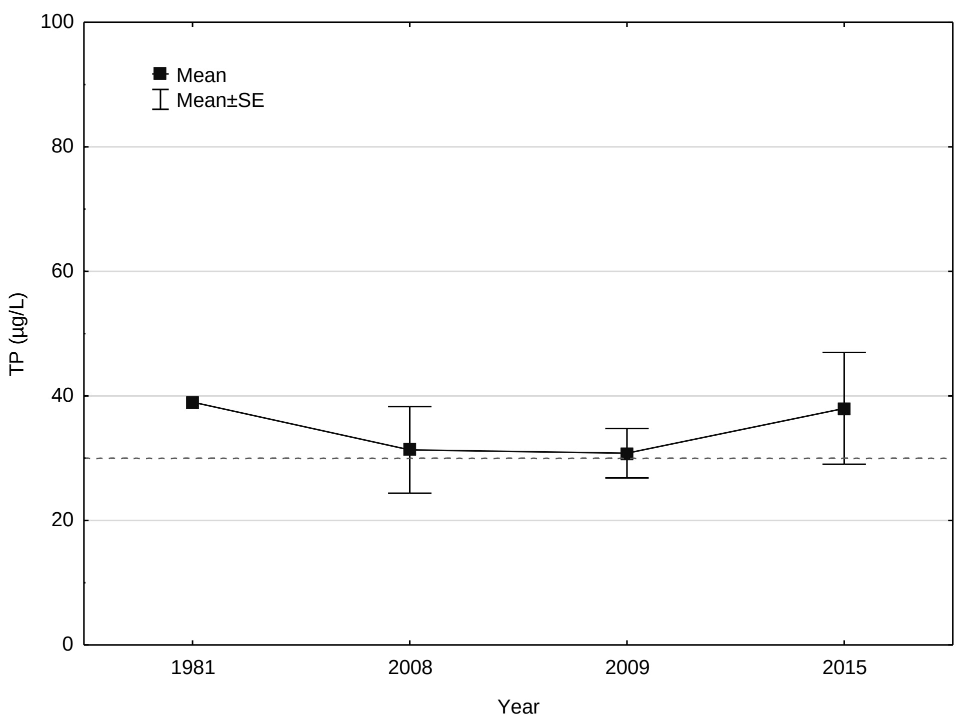

Figure A-18. Growing Season Means ± SE of Total Phosphorus for King Lake by Year
The dashed line represents the water quality standard for TP (30 µg/L)

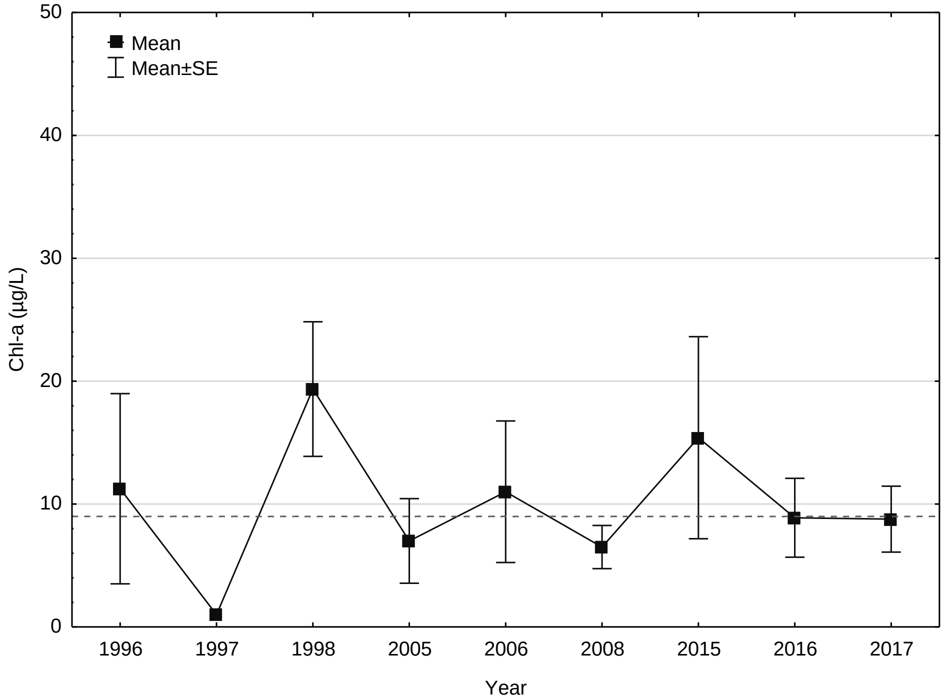

Figure A-19. Growing Season Means ± SE of Chlorophyll-a for King Lake by Year
The dashed line represents the water quality standard for Chl-a (9 µg/L)

