Final Lake of the Woods Excess Nutrients Total Maximum Daily Load

Addressing excess phosphorus concentrations by quantifying phosphorus sources, identifying treatment alternatives, and developing a future monitoring plan.

MINNESOTA POLLUTION CONTROL AGENCY

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Acronyms

AUID	assessment unit ID
BMP	Best Management Practice
BWSR	Board of Water and Soil Resources
CAFO	concentrated animal feeding operation
Chl-*a*	Chlorophyll-*a*
CWA	Clean Water Act
CWQG	Canadian water quality guidelines
DO	dissolved oxygen
DNR	Minnesota Department of Natural Resources
DP	Dissolved phosphorus
EC	Environment Canada
ECCC	Environment and Climate Change Canada
EPA	United States Environmental Protection Agency
EQuIS	Environmental Quality Information System
FWMC	flow weighted mean concentration
GDD	growing degree days
GW	groundwater
HAB	harmful algal blooms
hm^3	cubic hectometers
HWSD	Harmonized World Soil Database
HSPF	Hydrologic Simulation Program - FORTRAN
IJC	International Joint Commission
IMA	International Multi-Agency Arrangement
IMPLND	Impervious land
km	kilometer
km^2	square kilometers
LA	load allocation
lb	pound
LoW	Lake of the Woods

LWCB	Lake of the Woods Control Board
m	meter
mg L^{-1}	milligrams per liter
mg m^{-2} d^{-1}	milligrams per square meter per day
MGDD	Modified growing degree days
mi^2	square miles
mL	milliliter
MDA	Minnesota Department of Agriculture
MIDS	Minimal Impact Design Standards
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
NPDES	National Pollutant Discharge Elimination System
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
OMECC	Ontario Ministry of the Environment and Climate Change
OP	orthophosphate
ORVW	Outstanding resource value waters
P	Phosphorus
PDS	Partial duration series
PERLND	Pervious land
PF	Precipitation frequency
PMP	Probable maximum precipitation
POS	Plan of Study
RC	reserve capacity
RR	release rate
SCWRS	Saint Croix Watershed Research Station
SDS	state disposal system
SFIA	Sustainable Forest Incentive Act
SOP	standard operating procedure
SSTS	subsurface sewage treatment systems

SWCD	Soil and Water Conservation District
SWPPP	Stormwater Pollution Prevention Plan
t	metric ton
TAC	technical advisory committee
TKN	total Kjeldahl nitrogen
TMDL	Total Maximum Daily Load
TN	total nitrogen
TP	total phosphorus
TSI	Trophic state index
TSS	total suspended solids
$\mu g\ L^{-1}$	microgram per liter
WLA	wasteload allocation
WRAPS	Watershed Restoration and Protection Strategies
WWTP	Wastewater treatment plant

Executive Summary

Section 303(d) of the Clean Water Act (CWA) requires the completion of a total maximum daily load (TMDL) study for water bodies found to not meet a water quality standard and listed as impaired. This Lake of the Woods (LoW) Nutrient TMDL Study addresses the aquatic recreation impairment of Minnesota's portion of the LoW caused by excess nutrients. Minnesota's portion of the LoW does not meet water quality standards because of excessive total phosphorus (TP) and Chlorophyll-*a* (Chl-*a)* concentrations (related to nuisance algal blooms) and violation of the Secchi disk (transparency) standard. Phosphorus (P) is the focus of this TMDL study because it drives a wide array of lake biological responses that affect beneficial uses. While the LoW has a long history of nutrient and organic enrichment, the past several decades have been marked by successes in reducing P loading (particularly dissolved P, which is more readily available for algal growth) to the Rainy River from wastewater discharges. Ongoing P-reduction efforts are a management priority in both Minnesota and Canada. This TMDL study quantifies P reductions that are necessary to satisfy applicable lake TP and response variable standards, and provides measurable benchmarks to gauge future progress in achieving reductions required to reduce nuisance algal blooms and achieve designated beneficial uses.

The LoW Basin covers approximately 70,000 square kilometers (km^2) (27,000 square miles [mi^2]) and comprises portions of Minnesota (United States [U.S.]) and Ontario and Manitoba, Canada. Minnesota water quality standards do not apply to Canadian waters; as such, a reduced portion of the basin (the TMDL Study Area) was defined to include only the area necessary to characterize the entirety of the U.S. portion of the LoW. The TMDL Study Area, therefore, includes all areas upstream of the northern (downstream) boundary of Little Traverse Bay at Big Narrows, Ontario, near Minnesota's Northwest Angle.

The Rainy River is the largest source of water and P to the LoW. This study establishes two boundary conditions on the Rainy River: (1) the upper boundary condition at the outlet of Rainy Lake at Fort Frances, Ontario/International Falls, Minnesota, and (2) the lower boundary condition at the mouth of the Rainy River at Wheelers Point, Minnesota. Boundary conditions were necessary for future assessments of progress to numeric goals because study period (2005 through 2014) TP concentrations at both the upper and lower boundary conditions are lower than applicable river eutrophication standards. It is expected that maintaining or improving current river TP concentrations, will put the LoW on a trajectory to meet the TMDL goal.

The TMDL Restoration Area was defined as the portion of the TMDL Study Area both within the U.S. and not in the Rainy Lake drainage area. Because study period TP concentrations of outflow from Rainy Lake to the Rainy River are well below the river eutrophication standard for the Rainy River, and because the Rainy Lake Watershed is relatively undeveloped, no reductions are proposed for the Rainy Lake Watershed in this TMDL study. As such, the TMDL Restoration Area is the only portion of the TMDL Study Area where load reductions are proposed, with the exception of acknowledged load reductions from the Fort Frances Resolute Abitibi (Abitibi) paper mill due to plant idling and internal loading reductions from Canadian portions of the LoW that are occurring as a result of natural processes. The TMDL study also proposes set-aside loads, known as Reserve Capacity (RC), to account for potential future growth and the resulting loads from Canadian sources.

The P income-outgo budgets and a lake response model were developed to define multi-year mean conditions for the study period and target goals for Minnesota sources expressed as allocations. Allocations are defined as load allocations (LAs) for nonpoint sources (diffuse runoff, lake internal sources, and atmospheric deposition) and wasteload allocations (WLAs) for regulated (point) sources, as defined by Minnesota and the CWA. The LA reductions were developed based on the assumption that all tributaries would meet river eutrophication standards. The P-loading reductions associated with shoreline erosion, internal loading, and septic systems are also defined in this study.

Point sources in the TMDL Restoration Area include National Pollutant Discharge Elimination System/State Disposal Systems (NPDES/SDS) regulated wastewater treatment facilities (domestic and industrial), regulated industrial and construction stormwater sources, and Municipal Separate Storm Sewer Systems (MS4). Lastly, the TMDL includes a required margin of safety (MOS) allocation (5%) to account for various estimating uncertainties incorporated into the TMDL, and an RC allocation for future growth. While this TMDL applies only to the Minnesota portions of the watershed, Canadian partners have used similar Rainy River water quality guidelines and have dedicated resources for improving Rainy River and LoW water quality. The Minnesota Pollution Control Agency's (MPCA) jurisdiction does not include Canadian water or Canadian P sources, therefore, no reductions are required from Canadian sources. However, two reductions are included from Canadian sources based on the available information: a reduction in internal P loading from Canadian portions of the LoW and a reduction from the paper mill in Fort Frances, Ontario, as a result of the plant idling several years ago. Neither of these reductions require action by Canadian authorities, but are accounted for as part of this study because the reductions from internal P loading are occurring naturally over time and the reductions resulting from the idling of Abitibi have occurred since the baseline year of the project (2005).

The LoW has been cooperatively managed by the U.S., Canadian, Tribal, and First Nations governments, through the International Joint Commission (IJC), since the Boundary Waters Treaty was signed in the early 1900s. The International Multi-Agency (IMA) Working Arrangement was signed by numerous federal, state, provincial, tribal, and county authorities to foster trans-jurisdictional coordination and collaboration to enhance and restore water quality in the LoW Watershed. The IMA Working Arrangement's Technical Advisory Committee (TAC) advances key issues, such as the factors influencing algal bloom formation and advancing basin core monitoring and information sharing (e.g., the State of the Basin Reports). The formation of the IJC's International Rainy - LoW Watershed Board, with the mandate to monitor ecosystem health in the LoW provides additional credence to the management and restoration objectives of the binational efforts and actions. The IJC's recent recommendation that the international partners work together toward establishment of shared, multinational P objectives is a testament to this outcome. Minnesota is committed to continuing to work with its international partners to protect water quality in the LoW Basin.

In total, this TMDL study recommends an annual P reduction of 141.0 metric tons (t) to the LoW, which corresponds to a 17.3% load reduction from the TMDL Study Area, though all reductions are coming from sources within the Restoration Area. This includes reductions of 26.6 t from wasteload sources (a 36.7% reduction) and 115.3 t (15.5%) from load sources. A load increase of 0.9 t is associated with RC sources.

A total of 19 individual NPDES point sources are assigned WLAs in this study: 14 domestic wastewater sources and 5 industrial wastewater sources. Eleven of the 14 domestic and 1 of the industrial wastewater permits already include TP effluent limits consistent with TMDL WLAs. The remaining three domestic wastewater permits (numbers 1, 2, and 3 below) will include updated TP load limits upon permit reissuance. The remaining four industrial wastewater permits (numbers 4, 5, and 6 below) will include TP limits upon permit reissuance if they are found to have reasonable potential to cause or contribute to the impairment. Facilities whose permits are not yet consistent with TMDL WLAs can be summarized as follows:

1. A draft permit for one large domestic wastewater (North Koochiching Area Sanitary District [NKASD] Wastewaster Treatment Plant [WWTP]) is currently posted for public comment and includes a TP load limit equal to the proposed WLA;
2. One small domestic facility permit (Springsteel Island Sanitary District) that does not currently include an annual TP load limit;
3. One small domestic facility permit (ISD 2142 Pre-Kindergarten to Grade 12 N School) that does not currently include any TP effluent limits;
4. One very large industrial wastewater facility permit (Boise White Paper LLC – Intl Falls) that does not currently include any TP effluent limits;
5. Two metallic mining facility permits that do not currently include any TP effluent limits; and
6. One peat mining facility permit has been issued but the facility has not yet been built.

Of the 19 Minnesota wastewater facilities in the LoW Watershed that will have allocations as a result of this TMDL study, 17 have attained compliance with their proposed TMDL WLAs over the past 5 years (2016 through 2020). The two exceptions are:

1. The Bigfork WWTP reported discharging 232 kilograms per year (kg/yr) of TP in 2016, exceeding its proposed 216 kg/yr WLA by 7%; and
2. The Hibbing Taconite Co. is estimated to have discharged 671 kg/yr of TP in 2016, exceeding its proposed 497 kg/yr WLA by 35%.

1. Project Overview

1.1 Purpose

Section 303(d) of the CWA requires the MPCA to identify waterbodies that do not meet water quality standards, and to develop TMDL studies for those waterbodies. A TMDL is the amount of a pollutant that a waterbody can assimilate without exceeding established water quality standards. Through a TMDL, pollutant loads are allocated to permitted and nonpermitted sources that discharge or drain to the waterbody.

In 2008, the LoW (Assessment Unit Identification [AUID] numbers 39-0002-01 and 39-0002-02) was added to Minnesota's 303(d) list of impaired waterbodies as being impaired for aquatic recreation due to excessive TP and Chl-*a* concentrations (related to nuisance algal blooms) and violation of the Secchi disk (transparency) standard. Three years (1999, 2005, and 2006) of growing season water quality data were available at that time, and growing season mean TP concentrations exceeded the water quality standard in all three years; growing season mean Chl-*a* concentrations exceeded the standard in 1999 and 2006. The MPCA's assessment of nonsupport was corroborated by remote sensing imagery from August 2006, which showed a severe algal bloom in the Minnesota portion of the LoW. These factors led to the recreational use impairment declaration.

The goal of this TMDL study is to quantify the pollutant reductions needed to meet state water quality standards and the appropriate endpoint for nutrients in the lake. This TMDL study quantifies existing P loads, defines the LoW loading capacity, and allocates P loads to point and nonpoint sources. This study also identifies treatment alternatives and includes a future monitoring plan to assess progress toward meeting water quality goals.

The LoW is an international water, and the LoW Basin covers approximately 70,000 km^2 (27, 000 mi^2) and comprises portions of Minnesota (U.S.) and Ontario and Manitoba, Canada (Figure 1-1Figure 1-2, Figure 1-3and Figure 1-4). Minnesota water quality standards do not apply to Canadian waters; as such, a reduced portion of the basin (the TMDL Study Area [Figure 1-2]) was defined to include only the area necessary to characterize the entirety of the U.S. portion of the LoW. The TMDL Study Area, therefore, includes all areas upstream of the northern (downstream) boundary of Little Traverse Bay at Big Narrows, Ontario, near Minnesota's Northwest Angle. This TMDL study does not require reductions from Canadian sources.

Because this study builds on nine Hydrologic Simulation Program – FORTRAN (HSPF) models (Figure 3-24) for the LoW Basin (Lupo 2016), the downstream boundary of the TMDL Study Area was chosen to correspond to HSPF boundaries and lies at the northern end of Little Traverse Bay at Big Narrows (Figure G-3).

An additional area is defined as the TMDL Restoration Area (Figure 1-3). The TMDL Restoration Area is the portion of the TMDL Study Area both within the U.S. and not in the Rainy Lake drainage area. Because TP concentrations of outflow from Rainy Lake to the Rainy River are well below the river eutrophication standard for the Rainy River and because the Rainy Lake Watershed is relatively undeveloped, no reductions are proposed for the Rainy Lake Watershed in this TMDL study. The TMDL Restoration Area is the only portion of the TMDL Study Area where load reductions are proposed, with the exception of acknowledged load reductions from the Abitibi paper mill due to plant idling and internal loading reductions from Canadian portions of the LoW that are occurring as a result of natural processes.

Figure 1-1 shows an aerial view of the LoW Basin, and Figure 1-2 shows the location of LoW within the TMDL Study Area. Figure 1-3 shows the TMDL Restoration Area and Figure 1-4 shows a close-up of the LoW within the TMDL Study Area. Note that the basis of this TMDL study is only the portion of the LoW within the TMDL Study Area, as including additional areas was not necessary to meet water quality standards due to the limitations of MPCA jurisdiction to those waters. Table 1-1 provides a summary of the LoW classifications and 303(d) listing information. The LoW consists of two distinct AUIDs: one for Four Mile Bay and one for the main portion of the lake comprising the portions of Big Traverse, Little Traverse, and Muskeg Bays within the U.S.

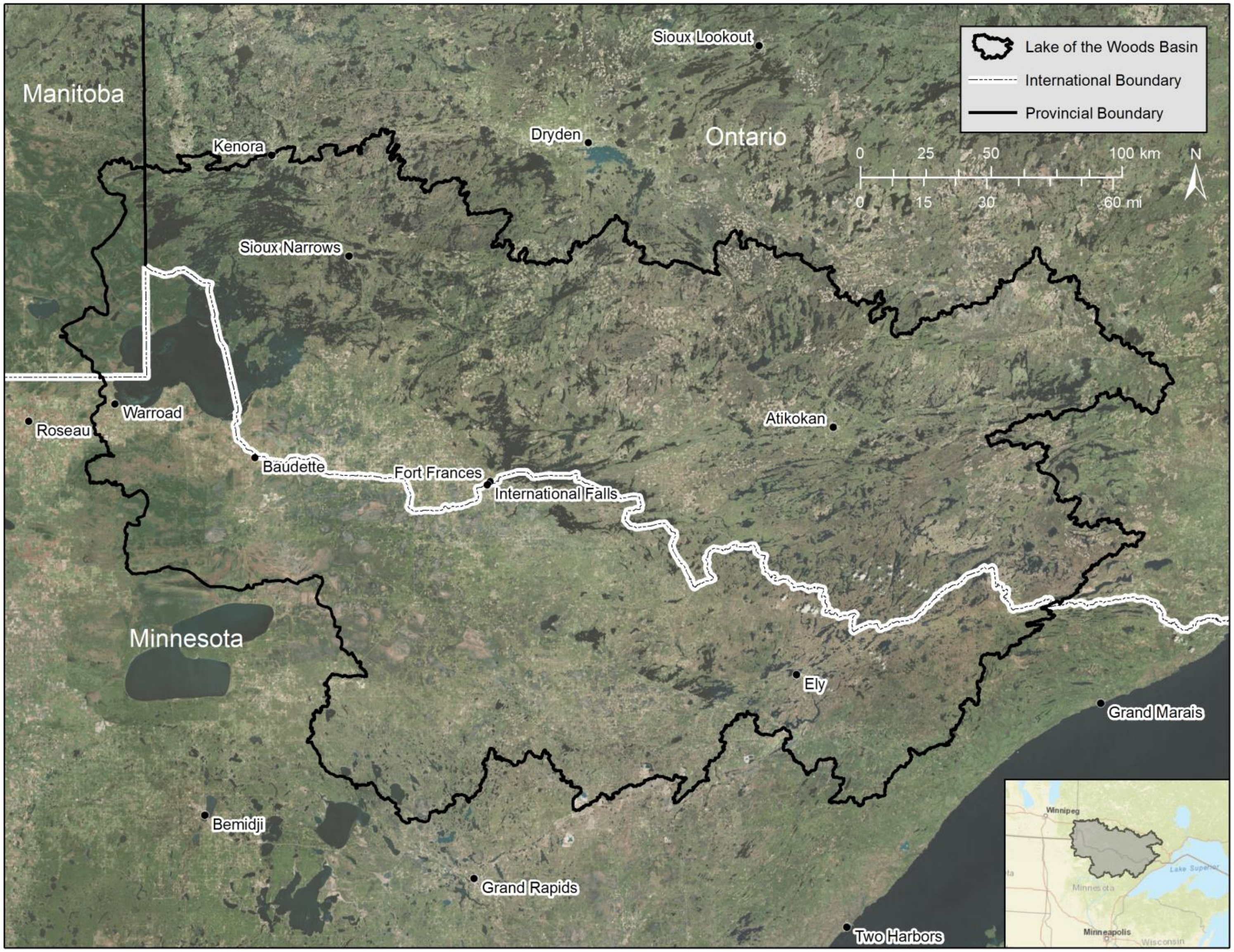


Figure 1-1. Aerial View of the Lake of the Woods Basin

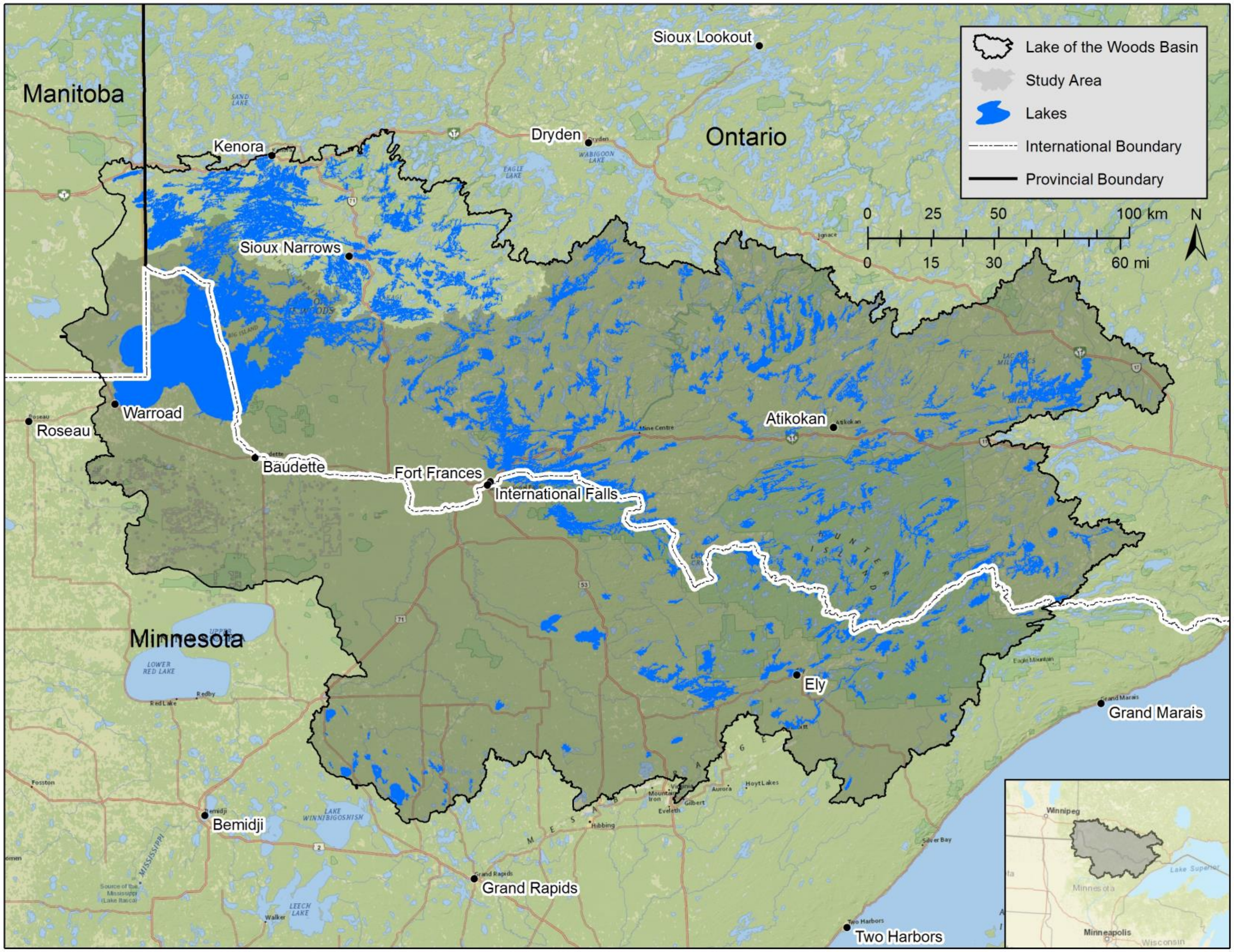


Figure 1-2. The Lake of the Woods Basin and TMDL Study Area

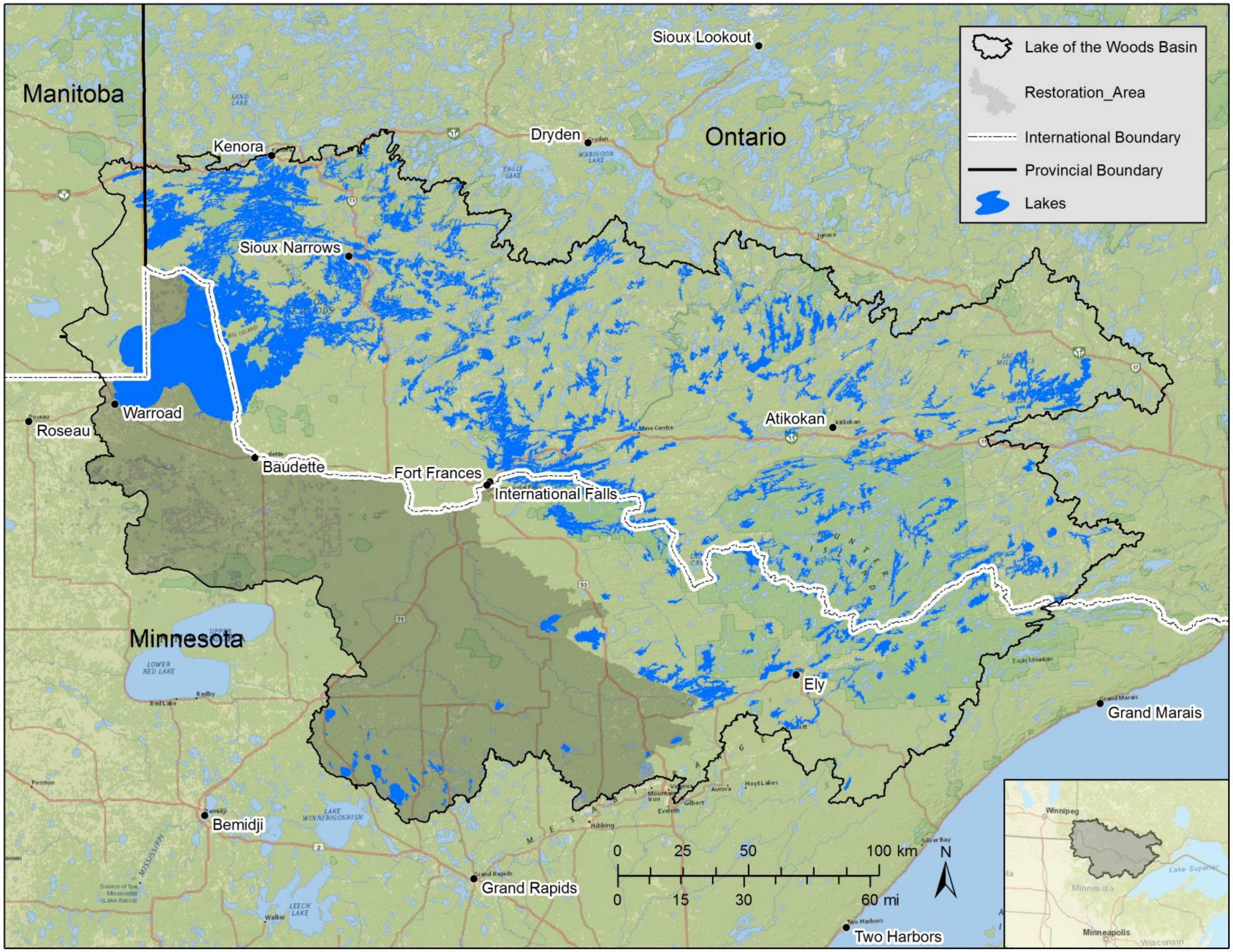


Figure 1-3. The Lake of the Woods TMDL Restoration Area

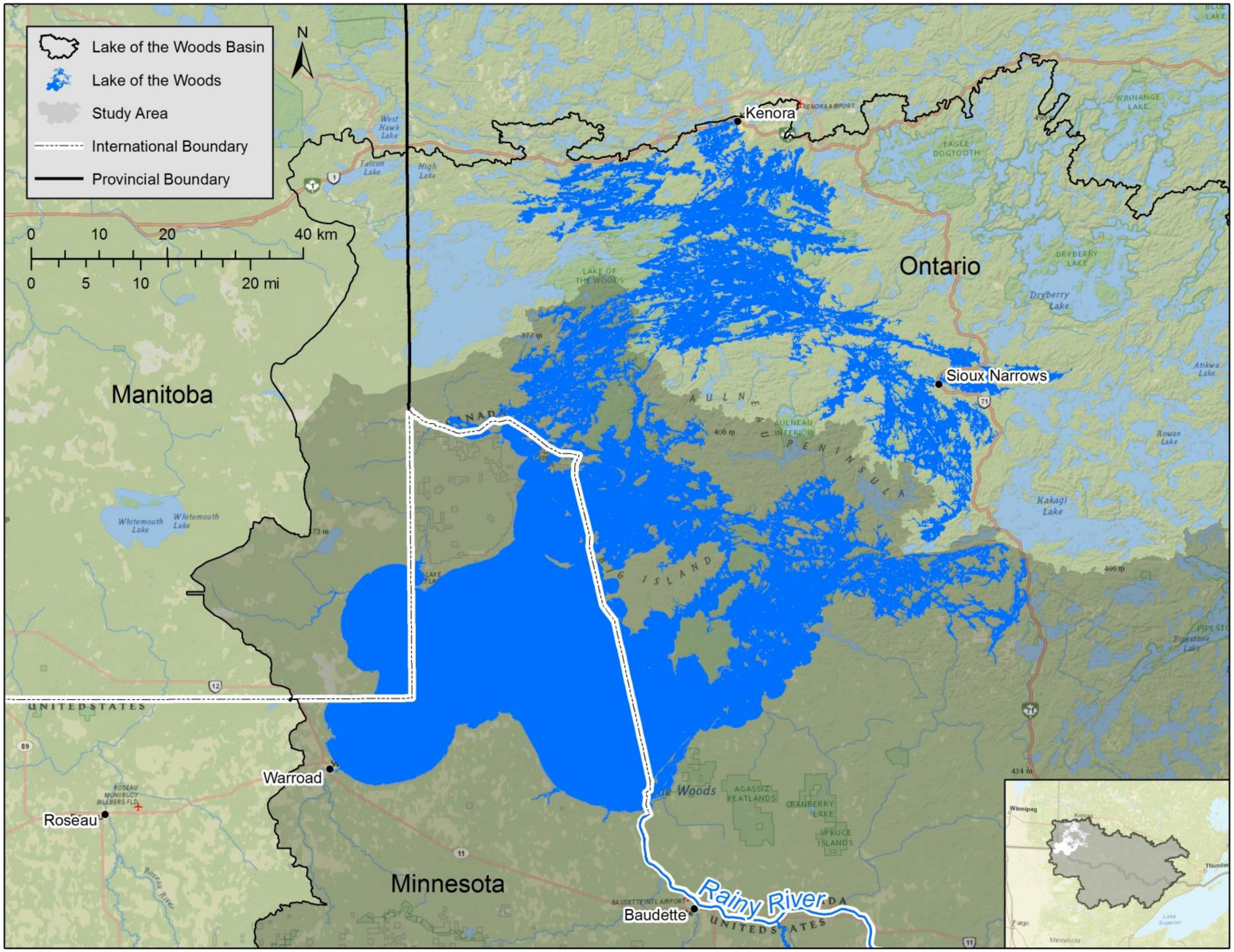


Figure 1-4. The Lake of the Woods within the Basin and TMDL Study Area

Table 1-1. Water quality impairments addressed by this TMDL study.

Lake Name	Lake ID	Lake Classification	Beneficial Use	Year Listed	Impairment
Lake of the Woods (Main)	39-0002-01	Deep	1B, 2Bd, 3A	2008	Nutrient/eutrophication biological indicators
Lake of the Woods (4 Mile Bay)	39-0002-02	Shallow	1B, 2Bd, 3A	2008	Nutrient/eutrophication biological indicators

1.2 Priority Ranking

The MPCA's schedule for TMDL study completions, as indicated on the 303(d) impaired waters list, reflects Minnesota's priority ranking of this TMDL study. The MPCA developed a state plan for Minnesota's TMDL Priority Framework Report to meet the needs of the U.S. Environmental Protection Agency's (EPA) national measure (WQ-27) under the EPA's Long-term Vision for Assessment, Restoration and Protection under the CWA 303(d) Program. As part of these efforts, the MPCA identified water quality-impaired segments that will be addressed by TMDL studies by 2022. This TMDL study is part of that MPCA prioritization plan to meet the EPA's national measure.

2. Applicable Water Quality Standards and Numeric Water Quality Targets

2.1 Designated Uses

The LoW has been assigned beneficial use classifications of 1B, 2Bd, and 3A (Minn. R. 7050.0470, subp. 2). Class 1 waters shall have quality "such that without treatment of any kind the raw waters will meet in all respects both the primary (maximum contaminant levels) and secondary drinking water standards issued by the EPA" (Minn. R. 7050.0222, subp. 2). Class 2Bd waters "shall be such as to permit the propagation and maintenance of a healthy community of cool or warm water sport or commercial fish and associated aquatic life and their habitats" (Minn. R. 7050.0222, subp. 3). Beneficial use class 3A corresponds to industrial consumption and pertain to chlorides, hardness, and pH values which are not considered in this TMDL study.

2.2 Applicable Water Quality Standards

A lake is considered impaired if summer-average TP concentrations exceed the applicable TP standard and one or both eutrophication response standards (Chl-*a* and Secchi transparency) are exceeded (Minn. R. 7050.0150, subp. 5a). Minn. R. 7050.0150, subp. 4, defines summer-average as "a representative average of concentrations or measurements of nutrient enrichment factors, taken over one summer season," where the summer season is defined as "a period annually from June 1 through September 30." 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 TP target, the Chl-*a* and Secchi transparency standards will likewise be met. Applicable water quality standards for the LoW are listed in Table 2-1.