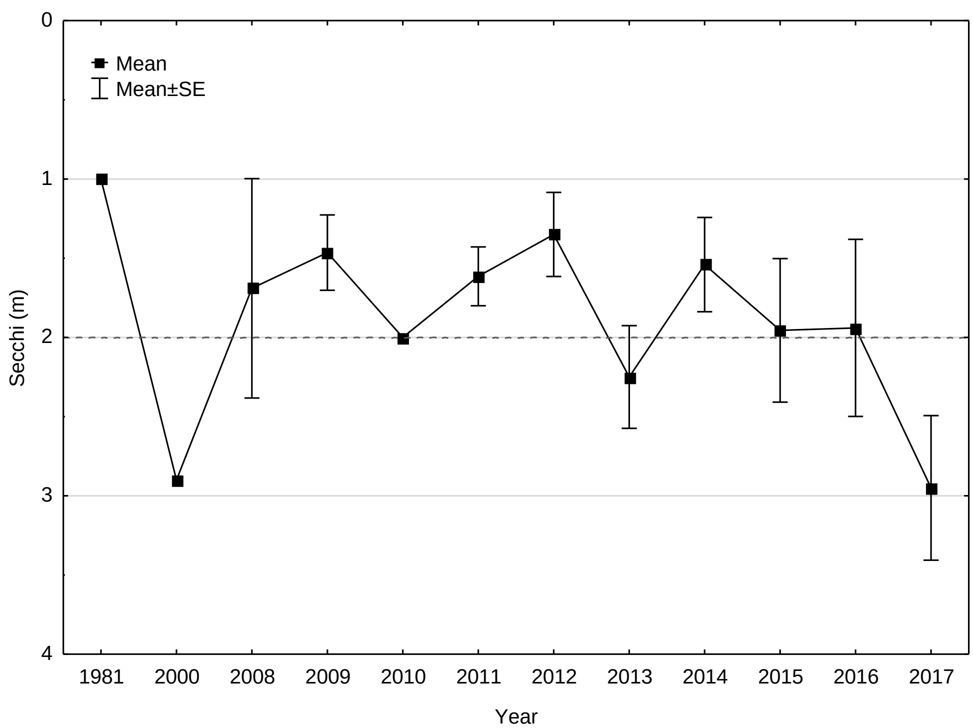

Figure A-20. Growing Season Means ± SE of Secchi transparency for King Lake by Year
The dashed line represents the water quality standard for transparency (2.0 m)