Table 2-1. Lake nutrient/eutrophication standards for lakes, shallow lakes, and reservoirs in the Northern Lakes and Forest Ecoregion (Minn. R. 7050.0222, subp. 4).

TP (ppb)	Chl-*a* (ppb)	Secchi Depth (m)
≤ 30	≤ 9	≥ 2.0m

While the LoW geographically lies within the Northern Minnesota Wetlands Ecoregion, the MPCA assessed the lake against the Northern Lakes and Forest (NLF) Ecoregion standards because most of the drainage basin lies within the NLF Ecoregion. Minn. R. 7050.0222, subp. 2a.(E), states, "Eutrophication standards applicable to lakes and reservoirs that lie on the border between two ecoregions or that are in the Red River Valley (also referred to as Lake Agassiz Plains), Northern Minnesota Wetlands, or Driftless Area Ecoregion must be applied on a case-by-case basis. The commissioner shall use the standards applicable to adjacent ecoregions as a guide."

2.3 Antidegradation

Antidegradation is defined in Minn. R. 7050.0250 with the purpose of protecting water quality from deterioration to retain highly-valued recreational and other beneficial uses for future generations. Minn. R. 7050.0250 states, in part, that “To accomplish this purpose:

a. existing uses and the level of water quality necessary to protect existing uses shall be maintained and protected
b. degradation of high water quality shall be minimized and allowed only to the extent necessary to accommodate important economic or social development
c. water quality necessary to preserve the exceptional characteristics of outstanding resource value waters (ORVW) shall be maintained and protected
d. proposed activities with the potential for water quality impairments associated with thermal discharges shall be consistent with Section 316 of the CWA, United States Code, title 33, Section 1326.”

Antidegradation aspects noted above are important for future management of the LoW Basin. The basin includes ORVWs in the Boundary Waters Canoe Area Wilderness and Voyageurs National Park (Minn. R. 7050.0335). This TMDL study establishes Rainy River water quality boundary conditions at both the upper boundary condition (Fort Frances, Ontario/International Falls, Minnesota) and the lower boundary condition (Wheelers Point, Minnesota). These boundary conditions are defined by flow-weighted mean TP concentrations that are lower than Minnesota’s river eutrophication standards. Lastly, Minn. R. 7050.0250 allows for lowering of water quality as necessary to accommodate important economic and social development by a process defined in the antidegradation rules. Additional guidance on natural background protocols is provided by the MPCA (2009).

3. Watershed and Waterbody Characterization

The LoW Basin covers a large area across northern Minnesota and portions of southern Manitoba and Ontario. The physical and climate characteristics of the lake and basin are described below. This chapter also provides an assessment of the P sources in the basin and an overview of the models that were used to evaluate source contributions.

3.1 Settlement and Development

The LoW lies on the U.S.-Canada border in northern Minnesota (U.S.) and southeastern Manitoba and southwestern Ontario, in Canada. Warroad, Minnesota, (population of approximately 1,800) is the largest Minnesota community on the shores of the LoW. Kenora, Ontario (population of approximately 15,300), located at the LoW outlet to the Winnipeg River, is the largest city in the LoW Basin. The LoW name is a direct translation from the French Lac des Bois, found on maps as early as 1737 (Upham 2001) and given because the lake was, and still is, surrounded largely by forests. The first written account of a European reaching the LoW was that of Jacques de Noyon in 1688 (Burpee 1910). At that time, the lake was also known as Lac des Îles (Lake of the Islands). Further European exploration and exploitation began with La Verendrye's journey to the LoW in 1732 (Burpee 1910) and construction of Fort St. Charles on Magnuson's Island on the lake's west side, near what is now the Northwest Angle. Historically, the LoW Basin was home to extensive forestry activity, with paper mills operating in Kenora, Fort Frances, and International Falls. In the U.S., large-scale settlement along the LoW and the Rainy River did not occur until the early 20th century, with the cities of International Falls, Baudette, and Warroad growing rapidly from 1910 to approximately 1930. However, the populations of Koochiching and LoW Counties have fallen since peaks in the mid-1900s. Attempts to increase agricultural production in the early 1900s by artificially draining large areas of the basin were largely unsuccessful due to the difficulty of effectively draining wetland soils for agricultural production, as well as the short growing season. Thus, agricultural production has been less intense than in southern Minnesota. However, advances in crop genetics (e.g., crops that can tolerate short growing seasons) and tile drainage have led to increases in row crop agriculture in the Baudette area over the last decade.

3.2 Lake Physical Characteristics

Lake and watershed characteristics for the LoW and the portion of the LoW that is in the TMDL Study Area are given in Table 3-1. The LoW has a total surface area of approximately 3,846 km^2 (1,485 mi^2). Its watershed area (including the lake surface) is approximately 69,559 km^2 (26,857 mi^2), which yields a watershed to lake surface ratio of 18:1. The portion of the LoW in the TMDL Study Area has a surface area of 2,664 km^2 (1,037 mi^2) and a total watershed area of 62,654 km^2 (24,191 mi^2), which results in a watershed to lake area ratio of 23:3 for the TMDL Study Area.

3.2.1 Lake Segmentation

The portion of the LoW within the TMDL Study Area was partitioned into five segments, as shown in Figure 3-1, for lake modeling purposes. The LoW TMDL Study used the BATHTUB lake model, which is discussed in Section 4.2. The five lake segments used in this study are Sabaskong, Four Mile, Muskeg, Big

Traverse, and Little Traverse Bays. The segmentation was based on a combination of past work (Anderson et al. 2013), natural boundaries, and HSPF model boundaries (Lupo 2016). Segment characteristics are summarized in Table 3-2. Mean and maximum depth values are based on lake bathymetry data provided by the MPCA (MPCA 2015a).

Table 3-1. Morphometric and select watershed characteristics for the LoW and the portion of the LoW within the TMDL Study Area.

Characteristic	Lake of the Woods	Lake of the Woods TMDL Study Area	Source
Lake Surface Area (km^2/mi^2)	3,846/1,485	2,664/1,037	Derived from MPCA Bathymetry (MPCA 2015a)
Drainage Area, including Lake of the Woods (km^2/mi^2)	69,559/26,857	62,654/24,191	Model Subwatersheds (Lupo 2016)
Watershed Area to Lake Area Ratio	18.1	23.3	Calculated
Lake Volume (hm^3/acre-feet)	22,800/18,484,288	16,301/13,215,455	Derived from MPCA Bathymetry (MPCA 2015a)
Water Residence Time (years)	1.34	1.22	Calculated

3.2.2 Lake Water Levels

Figure 3-2 shows LoW water level data for the study period (Environment and Climate Change Canada 2016b) as measured at Cyclone Island (near the Northwest Angle). Lake water levels varied by approximately 1.5 meters (m) (5 feet [ft]) over the study period, while annual fluctuations were typically 1 m (3 ft) or less. Annual peak water levels typically occur in late spring or early summer following typical low-water levels in late March or April. Based on normal surface area and volume, lake-level fluctuations of 1 m represent changes in volume of approximately 17% in the LoW. The estimated water residence times (the time required to fill an empty lake basin) for the entire lake and the portion of the LoW within the TMDL Study Area are approximately 1.34 and 1.22 years, respectively, as estimated from lake volume and mean annual external inflows developed as part of this study. Residence times for individual lake segments in the TMDL Study Area are listed in Table 3-2 and vary from less than one day (Four Mile Bay) to eight years (Sabaskong Bay).

3.3 Watershed Characteristics

The LoW lies on the western edge of its watershed and drains, from east to west, parts of Cook, Lake, Saint Louis, Itasca, Koochiching, Beltrami, LoW, and Roseau Counties in Minnesota. The basin drains the entirety of the Rainy River District, Ontario, as well as portions of the Thunder Bay and Kenora Districts, Ontario, and Eastman Region, Manitoba. The basin is dominated by open water (16.3%), forests (50.8%), and wetlands (28%), with smaller areas of agricultural (3%) and developed lands (1.7%) (Olmanson 2015). The LoW tributaries are shown in Figure 3-3. The main tributary to the LoW is the Rainy River, which drains approximately 54,700 km^2 (21,100 mi^2), or approximately 87% of the TMDL Study Area. The remaining 13% of the drainage area—8,000 km^2 (3,100 mi^2)—covers the smaller tributary watersheds (5.2%), the LoW itself (4.3%), and direct lakeshed drainage (3.3%). The second largest tributary after the

Rainy River is the Warroad River, which has a drainage area of 716 km^2 (276 mi^2) and flows into Muskeg Bay. Detailed maps of tributaries to the LoW are shown in Figure 3-4, Figure 3-5, and Figure 3-6.

The U.S. Highways 53 and 71, Minnesota Highway 11, and the Trans-Canada Highway (Ontario Highways 11 and 71) provide regional access to the LoW Basin. The area offers myriad recreational opportunities, including fishing, hunting, snowmobiling, hiking, and paddling. Public lands, including Voyageurs National Park and Boundary Waters Canoe Area Wilderness in Minnesota and Quetico Provincial Park in Ontario, provide opportunities for outdoor recreation and wilderness experiences. As a result, tourism is an economic driver in the basin, with 1,750,000 to 2,750,000 angler-hours per year reported for the LoW alone (DNR 2015). The majority of urban and agricultural areas are present along the Rainy River corridor and the southern shore of the LoW.

3.3.1 Ecoregions

The LoW Basin lies within the Northern Forests Level I Ecoregion and almost entirely within the Mixed Wood Shield Level II Ecoregion (EPA 2017a). The extreme northeastern portion of the basin (approximately 5% of the basin) lies within the Softwood Shield Level II Ecoregion. More detailed (Level III and IV) ecoregion boundaries were obtained (Agriculture and Agri-Food Canada 2017; EPA 2017b) and are shown in Figure 3-7. The Minnesota portion of the basin is located within the Northern Minnesota Wetlands and NLFs Level III Ecoregions. The Northern Minnesota Wetlands Ecoregion is flat and dominated by wetlands and forests. Artificial drainage has made agriculture possible in parts of the ecoregion. The NLF Ecoregion is typified by rolling hills and lakes. The Peatlands, Forested Lake Plains, and Boundary Lakes and Hills Level IV Ecoregions predominate in the U.S. portion of the basin. The Canadian Level III Ecoregions within the Basin are the LoW, Rainy River, Thunder Bay-Quetico, and Lake Nipigon.

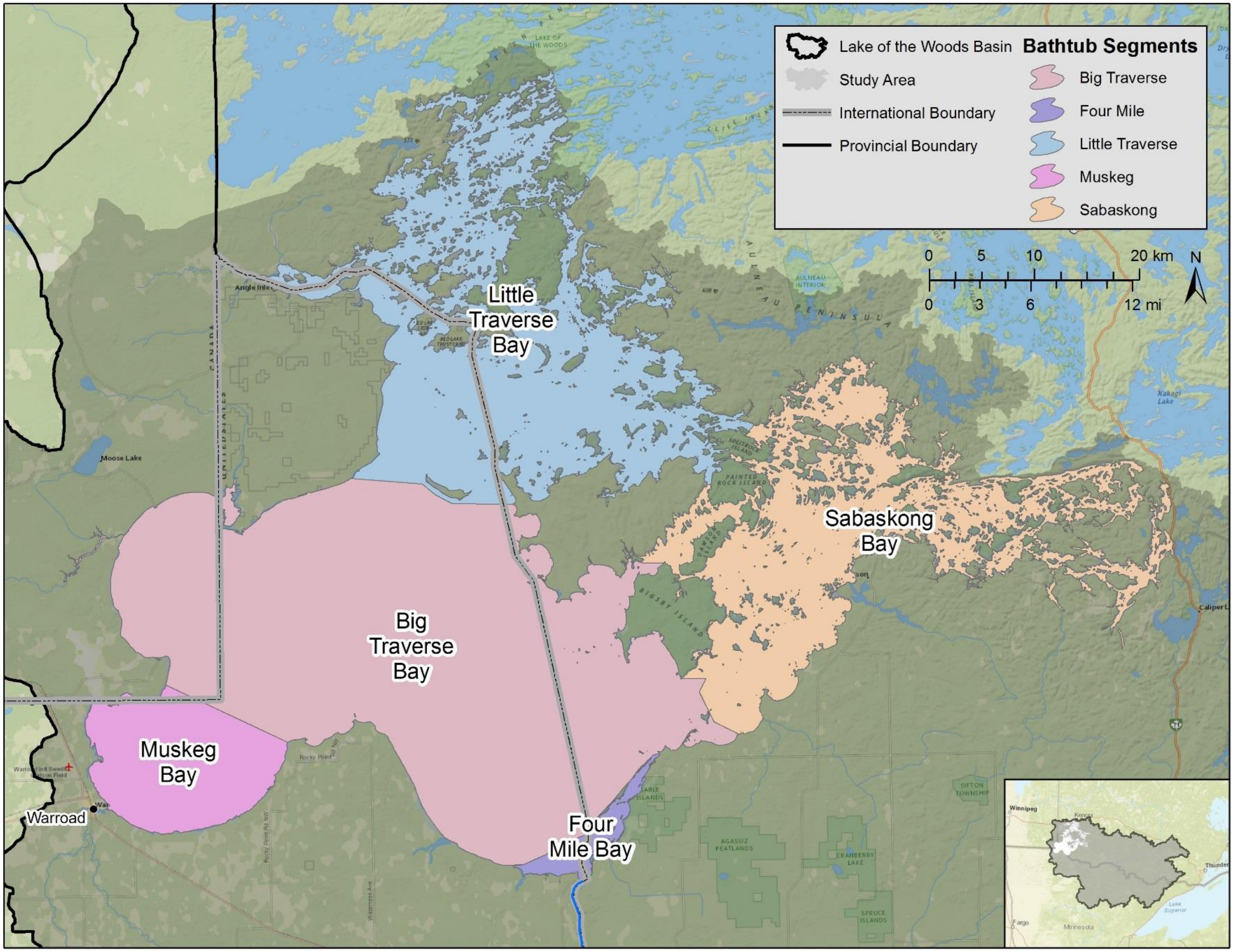


Figure 3-1. The Lake of the Woods BATHTUB Model Segmentation

Table 3-2. TMDL Study Area lake segment characteristics.

Segment	Area (km^2) (mi^2)	Maximum Depth (m) (ft)	Mean Depth (m) (ft)	Residence Time (years)
Sabaskong	518 (200)	17.6 (57.9)	3.6 (11.9)	8.01
Four Mile	31 (12)	4.5 (14.7)	1.0 (3.3)	0.0024
Muskeg	190 (73)	10.0 (32.8)	5.6 (18.3)	7.18
Big Traverse	1249 (482)	12.1 (39.6)	8.2 (26.9)	0.78
Little Traverse	697 (269)	28.3 (92.8)	4.6 (15.1)	0.24

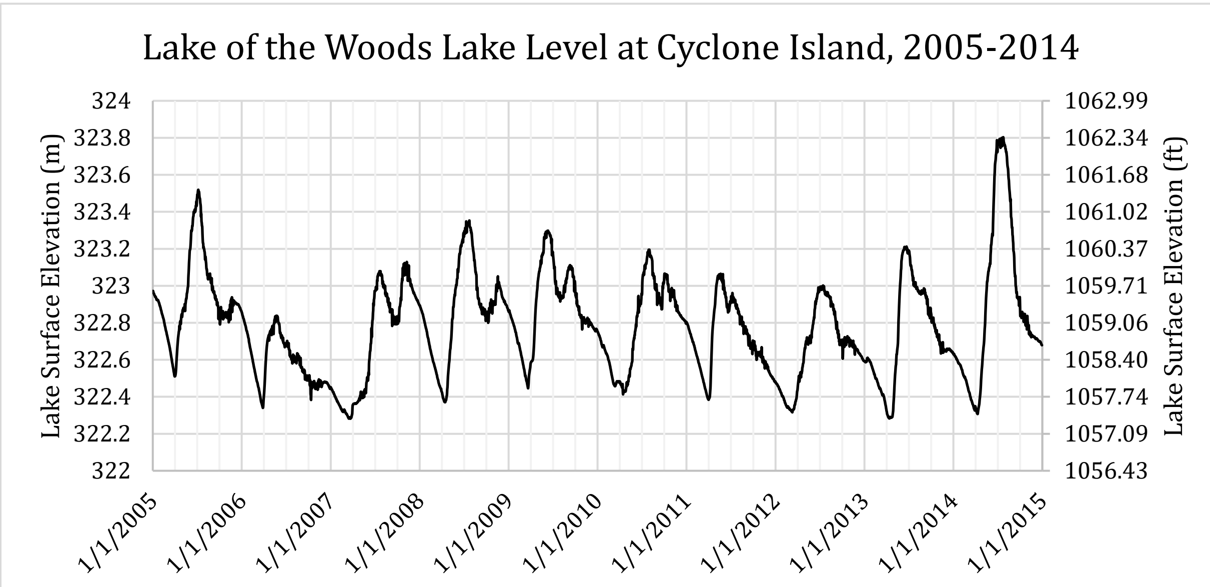


Figure 3-2. Lake Level Recordings for the Lake of the Woods, 2005–2014 (Environment and Climate Change Canada 2016b)

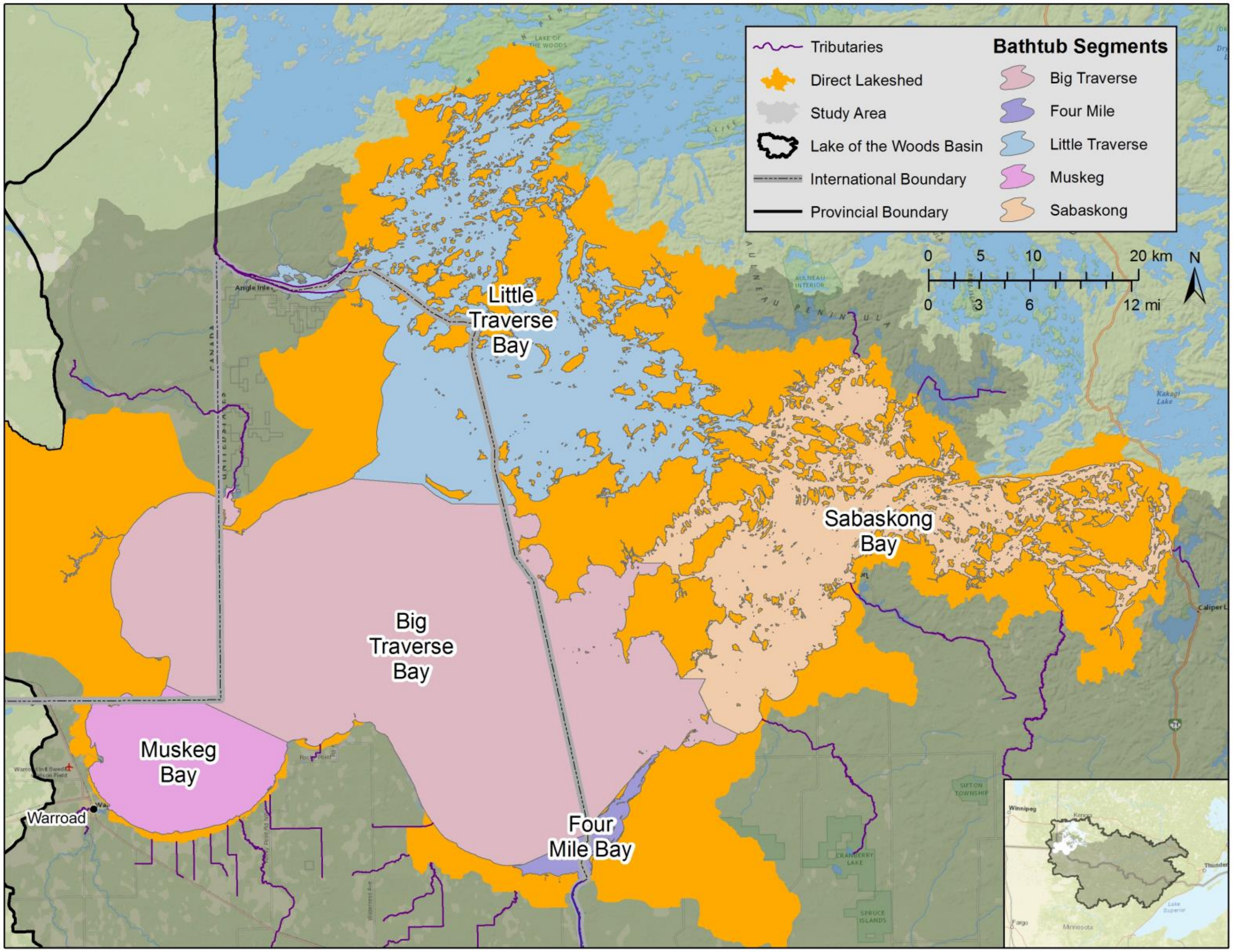


Figure 3-3. The Lake of the Woods Tributaries

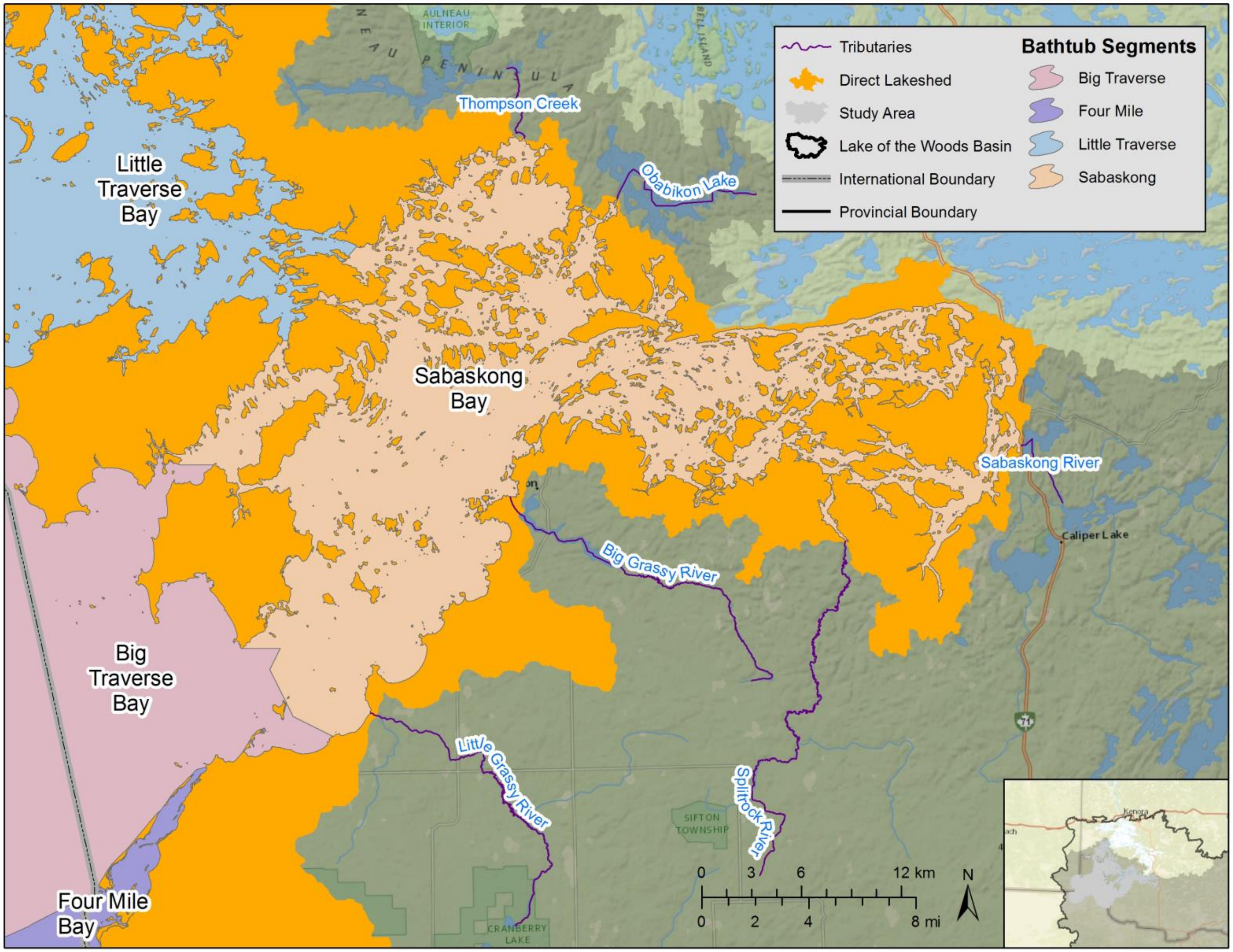


Figure 3-4. Sabaskong Bay Tributaries

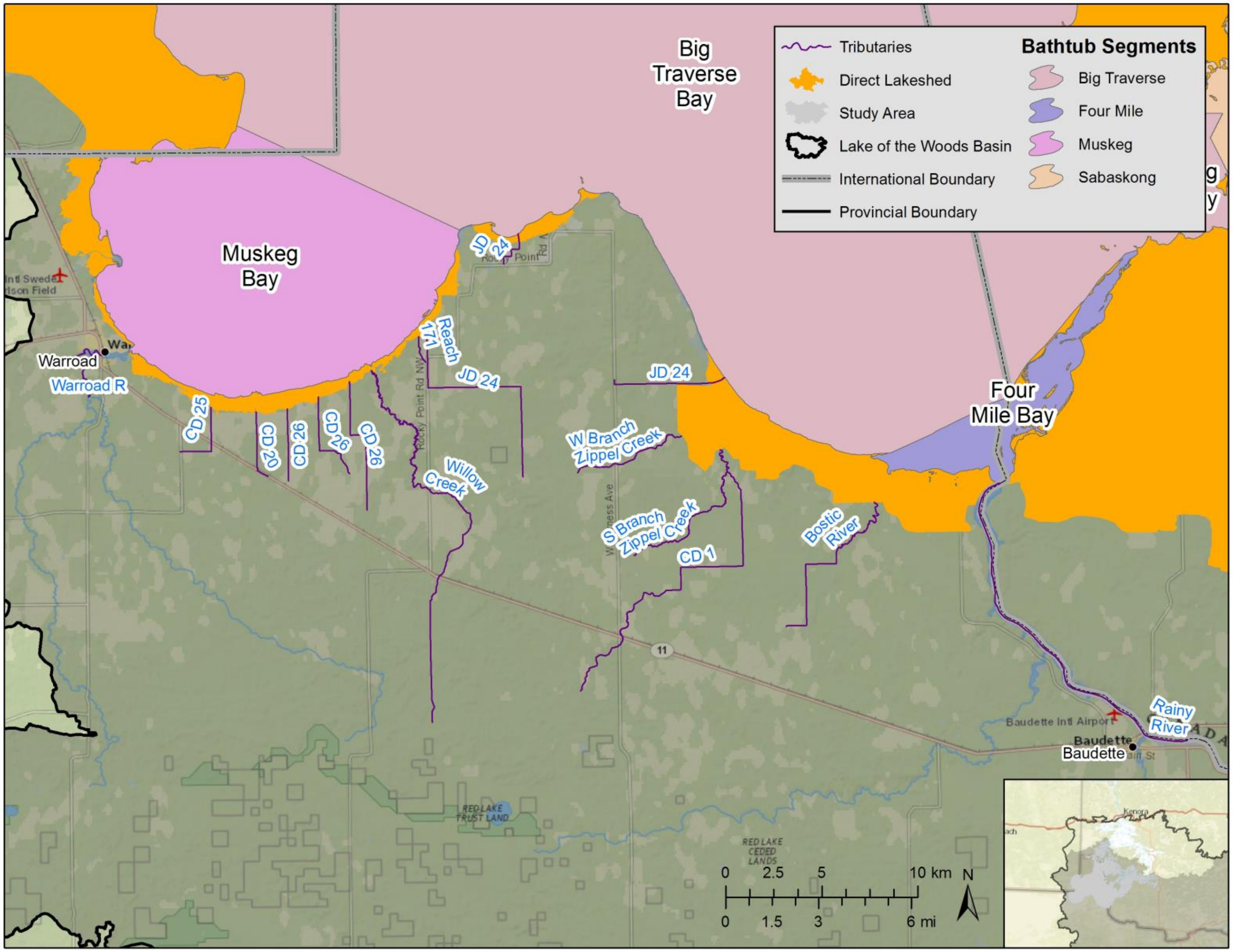


Figure 3-5. The Lake of the Woods South Shore Tributaries

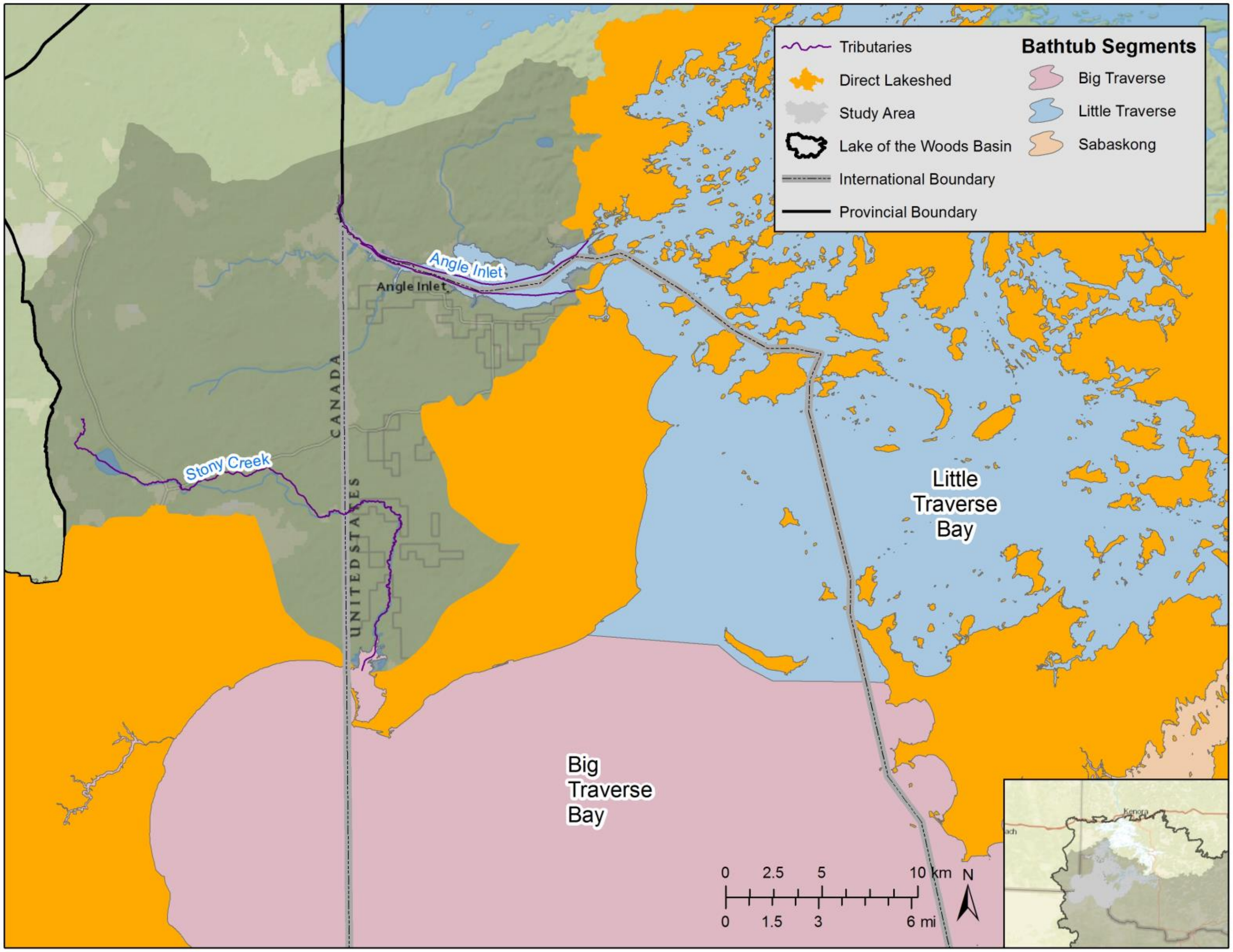


Figure 3-6. The Lake of the Woods Northwest Tributaries

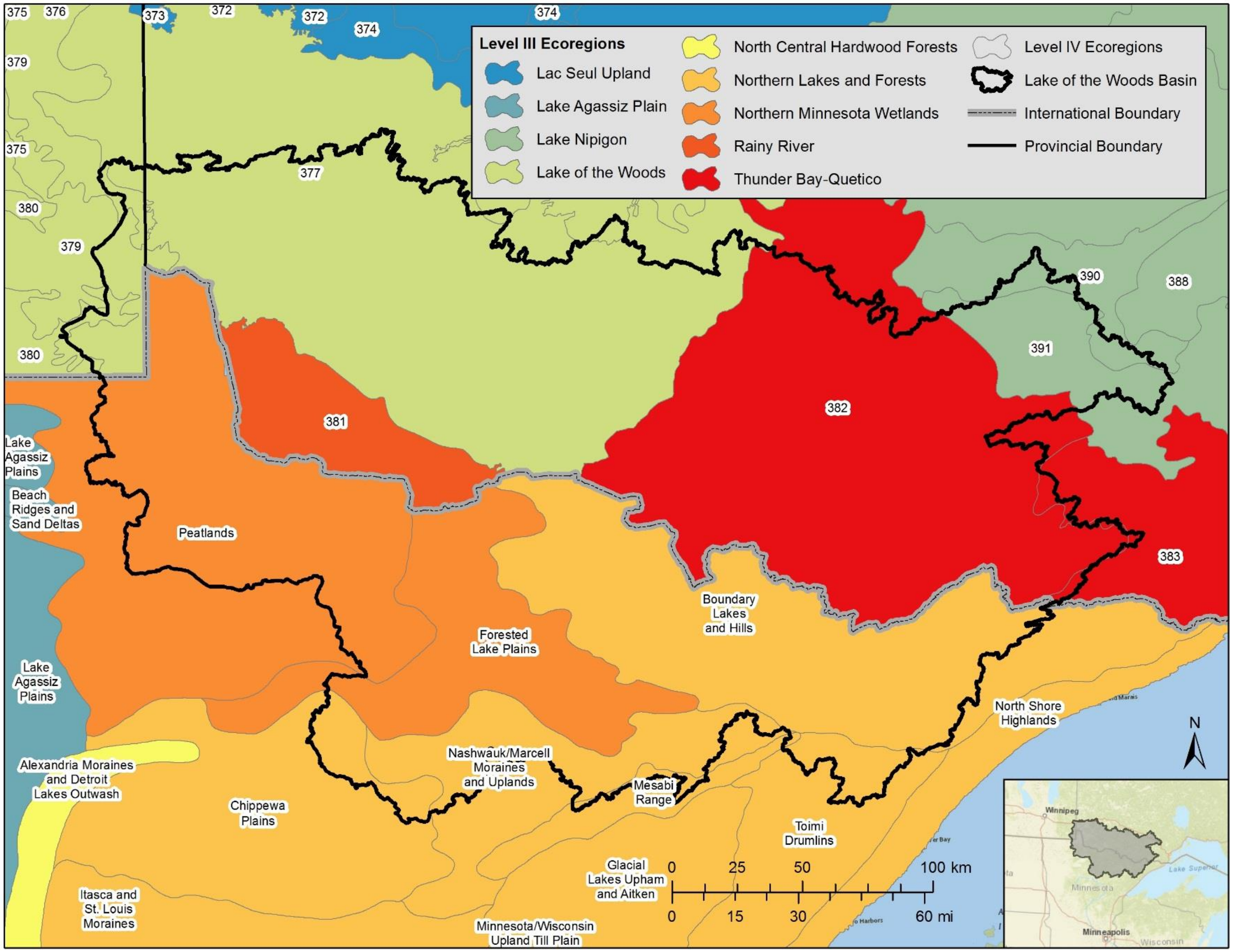


Figure 3-7. Level III (Shaded to Match Legend) and IV (Labeled on the Map with Boundaries in Gray) Ecoregions in the Lake of the Woods Basin

3.3.2 Watershed Relief

The basin ranges from rolling hills and lakes in the east, to flat areas in the west. The western portion of the basin was part of Glacial Lake Agassiz. The change in elevation along the Rainy River from International Falls to the LoW is approximately 50 feet, which corresponds to an average slope of approximately 0.01% for the Rainy River. Basin topography is shown in Figure 3-8.

3.3.3 Soils

The LoW Basin contains two distinct geologic regions: the Canadian Shield and Glacial Lake Agassiz Lakebed. Waters (1977) described the Rainy Lake outlet at International Falls/Fort Frances as the boundary of the two regions, with the Canadian Shield region predominating upstream of International Falls. The Canadian Shield portion of the basin is typified by rocky shorelines and bedrock overlain by a thin layer of soil (generally less than 1 foot in depth) (International Rainy Lake Board of Control and International Lake of the Woods Control Board (LWCB) 1984; DeSellas et al. 2009; Hyatt et al. 2011). The Glacial Lake Agassiz lake portion of the basin is relatively flat and is dominated by wetlands, peat bogs, and marshes (Hyatt 2011).

Soil classification data were obtained from the Harmonized World Soil Database (HWSD) version 1.21 (Food and Agriculture Organization, International Institute for Applied Systems Analysis, International Soil Reference and Information Centre, Institute of Soil Science, Chinese Academy of Sciences, and Joint Research Centre 2012). The HWSD data were summarized by dominant soil classification and are shown in Figure 3-9. Histosols are soils with high organic matter content and no permafrost; most histosols are saturated year round and typically coincide with bogs or peat (U.S. Department of Agriculture, NRCS 2006). Luvisols (known in the U.S. as alfisols) have a noticeable difference in texture in the soil profile, with the surface horizon depleted of clay and clay accumulation present at a lower horizon (International Soil Reference and Information Centre 2018). Podzols (known in the U.S. as spodosols) tend to coincide with evergreen forests in humid climates and are formed by a weathering process that strips organic matter from the surface horizon and deposits it in the subsoil (U.S. Department of Agriculture, NRCS 2006). Podzoluvisols (also known as albeluvisols) have formation processes similar to podzols and luvisols.

The portion of the basin draining to Rainy Lake is dominated by podzols, with areas of podzoluvisols in the Rainy Headwaters, Vermilion, and Rainy Lake HSPF model areas. The TMDL Restoration Area comprises predominantly histosols and podzoluvisols, with a small area of luvisols present in the International Falls area. Luvisols are primarily present within the portion of the TMDL Study Area north of the Rainy River.

Hydrologic soil-group data were obtained for the U.S. portion of the basin and are shown in Figure 3-10 (adapted from Lupo [2016]). Hydrologic soil groups A or B are present in large quantities in the eastern portion of the basin, while the rest of the basin is dominated by hydrologic soils groups C and D or dual classifications (A/D, B/D, or C/D). Dual-classification hydrologic soil groups denote that the soil's hydrologic response can be improved (for agricultural use) from a D to an A, B, or C with artificial drainage. Hydrologic soil groups were used in HSPF modeling to classify forest land use types into two groups based on hydrologic soil response (A or B and C or D).

Figure 3-8. The Lake of the Woods Basin Topography

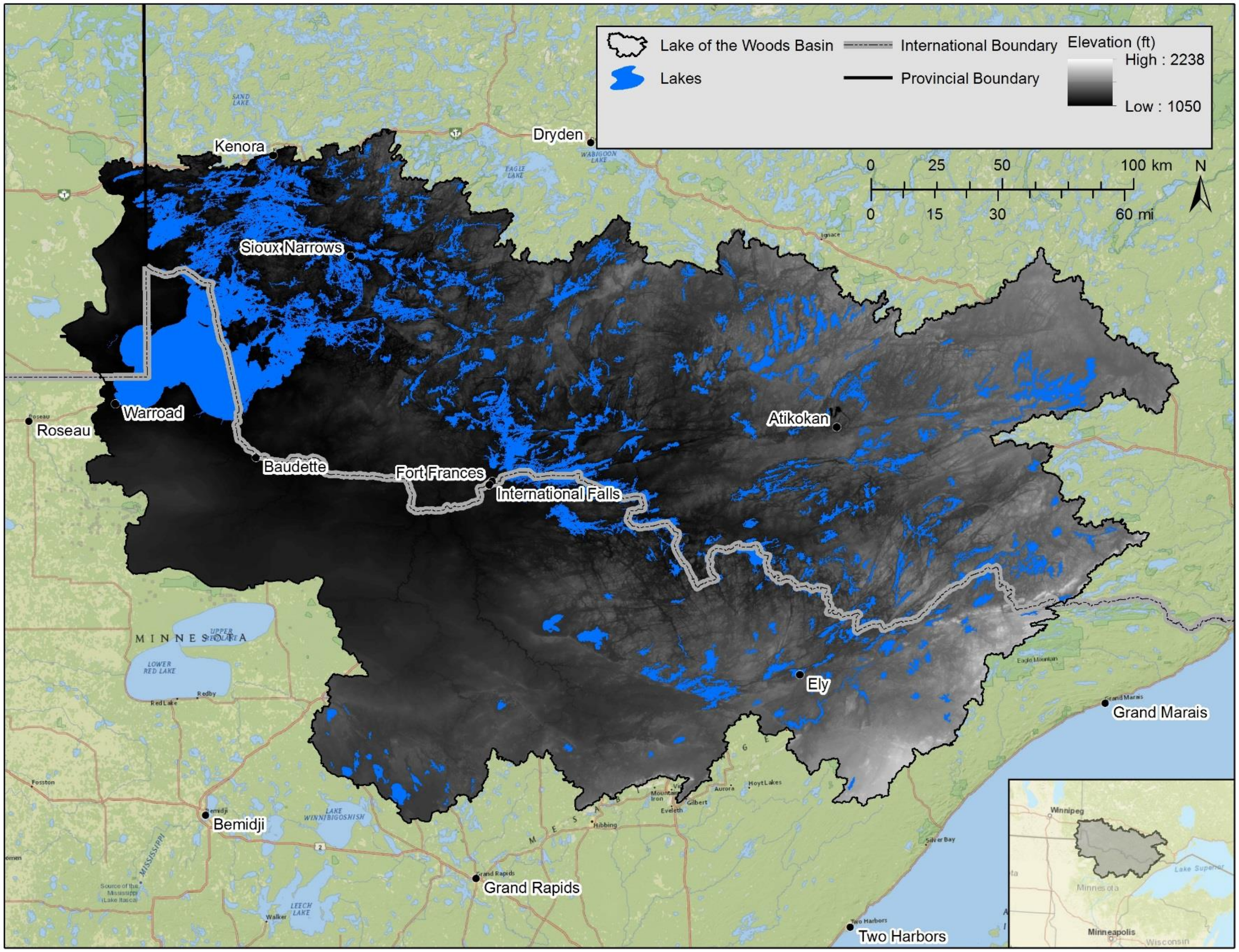
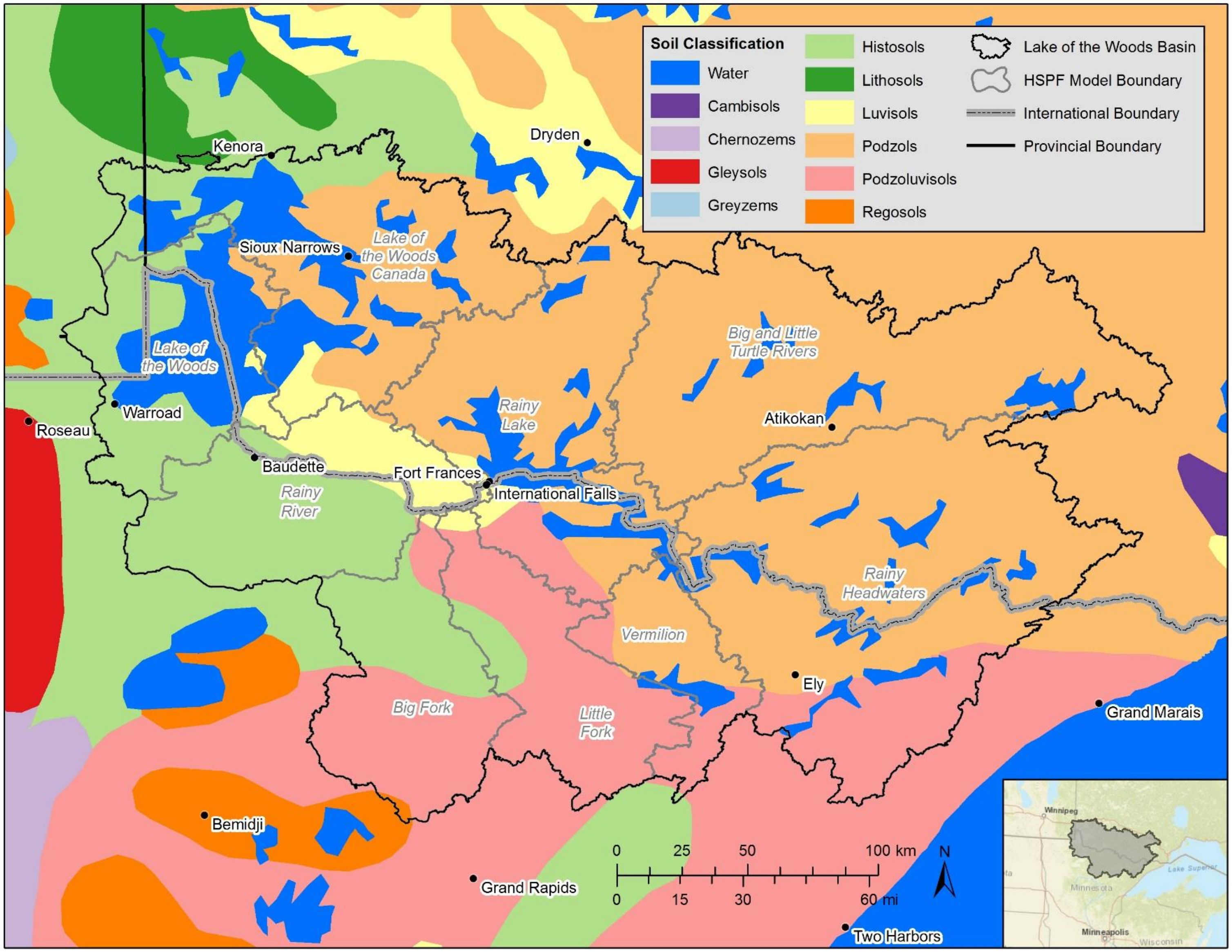


Figure 3-9. Dominant Soil Classifications Within the Lake of the Woods Basin Shown With HSPF Model Boundaries



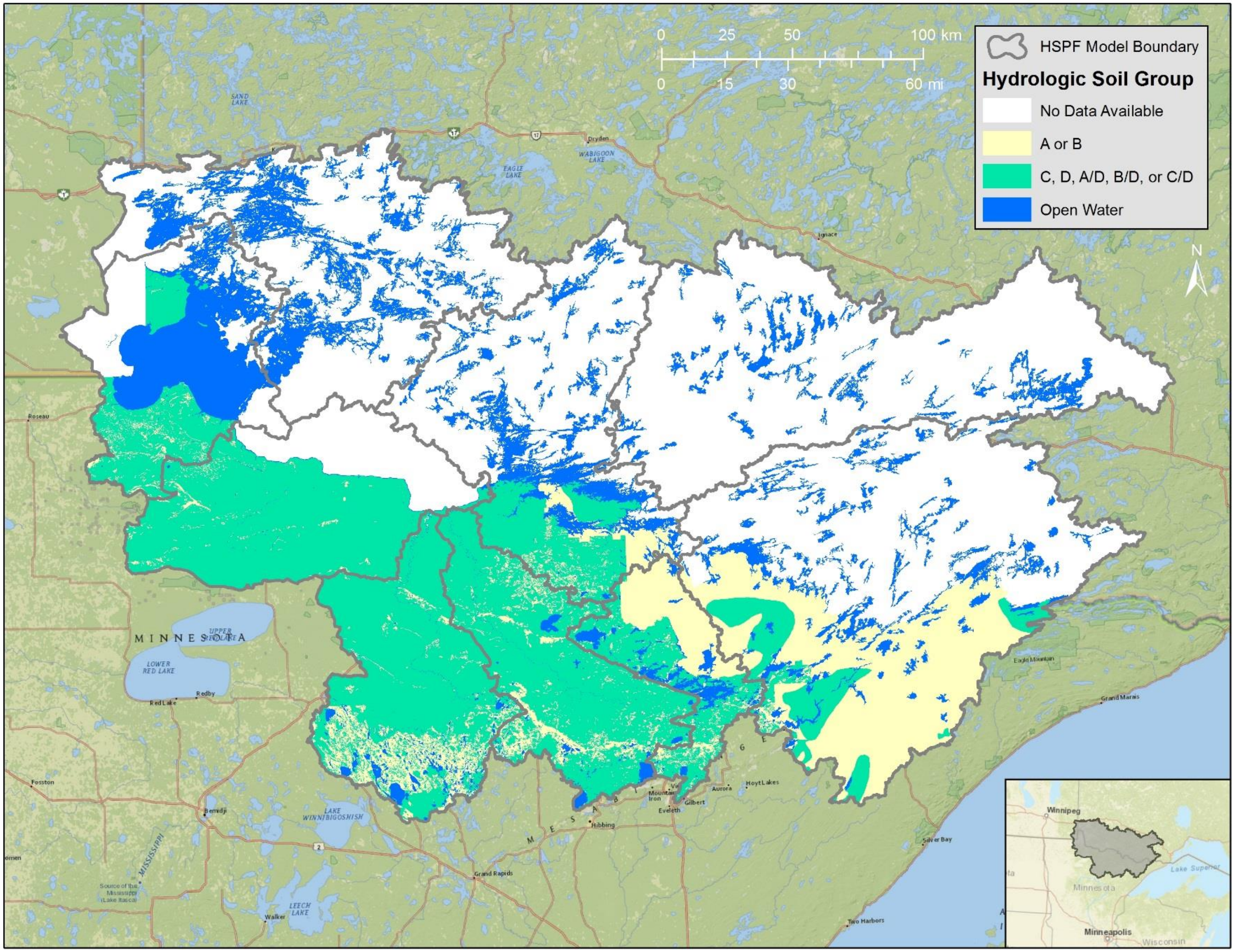


Figure 3-10. Hydrologic Soil Group Classifications

3.3.4 Land Use

The 2016 HSPF model update for the LoW Basin (Lupo 2016) incorporated updated land use developed by the University of Minnesota (UMN) Remote Sensing and Geospatial Analysis Laboratory (UMN-RSGAL) (Olmanson 2015) for 2010 conditions. The UMN-RSGAL land use data were developed for the entire LoW Basin and provided a harmonized dataset for the entire LoW Basin. Data were aggregated to simplify HSPF model parameterization according to Table 3-3 to create the HSPF land uses (Lupo 2016). The resultant HSPF model land use map is shown in Figure 3-11.

Table 3-3. UMN-RSGAL Lake of the Woods Basin Land Cover Summary and Reclassification for HSPF (Lupo 2016).

UMN-RSGAL 2010 Land Cover	Percent of Basin	HSPF Land Cover	Percent of Basin
Coniferous Forest	15.00	Mature Coniferous Forest	42.93
Mixed Forest	18.17		
Sparse Forest	9.76		
Lakes and Ponds	17.68	Wetland	40.64
Herbaceous Wetlands	5.97		
Woody Wetlands	16.98		
Wetland/Sandbar	0.01		
Regenerating Forest	5.60	Young Forest	6.54
Regenerating Forested wetland	0.94		
Deciduous Forest	6.19	Mature Deciduous Forest	6.19
Hay and Pasture	1.83	Grassland/ Pasture	1.83
Developed High Density	0.05	Developed	1.43
Developed Medium Density	0.16		
Developed Low Density	0.62		
Developed Managed Grass	0.01		
Developed Roads	0.48		
Extraction	0.11		
Row Crops and Small Grains	0.44	Agriculture	0.44

Approximately 55% of the LoW Basin is classified as forested, with mature forests making up nearly half (49%) of the TMDL Study Area; the remainder is dominated by wetlands (23%) and open water (18%). The remaining 4% of the basin comprises grassland, agriculture, and developed land. Agricultural land uses are predominately present south of the lake and along the Rainy River corridor; a mixture of cultivated crops and hay/pasture is on both sides of the border, with cultivated crops more prevalent in the U.S. The lake is surrounded to varying degrees by forests, with deciduous forest notable on the U.S. side of the border and mixed forests predominating on the Canadian side. Wetlands are dominant to the south of the lake from Koochiching County and west, and on the western side of the lake in Manitoba and the Northwest Angle.

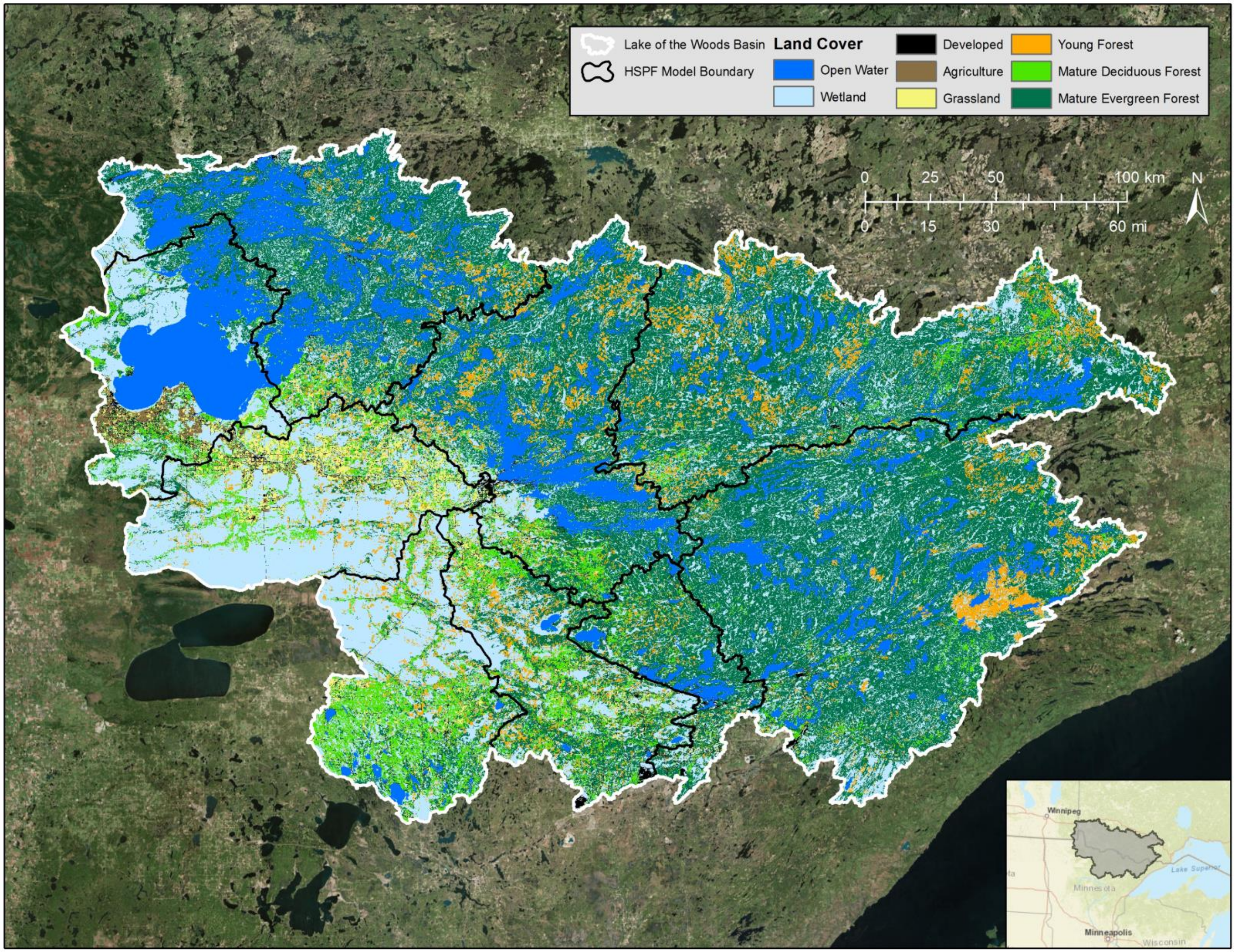


Figure 3-11. 2010 Basin Land Use as Modeled in HSPF (Adapted From Olmanson [2015])

Because of the prevalence of forested land in the basin, more detailed forest land use classes were created by overlaying hydrologic soil group data (two classes: A or B and C or D) and forest type (e.g., young forest, mature coniferous, and mature deciduous). This classification results in six unique combinations of forest type and soil type, which affords a more accurate representation of hydrologic processes for each forest type (i.e., more runoff with C or D soils because of poor drainage, more runoff from young forest). Final HSPF model land classifications are summarized in Table 3-4. Further discussion of HSPF modeling of the LoW Basin is included in Section 3.9.

Table 3-4. Summary of modeled land use classifications for LoW Basin and TMDL Study Area (adapted from Olmanson [2015] and Lupo [2016]).

HSPF Land Use	LoW Basin		TMDL Study Area	
	Area (km^2)	Percent	Area (km^2)	Percent
Mature Evergreen Forest (CD Soils)	24,918	35.8	21,403	34.2
Mature Evergreen Forest (AB Soils)	4,723	6.8	4,723	7.5
Young Forest (CD Soils)	4,011	5.8	3,772	6.0
Mature Deciduous Forest (CD Soils)	3,734	5.4	3,709	5.9
Mature Deciduous Forest (AB Soils)	569	0.8	569	0.9
Young Forest (AB Soils)	529	0.8	529	0.8
Wetland	19,518	28.1	18,206	29.1
Open Water	8,949	12.9	7,204	11.5
Grasslands	1,272	1.8	1,270	2.0
Developed	992	1.4	928	1.5
Agriculture	305	0.4	304	0.5
Total	69,520		62,617	

3.3.5 Demographics and Growth Projections

The U.S. population in the LoW Basin was approximately 47,000 for both the 2000 and 2010 U.S. Censuses (adapted from Minnesota Legislature Coordinating Commission [2016]); census population by county is presented in Table 3-5. A map of the basin with counties (U.S.) and districts (Canada) is shown in Figure 3-12. Two-thirds of the population live in Saint Louis and Koochiching Counties, while the highest mean population density is in Roseau County. Large parts of the eight-county area are not within the LoW Basin, including population centers such as Duluth, Bemidji, and Grand Rapids. Koochiching and LoW Counties are the only counties with a majority of inhabitants living in the basin. The projected total eight-county population through 2045 is shown in Table 3-6.

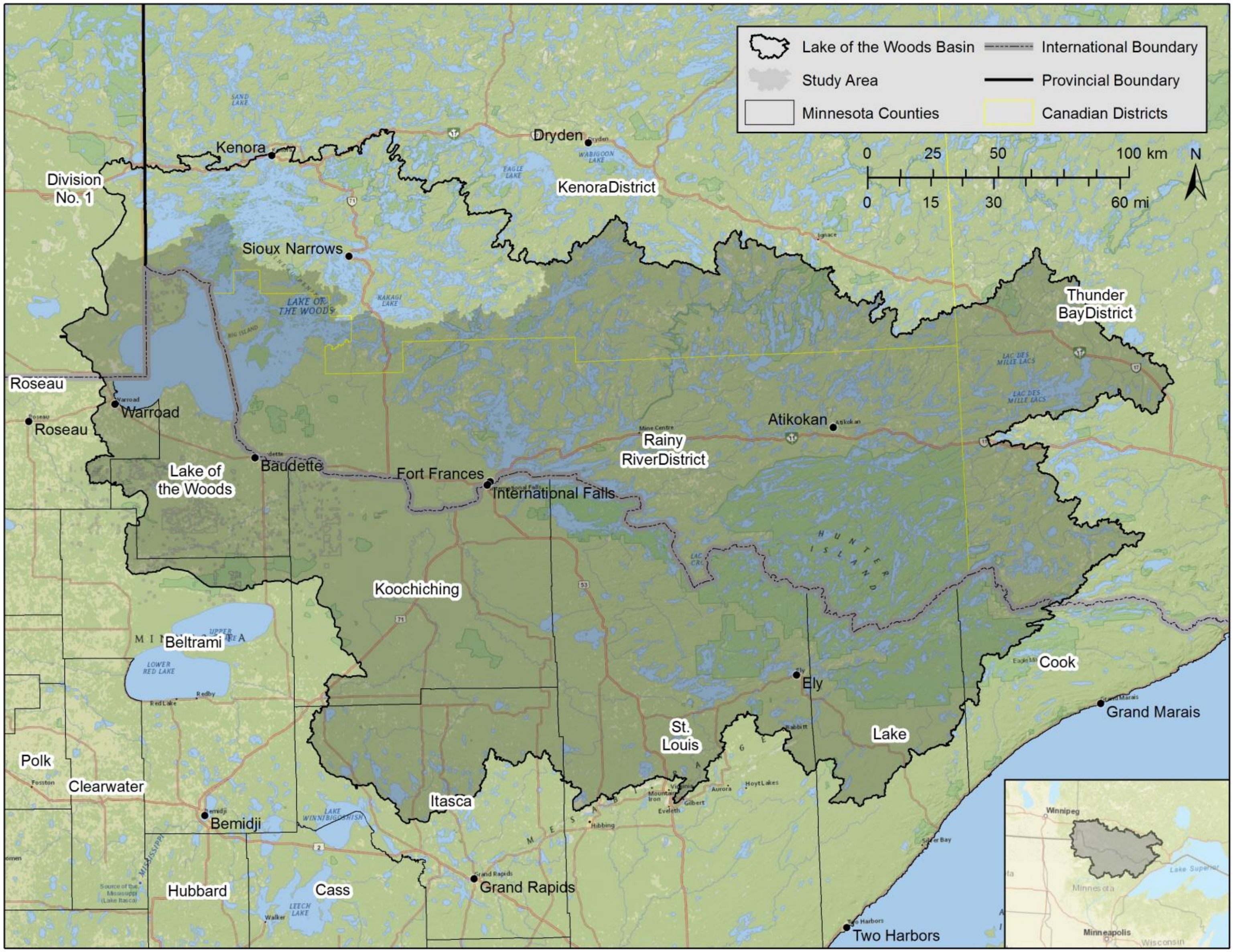


Figure 3-12. Jurisdictional Map of the Lake of the Woods Basin

Table 3-5. 2000 and 2010 population within the LoW Basin, by county (Adapted from the Minnesota Legislature Coordinating Commission [2016]).

County	Census Population			2010 Population Density
	2000	2010	% change	Inhabitants (mi²)
Cook	138	130	–5.8	0.6
Lake	693	717	3.5	1.4
Saint Louis	18,345	18,413	0.4	12.0
Itasca	4,917	5,126	4.3	5.9
Koochiching	13,387	12,993	–2.9	13.3
Beltrami	12	21	75.0	2.9
Lake of the Woods	4,238	4,045	–4.6	8.9
Roseau	5,079	5,232	3.0	33.7
Total	**46,809**	**46,677**	**–0.3**	**9.9**

Table 3-6. Estimated full county populations for counties partially or fully within the LoW Basin (Dayton 2014).

County	Estimated Population			
	2015	2025	2035	2045
Cook	5,376	5,368	5,016	4,628
Lake	11,217	11,335	11,013	10,521
St. Louis	200,077	201,472	198,058	189,161
Itasca	47,344	48,834	48,543	47,721
Koochiching	13,589	13,783	13,651	13,240
Beltrami	46,103	49,517	51,946	54,142
Lake of the Woods	4,149	4,192	4,059	3,869
Roseau	16,279	17,221	18,073	18,449
Total	**344,134**	**351,722**	**350,359**	**341,731**

Estimated population data published by the Minnesota State Demographic Center (Dayton 2014) are summarized by county in Table 3-6. These data are for the entire area of each county and thus include areas not in the LoW Basin. Total population for LoW Basin counties is expected to increase from 2015 to 2025, while the estimated 2045 population is lower than the estimated 2015 population.