B.6 Little Cowhorn Lake

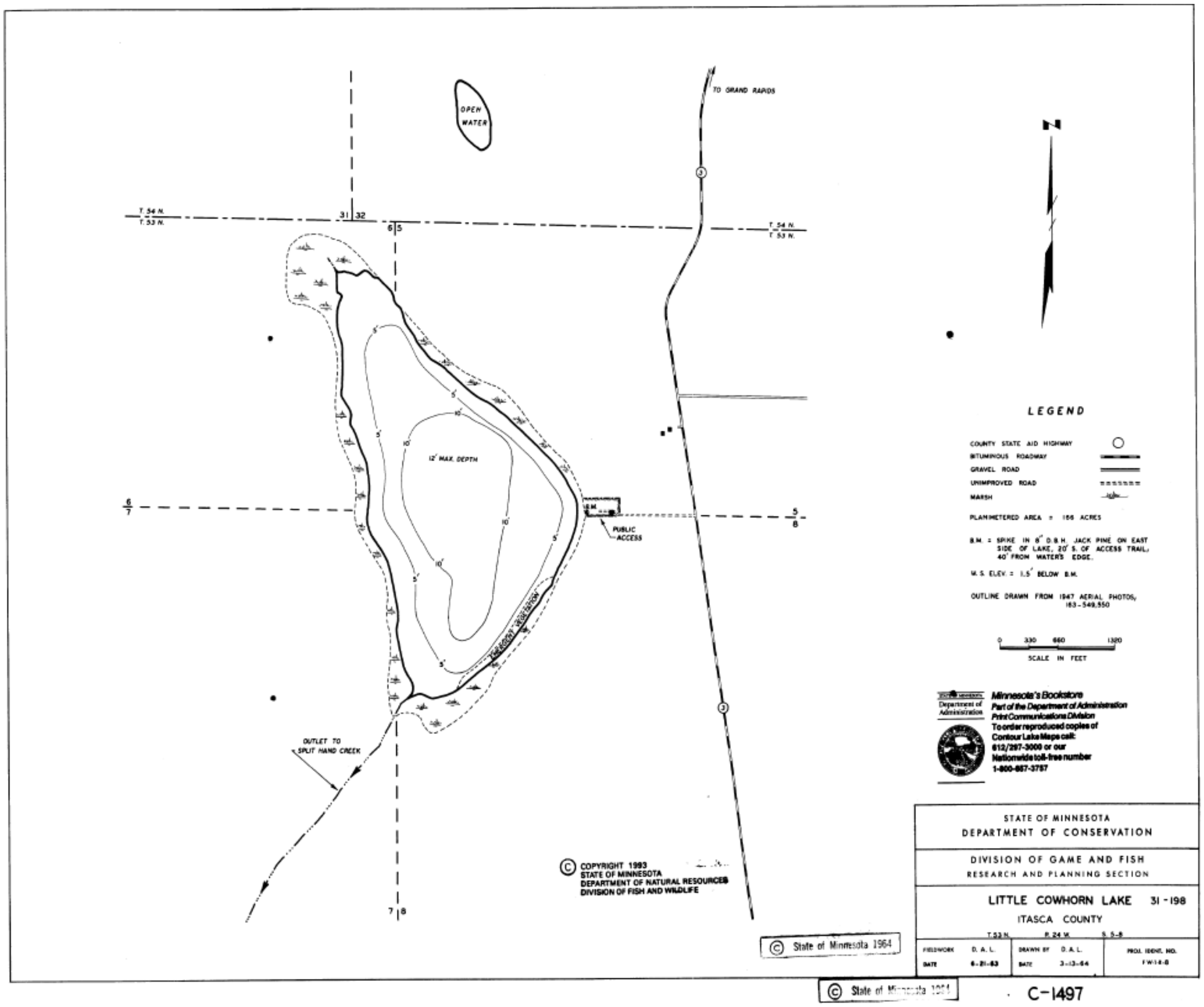

Figure A-21. Little Cowhorn Lake Bathymetric Map (DNR, June 1963)

Aquatic Plant and Fish Community

DNR completed a Minnesota Biological Survey of Little Cowhorn Lake on June 26, 2000. At the time of the survey, the aquatic plant community was diverse with submersed, floating, emergent and shoreline species. No invasive species were observed.

The most recent DNR fish survey was completed on July 8, 2002. This survey noted:

- The lake has a long history of low winter oxygen levels with many severe winterkills documented.
- There is heavy submergent aquatic vegetation.
- The gill net and trap net catch rates for all fish species were ecologically similar to other lakes that have a history of winterkill, but Little Cowhorn Lake could very well be the most susceptible of this group in this management area.
- There are high numbers of black bullheads, minnow, and young of year yellow perch.

Growing Season Annual Average Water Quality Figures

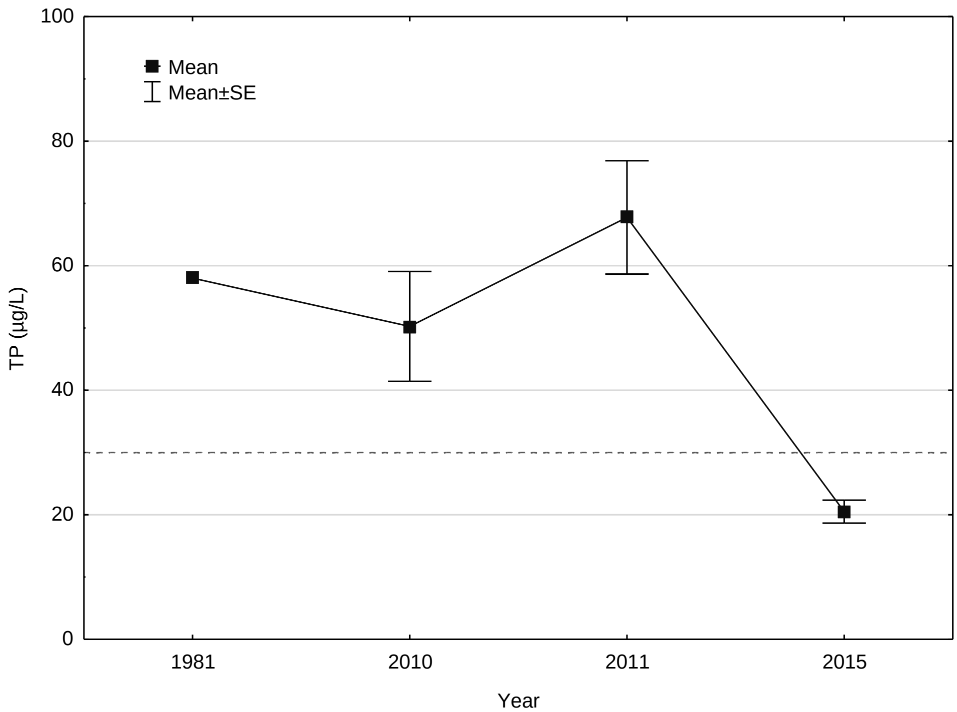

Figure A-22. Growing Season Means ± SE of Total Phosphorus for Little Cowhorn Lake by Year
The dashed line represents the water quality standard for TP (30 µg/L)