3.3.6 Tribal Lands

Portions of lands owned by the Bois Forte Band of Chippewa, the Leech Lake Band of Ojibwe, the Minnesota Chippewa Tribe, and the Red Lake Nation are within the LoW Basin. First Nations lands are included in the Canadian portion of the TMDL Study Area. Tribal areas within the U.S. are shown in Figure 3-13. The Bois Forte Band of Chippewa has tribal land in the Vermilion, Little Fork, and Big Fork Hydrologic Unit Code (HUC) -8 Watersheds. The Leech Lake Band of Ojibwe has tribal land in the Big Fork Watershed. The Minnesota Chippewa Tribe has lands within the Vermilion and Little Fork HUC-8 Watersheds. The Red Lake Nation has tribal lands in the Lower Rainy River, Rapid River, and LoW HUC-8 watersheds. Tribal lands are outside the jurisdiction of the state of Minnesota; therefore, no reductions are required from sources within these lands.

In August 2018, the MPCA sent letters to the Bois Forte Band of Chippewa, the Leech Lake Band of Ojibwe, the Minnesota Chippewa Tribe, and the Red Lake Band of Chippewa Ojibwe, which briefly explained the TMDL study and invited the tribal contacts to partner with the MPCA on the project.

3.4 Climate

Climate data were reviewed to define conditions that affect the LoW water quality and to inform future monitoring, particularly with respect to internal P loading. This analysis included a review of precipitation, lake evaporation, temperature, wind direction and speed, and open water/ice cover. Summaries of climate data are included in the following sections; more detailed information is available in Appendix A.

3.4.1 Temperature

Mean monthly precipitation and normal maximum, mean, and minimum daily temperatures for the 1981 through 2010 period for Warroad and International Falls, Minnesota, are shown in Figure 3-14 and Figure 3-15, respectively. Mean daily temperatures vary from minimum values of approximately –20 degrees Celsius (°C) (–4 degrees Fahrenheit [°F]) in January to maximum temperatures of approximately 25°C (77°F) in July and August. Mean daily temperature fluctuations vary from 10°C (18°F) during the winter to 15°C (27°F) in the summer months.

Detailed mean annual and summer-season temperature data for 1895 through 2016 are included in Appendix A for Minnesota Climate Divisions 2 (north central) and 3 (northeast). These data show that average annual temperatures increased by 0.2°C/decade (0.3°F/decade) from 1895 to 2016 for both Climate Divisions 2 and 3; summer-season mean temperatures over the same period increased by 0.1°C/decade (0.2°F/decade). Higher mean temperatures may lengthen summer seasons and increase lake temperatures, biological activity (algal production), and lake-sediment chemical reaction kinetics.

3.4.2 Precipitation

Mean monthly precipitation for Warroad and International Falls, Minnesota, are shown in Figure 3-14 and Figure 3-15, respectively. Mean annual precipitation (1981 through 2010) is nearly equal between Warroad (62.2 centimeters [cm] or 24.9 inches [in]) and International Falls (61.5 cm or 24.2 in); however, Warroad receives more rainfall during the summer, and International Falls receives more precipitation in the spring and fall. Precipitation peaks during the summer season at both locations, with June precipitation of 11 cm (4.4 in) in Warroad and 10 cm (3.9 in) in International Falls.

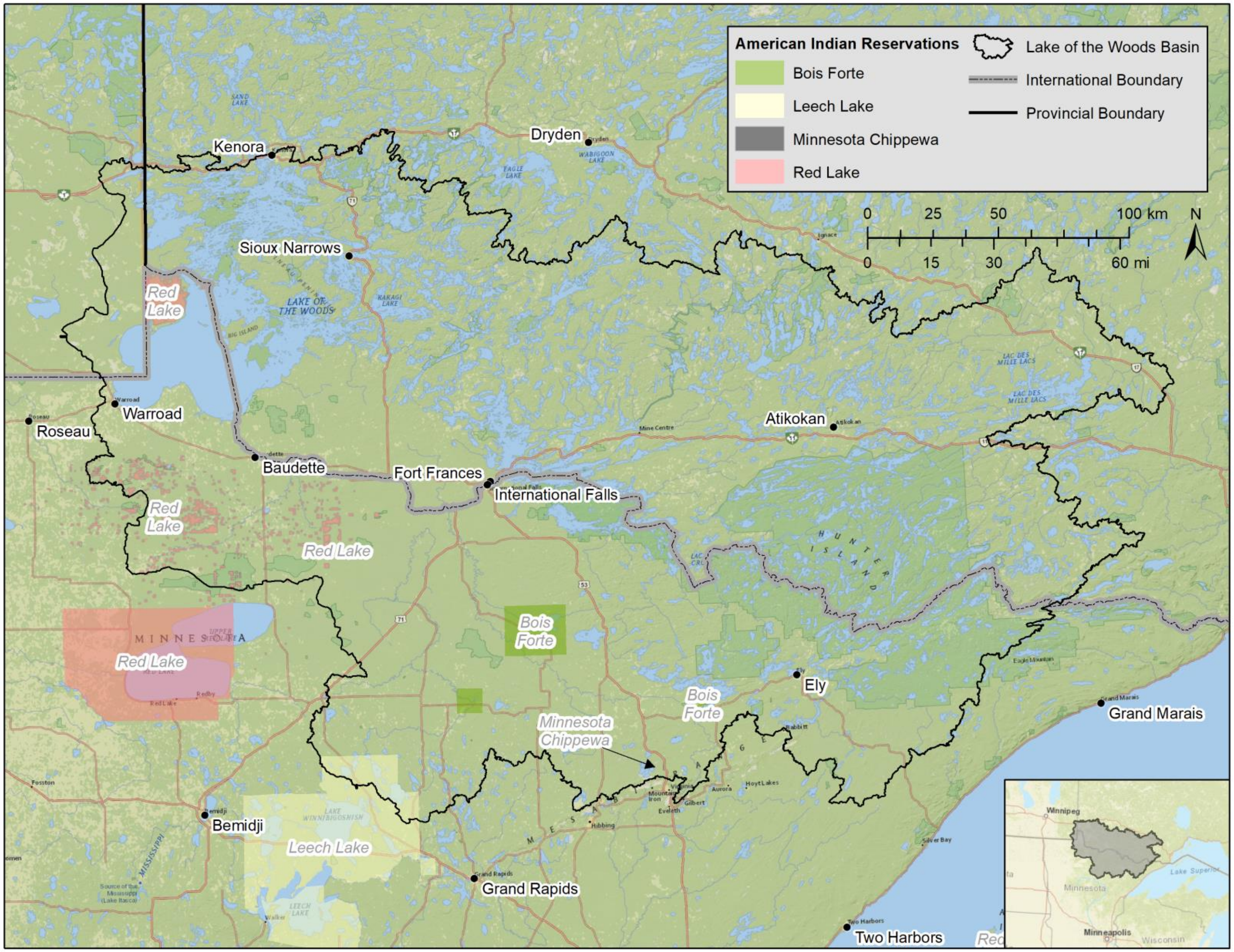


Figure 3-13. Tribal Areas in and Near the U.S. Portion of the TMDL Study Area (Adapted From the U.S. Census Bureau [2018])

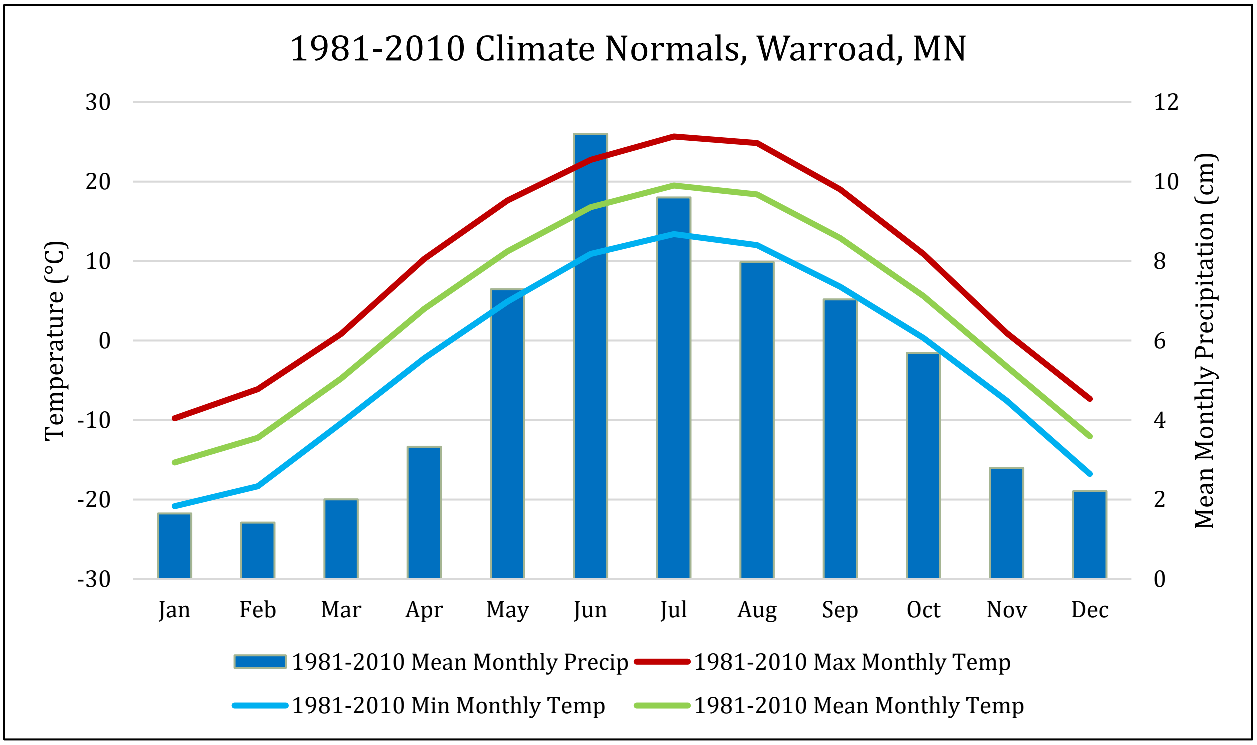


Figure 3-14. Observed Monthly Temperature and Precipitation for Warroad, MN, 1981–2010 (Midwestern Regional Climate Center 2016)

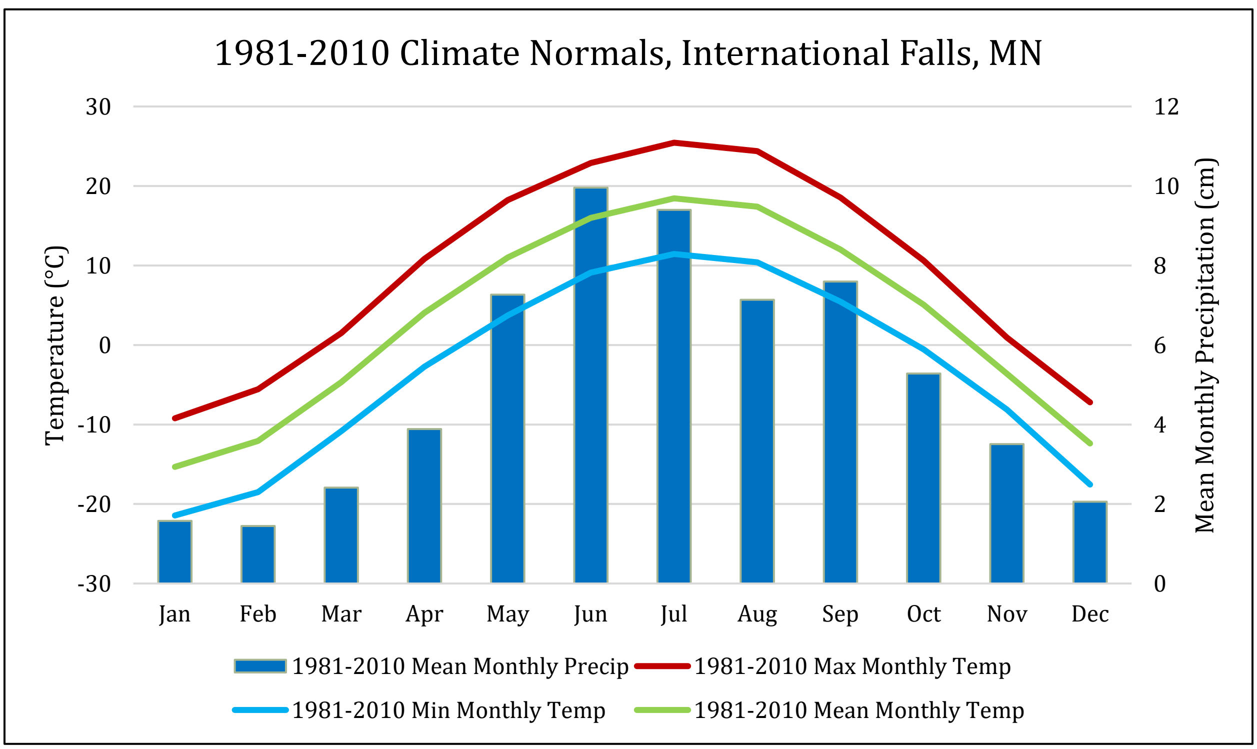


Figure 3-15. Observed Monthly Temperature and Precipitation for International Falls, MN, 1981–2010 (Midwestern Regional Climate Center 2016)

Annual precipitation (1910 through 2011) for Warroad, Minnesota, is shown in Figure 3-16. Annual precipitation is shown for years that have at least 350 days of data. Precipitation has increased over the past century with the four highest annual totals occurring since 1991. The five-year mean annual precipitation values were between 45 and 58 cm (18 to 23 in) before 1960, but have showed more variation in recent decades. Since 1988, the five-year mean annual precipitation values have ranged from 47 to 75 cm (18 to 30 in), with most values greater than 60 cm (24 in). More detailed precipitation information is presented in Appendix A.

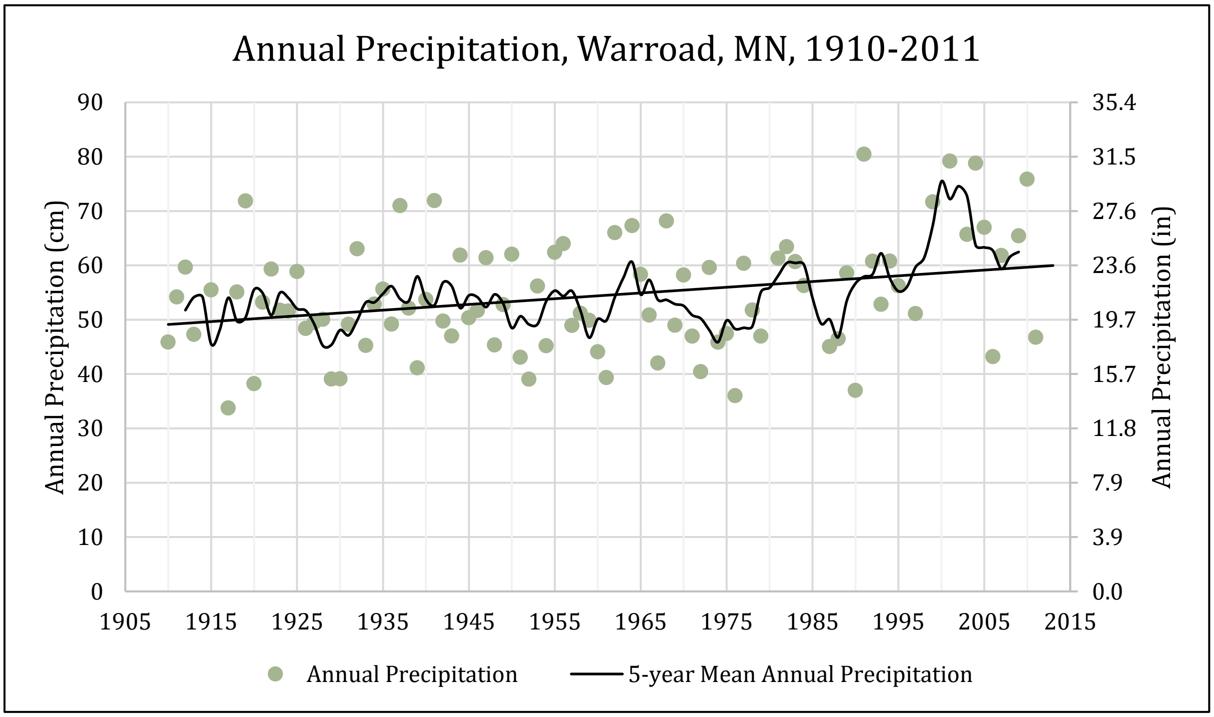


Figure 3-16. Observed Annual Precipitation for Warroad, MN, 1910–2011 (Midwestern Regional Climate Center 2016)

3.4.3 Lake Evaporation

Mean annual lake evaporation ranges from approximately 600 millimeters (mm) to 700 mm across the LoW, increasing to the south and west across the lake (den Hartog and Ferguson 1978). On average, annual lake evaporation is greater than annual precipitation (approximately 600 mm) for the LoW. Lake evaporation was estimated visually for each bay and an area-weighted mean annual evaporation from the portion of the LoW in the TMDL Study Area was calculated as 652mm (detailed data are included in Appendix G). Annual lake evaporation for the U.S. portion of the LoW was reported as less than 711 mm (28 in), with a value of approximately 559 mm (22 in) reported for evaporation from May to October (Farnsworth and Thompson 1982).

3.4.4 Wind

Wind drives lake dynamics because of the large open water expanses of the LoW. Wind data for 1996 through 2017 were obtained for Flag Island, which is located in Little Traverse Bay near the U.S./Canadian border (Iowa Environmental Mesonet 2017). These data are presented more fully in Appendix A. On an annual basis, winds from the northwestern quadrant (32%) and south-southeastern octant (24%) dominate. North and northwest winds prevail during colder months (October through May), while winds from June through September tend to be split between northwest and a tightly focused range from the south-southeast. Thus, both warm (from the south) and cool (from the north) wind patterns affect the lake and lake mixing throughout the summer season. Cooler and cold months also show more prevalent high winds (at least 20 miles per hour [mph]) than during the warm months.

3.4.5 Wind Speed and Dissolved Oxygen Concentration

During 2015, researchers from the Science Museum of Minnesota's Saint Croix Watershed Research Station (SCWRS) collected dissolved oxygen (DO) monitoring data at three buoy locations in the LoW (two in Big Traverse Bay and one in Muskeg Bay) 0.5 m (1.6 ft) above the lake bottom (Heathcote 2015). Several events that showed sustained (one week or more) DO depletion (approximately 0.4–0.5 milligrams per liter per day [mg L^{-1} d^{-1}]) were observed from June through September 2015, which suggests that approximately 16 to 20 days of continuous depletion would result in hypoxia (DO concentration of less than 2 milligrams per liter [mg L^{-1}]) assuming an initial DO concentration of 10 mg L^{-1}.

The DO concentration data (Heathcote 2015) were paired with wind speed data from Flag Island (Iowa Environmental Mesonet 2017) to investigate a possible link between wind speed and DO concentration driven by wind mixing effects. A brief analysis showed that the sustained periods of depletion are all coincident with daily mean wind speeds of approximately 5 meters per second (m s^{-1}) (11 mph) or less. The end of each of the extended depletion events coincided with at least one day of higher mean wind speed (typically 7 m s^{-1} or greater). These data suggest the importance of wind speed as a control on lake mixing and, in effect, internal P loading, which is sensitive to DO concentration at the water-sediment interface. More complete data concerning wind speed and DO concentrations are included in Appendix A.

3.4.6 Open Water and Ice Cover

The length of the open water and ice cover seasons plays a role in controlling internal lake processes. Maximum sedimentation rates occur during calm periods, including when ice cover prevents wind-driven lake mixing. The U.S. portion of the LoW has an average ice-out date of April 29 (Minnesota Climatology Working Group 2013) and average ice-on in mid- to late-November (LoW Tourism 2017), which results in an open-water period of approximately 198 days. For more than half of the year, the lake is susceptible to wind mixing and resuspension of sediment and P. Anaerobic conditions during ice-cover periods were reported in Big Traverse Bay near the Rainy River outlet in 2017 (Valipour 2018).

3.5 Rainy River

The Rainy River drains nearly 80% of the LoW Basin (and more than 87% of the TMDL Study Area) and dominates the lake's dynamics. The Rainy River originates at the Rainy Lake outlet at Fort Frances/ International Falls and flows westward for approximately 85 miles to its mouth at Wheelers Point where it enters Four Mile Bay. Rainy Lake constitutes nearly 70% of the Rainy River's drainage area; other major tributaries are the Little Fork, Big Fork, and Rapid Rivers. Figure 3-17 shows the Rainy Lake Lakeshed, the Lower Rainy River, and direct watershed drainage areas within the TMDL Study Area and basin. Areas that are not highlighted are not included in the TMDL Study Area. Mean annual discharge from the Rainy River is approximately 12,700 cubic hectometers (hm^3), which is 87% of the mean annual outflow from the LoW at Kenora (14,500 hm^3). Mean annual TP load carried to the LoW by the Rainy River is 362.7 metric tons per year (t y^{-1}), which constitutes 45% of the total load (814.9 t y^{-1}) from the TMDL Study Area. A more detailed analysis and discussion regarding the Rainy River is included in Appendix B.

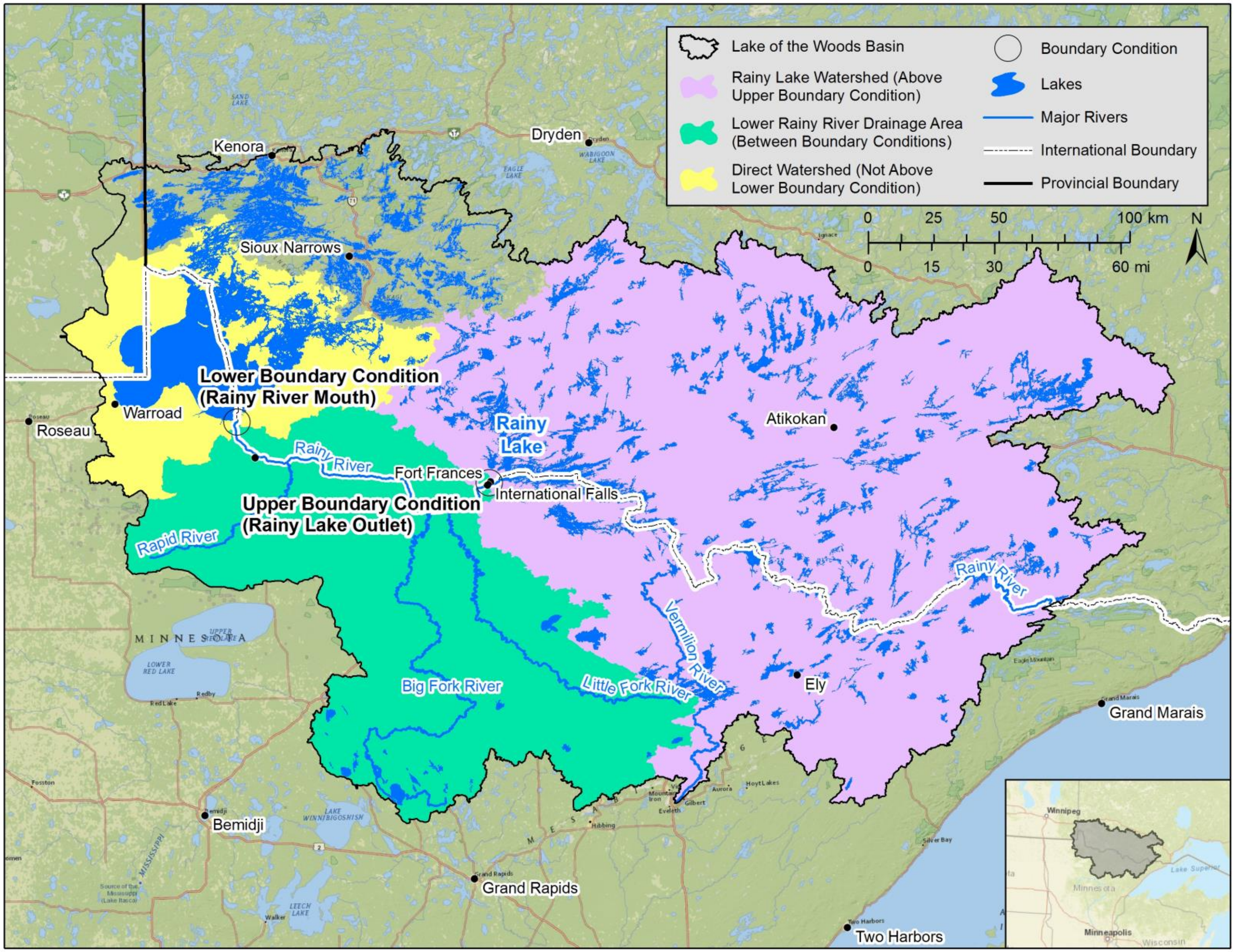


Figure 3-17. Basin with Rainy Lake, Rainy River, and Direct Watershed Drainage Areas Highlighted

3.5.1 Hydrology

The HSPF-simulated monthly mean Rainy River discharge for the study period is shown in Figure 3-18. Discharge is relatively low from September through March (500 to 830 hm^3/month), increases in April with spring runoff, peaks in June (more than 2,100 hm^3), and declines through the summer season. Approximately 57% of the Rainy River's discharge occurs from April to July. Mean summer-season discharge (5,022 hm^3) constitutes 40% of the mean annual discharge (12,739 hm^3).

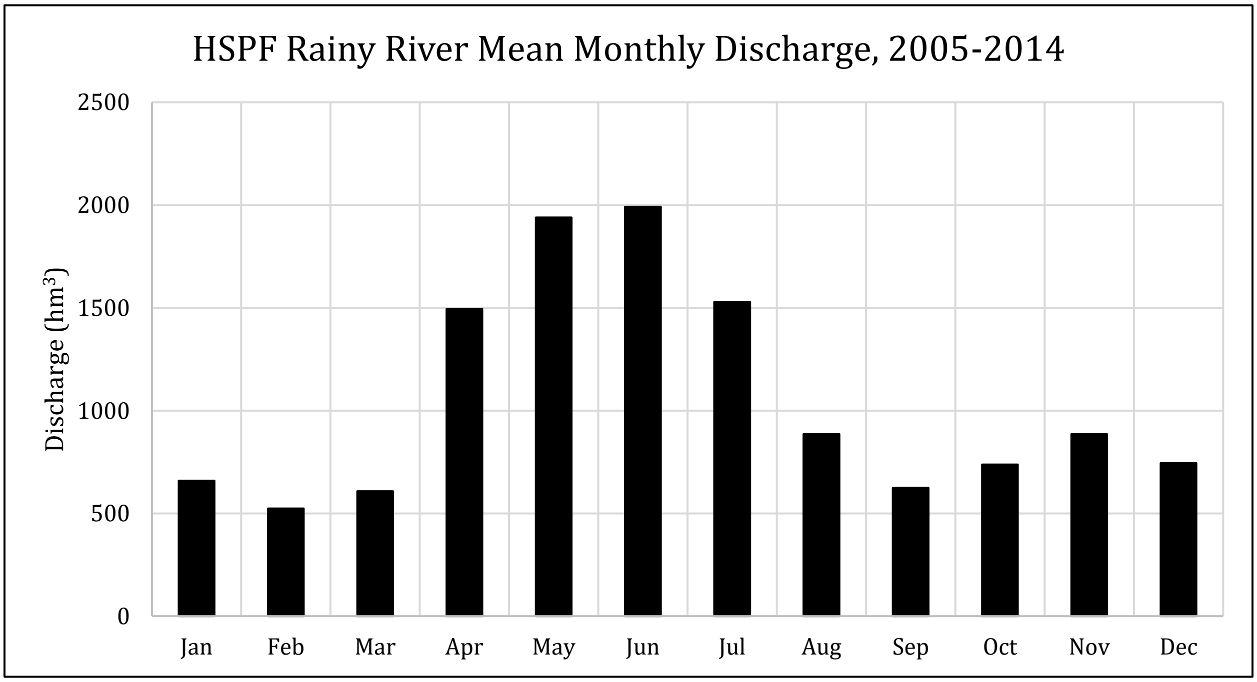


Figure 3-18. Rainy River HSPF-Simulated Mean Monthly Discharge for the TMDL Period (2005–2014)

3.5.2 Water Quality

The MPCA's North River Nutrient Region river eutrophication TP standard, which applies to the Rainy River, is 50 µg L^{-1}. The IJC has established a TP alert level of 30 µg L^{-1} for the Rainy River based on the potential for eutrophication of downstream receiving waters (Environment Canada 2014). Alert levels are used to identify potential problems in international boundary waters. The IJC's alert level is set based on the most stringent water quality guideline being used by local, state, provincial, or federal agencies – for TP in the Rainy River, the alert level is based on Ontario's Interim Provincial Water Quality Objective.

3.5.2.1 Phosphorus Loading

Mean annual Rainy River TP and dissolved P loads to the LoW of 362.7 t and 181.9 t, respectively, were estimated by HSPF for the TMDL study period. Monthly P loads peaked in April and May, followed by a decline through the summer season. Approximately two-thirds of annual P loading occurs from April to July. The HSPF-estimated, flow-weighted mean TP and dissolved P concentrations of 28 µg L^{-1} and 14 µg L^{-1}, respectively, are consistent with recent MPCA monitoring data and Environment Canada monitoring data from 2009 to 2011 from the Rainy River at Oak Groves, Ontario (Environment Canada 2014). The MPCA's Watershed Pollutant Load Monitoring Network estimated a mean annual TP load of 374.8 t and a flow-weighted mean TP concentration of 33 µg L^{-1} for 2010 through 2015 for the Rainy River at Manitou Rapids, which is located approximately 74 river km (46 river mi) upstream of Four Mile Bay and thus does not include the entire Rainy River Basin.

3.5.2.2 Historical Water Quality

Historically, the pulp and paper plants in Fort Frances and International Falls and the WWTPs located along the Rainy River discharged organic waste (e.g., wood chips and fine-fiber particulate matter) and dissolved organic compounds into the Rainy River. Historical loads from the Rainy River have been calculated at 1,000 t/yr, with a large decline occurring after the 1970s (Hargan 2011). These pollutant loads were significantly reduced as a result of wastewater treatment upgrades, which resulted in reductions of 5-day biological oxygen demand (BOD_5) loading by the mid-1980s (Beak Consultants Limited 1990). Beak Consultants Limited (1990) summarized shifts in benthic biology from 1969 to 1983 due to reduced wood solids loading to the Rainy River and the LoW. A degraded zone was identified well into Big Traverse Bay in 1969; wood fibers were noted in lake sediments and benthic species included pollution-tolerant species such as the sludge worm (*Limnodrilus hoffmeisteri*), midge larva (*Chrionomus*), and the amphibod *Asellus.*

Data reported by Beak Consultants Limited (1990) show decreased pollutant concentrations from the 1950s to the 1980s. The TP and BOD_5 concentrations in the 1980s were reduced by approximately 65% and 75% from their respective 1950s values. Reductions were also reported for nitrogen (total Kjeldahl nitrogen [TKN] and nitrogen+nitrate [NO_3]), total suspended solids (TSS), and iron (Fe). Historical TP concentrations and ranges generally agreed with back-calculated TP values based on historical BOD_5 data. Present-day, flow-weighted mean concentrations at Wheelers Point, Minnesota, vary from about one-fourth to one-third of 1950s to 1970s arithmetic means reported by Beak (1990) for the site near Baudette, Minnesota.

The TMDL study reviewed data from 43 TP, 45 BOD_5, and 45 TSS samples collected from 1974 to 1977, under the MPCA's Routine River Monitoring Program at a Rainy River site west of International Falls, Minnesota, (off of Shorewood Drive) (MPCA 2016a). The TP, BOD_5, and TSS arithmetic means were higher than 1970s values reported by Beak Consultants Limited (1990) for the site near Baudette, Minnesota. The TP concentrations from 1979 through 1985 at Oak Groves, Ontario reported by Environment Canada (2014) are consistent with TP concentrations from the 1980s reported by Beak (1990) for the site near Baudette, Minnesota.