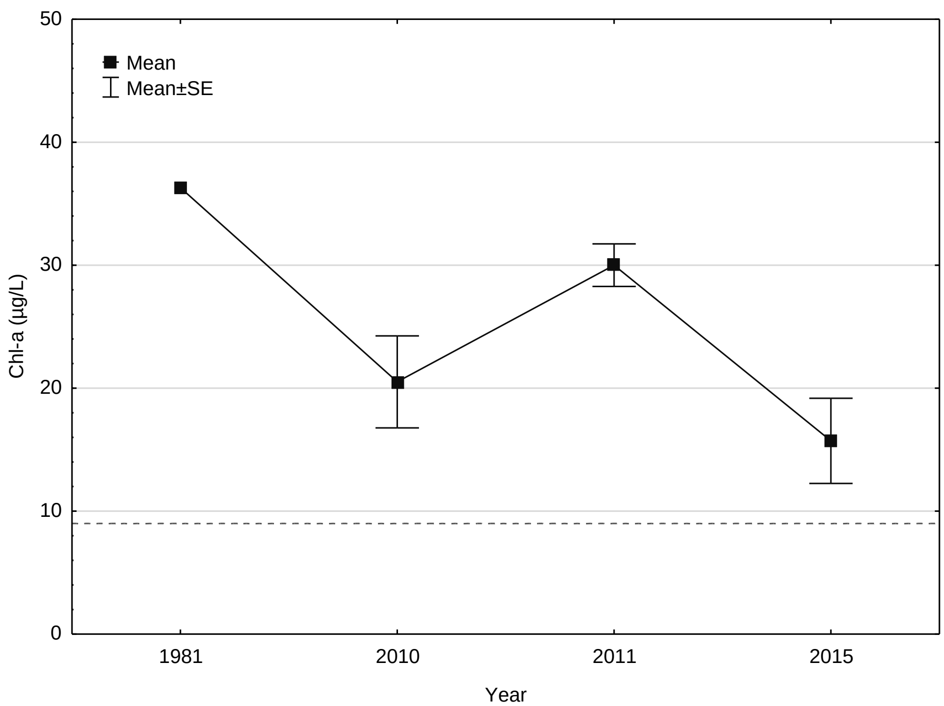

Figure A-23. Growing Season Means ± SE of Chlorophyll-a for Little Cowhorn Lake by Year
The dashed line represents the water quality standard for Chl-a (9 µg/L)

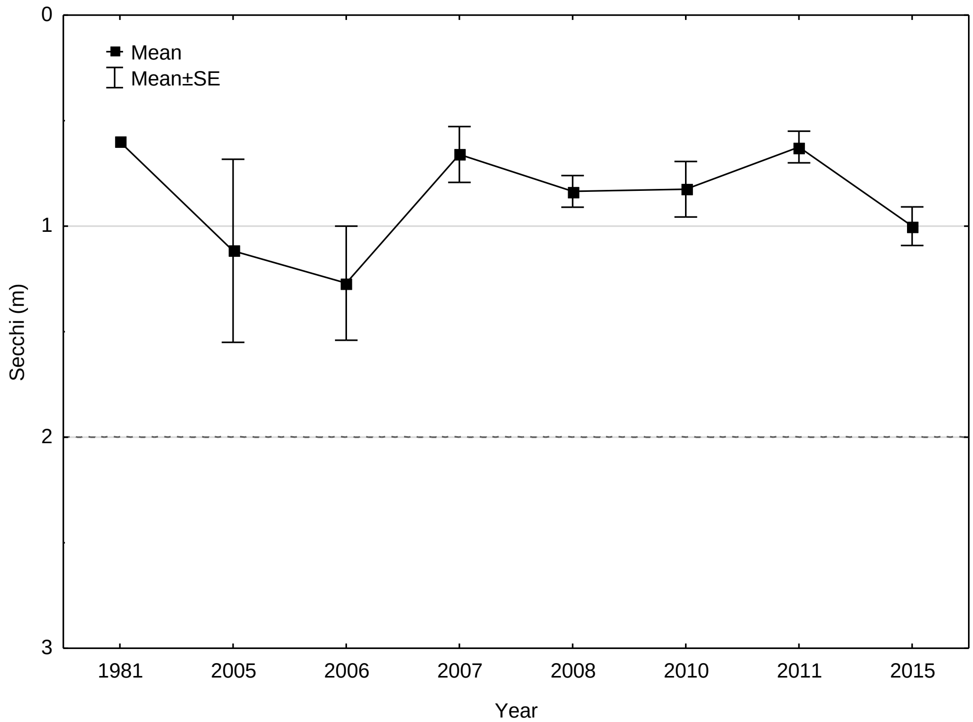

Figure A-24. Growing Season Means ± SE of Secchi transparency for Little Cowhorn Lake by Year
The dashed line represents the water quality standard for transparency (2.0 m)