3.6 Water Quality Data

Water quality data for the LoW are summarized in the following sections. Lake eutrophication standard parameters (TP, Chl-*a*, and Secchi disk depth) are included along with DO concentration, temperature profiles, lake Chl-*a* response, and the Trophic Standard Index (TSI). Available data for the study period were obtained from the MPCA, Ontario Ministry of the Environment and Climate Change (OMECC), and EPA. Data obtained from EPA were collected by the Red Lake Department of Natural Resources. Data from OMECC were obtained for Sabaskong Bay only.

The TP, Chl-*a*, and TSS concentrations, Secchi disk, and turbidity data for the five bays of the LoW were summarized as summer-average values for the study period (2005 through 2014) and are shown in Table 3-7. A more detailed summary of water quality parameters is provided in Appendix D.

Table 3-7. Study period summer-average (June – September) water quality parameter values (2005 - 2014).

Bay	TP Concentration ($\mu g\ L^{-1}$)	Chl-*a* Concentration ($\mu g\ L^{-1}$)	Secchi Disk Depth (m)	Turbidity (FNU)	TSS Concentration ($mg\ L^{-1}$)
Sabaskong	26.9	6.4	1.3	No data available	
Four Mile	33.0	5.2	1.3	2.8	10.5
Muskeg	37.7	12.2	1.1	2.9	9.3
Big Traverse	35.7	9.3	1.2	3.7	7.8
Little Traverse	33.6	9.5	1.4	3.5	8.7

FNU = Formazin Nephelometric Unit.

3.6.1 Phosphorus

Mean monthly TP concentrations by bay are summarized in Figure 3-19, with the lake eutrophication standard of ≤ 30 $\mu g\ L^{-1}$ plotted in red. Big Traverse, Little Traverse, and Muskeg bays' mean TP concentrations increase from June values at or near the water quality standard to August concentrations ranging from 39 $\mu g\ L^{-1}$ (Little Traverse) to 50 $\mu g\ L^{-1}$ (Big Traverse). Each bay's mean TP concentration declines in September, except for Muskeg which reaches its peak summer mean monthly concentration of 50 $\mu g\ L^{-1}$ in September. In contrast, Four Mile Bay monthly mean TP concentrations vary from 30 to 35 $\mu g\ L^{-1}$ throughout the summer season with a peak value of 35 $\mu g\ L^{-1}$ in July.

3.6.2 Chlorophyll-a

Because of the naturally low transparency in the LoW in some basins early in the growing season, Chl-*a* is the primary response variable used to express high levels of algae due to eutrophication. Mean monthly Chl-*a* concentrations by bay are summarized in Figure 3-20, with the lake eutrophication standard of ≤ 9 $\mu g\ L^{-1}$ plotted in red. No mean monthly values exceed the water quality standard of 9 $\mu g\ L^{-1}$ in June or July. Mean monthly concentrations in Muskeg and Big Traverse Bays more than double from July to August and then plateau from August to September. Little Traverse Bay Chl-*a* concentrations increase by approximately 75% from July to August, followed by an approximately 50% reduction from August to September. The monthly pattern of Chl-*a* fluctuation in Four Mile Bay is muted compared to the fluctuations observed in other bays, as was the case with its monthly TP fluctuation. Four Mile Bay was the only segment with all four monthly values below the lake eutrophication standard, likely due to its low residence time (less than one day) and bog-stained waters, both of which limit algal growth.

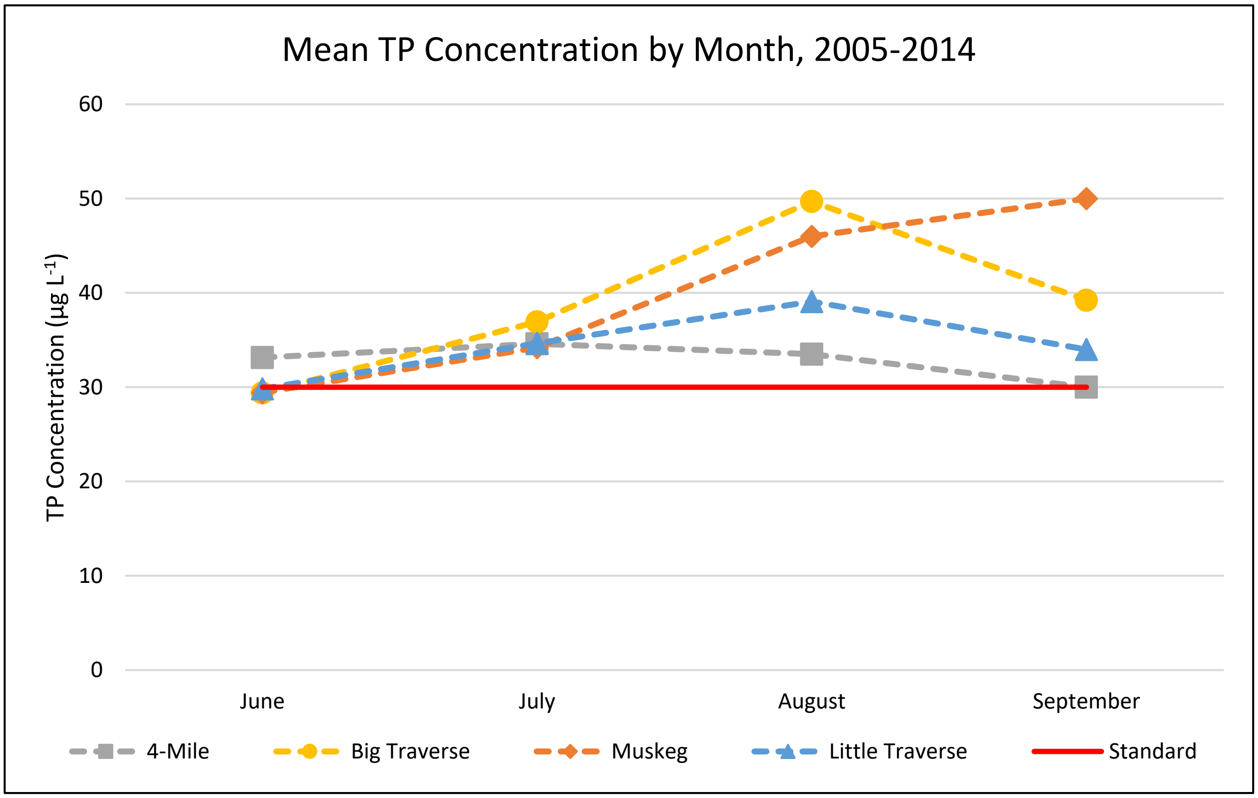


Figure 3-19. Mean Monthly TP Concentration, 2005–2014. The red line represents the TP standard of ≤30 µg L^{-1}

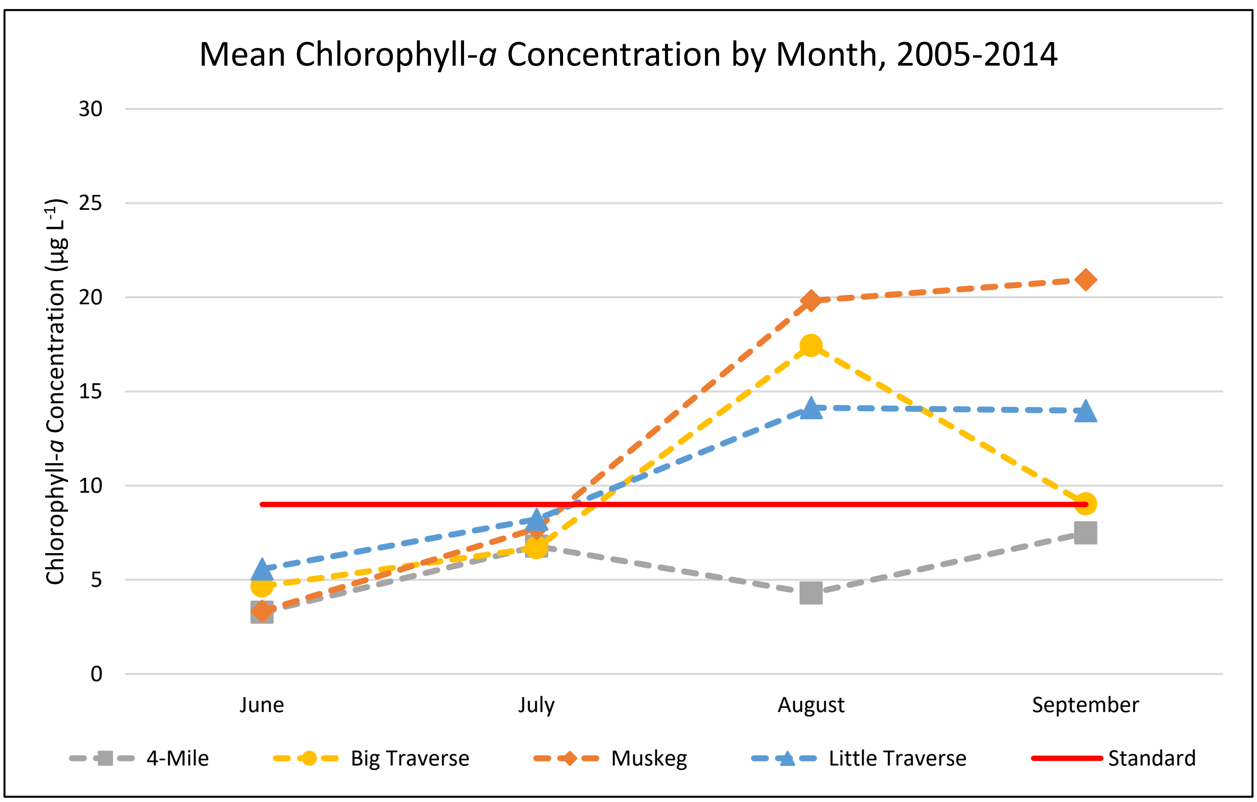


Figure 3-20. Mean Monthly Chl-*a* Concentration, 2005–2014. The red line represents the Chl-*a* standard of ≤9 µg L^{-1}

3.6.3 Secchi Depth

Mean monthly Secchi disk depths by bay are summarized in Figure 3-21 with the lake eutrophication standard of ≥ 2.0 m plotted in red. Mean monthly Secchi disk depths exceeded the standard of 2.0 m for all months and bays. Values for all bays generally worsen throughout the summer season, with the exception of increased transparency in Little Traverse Bay from July through September. Transparency may be influenced by summer season mean TSS concentrations (Appendix D, Table D-1) that are higher (by a factor of 4 to 5) than the 75th percentile value (2 mg L^{-1}) for reference lakes in the NLFs ecoregion (Heiskary and Wilson 2005). Higher TSS concentrations reduce light transmission and Secchi transparencies accordingly. Dissolved organic matter (referred to as bog stain) further limits the ability of the LoW to achieve the transparency standard.

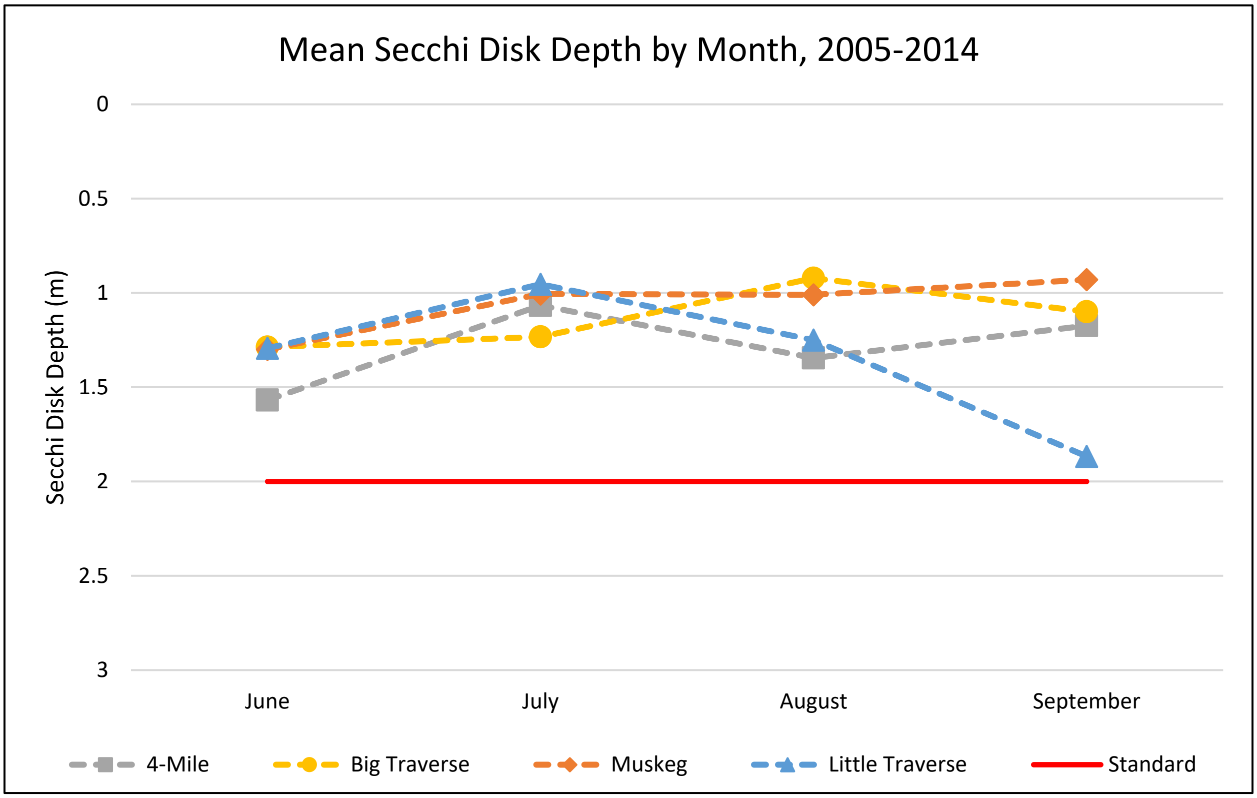


Figure 3-21. Mean Monthly Secchi Disk Depth, 2005–2014. The red line represents the Secchi depth standard of ≥2.0 meters

3.6.4 Temperature and Dissolved Oxygen

Available temperature and DO data from 1999 through 2010 were examined to understand lake mixing patterns, which affect biological responses and lake P dynamics. Lake bottom water temperature and DO concentration impact internal P loading and are important for characterizing in-lake nutrient dynamics. A detailed summary of data is included in Appendix D. Data that predate the study period (2005 through 2014) were included to allow a more complete understanding of lake characteristics. Temperature and DO data were noted to have been collected concurrently.

Sport fisheries generally require DO concentrations of at least 5 mg L^{-1}. Only one of the 1,467 DO concentration observations from 1999 through 2010 was below 5 mg L^{-1}. The DO concentrations were generally 7 mg L^{-1} or greater; DO depletion with depth was most pronounced in Little Traverse Bay because of reduced mixing of the lake profile. Data suggest that Four Mile, Muskeg, and Big Traverse Bays are well mixed and Little Traverse Bay is less well mixed, likely because this bay has deeper waters than other bays in the TMDL Study Area.

3.6.5 Algal Bloom Frequencies

Lake eutrophication standards were developed based on Minnesota lake data statistics for the summer season based on surface grab samples (shallow lakes) and integrated samples (deeper lakes), as defined by the MPCA's Standard Operating Procedure ([SOP] MPCA 2015b). Autumn algal bloom sampling data, including bloom frequency distributions, were not factored into the lake standards development. Muskeg Bay (and to a lesser extent Big Traverse Bay) was noted to have Chl-*a* concentrations from 30 µg L^{-1} to 60 µg L^{-1} more frequently than historical distributions (Heiskary and Walker 1988; Heiskary and Wilson 2005) that were used to develop lake eutrophication standards. The increase in frequency of Chl-*a* concentrations above 30 µg L^{-1} is likely caused by the prevalence of cyanobacteria, particularly *Aphanizomenon*, which were noted by U.S. and Canadian monitoring efforts (Environment Canada 2014). Concurrently monitored TP concentrations may be influenced by cyanobacterial dominated blooms as they accumulate at or near the water surface.

Figure 3-22 depicts the observed distribution of the LoW summer-season, surface water, Chl-*a* concentrations (µg L^{-1}) provided by the MPCA (MPCA 2016b). This distribution is similar to summer-season, Chl-*a* bloom frequencies that are defined from statewide mean Chl-*a* concentrations (Heiskary and Walker 1988). For typical Minnesota lakes, the monitored, summer average Chl-*a* concentrations of 5 µg L^{-1} to 10 µg L^{-1} suggest a relatively low (less than 5%) exceedance of 20 µg L^{-1} Chl-*a*, which are considered nuisance or severe nuisance blooms. As noted in Figure 3-22, nuisance and severe nuisance levels occurred in the LoW in less than 5% of summer samples. Algal blooms in excess of 40 µg L^{-1} were also noted in the LoW in approximately 3% of samples, which is a higher frequency than suggested by Heiskary and Walker's (1988) frequency distribution. Late summer and autumn algal blooms indicate the presence of cyanobacteria, *Aphanizomenon*, which has been noted to have both warmer (summer) and cold water (autumn) growth phases (Yamamoto 2009).

3.6.6 Trophic State Indices

Following the work of Dillon and Rigler (1974) and Jones and Bachmann (1976) that found statistical linkages of lake Chl-*a* and TP, the interrelationships of lake nutrients (P) and lake responses (Chl-*a* and Secchi transparency) have been extensively investigated over the past several decades. Carlson (1977) used these defined relationships to develop a numerical trophic state index (TSI) for TP (TSI-TP), Chl-*a* (TSI-Chl), and Secchi (TSI-SD). Each increase of 10 TSI units represents a doubling of TP or halving of Secchi transparency, while Chl-*a* concentrations double with every seven TSI units (Carlson 1980). Similar TSI values are expected for each of the three parameters if typical interrelationships are evident. Differences among variables indicate that other potential causal factors may be present.

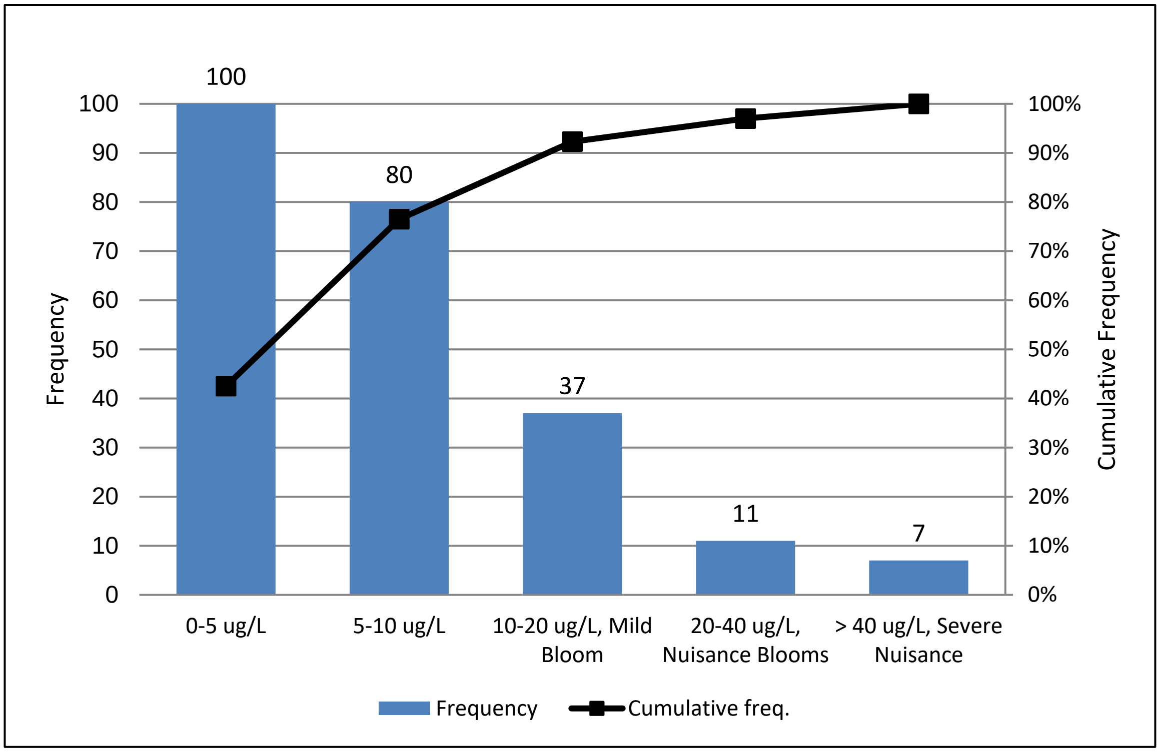


Figure 3-22. Epilimnetic Lake of the Woods Chl-*a* Data, 1999–2010. Graphic provided by MPCA (2016)

The TSI values were calculated by using Carlson's TSI equations (1980) and are based on summer-average values by bay for the TMDL study period; TSI values by bay are plotted in Figure 3-23. Comparing the calculated TSI-TP, TSI-Chl, and TSI-SD values shows TSI-SD values are higher than TSI-TP or TSI-Chl by 34 to 49 units for all bays except Sabaskong. Higher TSI-SD values suggest reduced light transmission from the collective impacts of suspended solids, color, and organic material, including algae. Meanwhile, the similar values calculated for TSI-TP and TSI-Chl for each bay indicate consistency with typical TP/Chl-*a* relationships. Sabaskong Bay shows good agreement between all three TSI parameters, which indicates more typical TP/Chl-*a*/Secchi disk interrelationships.

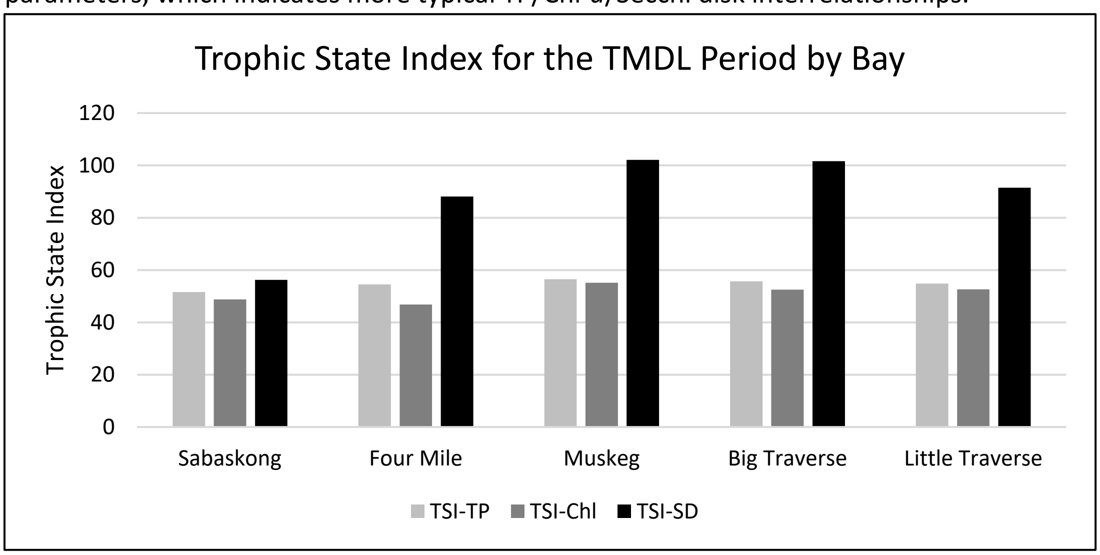


Figure 3-23. 2015 Trophic State Indices for the Lake of the Woods by Bay

3.7 Water Quality Trends

No evidence of detectable trends for water clarity was found for the years 1993 to 2012 for both the LoW Main Basin (39-0002-01) and Four Mile Bay (39-0002-02) (MPCA 2018). The Rainy-LoW State of the Basin Report (2^{nd} Edition) (Clark et al. 2014) noted no significant trend for Chl-*a* within the LoW, with the exception of an increasing trend at the Monkey Rocks site in Little Traverse Bay. Clark et al., (2014) also noted no temporal change between 1980s to 2000s data with samples from all the LoW sites pooled.

3.8 Lake Biological Data

3.8.1 Fish Community

Tourism is an economic driver in the LoW Basin, with annual angler-hours of 1,750,000 to 2,750,000 reported for the LoW (DNR 2015). The LoW has a fishery primarily known for its walleye, sauger, and lake sturgeon, with yellow perch and northern pike also present. Lake sturgeon are also present in the LoW-Rainy River system; although the population is recovering from a period of low abundance caused by overharvest and pollution. Tullibee (cisco) are also present and are an important food forage for walleye and northern pike. Tullibee can be an indicator of lake water quality because they are vulnerable to both DO depletion and temperature increases. As DO is depleted in deep, cool areas of lakes, tullibee are forced upward to warmer water where DO concentrations are higher. Tullibee mortality can occur if the combination of high water temperature and low DO concentrations creates too much stress on the fish.

The LoW and the Rainy River received infested waters designations in 2007 because of the presence of spiny waterflea (*Bythotrephes longimanus*) (DNR 2018a). Rusty crayfish (*Orconectes rusticus*) were documented in the Minnesota portion of the LoW in 2006 (DNR 2018b).

3.8.2 Aquatic Plants

No recent, published aquatic plant surveys are available. The Ontario LoW Fisheries Assessment Unit mapped critical fish habitat in Canadian portions of the lake in the early 1990s, but this information is not readily available.

3.9 HSPF Model Methodology

An HSPF model is a comprehensive watershed computer model of hydrology and water quality that includes modeling surface and subsurface hydrologic and water quality processes, which are linked and closely integrated with corresponding stream and reservoir processes. The HSPF framework can be used to determine the critical environmental conditions (e.g., certain flows or seasons) in a watershed by providing continuous flows and pollutant loads at any point within the system. An HSPF model simulates the fate and transport of modeled pollutants and can simulate subsurface concentrations in addition to surface concentrations (where appropriate). The following sections provide more detail on the source assessment approach and provide the quantitative results of the source load assessment described in greater detail by McCutcheon (2011a, 2011b, 2011c, 2012a, 2012b, 2014a, 2014b); Kenner (2014), Ackerman (2015), and Lupo (2015a, 2015b, 2016). The primary components of developing an HSPF model application include gathering and developing time-series data, segmenting and characterizing the watershed, and calibrating and validating the model. As discussed below, nine separate, linked HSPF models were created to represent the LoW Basin because of its size. The HSPF model boundaries within the Low Basin are shown in Figure 3-24.

3.9.1 Gathering and Developing Time-Series Data

Data required to develop and calibrate HSPF models are both spatially and temporally extensive. The modeling period in the LoW Basin is 1995 to 2014. Time-series data that were used to develop models included meteorological data, atmospheric deposition data, and point-source data. Precipitation, potential evapotranspiration, air temperature, wind speed, solar radiation, dew-point temperature, and cloud cover data are required to simulate hydrology (including snow-related processes).

3.9.2 Segmenting and Characterizing the Watershed

Because of the size of the LoW Basin, nine separate HSPF models (shown in Figure 3-24) were created to represent smaller areas of the basin. The HSPF model boundaries were based largely on HUC-8 boundaries in the U.S.; model boundaries in Canada were created using ArcHydro. Note that the IJC's harmonized boundaries for the LoW Basin were not available when HSPF modeling work began; therefore, differences exist between HSPF model boundaries and the IJC's harmonized boundaries. Four of the nine HSPF models drain to Rainy Lake; the Rainy River receives runoff from Rainy Lake and an additional three HSPF models. The remaining two HSPF models represent the LoW, its lakeshed, and smaller tributaries. A total of 1,022 subwatersheds were delineated within these 9 HSPF models to capture hydrologic and water quality variability.

Within each HSPF model, the basin was segmented into individual land areas and channel segments that are assumed to demonstrate relatively homogeneous hydrologic, hydraulic, and water quality characteristics. This segmentation provides the basis for assigning inputs and/or parameter values or functions to remaining portions of a land area or channel length contained in a model segment. The individual land and channel segments are linked together to represent the entire project area.

Land segmentation was defined by land cover and soil hydrologic group. Land use and land cover affect the hydrologic and water quality response of a watershed through their impact on infiltration, surface runoff, and water losses from evapotranspiration. Water movement through the system is affected by land cover. Land use (as estimated by land cover) affects the rate of pollutant accumulation because certain land uses often support different pollutant sources.

As discussed in Section 3.3.4, UMN-RSGAL land cover data (Olmanson 2015) were combined into 12 groups with similar characteristics and integrated with riparian areas according to Figure 3-25. Urban categories were divided into pervious and impervious areas based on an estimated percentage of effective impervious area. The term "effective" implies that the impervious region is directly connected to a local hydraulic conveyance system (e.g., open channel and river), and the resultant overland flow will not run onto pervious areas but will directly enter the reach network.

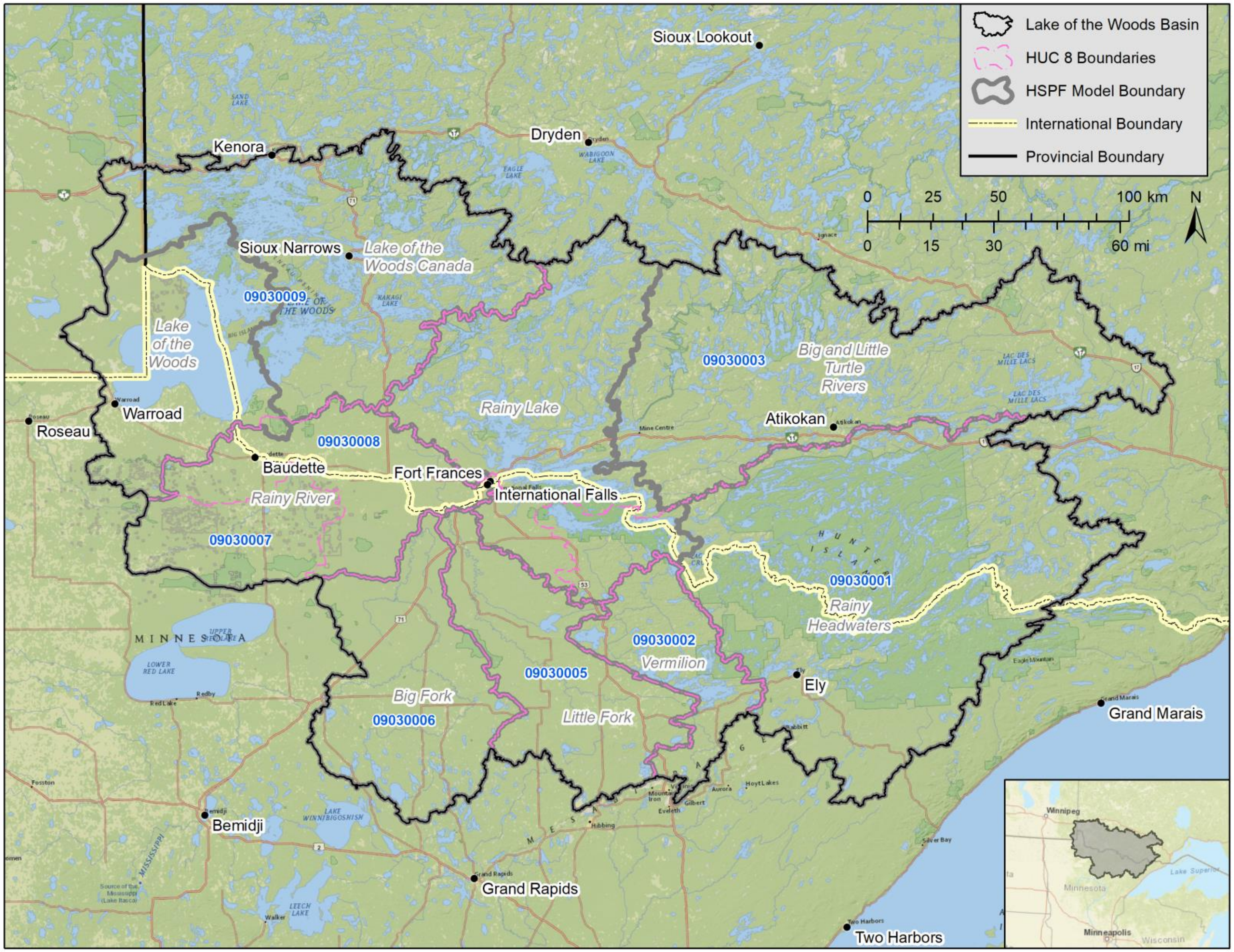


Figure 3-24. HSPF Model Boundaries within the Lake of the Woods Basin

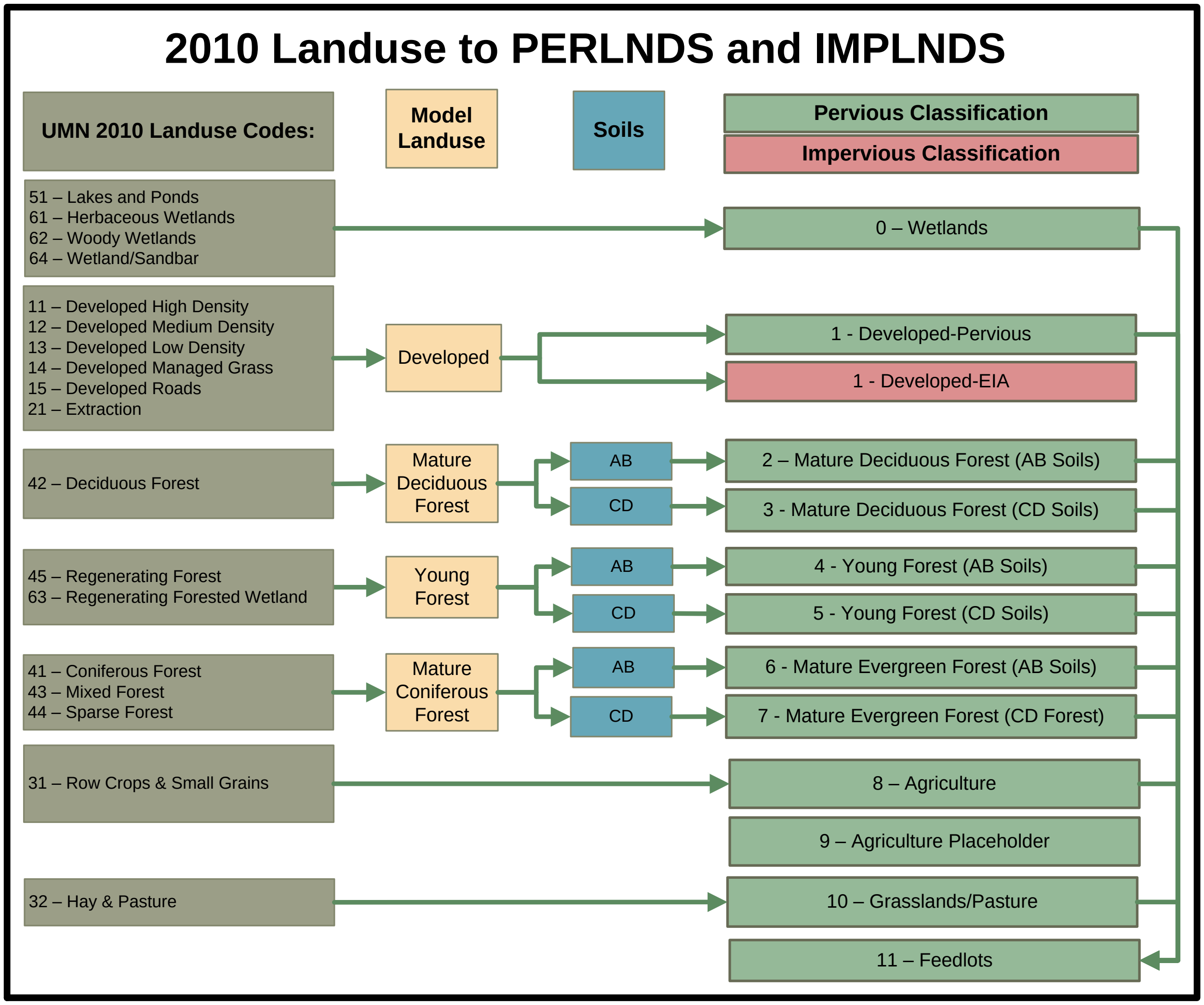


Figure 3-25. Land Cover Category Aggregation Schematic

The channel segmentation considers river travel time, riverbed slope continuity, temporal and spatial cross section, morphologic changes or obstructions, the confluence of tributaries, impaired reaches, and locations of flow and water quality calibration and verification gages. After the reach network was segmented, hydraulic characteristics of each reach were computed, and the areas of the land cover categories that drain to each reach were calculated. Reach hydraulics are specified by a reach function table (F-table), which contains the reach surface area, volume, and discharge as functions of depth. F-tables were developed for each reach segment by using channel cross-sectional data. Unsurveyed tributaries were assigned the geometry of hydraulically similar channels.

3.9.3 Model Calibration and Validation

Model calibration involved hydrologic and water quality calibration by using observed flow and water quality data to compare to simulated results. Because water quality simulations depend highly on watershed hydrology, the hydrology calibration was completed first, followed in order by calibration of sediment, temperature, and nutrient/oxygen/Chl-*a*. Stream discharge sites with time-series data were used for the calibration and validation. Data from all but the first year of the simulation period were used to calibrate the model. The initial year (1995) was simulated for the model to adjust to existing conditions. The 19-year simulation period included a range of dry and wet years. This precipitation range improves the model calibration and provides a model application that can simulate hydrology and water quality for a range of climatic conditions.

Hydrologic calibration is an iterative process intended to match simulated flow to observed flow by methodically adjusting model parameters. The HSPF hydrologic calibration is divided into four sequential phases of adjusting parameters to improve model performance relating to annual runoff, seasonal or monthly runoff, low- and high-flow distribution, and individual storm hydrographs. By iteratively adjusting calibration parameters within accepted ranges, the simulation results are improved until an acceptable comparison of simulated results and measured data is achieved. The procedures and parameter adjustments involved in these phases are more completely described in Donigian et al. (1984) and Lumb et al. (1994). Maintaining a high-quality calibration at multiple gages during the entire simulation, while also maintaining consistent model parameters throughout the watershed served as the basis for the model validation.

The hydrology calibration was evaluated by using a weight-of-evidence approach based on a variety of graphical comparisons and statistical tests. The performance criteria are described in more detail in Donigian (2002). Graphical comparisons included monthly and average flow-volume comparisons, daily time-series data comparisons, and flow-duration plots. Statistical tests included annual and monthly runoff errors, low-flow and high-flow distribution errors, and storm-volume and peak-flow errors. The flow calibration time series from Rainy River at Manitou Rapids is shown in Figure 3-26.

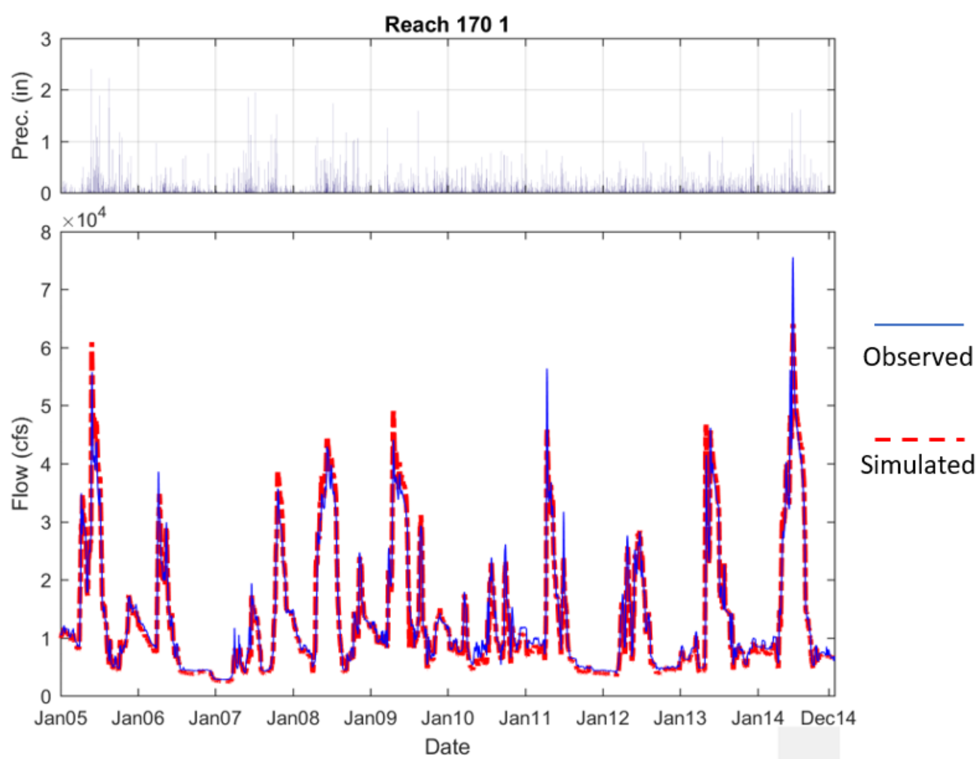


Figure 3-26. Flow Time Series on the Rainy River at Manitou Rapids.

The water quality calibration optimized alignment between the loads that were predicted to be transported throughout the system and the observed in-stream concentrations. Water quality data from monitoring sites were used to calibrate the model to observed conditions. Many parameters can be adjusted to calibrate water quality loads and concentrations. The TP concentration calibration time series from Rainy River near Manitou Rapids is shown in Figure 3-27. More detailed information on the HSPF model application and model calibration results (hydrology and water quality) can be found in the LoW project modeling memos (McCutcheon 2011a, 2011b, 2011c, 2012a, 2012b, 2014a, 2014b; Kenner 2014; Ackerman 2015; Lupo 2015a, 2015b, 2016).

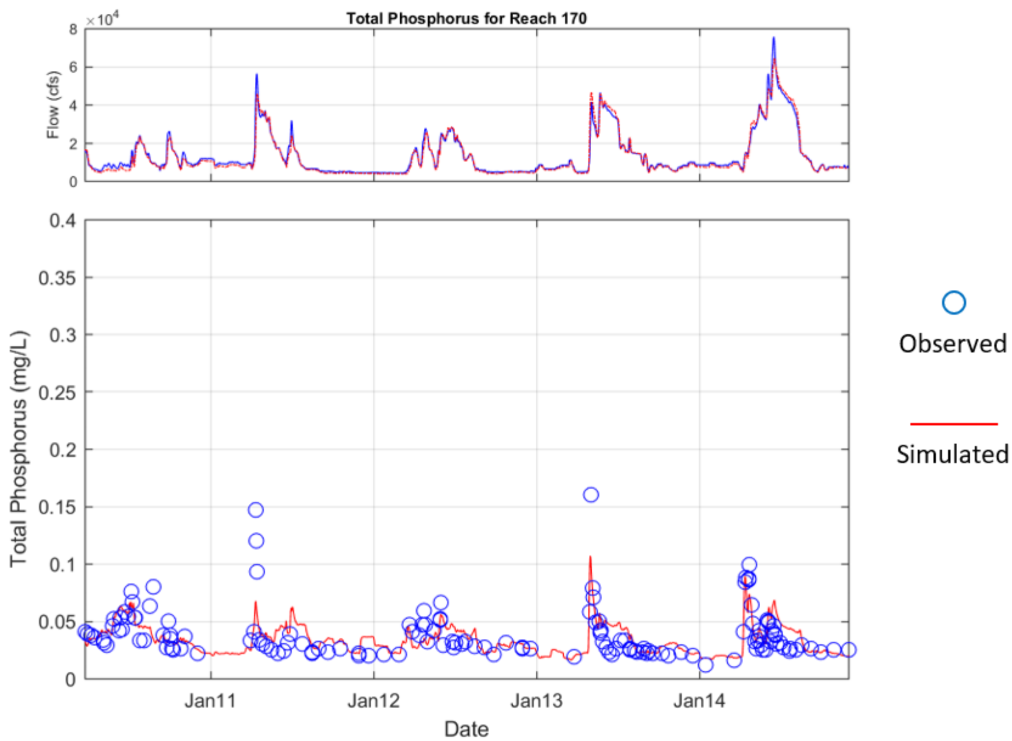


Figure 3-27. TP Concentration Time Series for the Rainy River Near Manitou Rapids (S006-897)

3.10 Phosphorus Source Summary

A general description of P sources and potential sources, both natural and anthropogenic, within the TMDL Study Area, focusing mainly on the TMDL Restoration Area, is included in the following sections. More detailed information relating to P sources, loads, and required reductions is provided in Chapter 4 and in appendices as noted in the text.

3.10.1 Permitted Sources

Permitted (point) sources in this TMDL study are permitted entities with identifiable discharges to surface waters of Minnesota that are regulated by NPDES/SDS permits. These sources include the following:

1. Domestic wastewater;

2. Industrial wastewater;
3. Industrial stormwater;
4. Construction stormwater;
5. CAFOs; and
6. MS4s.

3.10.1.1 Domestic Wastewater (NPDES/SDS)

Domestic wastewater treatment plants (WWTP) that discharge to waters of Minnesota are regulated by NPDES/SDS permits, which are administered by the MPCA. A total of 14 domestic WWTPs exist within the TMDL Restoration Area. Four WWTPs, permitted by the Ontario Ministry of Environment, Conservation, and Parks, are found within the Canadian portion of the TMDL Study Area not above the upper boundary condition (Lupo 2015b).

3.10.1.2 Industrial Wastewater (NPDES/SDS)

Industrial wastewater discharges to waters of Minnesota are also subject to NPDES/SDS permits. Five industrial wastewater sources exist within the TMDL Restoration Area, including a paper mill in International Falls, Minnesota, and taconite mines in the headwaters of the Little Fork River. One of the five U.S. permitted industrial wastewater sources (Berger Horticultural Products – Pine Island Bog) has not yet discharged. Berger Horticultural Products original permit was issued in 2003. When reissued, Berger's permit will contain a P effluent limit consistent with the TMDL study's LA. The pulp and paper mill in Fort Frances, Canada, is the only industrial wastewater source within the Canadian portion of the TMDL Study Area that is below the upper boundary condition. Although this mill has been idle since November of 2012, periodic discharges of the wastewater pond occur as a result of stormwater, sumps, and landfill leachate. An additional Canadian industrial wastewater source, New Gold Mine, has not yet discharged and is included in the RC portion of this study. As reported to the MPCA, New Gold Mine intends to recycle all their water and plans only to discharge during unusual operating circumstances. The New Gold Mine is permitted by Ontario Ministry of Energy, Northern Development and Mines.

3.10.1.3 Industrial Stormwater (NPDES/SDS)

Industrial stormwater runoff is a regulated source as defined by the MPCA's reissued Multi-Sector Industrial Stormwater NPDES/SDS General Permit (MNR050000), which applies to facilities with Standard Industrial Classification Codes in ten categories of industrial activities with the potential for significant materials and activities exposed to stormwater and that may leak, leach, or decompose and be carried off site. Facilities can obtain a no exposure exclusion if the site's operations occur under-roof. The permittee is required to develop and implement a stormwater pollution prevention plan (SWPPP) that details stormwater best management practices (BMP) implemented to manage stormwater at the facility. Permitted facilities are also required to perform runoff sampling. The MPCA's (2017a) records were reviewed, and 14 permitted facilities not covered under no exposure exclusions were identified within the TMDL Restoration Area; these facilities are listed in Appendix E.

3.10.1.4 Construction Stormwater (NPDES/SDS)

Runoff from construction sites is a regulated source as defined by the MPCA's General Permit Authorization to Discharge Stormwater Associated with Construction Activity under the NPDES/SDS Program (Permit MNR100001). Exposed soil surfaces from construction sites can be eroded, and particle-bound P can be carried away from construction sites. Permits are required for construction activities that disturb the following:

1. One acre or more of soil; or
2. less than one acre if:
   a. The area is part of a 'larger common plan of development or sale' larger than one acre.
   b. The MPCA determines that the activity poses a risk to water resources.

3.10.1.5 Confined Animal Feeding Operations (NPDES/SDS)

A feedlot, or concentrated animal feeding operation (CAFO), is subject to regulation under an NPDES/SDS permit if it meets federal large CAFO thresholds, which vary by animal type (e.g., 700 or more mature dairy cows) and discharges to a water of the U.S. (MPCA 2015c). When NPDES/SDS permit thresholds are not met, an SDS permit may be required if the number of animal units exceeds 1,000 (MPCA 2015c). The MPCA's data (MPCA 2017b) showed no feedlots that exceed large CAFO (NPDES/SDS) or SDS permit thresholds within the TMDL Restoration Area. Because none of the feedlots meet the NPDES/SDS permit thresholds, no CAFO load was included in this study. The MPCA's data summarizing the number of feedlots and total animal count in the TMDL Study Area are included in Appendix E.

3.10.1.6 Municipal Separate Storm Sewer Systems (NPDES/SDS)

Municipal stormwater permits are required for specified Phase II cities defined as MS4s by permit (General Permit Authorization to Discharge Stormwater Associated with Small MS4 Under the NPDES/SDS) (MNR040000). The MS4s are defined by the MPCA as conveyance systems (roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, and storm drains) that are owned or operated by a public entity such as a state, city, town, county, district, or other public body. Runoff from rainfall and snowmelt carries pollutants to storm sewer conveyances. Loading is largely influenced by the amounts and distribution of impervious areas such as roof tops, sidewalks, driveways/parking lots, streets, and other compacted surfaces. Lawns, soils, grass clippings, organic debris, road surface particles, vehicular debris, eroded soil particles, pet and wildlife wastes, and atmospheric deposition are all potential P-containing substances. The Hibbing, Minnesota, MS4 is the only regulated MS4 located in the TMDL Restoration Area and is located in the headwaters of the Little Fork River. The city of International Falls is expected to be subject to an MS4 permit in the future as it is a city with a population greater than 5,000 people that drains to an impaired water (LoW); as a result, a WLA was assigned to the city of International Falls to account for coverage under a future MS4 NPDES/SDS permit.

3.10.2 Nonpermitted Sources

Nonpermitted sources (also referred to as nonpoint sources) of P result from both natural processes and anthropogenic effects. Nonpoint loading tends to be diffuse in comparison to permitted sources. Nonpoint sources range from natural background conditions (loading from undisturbed areas such as wetlands or forests) to more intense land uses (e.g., roads, urban areas, and agricultural areas) that produce stormwater runoff with higher nutrient levels. The following nonpermitted sources of P were considered in this study:

1. Tributary loading;
2. Direct lakeshed loading;
3. Shoreline erosion loading;
4. Subsurface sewage treatment systems (SSTSs);
5. Atmospheric deposition; and
6. Internal P loading.

3.10.2.1 Tributary Loading

While tributaries carry P from both nonpoint sources (i.e., watershed runoff) and upstream point sources (permitted sources) to the LoW, tributary loading, as discussed in this section, is only the nonpoint portion of that load (i.e., excluding loads that originate from permitted sources). Nonpoint loading occurs as a result of rainfall-runoff processes that can detach and transport sediment and associated P, and transport dissolved P to downstream waters. Susceptibility to detachment and erosion by rainfall-runoff processes depends on land use because more disturbed land uses (e.g., agriculture) will generally produce more runoff and P loads than more natural land uses (e.g., forest). Soil types also play a role in the amount of runoff and P that are delivered to a stream and carried downstream. Tributary loading can also include P loading associated with channel bed and bank sediment loads.

3.10.2.2 Direct Lakeshed Loading

Direct lakeshed loading is similar to tributary loading in that it depends on land use and soil types; however, it originates closer to the lakeshore and is typically carried either overland to the lake or through smaller streams than those included in tributary loading. The direct lakeshed drainage area is shown in Figure 3-28.

3.10.2.3 Shoreline Erosion Loading

Shoreline erosion loading is P loading associated with shoreline erosion. Shoreline erosion can be caused by various factors, including wave action, runoff, ice, and wind.

3.10.2.4 SSTSs

Septic systems, or SSTSs, treat sewage from homes and businesses that are not served by domestic WWTPs.

3.10.2.5 Atmospheric Deposition

Atmospheric deposition of P on the lake surface is an important part of the lake P budget because of the large surface area of the LoW. Atmospheric deposition occurs in both wet (carried by precipitation) and dry (dry particles carried as dust) forms. Unlike other nonpoint sources, such as watershed runoff or septic loading, atmospheric P deposition originates outside of the basin and cannot be controlled.

3.10.2.6 Internal P Loading

Lake nutrient cycling (or internal loading) refers to several processes that can result in P release into the water column where it is available for algal growth. The P is released from lake sediments in both aerobic and anaerobic conditions as moderated by amounts of available iron and other factors such as legacy loading. Resuspension of sediments that result from wind mixing may cause resuspension of particulate and loosely associated P.

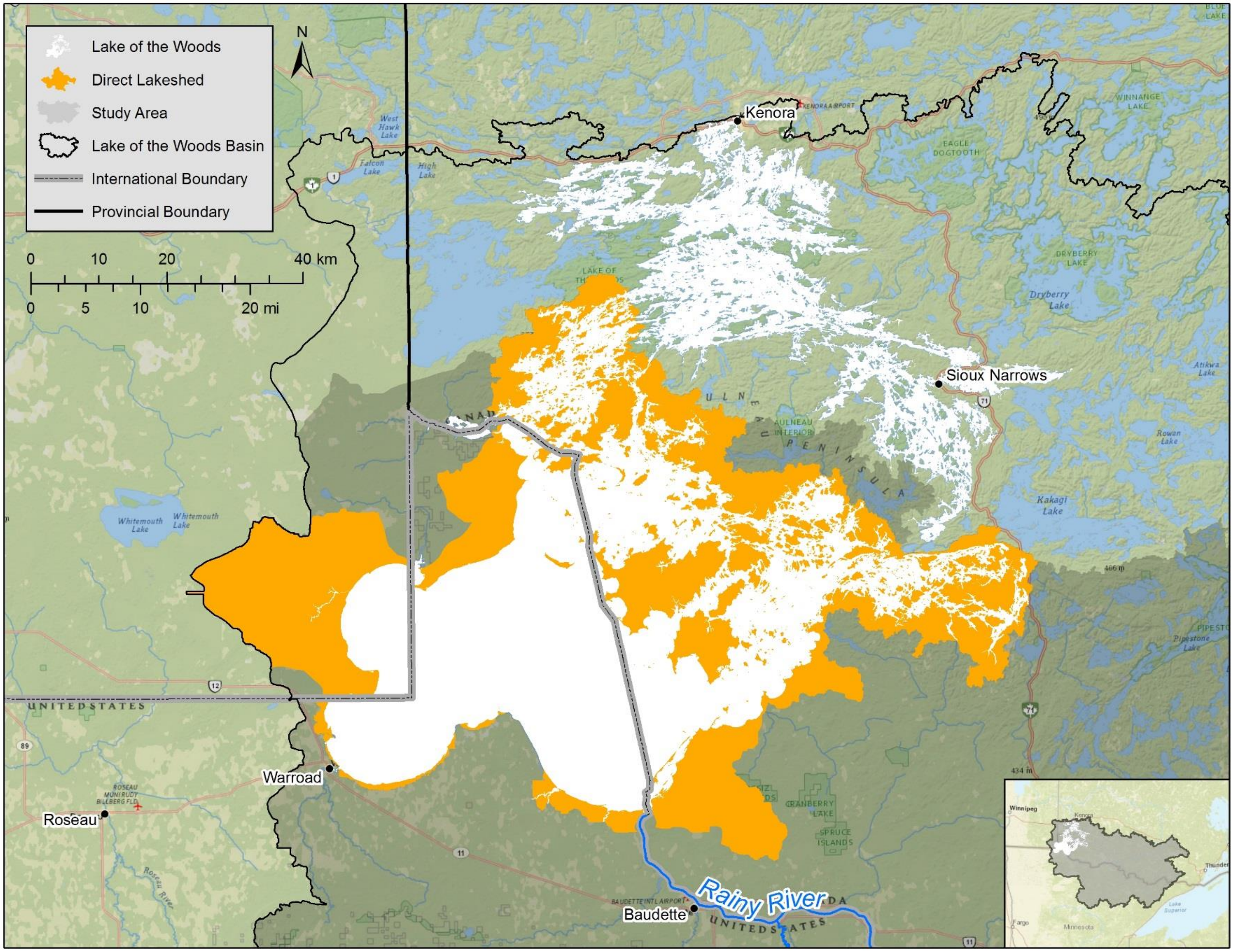


Figure 3-28. The Lake of the Woods Direct Lakeshed Drainage Area Shown Within the TMDL Study Area and Basin

3.10.2.7 Natural Background

"Natural background" (natural causes) is defined in the Minnesota Rules as "the multiplicity of factors that determine the physical, chemical, or biological conditions that would exist in the absence of measurable impacts from human activity or influence" (Minn. R. 7050.0150). Natural background is also defined in the Clean Water Legacy Act as "characteristics of the water body resulting from the multiplicity of factors in nature, including climate and ecosystem dynamics, that affect the physical, chemical, or biological conditions in a water body, but does not include measurable and distinguishable pollution that is attributable to human activity or influence" (Minn. Stat. § 114D.10).

Natural background sources include surface runoff from the natural landscape, background stream channel erosion, groundwater discharge, and atmospheric deposition, including windblown particulate matter from the natural landscape. Internal P loading can be of both anthropogenic and natural origin.

4. TMDL Development

The Loading capacity for the LoW was determined by using a calibrated BATHTUB lake eutrophication model. Reductions were developed iteratively until proposed reductions met the required load reduction.

4.1 TMDL Equation

The loading capacity, or the TMDL, is defined as the maximum allowable load that will allow water quality standards to be met. The TMDL equation is as follows:

$$\mathbf{TMDL} = \sum(\mathbf{WLA}) + \sum(\mathbf{LA}) + \mathbf{MOS} + \mathbf{RC} \qquad \text{4-1}$$

where:

TMDL = total maximum daily load, defined as the maximum allowable load that will still allow the lake to achieve water quality standards

WLA = wasteload allocation, the pollutant load from permitted source (NPDES/SDS)

LA = load allocation, the pollutant load from nonpermitted sources

MOS = margin of safety, usually expressed as a percent of the TMDL, used to increase the likelihood of compliance by accounting for potential unknown or unquantifiable nutrient sources

RC = reserve capacity, a load apportioned to account for anticipated future growth or land use change.

4.2 Lake Modeling

The BATHTUB lake eutrophication model (Version 6.14d) (Walker 2006), developed for the U.S. Army Corps of Engineers (USACE), was used to predict the in-lake response to nutrient loading. The BATHTUB model uses steady-state water and nutrient mass balances to model advective transport, diffusive transport, and nutrient sedimentation (Walker 2006). Lake response (expressed as summer-average TP and Chl-*a* concentrations and Secchi disk depth) is predicted by empirical relationships that relate total annual P load to lake summer-average conditions (Walker 1985; Walker 1996). The BATHTUB model allows users to specify single lake segments or multiple segments with complicated flow routing; lake response is calculated for each lake segment based on user-entered characteristics, and results are reported for each bay and on an area-weighted basis for the entire lake.

Tributary inflows are entered as mean annual flow volume (hm^3), and pollutant concentrations are entered as flow-weighted mean concentrations. Other inputs include mean annual precipitation, mean annual lake surface evaporation, change in storage volume, atmospheric pollutant deposition, and internal loading release rates (RRs). Observed lake water quality data (TP, Chl-*a*, Secchi disk depth, conservative substances) are entered as summer-average (June–September) values for the period of interest. The BATHTUB model includes a myriad of model choices for predicting TP, Chl-*a*, Secchi disk, and other lake responses based on model input. The BATHTUB model can be calibrated by adjusting internal loading rates (if unknown), calibration coefficients (by lake segment), or model coefficients (globally for all segments). Detailed information regarding development and calibration of the existing conditions for the BATHTUB model and development of the proposed conditions model are included in Appendix G.

4.2.1 BATHTUB Lake Segmentation

The portion of the LoW in the TMDL Study Area was segmented into five bays as shown in Figure 3-1. Segment characteristics (area, mean depth, fetch) and mean summer season water quality parameters were developed for each segment; more detailed information is included in Appendix G.

4.2.2 BATHTUB Hydrologic and Pollutant-Loading Input

Hydrologic inputs to the BATHTUB model include precipitation, evaporation, change in water level over the modeling period, tributaries (explicitly modeled in the LoW Basin HSPF models), direct watershed drainage (draining to the LoW directly or through minor streams), point sources, and septic systems. Pollutant loading inputs are associated with atmospheric deposition (wet and dry), tributaries, direct watershed drainage, point sources, septic systems, and internal P loading. A detailed description of each of these hydrologic and water quality pollutant inputs is included in Appendix G.

4.2.2.1 Attenuation and Delivery Ratios

An analysis and quantification of P load attenuation from upstream sources of the LoW was undertaken to allow for a complete accounting of loads at both the source and at the LoW. If all of the upstream loads (not those that discharge directly to the LoW) were summed as the loads at the source (i.e., the end of an NPDES/SDS point source pipe draining to Rainy River or at the mouth of a river draining to Rainy River), the total would exceed the actual load delivered to the LoW. This attenuation is verified by comparing monitored and estimated P loading from upstream sources (tributaries and point sources) to the estimated P loading from Rainy River to the LoW based on monitoring data at Wheelers Point. These results are apparent in the HSPF model results for the study period. For example, for sources drained by Rainy River, the total of the mean annual study period load at the source is 433,677 kg/y, while the mean annual load delivered to the LoW from Rainy River is 362,660 kg/y. Using the actual load delivered to the LoW is critical for the BATHTUB model to accurately characterize external nutrient inflow to the LoW and predict the subsequent in-lake response. For the existing conditions BATHTUB model, attenuation was applied to sources from two areas/sources:

1. All of the sources drained by Rainy River, and
2. Williams WWTP and Williams Creek (County Ditch 1).

Attenuation is accounted for in this TMDL study using delivery ratios, which are defined for each source as the ratio of load at the source that is delivered to the LoW. For example, a delivery ratio of 94% means that 94% of the load at the source is delivered to the LoW and corresponds to an attenuation of 6%.

A delivery ratio was developed for each individual reach of the lower reaches of the Rainy River (between the Rainy Lake outlet and Wheelers Point). The delivery ratio of each individual reach was determined as the total load leaving each reach divided by the total load entering each reach. Delivery ratios were based on mean annual loads from the HSPF model for the study period. Delivery ratios for sources traveling through multiple reaches of the Lower Rainy River were calculated as the product of delivery ratios from each reach through which the source's load travels on its path to the LoW. This initial analysis allows for the calculation of the load delivered to the LoW from any source discharging directly to Rainy River.

Further analysis was required to develop delivery ratios for point sources within the Little Fork and Big Fork Rivers, as they do not discharge directly to Rainy River. An analysis was undertaken to develop the delivery ratio for each point source within the Little Fork and Big Fork River Watersheds. The mean annual study period loads from the Little Fork and Big Fork River Watershed HSPF models were then split into loads from nonpoint and point sources to represent the portion of the load delivered from each watershed that was associated with watershed runoff and point source discharge, respectively. Final delivery ratios for each of the point sources in the Little Fork and Big Fork River Watersheds were then determined as the product of delivery ratios from the point source to the Rainy River and the corresponding delivery ratio within Rainy River to the LoW.

A similar analysis was undertaken to determine the delivery ratio from the Williams WWTP to the LoW. All of the other existing sources within the TMDL Study Area discharge directly to the LoW and were, therefore, assigned delivery ratios of 100%. Delivery ratios were developed for both TP and ortho-phosphorus (OP). Further discussion of attenuation is included in Appendix E.

4.2.3 Modeling Sequence

The existing conditions BATHTUB model was constructed with mean annual loads and summer-average water quality data for the study period. The BATHTUB model was calibrated to accurately represent the in-lake response to combined internal and external P loading. Calibration was accomplished by adjusting calibration coefficients, which are listed in the following section. The calibrated BATHTUB model was then used to determine the P loading capacity and reductions required to achieve water quality standards.