B.7 Split Hand Lake

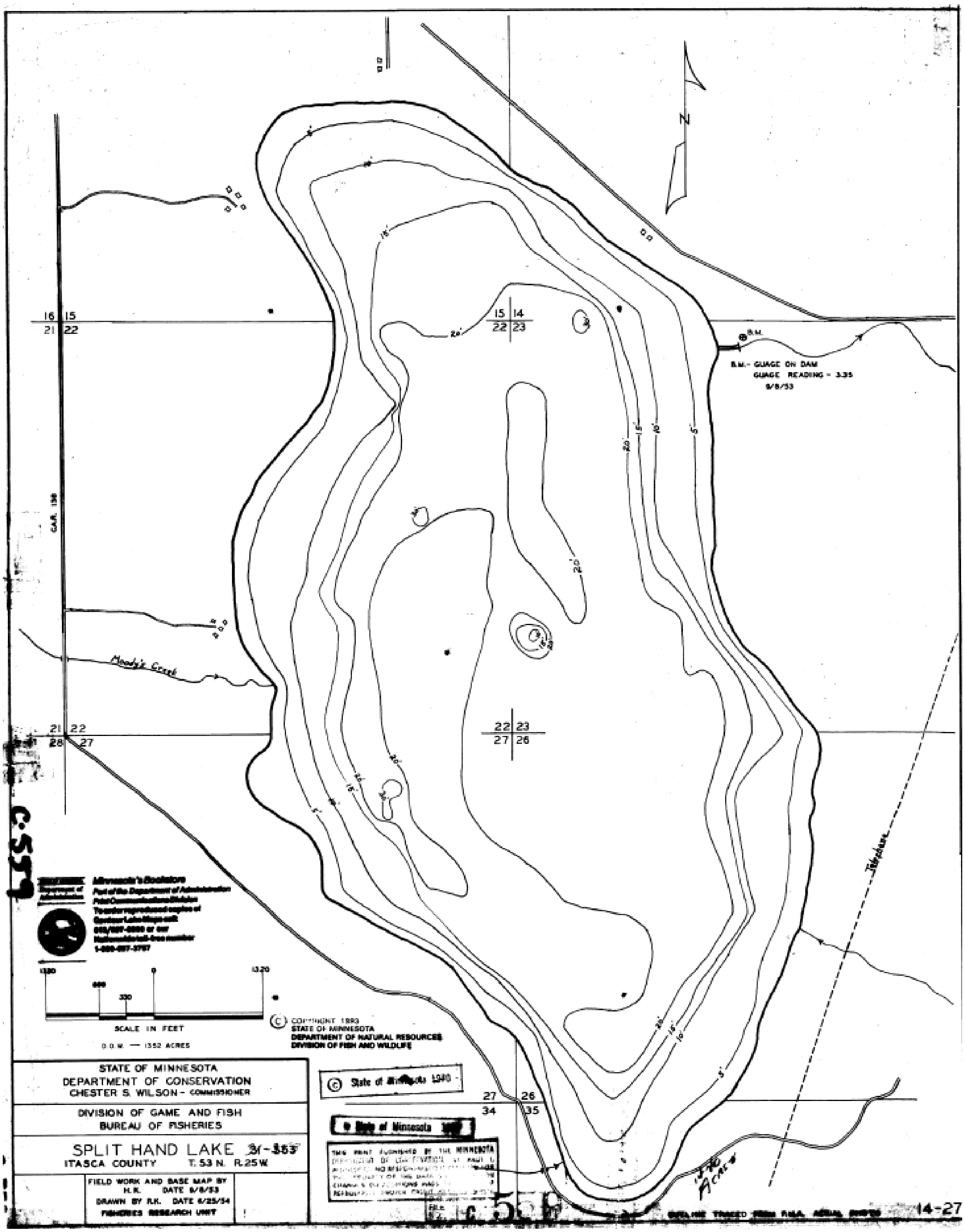

Figure A-25. Split Hand Lake Bathymetric Map (DNR, September 1953)

Aquatic Plant and Fish Community

DNR completed a Minnesota Biological Survey of Split Hand Lake on June 19, 2000. At the time of the survey, the aquatic plant community was diverse with submersed, floating, emergent and shoreline species. No invasive species were observed.

The most recent DNR fish survey was completed on July 28, 2008. This survey noted:

- The lake is highly fertile and has poor water clarity much of the year.
- Much of the shoreline is in a natural state consisting primarily of forest and secondarily of wetland.
- There is a connection to Little Split Hand Lake and the Mississippi River via the outlet, Split Hand Creek.
- There is a diverse, aquatic plant community. Submerged plants were widespread, but limited to depths of five feet or less. Flatstem, variable, claspingleaf, and narrow leaf pondweeds were the most widespread submergent plants and occurred in over 50% of transects.
- The fish community was relatively diverse.
- Yellow perch was the most common species captured, and historically have been abundant in Split Hand Lake.
- Tullibee were captured in relatively low numbers. Reductions in the tullibee population could result in reduced pike and walleye production and limit growth and size structure.