4.2.4 BATHTUB Calibration and Results

The existing conditions BATHTUB model was calibrated to reflect the in-lake response to external and internal loads; calibration statistics are shown in Table 4-1.

Table 4-1. BATHTUB calibration statistics.

Segment	TP Calibration Factor	TN Calibration Factor	Chl-*a* Calibration Factor
Sabaskong	0.94	No TN data	0.85
Four Mile	1.14	1.20	0.57
Muskeg	1.29	1.20	1.16
Big Traverse	1.24	1.24	0.93
Little Traverse	1.17	1.29	1.01

4.3 Loading Capacity

The calibrated BATHTUB model was used to determine the loading capacity (TMDL) for the portion of the LoW in the TMDL Study Area, which is the maximum P load that allows the LoW to achieve its summer-average TP standard of 30 µg L^{-1}. The loading capacity was developed iteratively as load-reduction scenarios were developed. This iterative process was necessary because of varying TP/dissolved P ratios from different P sources. In-lake water quality is more sensitive to dissolved P loading than particulate P because of its higher bioavailability and thus, different combinations of load reductions result in different loading capacities. The loading capacity for TP for the LoW in the TMDL Study Area is 709,522.4 kg y^{-1} (1,943.9 kg d^{-1}).

4.4 Wasteload Allocation Methodology

The study period mean annual P load from permitted sources is 89,189.0 kg y^{-1}, and the WLA and acknowledged loads (from Canadian sources) are 39,400.0 kg y^{-1} and 6,347.5 kg y^{-1}, respectively, which correspond to a reduction of 43,441.4 kg y^{-1} or 48.7% of the study period mean annual load. Study period mean annual loads, WLAs, and acknowledged loads by permitted source category are included in Table 4-2. Study period mean annual loads are from the calibrated HSPF model (Lupo 2015b). A detailed enumeration of each permitted source category's loading is provided in the following sections.

Table 4-2. Study period mean annual loads (Lupo 2015b), wasteload allocations, and acknowledged loads for permitted sources.

Permitted Source Category	Study Period Mean Annual TP Load (kg y^{-1})		Wasteload Allocation TP Load (kg y^{-1})	Acknowledged TP Load from Canadian Sources (kg y^{-1})
	US	Canada		
Domestic Wastewater	8,306.5	1,167.5	5,221.0	1,167.5
Industrial Wastewater	35,912.8	43,513.7	33,662.0	5,180.0
Industrial Stormwater	193.9	0	193.9	0
Construction Stormwater	94.6	0	94.6	0
CAFOs	0	0	0	0
MS4s	0	0	228.6	0
Total	**44,507.8**	**44,681.2**	**39,400.0**	**6,347.5**

4.4.1 Domestic Wastewater

Total study period mean annual loads, WLAs, and acknowledged loads are shown in Table 4-3. The total study period mean annual load was 9,474.0 kg y^{-1}. The WLA and acknowledged loads are 5,221.0 kg y^{-1} and 1,167.5 kg y^{-1}, respectively, which correspond to a reduction of 1,918.0 kg y^{-1} or 23.1%. Study period mean annual loads were taken from the HSPF output. The WLAs and acknowledged loads were determined as the product of each facility's design discharge and permitted P concentration.

Table 4-3. Study period mean annual domestic WWTP loads (Lupo 2015b), wasteload allocations, and acknowledged loads from sources not above the upper boundary condition.

Source Country	Study Period Mean Annual TP Load (kg y^{-1})	Wasteload Allocation TP Load (kg y^{-1})	Acknowledged TP Load from Canadian Sources (kg y^{-1})
US	8,306.5	5,221.0	-
Canada	1,167.5	-	1,167.5
Total	**9,474.0**	**5,221.0**	**1,167.5**

A detailed breakdown of loads for the 14 regulated U.S. domestic WWTPs is given in Table 4-4. The total study period mean annual load from U.S. sources is 8,306.5 kg y^{-1}, and the proposed reduction is 3,085.5 kg y^{-1}. The total study period WWTP load from Canadian sources is 1,167.5 kg y^{-1}. No reductions are proposed for these sources because they are outside of the MPCA's jurisdiction. A summary of loading from the four Canadian domestic WWTPs is given in Table 4-5. Loads from WWTPs in Canada serving First Nations communities were not explicitly included in this study because of incomplete data, but are reflected implicitly in estimates of septic system loading from communities not treated by WWTPs or treated by WWTPs with insufficient data to include explicitly. Thus, populations whose sewage is not treated by one of the four explicitly modeled Canadian WWTPs were reflected in the number of people estimated to be served by SSTSs. Standard loading assumptions for septic systems would then have been applied to such areas in Canada as they were to areas in the U.S. Nutrient attenuation was not accounted for in development of WLAs or acknowledged loads.

Table 4-4. U.S. domestic WWTPs in the TMDL Restoration Area.

Domestic WWTP	HUC-8 Watershed	Study Period Mean Annual TP Load (kg y^{-1})	Wasteload Allocation TP Load (kg y^{-1})
Springsteel Island Sanitary District	Lake of the Woods	5.4	10.0
Williams WWTP	Lake of the Woods	53.0	87.0
Big Falls WWTP	Big Fork River	19.7	119.0
Bigfork WWTP	Big Fork River	251.5	216.0
Effie WWTP	Big Fork River	33.8	102.0
DNR Scenic State Park	Big Fork River	14.4	21.0
Northome WWTP	Big Fork River	68.7	122.0
Cook WWTP	Little Fork River	398.4	509.0
ISD 2142 Pre–Kindergarten to Grade 12 N School	Little Fork River	11.8	44.0
Littlefork WWTP	Little Fork River	146.7	229.0
Anchor Bay Mobile Home Park	Lower Rainy River	68.7	44.0
Baudette WWTP	Lower Rainy River	3,244.5	367.0
ISD 363 – Indus School	Lower Rainy River	13.6	34.0
NKASD WWTP	Lower Rainy River	3,976.3	3,318.0
Total		**8,306.5**	**5,221.0**

Table 4-5. Canadian domestic WWTPs not above the upper boundary condition.

Domestic WWTP	Receiving Water	Study Period Mean Annual TP Load (kg y^{-1})	Acknowledged TP Load (kg y^{-1})
Township of Chapple Lagoon (Barwick)	Lower Rainy River	6.0	6.0
Emo WWTP	Lower Rainy River	353.9	353.9
Fort Frances WWTP	Lower Rainy River	779.6	779.6
Rainy River WWTP	Lower Rainy River	28.0	28.0
Total		**1,167.5**	**1,167.5**

Note that although the city of Warroad, Minnesota, is located on Muskeg Bay, the city's wastewater stabilization ponds are located 5 ½ miles northwest of Warroad, and do not discharge to the LoW. The facility effluent discharges to a ditch system which flows west to Sprague Creek and ultimately to the Roseau River.

Table 4-6 presents the characteristics and proposed WLAs (both yearly and daily) of the 14 domestic wastewater point sources in the TMDL Restoration Area, including the expiration date for each permit. Eleven of the domestic wastewater permits already include TP effluent limits consistent with TMDL WLAs. The three exceptions are ISD 2142 (no current TP effluent limit), NKASD (a draft permit is currently posted for public comment and includes a TP load limit equal to the TMDL WLA) and Springsteel Island (no existing annual TP load limit). All three will include WLA equivalent TP limits upon permit reissuance. Sources with expired permits are required to operate under the conditions of their expired permit until their permit is reissued. The WLAs for stabilization ponds and mechanical plants were determined as follows:

Wastewater Stabilization Pond: Controlled discharges from stabilization ponds occur twice a year. The permitted effluent flow rate was calculated as a maximum six inches of drawdown per day over the area of the secondary pond. This flow rate was multiplied by the P effluent limit to determine the daily WLA. For facilities that do not have a P effluent limit, a P effluent concentration of 2 mg L^{-1} was assumed. The average wet weather influent flow of the facility was used to calculate the yearly WLA.

Mechanical Wastewater Plants: Discharges from mechanical plants are typically continuous. The WLA is the product of the average wet weather design flow rate and the P effluent limit concentration. For facilities without a P effluent limit, a representative effluent concentration was determined from analysis of monitoring data.

Table 4-6. U.S. domestic WWTP wasteload allocations in the TMDL Restoration Area.

Domestic WWTP	NPDES/SDS Permit Number	Permit Issuance Date	Permit Expiration Date	HUC-8	Receiving Water	Effluent Type	Effluent TP WLA (kg d^{-1})	Effluent TP WLA (kg y^{-1})
Anchor Bay Mobile Home Park	MN0046213	10/30/2012	9/30/2017	Rainy River - Baudette	Rainy River	Intermittent	1.1[(a)]	44
Baudette WWTP	MN0029599	10/6/2011	8/31/2015	Rainy River - Baudette	Rainy River	Controlled	9.6[(a)]	367
Big Falls WWTP	MNG580135	4/25/2003	8/31/2015	Big Fork River	Big Fork River	Controlled	2.5[(a)]	119
Bigfork WWTP	MN0022811	10/22/2010	5/31/2016	Big Fork River	Big Fork River	Intermittent	4.4[(a)]	215

Domestic WWTP	NPDES/SDS Permit Number	Permit Issuance Date	Permit Expiration Date	HUC-8	Receiving Water	Effluent Type	Effluent TP WLA (kg d^{-1})	Effluent TP WLA (kg y^{-1})
Cook WWTP	MNG580179	6/9/2011	8/31/2015	Little Fork River	Little Fork River	Controlled	10.9[(a)]	509
Effie WWTP	MN0067555	11/19/2010	1/31/2017	Big Fork River	Wetland	Continuous	0.3	102
ISD 2142 Pre-Kindergarten to Grade 12 N School	MN0069850	2/14/2012	12/31/2015	Little Fork River	Flint River	Continuous	0.1	44
ISD 363 - Indus School	MN0049263	5/9/2014	12/31/2016	Rainy River - Baudette	Rainy River	Continuous	0.1	34
Littlefork WWTP	MNG580081	1/18/2011	8/31/2015	Little Fork River	Beaver Brook	Controlled	5.6[(a)]	229
DNR Scenic State Park	MN0049891	11/4/2010	12/31/2023	Big Fork River	Cedar Lake	Periodic/ Seasonal	0.1[(a)]	21
NKASD WWTP	MN0020257	6/25/2012	12/31/2016	Rainy River - Baudette	Rainy River	Continuous	9.1	3,318
Northome WWTP	MNG580185	2/1/2019	8/31/2015	Big Fork River	Caldwell Brook	Controlled	3.0[(a)]	122
Springsteel Island Sanitary District	MN0068322	10/1/2014	3/31/2017	Lake of the Woods	Lake of the Woods	Continuous	0.03	10
Williams WWTP	MN0021679	11/19/2010	5/31/2016	Lake of the Woods	Williams Creek	Controlled	2.1[(a)]	87

(a) Daily WLAs for sites not operating under continuous discharge are greater than 1/365th of the annual WLA because of limited periods of discharge.

4.4.2 Industrial Wastewater

Total industrial wastewater study period loads, WLAs, and acknowledged loads are summarized by country in Table 4-7. The total study period mean annual load is 79,426.5 kg y^{-1}. The WLA and acknowledged loads are 33,662.0 kg y^{-1} and 5,180.0 kg y^{-1}, corresponding to a reduction of 40,584.5 kg y^{-1} or 51.1%. Study period mean annual loads were taken from HSPF output and WLAs for U.S. sources were determined from permitted loads.

Table 4-7. Study period mean annual industrial wastewater loads, wasteload allocation, and acknowledged load from sources not above the upper boundary condition.

Source Country	Study Period Mean Annual TP Load (kg y^{-1})	Wasteload Allocation TP Load (kg y^{-1})	Acknowledged TP Load from Canadian Sources (kg y^{-1})
US	35,912.8	33,662.0	-
Canada	43,513.7	-	5,180.0
Total	**79,426.5**	**33,662.0**	**5,180.0**

A detailed breakdown of study period mean annual loads and WLAs from the five U.S. industrial wastewater sources in the TMDL Restoration Area is presented in Table 4-8. The total study period mean annual load from U.S. industrial wastewater sources is 35,912.8 kg y^{-1}. The total WLA is 33,662.0 kg y^{-1}, a decrease of 2,250.8 kg y^{-1} or 6.3%.

Table 4-8. U.S. industrial wastewater loads in the TMDL Restoration Area.

Industrial WWTP	Receiving Water	Study Period Mean Annual TP Load (kg y^{-1})	Wasteload Allocation TP Load (kg y^{-1})
Marvin Windows and Doors	Lake of the Woods	4.0	4.0
Berger Horticultural Products – Pine Island Bog (not yet operational)	Big Fork River	0	30.0
US Steel – Minntac Tailings Basin Area	Little Fork River	27.1	30.0
Hibbing Taconite Co. – Tailings Basin Area	Little Fork River	340.5	498.0
Boise White Paper LLC – Intl Falls	Lower Rainy River	35,541.2	33,100.0
Total	**–**	**35,912.8**	**33,662.0**

The Abitibi pulp and paper mill in Fort Frances, Canada, which has been idle for several years, is the only industrial wastewater source in Canada that is not above the upper boundary condition. The study period mean annual load from this facility was 43,513.7 kg y^{-1} and the acknowledged load for this site is 5,180.0 kg y^{-1}, which was set equal to existing outflow as periodic discharges occur to address stormwater, sumps, and landfill leachate. The corresponding mean annual study period load and WLA for Boise White Paper LLC are 35,541.2 kg y^{-1} and 33,100.0 kg y^{-1}, respectively.

Table 4-9 presents the characteristics and proposed WLAs (both yearly and daily) of the five U.S. industrial wastewater point sources in the TMDL Restoration Area. The WLAs for stabilization ponds and mechanical plants were determined as appropriate for each facility as described in Section 4.4.1.

Table 4-9. U.S. industrial WWTP WLAs.

Industrial WWTP	NPDES/SDS Permit Number	HUC-8	Receiving Water	Effluent Type	Effluent TP WLA (kg d^{-1})	Effluent TP WLA (kg y^{-1})
Berger Horticultural Products – Pine Island Bog	MN0066052	Big Fork River	Black River	Periodic/ Seasonal	0.8[(a)]	30[(a)]
Boise White Paper LLC – Intl Falls	MN0001643	Rainy River – Baudette	Rainy River	Continuous	90.6[(b)]	33,100[(b)]
Marvin Windows & Doors	MN0055026	Lake of the Woods	Lake of the Woods	Continuous	0.01	4
US Steel – Minntac Tailings Basin Area	MN0057207	Little Fork River	Dark River	Seep	0.1[(c)]	30[(c)]
Hibbing Taconite Co. – Tails Basin Area	MN0049760	Little Fork River	Shannon River	Continuous	1.4	498

(a) Periodic discharge from March through December. Assumption of 40 days of discharge at one-half maximum effluent flow rate. Average peat mine TP concentration of 0.1 mg L^{-1}

(b) Proposed annual limit of 33,100 kg TP y^{-1}

(c) Assumed 1 million gallons per day (mgd) seepage from basin

4.4.3 Industrial Stormwater

The P loading from permitted industrial stormwater sites within the LoW Basin was estimated from MPCA permit data (MCPA 2017a). Fourteen permitted facilities not covered under no exposure exclusions were identified within the TMDL Restoration Area; these facilities are listed in Appendix E. The total area of these sites is 798 ha (1,972 ac). The industrial stormwater WLA is categorical (i.e., all industrial stormwater locations are included as a single WLA in the TMDL Allocations table). The percentage of industrial acres in the TMDL Restoration Area was multiplied by the TMDL allowable load to determine the industrial stormwater WLA, which resulted in an annual load of 193.9 kg yr^{-1}. No load reduction is proposed for industrial stormwater.

4.4.4 Construction Stormwater

The P loading from permitted construction stormwater sites within the LoW Basin was estimated from the MPCA permit data from 2005 to 2014 (MPCA 2015d). The total area of permitted construction sites that drain to the LoW was estimated by county as the product of the total permitted area by county and the portion of the county within the LoW Basin. Permitted construction sites were assumed to be evenly distributed throughout each county. The estimated permitted construction site area within the TMDL Study Area is 389.4 ha. The percentage of construction acres in the TMDL Restoration Area was multiplied by the TMDL allowable load to determine the construction stormwater WLA, which resulted in an annual load of 94.6 kg yr^{-1}. Detailed information that support these calculations is included in Appendix E. The construction stormwater WLA included in this TMDL study is categorical (i.e., all construction stormwater locations are included as a single WLA in the TMDL Allocations table). No change in loading is proposed for construction stormwater sites in this TMDL study.

4.4.5 CAFOs

No permitted CAFOs exist within the TMDL Restoration Area.

4.4.6 MS4

The Hibbing, Minnesota, MS4 is the only regulated MS4 located in the TMDL Restoration Area and is located in the headwaters of the Little Fork River. The city of Hibbing covers an area of 482 km^2 (186 mi^2) and approximately 41 km^2 (16 mi^2) are located within the TMDL Restoration Area. Approximately 30 km^2 (11 mi^2) of this area is covered by the Hibbing Taconite Company Tailings Basin Area, which is a regulated point source. As such, the load from the tailings basin area has already been explicitly accounted for in this TMDL study as an industrial wastewater source that discharges to the Little Fork River through its tributaries. The remaining 11 km^2 (5 mi^2) outside the tailings basin, but within the TMDL Restoration Area, is largely forested and undeveloped. There are no discharges to the city of Hibbing's stormwater conveyance system that are within the 11 km^2 area. Thus, no WLA was assigned to the City of Hibbing MS4.

The City of International Falls is expected to be subject to an MS4 permit in the future as it is a city with a population greater than 5,000 people that drains to an impaired water (the LoW). The City of International Falls MS4 was determined as the portion of the LoW loading capacity equal to the ratio of the area of the city of International Falls to the total TMDL Study Area. In other words, if the city of International Falls MS4 occupied 1% of the TMDL Study Area, it would be assigned a WLA equal to 1% of the LoW loading capacity. The city of International Falls covers 16.2 km^2 (6.3 mi^2) within the 62,654 km^2 (24,191 mi^2) TMDL Study Area (0.026%) and thus, was assigned a WLA of 228.6 kg y^{-1}.

4.5 Margin of Safety

The MOS is the portion of a TMDL study allocation that accounts for uncertainty in the loading calculations, and accounts for uncertainty in the loading calculations to further ensure achievement of water quality goals. The MOS can be defined both explicitly with a separate, quantified MOS load or implicitly by using conservative methodologies in loading calculations. In this TMDL study, an explicit 5% MOS (35,608.1 kg y^{-1}) was chosen based on the basin-wide mass balances developed via use of calibrated HSPF models for characterizing the TMDL Restoration Area and quantifying streamflow and nutrient loads.

The TMDL allocations described herein have been based on the best available information for the study period, including land cover that was incorporated into updated LoW Basin HSPF models and subject to rigorous state oversight. The dominant water and P source to the LoW is the Rainy River and its tributaries. The Rainy River's discharge and nutrient loading were calibrated to monitoring data, recent climate data, land use, and gauged flows using the HSPF model. Lake modeling was accomplished by using widely accepted standard assessment and quality control methods. Additional research that provided necessary background information included monitoring (US Geological Survey), BATHTUB and Flux modeling (St. Cloud State University), and paleolimnology assessment (Natural Resources Research Institute). Internal sediment generated P, the second largest P source, has been studied extensively by William James of UW-Stout University and the St. Croix Watershed Research Station (SCWRS) of the Science Museum of Minnesota (SCWRS) (James 2012, 2015, 2017a, 2017b, and Edlund et al. 2017). The SCWRS concluded from their sediment chemical and phyto-historical reconstruction of historical P loadings that the LoW sediment P mass (or internal loading) is projected to continue to decline and move toward a new equilibrium with a net loss of approximately 1% per year.

Because of the degree of rigor applied to the characterizations of the two largest P sources (tributary loading and internal loading) and the implicit MOS from WLAs and the SSTS LA, an explicit 5% MOS was determined to adequately account for uncertainty in the TMDL analysis.

4.6 Reserve Capacity

The RC was developed for three sites within the TMDL Study Area that are either proposed or not yet discharging: unsewered communities in the TMDL Restoration Area, New Gold Mine, and Fort Frances, Canada. The RC or acknowledged load (Canadian sources) for each location and the total RC (887.0 kg y^{-1}) are shown in Table 4-10.

An RC was included for potential discharge from areas within the TMDL Restoration Area that are currently not served by WWTPs. The New Gold Mine is a Canadian gold mine located approximately 20 km (12 mi) north of the Rainy River approximately halfway between Fort Frances, Canada, and Four Mile Bay. New Gold Mine is not yet discharging, but an acknowledged load (added as a RC) was assigned to the site based on permit information. An acknowledged load (added as a RC) was also assigned to potential development in Fort Frances, Canada. No attenuation was accounted for in the development of RC and acknowledged loads.

Table 4-10. RC Loads by Source.

Source	Reserve Capacity TP Load (kg y^{-1})	Acknowledged TP Load from Canadian Sources (kg y^{-1})
Unsewered Communities[a]	167.0	-
Fort Frances	-	300.0
New Gold Mine	-	420.0
Total	**167.0**	**720.0**

[a] Birch Beach, Sandy Beach, etc.

4.7 Load Allocation Methodology

After accounting for WLAs, MOS, and RC, the remaining loading capacity was apportioned to the following sources: tributaries, direct lakeshed, shoreline erosion, SSTSs, atmospheric deposition, and internal P loading. The study period mean annual P load from nonpermitted sources (to the LoW) is 742,617.0 kg y^{-1} and the LA is 627,279.7 kg y^{-1}, which corresponds to a reduction of 115,337.3 kg y^{-1} or 15.5% of the study period mean annual load. Study period mean annual loads and LAs by source category are included in Table 4-11. A detailed breakdown of each source category's loading is provided in the following sections.

Table 4-11. Study period mean annual loads, load allocations, and acknowledged loads by source category.

Source Category	Study Period Mean Annual TP Load (kg y^{-1})		Load Allocation (TP Load (kg y^{-1})	Acknowledged Load from Canadian Sources TP Load (kg y^{-1})
	US	Canada		
Tributary Loading 🍁	201,273.4	118,107.9	168,265.7	118,107.9
Direct Lakeshed Loading 🍁	2,340.7	14,771.5	2,340.7	14,771.5
Shoreline Erosion Loading	72,000.0	0.0	60,480.0	0.0
SSTS Loading 🍁	311.0	410.7	0.0	410.7
Atmospheric Deposition Loading 🍁	23,602.4	27,804.9	23,602.4	27,804.9
Internal P Loading 🍁	184,281.9	97,712.7	138,211.4	73,284.6
Total	**483,809.3**	**258,807.7**	**392,900.2**	**234,379.5**

🍁 denotes that all or part of the load from this source originates in Canada.

4.7.1 Tributary Loading

Tributary loading as discussed in this section is only the portion of the load delivered to the LoW by its tributaries that is attributable to nonpoint source loading. Thus, tributary loading presented in this section excludes loads carried to the LoW by tributaries that are attributable to point sources. Tributary loading is the largest source of P to the LoW, with the Rainy River accounting for more than 90% of the tributary load. Table 4-12 lists the HSPF-modeled tributaries that discharge directly to the LoW along with study period mean annual loads and LAs. Study period mean annual tributary loading was taken from HSPF model output. Loads in Table 4-12 are presented at the mouth of the tributary and, thus, correspond directly to loads entering the LoW from tributaries. Study period mean annual tributary loading to the LoW totals 319,381.2 kg y^{-1}. The LA totals 286,373.6 kg y^{-1}, which corresponds to a reduction of 33,007.6 kg y^{-1} or 10.3%.

The LAs were developed with the assumption that all upstream tributaries meet the northern river eutrophication standard of 50 µg L^{-1} TP. The LAs were reduced further in three cases (Big Fork River, Little Fork River, and Williams Creek) to ensure that the flow weighted mean concentration (FWMCs) corresponding to total LA and WLA carried at the mouth of a tributary would not exceed the northern river eutrophication standard. Although upstream tributaries with FWMCs that are greater than the water quality standard are not necessarily listed as impaired and in need of a TMDL study, tributary reductions are required to achieve overall reductions proposed in this TMDL study. Further details to support these reductions are discussed in the Chapter 6: Reasonable Assurance and Chapter 7: Implementation Strategy Summary. Although the Rainy River is not impaired itself, tributaries to the Rainy River exceed the northern river eutrophication standard of 50 ug L^{-1}. While the TP FWMC of the Rainy River at Wheelers Point was less than 30 ug L^{-1} for the study period, the LA for the Rainy River is nonetheless lower than the mean annual study period load. This reduction is not because of an explicit goal to reduce the FWMC in the Rainy River, but instead reflects reductions in upstream point source loading (based on permitted loads) and upstream LAs required to lower tributary FWMCs to the northern river eutrophication standard of 50 ug L^{-1}.

The Rainy River constitutes a large portion of the tributary inflow; therefore, a detailed account of the tributaries that drain to the Rainy River is presented in Table 4-13. Further detail regarding the load at the source (tributary mouth) and load to the LoW is provided because these upstream tributaries do not drain to the LoW directly. The largest components of the Rainy River LA are Rainy Lake (119,669.7 kg y^{-1}), Big Fork River (39,668.9 kg y^{-1}), Little Fork River (38,440.5 kg y^{-1}), Rapid River (19,986.1 kg y^{-1}), and Direct Drainage to Rainy River (19,405.9 kg y^{-1}).

Tributary loading and allocations provided in Table 4-12 and Table 4-13 are modeled values and are not intended to be prescriptive or represent attainability for each specific tributary.

4.7.2 Direct Lakeshed Loading

Study period mean annual direct lakeshed loading, from all contributing land areas regardless of jurisdiction, was taken from HSPF model output. Table 4-14 lists the study period mean annual loads and LAs for each direct lakeshed loading area. Sabaskong and Little Traverse Bays' direct lakeshed loading areas are both split across two HSPF-modeled reaches (subwatersheds), and loads are reported by reach. The study period mean annual direct lakeshed loading to the LoW is 17,112.1 kg y^{-1}. No direct lakeshed loading reductions are proposed.

4.7.3 Shoreline Erosion Loading

Houston Engineering and the LoW Soil and Water Conservation District (SWCD 2013) conducted a shoreline erosion study for the southern portion of the LoW extending east from Warroad, Minnesota, to Four Mile Bay. This study was used to provide the shoreline erosion estimates that are explicitly accounted for in the allocation table. The mean annual load of 72,000 kg as determined by this study was apportioned to the three bays (Four Mile, Big Traverse, and Muskeg) between Warroad, Minnesota, and the Rainy River based on shoreline length, as shown in Table 4-15. A reduction of 16% is proposed based on the length of shoreline protection projects already in place; these shoreline protection practices are assumed to be maintained in the future. Shoreland erosion rates are not available for the remaining shoreline areas; however, these sources are implicitly accounted for in the BATHTUB model through internal loading. The unexplained residual loading to the LoW (the loading that is calculated as the difference in increases in in-lake TP mass and the sum of the known or explicitly modeled external loads) that is entered as internal loading in BATHTUB reflects loading from sources that are not explicitly modeled in BATHTUB.

Table 4-12. Study period mean annual loads (Lupo 2015b), load allocations, and acknowledged loads for the LoW tributaries. Note that these loads do not include wasteloads that are delivered to the LoW by tributaries.

Tributary	Study Period Mean Annual TP Load (kg y^{-1})		Load Allocation TP Load (kg y^{-1})	Acknowledged TP Load from Canadian Sources (kg y^{-1})
	US	Canada		
Rainy River 🍁	182,447.6	108,245.3	156,677.9	108,245.3
Sabaskong River 🍁	-	2,232.6	-	2,232.6
Splitrock River 🍁	-	1,228.0	-	1,228.0
Thompson Creek 🍁	-	779.8	-	779.8
Obabikon Lake 🍁	-	457.7	-	457.7
Big Grassy River 🍁	-	1,108.2	-	1,108.2
Little Grassy River 🍁	-	2,333.7	-	2,333.7
Bostic River (231)	1,783.9	-	1,283.8	-
Williams Creek (County Ditch 1; 211)	1,101.8	-	617.4	-
South Branch Zippel Creek (213)	744.0	-	214.9	-
West Branch Zippel Creek (203)	1,887.6	-	879.3	-
Judicial Ditch 24 (201)	420.2	-	259.4	-
Judicial Ditch 24 (191)	1,256.2	-	465.5	-
Judicial Ditch 22 (181)	708.3	-	333.3	-
Reach 171	164.5	-	52.5	-
Willow Creek (161)	1,352.6	-	641.7	-
County Ditch 26 (151)	272.9	-	102.7	-
County Ditch 26 (141)	457.7	-	193.3	-
County Ditch 26 (131)	295.1	-	83.8	-
County Ditch 20 (121)	460.5	-	193.4	-
County Ditch 25 (113)	1,003.7	-	341.7	-

Tributary	Study Period Mean Annual TP Load (kg y⁻¹)		Load Allocation TP Load (kg y⁻¹)	Acknowledged TP Load from Canadian Sources (kg y⁻¹)
	US	Canada		
Warroad River 🍁 †	6,345.4	220.3	5,353.9	220.3
Stony Creek 🍁	307.3	438.7	307.3	438.7
Northwest Angle Inlet 🍁	264.0	1,063.7	264.0	1,063.7
Total	**201,273.4**	**118,107.9**	**168,265.7**	**118,107.9**

🍁 denotes that all or part of the load from this source originates in Canada

† HSPF model boundaries show that a portion of the modeled Warroad River Subwatershed extends into Canada and the runoff from that portion of the subwatershed drains directly to the lake

Table 4-13. Study period mean annual loads (Lupo 2015b), load allocations, and acknowledged loads for tributaries above the lower boundary condition at Wheelers Point. Note that these loads do not include wasteloads that are delivered to the LoW by tributaries.

Tributary	Study Period Mean Annual TP Load (kg y⁻¹)		Load Allocation TP Load (kg y⁻¹)	Acknowledged TP Load from Canadian Sources (kg y⁻¹)
	US	Canada		
Rainy Lake 🍁	36,176.6	83,493.1	36,176.6	83,493.1
Little Fork River	60,607.7	-	38,440.5	-
Big Fork River	41,002.4	-	39,668.9	-
Rapid River	19,986.1	-	19,986.1	-
La Vallee River 🍁	-	3,037.3	-	3,037.3
Black River	9,695.9	-	9,695.9	-
Sturgeon River 🍁	-	2,838.4	-	2,838.4
McCloud Creek	352.9	-	221.6	-
Whitefish Creek	531.2	-	320.8	-
Pinewood River 🍁	-	5,316.7	-	5,316.7
Silver Creek	1,114.2	-	631.1	-
Unnamed (391)	457.1	-	352.0	-
Baudette River	1,611.5	-	1,287.0	-
Miller Creek	420.4	-	215.3	-
Winter Road River	3,280.7	-	3,139.9	-
Wabanica Creek	1,364.8	-	696.2	-
Direct Drainage 🍁	5,846.1	13,559.8	5,846.1	13,559.8
Total (Rainy River)	**182,447.6**	**108,245.3**	**156,677.9**	**108,245.3**

🍁 denotes that all or part of the load from this source originates in Canada

Table 4-14. Study period mean annual direct lakeshed loading, load allocations, and acknowledged loads.

Direct Lakeshed Drainage Area by Bay	Study Period Mean Annual TP Load (kg y^{-1})		Load Allocation TP Load (kg y^{-1})	Acknowledged TP Load for Canadian Sources (kg y^{-1})
	US	Canada		
Sabaskong East 🍁	-	2,058.1	-	2,058.1
Sabaskong West 🍁	-	1,824.3	-	1,824.3
Four Mile 🍁	-	1,988.5	-	1,988.5
Big Traverse 🍁	614.1	5,526.8	614.1	5,526.8
Muskeg	218.5	145.7	218.5	145.7
Little Traverse South 🍁	1,121.7	1,682.6	1,121.7	1,682.6
Little Traverse North 🍁	386.4	1,545.5	386.4	1,545.5
Total	**2,340.7**	**14,771.5**	**2,340.7**	**14,771.5**

🍁 denotes that all or part of the load from this source originates in Canada

Table 4-15.Study period shoreline erosion phosphorus loading and load allocations.