Growing Season Annual Average Water Quality Figures

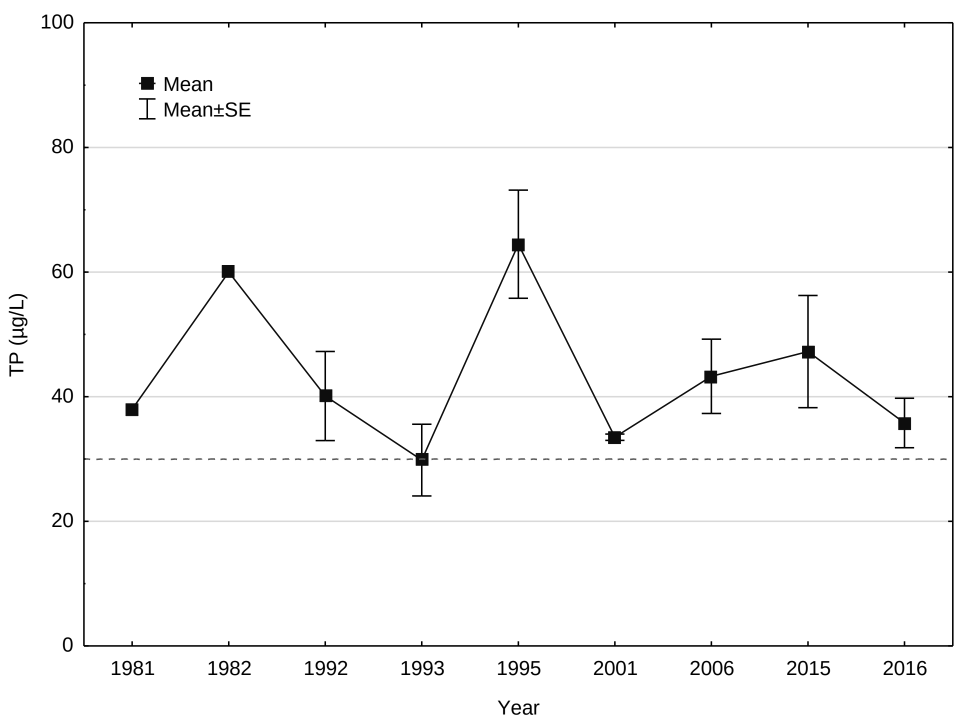

Figure A-26. Growing Season Means ± SE of Total Phosphorus for Split Hand Lake by Year
The dashed line represents the water quality standard for TP (30 µg/L)

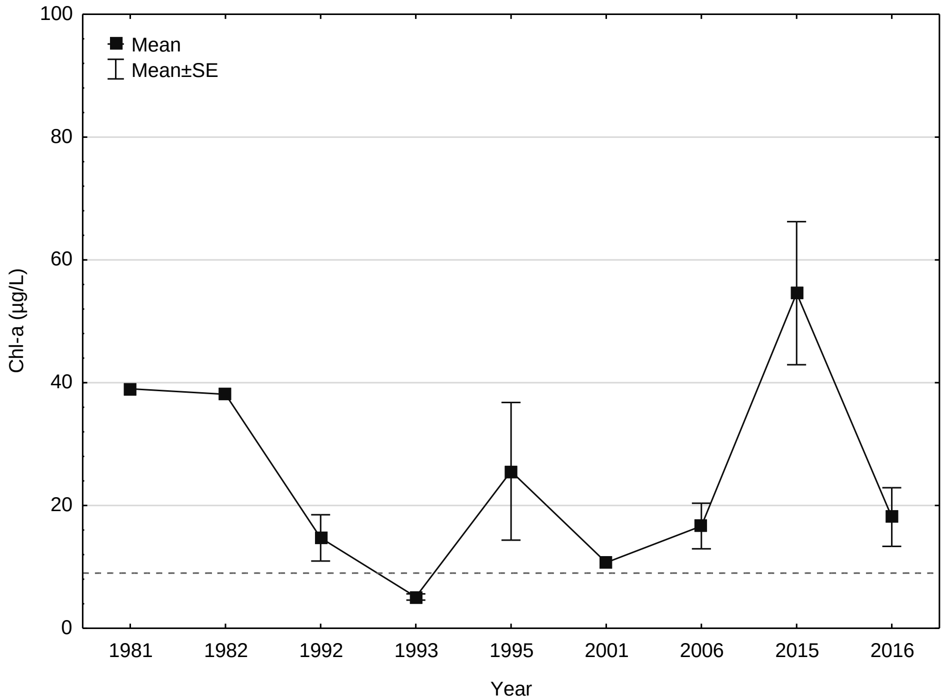

Figure A-27. Growing Season Means ± SE of Chlorophyll-a for Split Hand Lake by Year
The dashed line represents the water quality standard for Chl-a (9 µg/L)

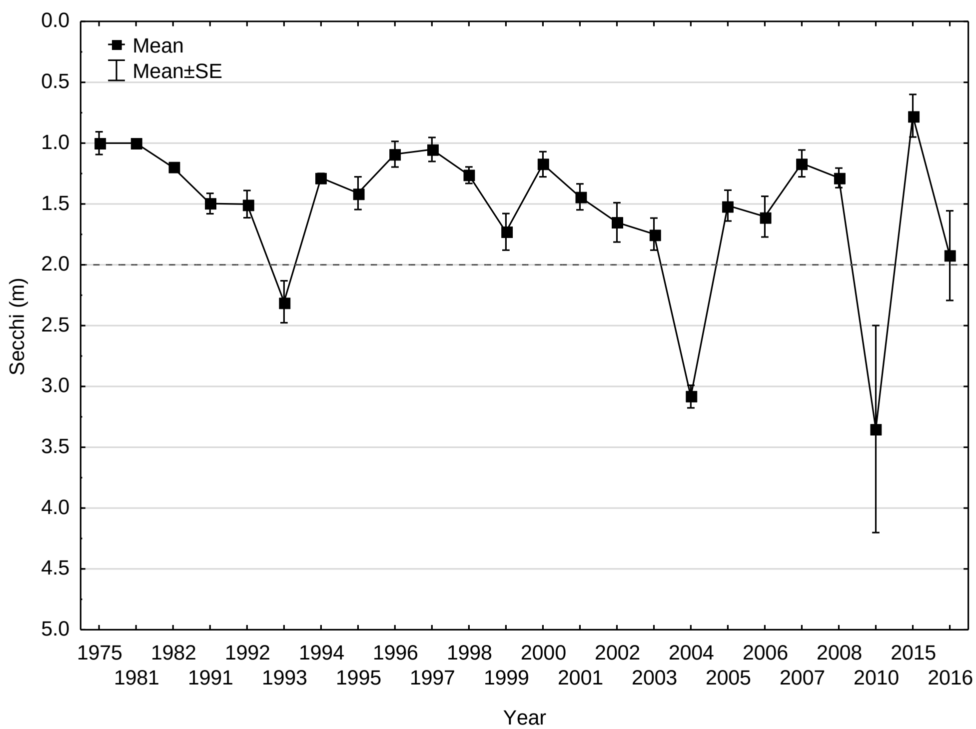

Figure A-28. Growing Season Means ± SE of Secchi transparency for Split Hand Lake by Year

The dashed line represents the water quality standard for transparency (2.0 m)

APPENDIX C. LOAD DURATION CURVE SUPPORTING INFORMATION

C.1 Flow and Water Quality Data Sources

Table A-29. *E. coli* load duration curve flow and water quality data sources

E. coli load duration curve flow and water quality data sources:				
Impaired Stream/ Reach AUID 07010103-XXX	Modeled Flow 2006-2015 HSPF Basin ID	Water Quality		Comments
		Data Source WQ Station ID	Date Range	
Split Hand Creek (-574)	261	S008-477	2015	
Hasty Brook (-603)	403	S005-777	2009-2010	Flow data area weighted to WQ Station
Willow River (-751)	530	S006-260	2010-2011	Flow data area weighted to WQ Station[1]
	590	S006-257		
Swan River (-753)	287	S000-936	2015	
Tamarack River (-758)	429	S008-441	2015	Flow data area weighted to WQ Station
Prairie River (-760)	170	S008-478	2015	Flow data area weighted to WQ Station

[1]The TMDL is based on flow and water quality data for WQ Station S006-257.

APPENDIX D.

D.1 Description of the Impairments and Stressors

The following section identifies and describes the causes of lake and stream impairments in the MRGRW and the pollutant-based stressors that will be addressed by TMDLs in this study. Table A-30 summarizes the pollutant TMDLs that will be completed for each impaired stream reach, listed by its AUID number.

Table A-30. Impairments addressed by pollutant TMDL for impaired streams

AUID	Stream Name	Impairment	Designated Use Class	*E. coli*	TP	TSS	Non-pollutant based stressor
512	Sandy River	M-IBI, F-IBI	2Bg, 3C				Wetland influenced
518	Minnewawa Creek	M-IBI, F-IBI	2Bm, 3C				Habitat, low DO, ditched
519	Minnewawa Creek	F-IBI	2Bg, 3C				low DO (wetland influenced)
574	Split Hand Creek	*E. coli*	2Bg, 3C	●			Direct livestock access At least 3 farms with cattle access to creek with significant bank erosion Not much beaver activity, a little between Split Rock and Little Split Rock (low gradient, wetland fringed)
590	Pickerel Creek	M-IBI, F-IBI	1B, 2Ag, 3B				Tailings basin drainage, high conductivity
603	Hasty Brook	*E. coli*	1B, 2Ag, 3B	●			Natural background (beavers)
717	Unnamed	F-IBI	2Bg, 3C				Natural background (beavers)
719	Unnamed	M-IBI	2Bg, 3C				Natural background (beavers)
722	Unnamed	F-IBI	1B, 2Ag*, 3B				Deferred, connectivity (beavers)
726	Unnamed	M-IBI, F-IBI	2Bg, 3C				Habitat
727	Unnamed	F-IBI	2Bg, 3C				Habitat
728	Unnamed	F-IBI	2Bg, 3C				Habitat, wetland influenced
730	Unnamed	F-IBI	2Bg, 3C				Habitat
731	Unnamed	F-IBI	2Bg, 3C			●	Deferred, sedimentation, habitat
733	Pokegama Creek	M-IBI, F-IBI	2Bg, 3C				Habitat, connectivity, altered hydrology, sedimentation
739	Unnamed	F-IBI	2Bg, 3C				Habitat, culvert issues, ditched
741	White Elk Creek	F-IBI	2Bg, 3C				Connectivity, altered hydrology (beavers, culverts)
749	Moose River	DO	2Bg, 3C				Natural background (DO)
751	Willow River	*E. coli*	2Bg, 3C	●			Unknown source
753	Swan River	*E. coli*	2Bg, 3C	●			Several permitted sources in the watershed
756	Unnamed	M-IBI, F-IBI	2Bg, 3C				Altered hydrology, low DO, habitat

758	Tamarack River	*E. coli*	2Be, 3C	●			Exceptional for aquatic life
760	Prairie River	*E. coli*	2Bg, 3C	●			Livestock
708	Mississippi River	AQL	**2Bg, 3C**			●	Turbidity/TSS

* Proposed designated use change

XXX – Impairment addressed by pollutant TMDL

XXX – TSS Impairment to be addressed in a future TMDL study.

D.1.1 Lake Eutrophication

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

D.1.2 Stream *E. coli*

The stream bacteria impairments in the MRGRW were characterized by high *E. coli* concentrations during June through September. Minnesota's *E. coli* water quality standards were developed to directly protect waters for primary (swimming and other recreation, where immersion and inadvertently ingesting water is likely) and secondary (boating and wading, where the likelihood of ingesting water is much less) body contact during the warm season months, as there is very little swimming in Minnesota during the cold season months. The TMDL study developed *E. coli* LDCs and TMDLs for all stream *E. coli* impairments.

D.1.3 Stream Fish and Macroinvertebrate Bioassessments

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

In 2018, the MPCA conducted a SID study to determine the cause of low fish and macroinvertebrate IBI scores in the MRGRW. The SID study results are summarized in Table A-31. The TMDL study developed LDCs and TMDLs for the pollutant-based stressors (TP, TSS) identified as needing TMDLs through the SID process.

The TMDL computations were completed for the mass pollutant based stressor TP. In the case of many stressors, a mass reduction is not the appropriate means of addressing these issues, thus no TMDL is computed (i.e., habitat stressors). Non-pollutant stressors will be addressed through the WRAPS process. The stream aquatic life impairment for F-IBI in stream reach -708, the Mississippi River, Swan River to Willow River, will be addressed in a separate TMDL study.

Table A-31. Summary of stressors causing biological impairment in MRGRW streams by location (AUID)

			Stressor								
Stream	**AUID Last 3 digits**	**Biological Impairment**	Dissolved Oxygen	Phosphorus	Conductivity	TSS	Connectivity	Altered Hydrology	Channel alteration	Temperature	Habitat
Sandy River	512	Fish and MI	•			•		•	•		•
Minnewawa Creek	518	Fish and MI	•			?		♦			
Minnewawa Creek	519	Fish	•					♦	♦		•
Split Hand Creek	574	None							•		•
Pickerel Creek	590	Fish and MI	•		?					•	x
Trib. to Bray Lake	722	Fish				?					
Trib. to Mississippi	726	Fish and MI						?		?	
Trib. to Mississippi	727	Fish	•					♦	♦		•
Trib. to Swan River	728	Fish	•					♦			•
Trib. to Mississippi	730	Fish					•	•			•
Trib. to Unnamed Cr Creek	731	Fish					•	•			•
Pokegama Creek	733	Fish and MI	•					♦	•		•
Trib. to Hill R Ditch	739	Fish	•				?	♦	♦		•
White Elk Creek	741	Fish	?				?		?		?
Unnamed Ditch	756	Fish and MI	•			x	•	♦	•		•

♦ A “root cause” stressor, which causes other consequences that become the direct stressors
• A direct stressor
x A secondary stressor
? Inconclusive