Shoreline Erosion by Bay	Study Period Mean Annual TP Load (kg y^{-1})	Load Allocation TP Load (kg y^{-1})
Four Mile	9,395.4	7,892.2
Big Traverse	36,000.0	30,240.0
Muskeg	26,604.6	22,347.8
Total	**72,000.0**	**60,480.0**

4.7.4 SSTSs

The SSTS loading was taken from HSPF-modeled output and is described in detail in Appendix E. Study period mean annual loads from (failing) SSTSs were included in the models for direct lakeshed loading areas. Septic system loading directly to the LoW is summarized in Table 4-16. Total study period mean annual septic loading is 721.7 kg y^{-1}, the LA is 0 kg y^{-1}, and the acknowledged load is 410.7 kg y^{-1}. The LA is based on the assumption that all failing septics will be brought into compliance and that future loading from septic systems will be indistinguishable from background groundwater loading. Because the MPCA does not have jurisdiction over Canadian sources, the proposed reduction applies only to U.S. SSTSs; no reduction is proposed for Canadian SSTS loading.

Table 4-16. Study period mean annual direct septic loading, load allocations, and acknowledged loads.

Bay/Lakeshed	Study Period Mean TP Load ($kg\ y^{-1}$)		Load Allocation TP Load ($kg\ y^{-1}$)	Acknowledged TP Load for Canadian Sources ($kg\ y^{-1}$)
	Load Originating in US	Load Originating in Canada		
Sabaskong East 🍁	0.0	22.4	0	22.4
Sabaskong West 🍁	0.0	130.4	0	130.4
Four Mile 🍁	85.9	21.5	0	21.5
Muskeg	19.7	0.0	0	0.0
Big Traverse 🍁	165.9	165.9	0	165.9
Little Traverse South 🍁	34.9	52.4	0	52.4
Little Traverse North 🍁	4.5	18.1	0	18.1
Total	**311.0**	**410.7**	**0**	**410.7**

🍁 denotes that all or part of the load from this source originates in Canada

4.7.5 Atmospheric Deposition

An atmospheric P deposition rate of 19.3 mg $m^{-2}y^{-1}$ (reported by Twarowski et al. [2007] for the Rainy River Basin) for average precipitation years was used in this TMDL study. The total atmospheric P load to the LoW within the TMDL Study Area is 51,407.3 kg y^{-1}. No reduction in atmospheric loading is proposed because it originates outside the basin and is not controllable.

4.7.6 Internal Phosphorus Loading

Internal P loading was estimated by using a detailed mass and water balance approach to determine monthly differences (by bay) between expected changes in in-lake TP concentrations, as estimated from external P loading, and actual changes in in-lake TP concentration, as estimated from water quality monitoring data. A detailed description of the analysis is included in Appendix F. The existing internal P load for the LoW within the TMDL Study Area is 281,994.7 kg y^{-1}.

4.8 Seasonal Variation and Critical Conditions

Lake water quality varies more seasonally (intra-year) than year-to-year (inter-year) because of temperature and precipitation cycles. In this annual cycle, the majority of annual watershed P loading is typically associated with the peak-flow events of spring and large storms that can set the stage for summer conditions. Hence, a greater monitoring emphasis is usually placed on characterizing the nature of P loading during higher flow periods.

Lakes with large fetches, such as the LoW, are subject to fluctuations of P concentrations because of wind mixing and resuspension, fluctuating Rainy River flows and flushing rates, and major runoff events that occur over the summer season. However, warmer summer temperatures can result in periodic, higher algal growth rates and higher Chl-*a* concentrations. Warmer summer lake temperatures can also increase the potential for lake internal P release or loading that can also contribute to increased algal Chl-*a*. This seasonal variation has been factored into the development of Minnesota's lake standards, based on swimmable and fishable beneficial uses, for the summer critical recreation period of June through September (Heiskary and Wilson 2005). This TMDL study's targeted allocations are based on Minnesota's lake standards and summer critical conditions.

4.9 TMDL Summary

The TMDL allocation table is summarized in Table 4-17. Total study period mean annual load to the LoW is 814,914.9 kg y^{-1} and the loading capacity is 709,522.4 kg y^{-1}. The MOS of 35,608.1 kg y^{-1} results in a required reduction of 141,000.6 kg y^{-1}. The detailed TMDL allocation table is included in Appendix C; the detailed table includes greater detail for each of the sources in the WLA section and the subwatersheds and tributaries in the LA section.

Table 4-17. The LoW TMDL summary.

LoW Load Allocation		Study Period Mean Annual TP Load		Load/Wasteload Allocation TP Load		Acknowledged TP Load for Canadian Sources		Estimated Load Reduction[a]	
		kg y^{-1}	kg d^{-1}	kg y^{-1}	kg d^{-1}	kg y^{-1}	kg d^{-1}	kg y^{-1}	kg d^{-1}
Wasteload	Total WLA	89,189.0	244.4	39,400.0	107.9	6,347.5	17.4	43,441.4	119.0
	Domestic Wastewater	9,474.0	26.0	5,221.0	14.3	1,167.5	3.2	3,085.5	8.5
	Industrial Wastewater	79,426.5	217.6	33,662.0	92.2	5,180.0	14.2	40,584.5	111.2
	MS4	0	0	228.6	0.6	0	0	-228.6	-0.6
	Industrial Stormwater	193.9	0.5	193.9	0.5	0	0	0	0.0
	Construction Stormwater	94.6	0.3	94.6	0.3	0	0	0	0.0
Load	Total LA	742,617.0	2,034.0	392,900.2	1,076.4	234,379.5	642.1	115,337.3	316.0
	Tributary Loading	319,381.2	874.4	168,265.7	461.0	118,107.9	323.6	33,007.6	90.4
	Direct Lakeshed Loading	17,112.1	46.9	2,340.7	6.4	14,771.5	40.5	0	0.0
	Shoreline Erosion Loading	72,000.0	197.3	60,480.0	165.7	0	0	11,520.0	31.6
	SSTS[b]	721.7	2.0	0	0	410.7	1.1	311.0	0.9
	Atmospheric Deposition	51,407.3	140.8	23,602.4	64.7	27,804.9	76.2	0	0.0
	Internal load	281,994.7	772.6	138,211.4	378.7	73,284.6	200.8	70,498.7	193.1
Reserve Capacity				167.0	0.5	720.0	2.0	-887.0	-2.4
Subtotal				432,467.3	1,184.8	241,447.0	661.5		
MOS (5%)[c]				35,608.1	97.6				
Total Load		831,806.0	2,278.4	709,522.4[d]	1,943.9[d]			157,891.7	432.5

(a) Estimated Load Reduction is the difference between the Study Period Mean Annual TP load and the sum of the following: LA/WLA TP Load from US sources and Acknowledged TP Load for Canadian sources

(b) The U.S. (Minnesota) LA for SSTS loading is zero; 410.7 kg y^{-1} of SSTS loading is acknowledged load from Canada (see Table 4-16 for more detail).

(c) A single margin of safety load was assigned for the entire TMDL drainage area and is reported in the LA/WLA column but applies to the entire TMDL drainage area due to the need to assign a single margin of safety load

(d) Total load reported in this cell is the sum of load and WLAs from US sources and acknowledged loads from Canadian sources

5. Future Growth Considerations

As it has been noted throughout this TMDL study, Minnesota has no jurisdiction regarding Canadian, Tribal, or First Nations' sources within the TMDL Study Area. Minnesota participates in a number of work groups intended to facilitate open lines of communication and cooperation with its international partners. It is through these workgroups that Minnesota would be made aware of any of its international partners' future growth or development plans and have the opportunity to discuss pollution reduction efforts to protect our shared waters.

The two Minnesota counties with the largest and most direct impact on the LoW are projected to have future population losses (2.6% for Koochiching County and 6.7% for LoW County) from 2015 to 2045 (Dayton 2014). However, in the event population does not follow the expected decline, population increases, or the distribution of the population changes, the process for evaluating needed changes to the TMDL allocations are discussed below.

5.1 New or Expanding Permitted MS4 WLA Transfer Process

Future transfer of watershed runoff loads in this TMDL study may be necessary if any of the following scenarios occur within the project TMDL Study Area:

1. New development occurs within a regulated MS4. Newly developed areas that are not already included in the WLA must be transferred from the LA to the WLA to account for the growth.
2. One regulated MS4 acquires land from another regulated MS4. Examples include annexation or highway expansions. In these cases, the transfer is WLA to WLA.
3. One or more nonregulated MS4s become permitted. If this has not been accounted for in the WLA or RC, 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, which 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 an NPDES/SDS permit. In this situation, a transfer must occur from the LA.
6. Load transfers will be based on methods consistent with those used in setting the allocations in this TMDL (a land-area basis). 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.

6. Reasonable Assurance

An important part of the TMDL implementation strategy is to provide reasonable confidence or assurance that the TMDL allocations will be met through implementation activities led by local, state, and federal entities.

As it has been noted throughout this TMDL study, Minnesota has no jurisdiction regarding Canadian, Tribal, or First Nations' sources within the TMDL Study Area. Minnesota participates in a number of work groups intended to facilitate open lines of communication and cooperation with its international partners. Table 6-1 lists examples of these work groups whose purposes are to: investigate and recommend solutions to transboundary issues; foster trans-jurisdictional coordination and collaboration on science and or management activities; and monitor and report on ecological health of the LoW and Rainy Lake boundary waters' aquatic ecosystem, including water quality. It is through these workgroups that Minnesota would be made aware of any of its international partners' future growth and development plans or any changes to monitored conditions, and have the opportunity to discuss how we can work together to protect our shared waters.

Table 6-1. Lake of the Woods International Partnerships

Name	Membership	Charge
International Joint Commission (IJC)	Three IJC commissioners from Canada and three from the US.	To review and approve projects that affect water levels and flows across the international boundary and investigate and recommend solutions to transboundary issues.
International Multi-agency Arrangement (IMA)	Manager-level staff at federal, state, provincial, Tribal, First Nations, and county governments with land and water authorities in the LoW Basin.	To foster trans-jurisdictional coordination and collaboration on science and or management activities to enhance/restore water quality in the LoW Watershed.
IMA – Technical Advisory Committee (IMA-TAC)	Technical staff from the agencies who are signatories of the IMA as well as experts from other agencies who have mandates that align with the purpose of the IMA, or support the TAC's subcommittees	The purpose of the TAC is to provide technical advice and expertise to the IMA Working Group in support of the objectives of the 2009 Arrangement.
International Rainy-Lake of the Woods Watershed Board (IRLWWB)	Ten members from Canada and ten members from the US representing all levels of government, indigenous communities, and local community interests.	To monitor and report on ecological health of the LoW and Rainy Lake boundary waters' aquatic ecosystem, including water quality, and to assist the IJC in preventing and resolving disputes regarding the watershed's boundary waters.

Name	Membership	Charge
IRLWWB Water Levels Committee	Four members from Canada and four members from the US, representing IJC, ECCC, local members, and ACOE.	To act as a technical advisor to the IJC on matters of water level regulation and review flow and level changes, maintenance issues, and other level and flow matters regarding the Rainy and Namakan Lakes.
IRLWWB Aquatic Ecosystem Health Committee	Membership is from relevant research and monitoring agencies within the Lake of the Woods Basin.	Assist the IJC's Rainy Lake of the Woods Watershed Board to fulfill its responsibilities under its directives with respect to water quality and aquatic ecosystem health monitoring, reporting, objectives and alerts, and other activities related to the Board's charge.
IRLWWB Engagement Committee	Five members from Canada and five members from US, representing local stakeholders, Red Lake DNR, and IAG.	To involve the public in the issues of water quality and quantity within the basin.

In addition to information obtained from the international work groups, Minnesota continues to sponsor monitoring and research projects in the LoW Basin.

In the event that Minnesota became aware that significant additional loads were to be added outside of its jurisdiction, the TMDL allocation strategy would be reviewed and revised if necessary.

The TMDL goals defined by this study are consistent with objectives defined in local county water plans that will be further refined by the MPCA's Watershed Restoration and Protection Strategy (WRAPS) program, as well as the Minnesota Board of Water and Soil Resources' (BWSR) One Watershed, One Plan program. Together, these two locally-led programs, conducted on a HUC-8 watershed level, will result in the assessment of watershed conditions and a 10-year implementation plan that prioritizes implementation actions for water quality improvement towards long-term goals. The WRAPS reports for the LoW, Big Fork, and Little Fork HUC-8 Watersheds are complete and the 1W1P is complete for the LoW Watershed. The eight LoW Basin counties and the tribal representatives have been active participants in the TMDL study planning and development process, and most have decades of water quality management experience. Stakeholder meetings have been conducted to provide comment/feedback and support, including local governmental units and NPDES/SDS permit holders who receive TMDL allocations.

Future water quality restoration efforts will be led by local and county entities and tribes within the LoW Basin. Funding resources may be obtained from the following state and/or federal programs:

- Minnesota Clean Water, Land, and Legacy Funds

- EPA funding, such as CWA Section 319 grants
- State Clean Water Partnership Loans
- Natural Resources Conservation Services (NRCS) cost-share funds
- Local governmental funds and utility fees
- Local and lake association and nonprofit-related resources

6.1 Nonregulatory

Local, state, and federal partners have worked closely over the past 20 years to characterize water quality in the LoW Basin and to devise restoration and protection strategies. Furthermore, the IJC recognizes the importance of binational study and management of the LoW Basin, and as such has requested and subsequently received the International Lake of the Woods Basin Water Quality Plan of Study (POS; IJC 2015), which outlines a future of binational cooperation to study and gain an understanding of: nutrient enrichment and harmful algal blooms (HABs); aquatic invasive species; and surface and groundwater contamination in the basin. This study was led by the IMA, which comprises eight government agencies, the Lake of the Woods Sustainability Foundation, and the Red Lake Nation. Effective long-term partnerships will remain an important base for leveraging future restoration and protection projects for the LoW.

At the federal level, funding or partnership programs may be available through CWA Section 319 grants, the United States Department of Agriculture – NRCS, and U.S. Forest Service watershed restoration programs and climate change and risk research programs. Various other funding and cost-share sources exist, which will be listed in WRAPS reports and One Watershed, One Plan documents completed throughout the basin. The implementation strategies described in this TMDL study, such as stabilizing riparian areas and restoring hydrology to drainage systems, have been demonstrated to be effective in reducing nutrient loading to lakes and streams. Programs are in place within the TMDL Restoration Area to continue implementing the recommended rehabilitative activities. Detailed monitoring will continue along with adaptive management assessments to periodically (every five years) evaluate the progress made toward achieving water quality goals.

6.2 Regulatory

6.2.1 Permitted MS4s

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

- Public education and outreach;
- Public participation;

- Illicit discharge detection and elimination program;
- Construction site runoff controls;
- Post-construction runoff controls; and
- Pollution prevention and municipal good housekeeping measures.

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

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

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

6.2.2 Permitted construction stormwater

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

6.2.3 Permitted industrial stormwater

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

6.2.4 Permitted wastewater

All municipal and industrial wastewater NPDES/SDS permits in the watershed will reflect limits consistent with WLAs described herein. Discharge monitoring is conducted by permittees and routinely submitted to the MPCA for review.

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

6.2.5 Subsurface Sewage Treatment Systems Program

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

These regulations detail:

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

Counties and other LGUs enforce Minn. R. chs. 7080, through 7083, through their local SSTS ordinance and issue permits for systems designed with flows up to 10,000 gallons per day. There are approximately 200 LGUs across Minnesota, and depending on the location, an LGU may be a county, city, township, or sewer district. The LGU SSTS ordinances vary across the state. Some require SSTS compliance inspections prior to property transfer, require permits for SSTS repair and septic tank maintenance, and may have other requirements, which are stricter than the state regulations.

Compliance inspections by counties and other LGU are required under Minnesota rules for all new construction and for existing systems if the LGU issues a permit for the addition of a bedroom. In order to increase the number of compliance inspections, the MPCA has developed and administers several grants to LGUs for various ordinances and specific actions. Additional grant dollars are awarded to counties that have additional provisions in their ordinance above the minimum program requirements. The MPCA has worked with counties through the SSTS Implementation and Enforcement Task Force (SIETF) to identify the most beneficial way to use these funds to accelerate SSTS compliance statewide.

The MPCA staff keep a statewide database of known imminent threat to public health or safety (ITPHS) systems that include “straight pipe systems”. These straight pipe systems are reported to the counties or the MPCA by the public. Upon confirmation of a straight pipe system, the county sends out a notification of noncompliance, which starts a 10-month deadline to fix the system and bring it into compliance.

7. Monitoring Plan

The MPCA completes a systematic assessment of the water quality in each of Minnesota's HUC-8 sized watersheds on a 10-year repeating cycle. During 2012 and 2013, the MPCA conducted Cycle I intensive water quality monitoring in the LoW Watershed (HUC 09030009), which included monitoring in the LoW. In 2015, the MPCA performed assessments of the data and confirmed that the LoW was impaired for aquatic recreation use due to HABs caused by excess nutrients. The Cycle I Monitoring and Assessment report was published in 2016 and can be found here: https://www.pca.state.mn.us/sites/default/files/wq-ws3-09030009.pdf. The MPCA is scheduled to begin its Cycle II intensive water quality monitoring efforts in the LoW Watershed in 2023.

Evaluating progress toward achieving TMDL load reductions will rely primarily on monitoring surface waters and tracking implementation activities. Monitoring climate conditions and invasive species is also an important consideration in evaluating and understanding changes to lake and stream water quality and the dynamics of this large lake system. The activities discussed below are a summary of monitoring actions that are directly related to the TMDL. In addition to these actions, there is a much larger effort to gather data and understand the Rainy River Basin and the LoW. The document *A Water Quality POS for the Lake of the Woods Basin* (IJC 2015) was developed by a binational study team and submitted by the IJC to the governments of Canada and the U.S. to guide future investments made into monitoring and research activities. The POS provided recommendations for a comprehensive approach for gathering data and conducting the research necessary to address: (1) nutrient enrichment and HABs, (2) aquatic invasive species, and (3) surface and groundwater contamination. Since then, the Environment and Climate Change Canada has developed and is implementing a Science Plan that acquires data to address nutrient enrichment and HABs as well as inform other projects identified in the POS. Minnesota has continued its investment into understanding the basin and lake through special studies conducted by the SCWRS, UMN, and others as well as watershed monitoring through the MPCA's Monitoring and Assessment and WRAPS programs. In April 2016, the IRLWWB established an Aquatic Ecosystem Health Committee (AEHC) that developed an annual reporting approach that incorporates water quality and other indicators of ecosystem health (IRLWWB 2017). This existing, coordinated plan for reporting provides for efficient and effective evaluation of the health of the watershed. The LoW partners will use the information contained in this report as well as other efforts to measure progress to evaluate adaptive management interventions and adjustments.

7.1 Surface Water

Surface water monitoring, subject to funding availability and priorities, will include the LoW, the Rainy River, and each major watershed to evaluate lake and stream water quality patterns. Lake and river monitoring will be conducted by a combination of county/SWCD technicians, researchers, state, federal, and international partners as part of the LoW restoration plan. Details of the lake and stream monitoring, including tiered and core monitoring programs, are outlined in the POS (IJC 2015). An internationally agreed-upon network of long-term, fixed-site monitoring stations should be established. Additional U.S. HUC-8 level monitoring efforts will be specified by the WRAPS reports. Use of complimentary and emerging technologies, such as remote sensing, should be used in addition to in-field monitoring efforts.

7.1.1 Lake Monitoring

The following are elements of the lake monitoring program. Standard operating plans should be developed and followed by all monitoring programs. The MPCA will work with agencies and entities that are monitoring the LoW water quality to coordinate activities and plans.

- Consistently use integrated surface sampling, specifically pertaining to nutrient and Chl-*a*/algal bloom sampling.
- Use consistent sampling depth for nutrient sampling.
- Use consistent laboratory analytical procedures for nutrients, with attention to assessment of total and dissolved P and nitrogen (N) fractions. The time required for shipment to laboratories should be conservatively incorporated into the planning.
- Continue automated buoy oxygen and temperature profile data collection.
- Assess the bottom layer temperature and DO levels, particularly when calm periods of approximately ten days or more are observed. These calm periods may be sufficient for lake oxygen depletion rates to generate anaerobic bottom layer conditions in the southern lake bays.
- Evaluate the utility of closer examination of lake sediment and water total iron concentrations. While lake sediments may have higher iron concentrations, some bays appear to have total iron to TP concentration ratios of less than 3:1 at times. The potential of lake sediment iron being influenced by factors such as sulphate/sulphide interactions should be considered and potentially evaluated.
- Continue climate data reporting and consider a brief annual climate reporting format as afforded by existing reporting stations and available resources. These data and reports may aid in summarizing annual reporting of ice-cover periods, ice-off dates, temperatures, precipitation, evaporation, lake levels, and wind to better track climate variability.
- Continue implementation of the Wind and Wave Monitoring Volunteer Program.

7.1.2 Rainy River and Tributary Monitoring

The following are elements of the river and tributary monitoring program. A manual of SOPs should be developed and followed by all monitoring programs. The MPCA's Watershed Pollutant Monitoring Network (WPLMN) is a long-term program that utilizes data collected from monitoring program partners to calculate pollutant loads. The WPLMN includes monitoring conducted in the Rainy River Basin HUC-8 watersheds as well as the Rainy River.

- Use shared site and flow methods for the calculation of annual loads and flow-weighted mean concentrations from Rainy River and tributary sites. In this regard, FLUX32 is a useful tool to assess loads and perform various sampling diagnostics. This work may also include integrating database capabilities for efficient extraction and assessment of data collected by various agencies.

- Consider sharing laboratory methods and quality assurance procedures including the analysis of splits, duplicates, and field blank samples by major laboratories with other agencies and entities monitoring LoW water quality to obtain consistency in sampling procedures.

8. Implementation Strategy Summary

Implementing the LoW TMDL study will be a collaborative effort between individuals and local, state, federal, provincial, and tribal governments. The overall effort will be led by the LoW and Koochiching SWCDs as the majority of the TMDL Restoration Area is located in these two counties. These SWCDs will provide technical support, funding coordination and local leadership. The SWCDs can leverage existing relationships and regulatory frameworks to generate support for the TMDL study implementation. These existing governmental programs and services will provide efficiency and related cost savings to the maximum extent possible.

8.1 Permitted Sources

Permitted sources within in the LoW Basin include wastewater, construction stormwater, industrial stormwater, and MS4s. The MPCA oversees the NPDES/SDS permitting programs to obtain compliance with waste load reductions.

A total of 19 individual NPDES/SDS point sources are assigned WLAs in this study: 14 domestic wastewater sources and 5 industrial wastewater sources. Eleven of the 14 domestic and 1 of the industrial wastewater permits already include TP effluent limits consistent with TMDL WLAs. The remaining three domestic wastewater permits (numbers 1, 2, and 3 below) will include updated TP load limits upon permit reissuance. The remaining four industrial wastewater permits (numbers 4, 5, and 6 below) will include TP limits upon permit reissuance if they are found to have reasonable potential to cause or contribute to the impairment. Facilities whose permits are not yet consistent with TMDL WLAs can be summarized as follows:

1. A draft permit for one large domestic wastewater NKASD WWTP is currently posted for public comment and includes a TP load limit equal to the proposed WLA;
2. One small domestic facility permit (Springsteel Island Sanitary District) that does not currently include an annual TP load limit;
3. One small domestic facility permit (ISD 2142 Pre-Kindergarten to Grade 12 N School) that does not currently include any TP effluent limits;
4. One very large industrial wastewater facility permit (Boise White Paper LLC – Intl Falls) that does not currently include any TP effluent limits;
5. Two metallic mining facility permits that do not currently include any TP effluent limits; and
6. One peat mining facility permit has been issued but the facility has not yet been built.

Table 4-6 lists the permitted sources and their assigned WLAs and the expiration dates for those permits. Sources with expired permits are required to operate under the conditions of their expired permit until their permit is re-issued.

8.1.1 Wastewater

All 19 NPDES permitted wastewater facilities in the Restoration Area are currently meeting their respective WLAs. Most of the permits already include effluent limits that are consistent with the TMDL's WLAs with the following exceptions:

1. Domestic wastewater – The NKASD WWTP permit and Springsteel Island Sanitary District WWTP permit TP effluent limits will be adjusted to be consistent with TMDL WLAs. The ISD 2142 Pre-Kindergarten to Grade 12 N School WWTP permit does not currently include any TP effluent limits. A new TP limit consistent with the TMDL's WLA will be developed at the time of permit reissuance.
2. Industrial – The Boise White Paper LLC – International Falls permit does not currently include any TP effluent limits. A new TP limit consistent with the TMDL's WLA will be developed at permit reissuance. The Berger Horticultural Products – Pine Island Bog, Hibbing Taconite Co. – Tails Basin Area and US Steel – Minntac Tailings Basin Area permits do not currently include any TP effluent limits. Permit limits consistent with TMDL WLAs will be developed at the time of permit reissuance if the discharges are found to have reasonable potential to cause or contribute to the impairment.

With two exceptions, all Minnesota wastewater facilities in the LOW Watershed have attained compliance with TMDL WLAs over the past five years (2016 through 2020). The two exceptions are:

1. The Bigfork WWTP reported discharging 232 kg/yr of TP in 2016, exceeding its 216 kg/yr WLA by 7%.
2. 2) The Hibbing Taconite Co is estimated to have discharged 671 kg/yr of TP in 2016, exceeding its 497 kg/yr WLA by 35%.

8.1.2 Construction Stormwater

The WLA for stormwater discharges from sites with construction activity reflects the total area of permitted construction sites (area greater than one acre) that are expected to be active in the watershed in a given year, as well as the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in the state's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). If a construction site owner/operator obtains coverage under the NPDES/SDS General Stormwater Permit and properly selects, installs, and maintains all BMPs required under the permit, including those related to impaired waters discharges and any applicable additional requirements found in Appendix A of the Construction General Permit, the stormwater discharges are expected to be consistent with the WLA in this TMDL study. All local construction stormwater requirements must also be met.

8.1.3 Industrial Stormwater

The WLA for stormwater discharges from sites with industrial activity reflects the number of sites in the watershed that require NPDES/SDS Industrial Stormwater Permit coverage, as well as 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 NPDES/SDS General Permit for Construction Sand & Gravel, Rock Quarrying and Hot Mix Asphalt Production Facilities (MNG490000). If a facility owner/operator obtains stormwater coverage under the appropriate NPDES/SDS Permit and properly selects, installs, and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL study. Facilities can obtain a no-exposure exclusion if the site's operations occur under-roof. The permittee is required to develop and implement an SWPPP that details stormwater BMPs to be implemented to manage stormwater at the facility. Permitted facilities are required to perform runoff sampling that compares to benchmark P concentrations as specified by the EPA. The P monitoring is required if a nutrient-impaired waterbody is located within one mile of the facility. All local stormwater management requirements must also be met.

8.1.4 MS4

Hibbing, Minnesota, at the headwaters of the Little Fork River Watershed, is the only regulated MS4 in the LoW Basin. No WLA was given to the city of Hibbing in this study because 30 of the 41 km^2 of the city of Hibbing's MS4 area that are in the TMDL Restoration Area are already covered by the Hibbing Taconite Company Tailings Basin Area, which is a regulated point source. The remaining 11 km^2 are mostly forested and undeveloped. There are no discharges to the city of Hibbing's stormwater conveyance system that are within the 11 km^2 area.

The city of International Falls is expected to be subject to an MS4 permit in the future, as it is a city with a population greater than 5,000 people that drains to an impaired water (LoW); a WLA was thus assigned to the city of International Falls when permitted as a MS4 (Table 8-1). Based on demographic growth projections, no additional new MS4s are expected within the TMDL Restoration Area.

Table 8-1. MS4 WLA.

MS4	Load Reduction at Source (t/y)	Percent Reduction
City of International Falls MS4	228.6	N/A

8.2 Nonpermitted Sources

Nonregulated rehabilitation actions within the impaired river reach and lake watersheds will require cooperative planning and implementation by: partnering counties; SWCDs; and regional, state, and federal agencies. Canadian partners, including ECCC and OMECC, have a commitment to improving the LoW water quality and watershed conditions. The TMDL table cannot technically account for their reductions as this TMDL study is a U.S. regulatory requirement. However, their efforts are an important aspect to restoring the LoW.

8.2.1 SSTSs

Because of the LoW Basin's rural nature, most homes and many businesses in the LoW Basin are served by SSTSs. Both LoW and Koochiching Counties have subsurface treatment system ordinances with detailed requirements and enforcement procedures. Future SSTS surveys will aid in obtaining 100% compliance and reducing nutrient loading from noncompliant systems.

8.2.2 Agricultural BMPs

The Agricultural BMP Handbook for Minnesota (Miller et al. 2012) provides information on the types of BMPs to be implemented in the watershed. Encouraging implementation of agricultural BMPs will substantially reduce agricultural lands' pollutants. The Minnesota Agricultural Water Quality Certification Program, implemented by the Minnesota Department of Agriculture (MDA), may be an important tool for increasing the adoption of agricultural BMPs. The NRCS and local SWCDs may be able to provide technical and financial services. Proper site designs, construction, and maintenance are key components for effective performance of agricultural best practices. Previous attempts to increase agricultural production in the watershed resulted in extensive ditching in the upstream areas of the LoW HUC-8. For these areas, agricultural drainage practices that reduce erosion, such as side inlets, will be implemented. Where agricultural production is not viable, efforts should be made to restore hydrology.

8.2.3 Forestry BMPs

Forestry operations of all sizes should adopt forest stewardship planning and follow the Minnesota Forest Resources Council *Forest Management Guidelines* (Minnesota Forest Resources Council 2012). Enrollment in Minnesota's Sustainable Forest Incentive Act (SFIA) will be encouraged. This program provides property owners with a payment for each acre of qualifying forest land that is enrolled. The qualifying enrollment criteria are agreeing not to develop land for a period of years and following a forest management plan.

8.2.4 Urban BMPs

Developed land use areas only account for 1.7% of the LoW basin and include the cities of Warroad, Baudette, and International Falls. Encouraging and tracking implementation of urban BMPs, as detailed by the Minnesota Stormwater Manual (MPCA 2016c) and minimal impact design standard (MIDS) will cover the spectrum of source, rate, and volume controls that will substantially reduce developed land's pollutant loading. In addition to the cities in the watershed, shoreland areas are subject to increasing land use pressure that could have reduced stormwater impacts by implementing urban BMPs. Proper site designs, construction, and maintenance are key components for effective performance of urban BMPs.

8.2.5 Riparian and Shoreland Management

Shoreline erosion, particularly on the south side of the LoW, is a substantial source of P loading to the lake. One compounding factor to reducing shoreline erosion is the extensive amount of mucky soils in this area. The LoW SWCD offers programs to help landowners acquire professional design-build landscaping services to provide landscape designs. Lake shore residents can develop individualized plans with the landscape services contractor who can begin installations as feasible with a phased implementation to increase efficiencies and reduce unit costs. The contractor could conduct site reviews, prepare designs with property owners, design specifications, complete installation per specifications, and provide long-term maintenance checklists. Education and partnered demonstration plots with community organizations or schools may be beneficial.

A 50-foot average riparian buffer width with a 30-foot minimum width has been recently required along public waters (Minn. Stat. 103F.48, Riparian Protection and Water Quality Practices). The LoW and Koochiching SWCDs are the point of contact for requirements and technical assistance for implementing buffers along public waters and shore lands. The Clean Water Legacy Fund included five million dollars available for local government implementation through BWSR. The SWCDs will identify and prioritize placement of perennial vegetation buffers along small streams and headwater areas.

8.2.6 Internal Loading

The LoW internal loading is an important portion of the P budget. Because of the size and nature of this lake, management actions aimed at controlling the internal release of P are not possible. However, the internal P loading is the result of excessive historical watershed loading, which has been greatly reduced over the past 50 years and continues to decline. The SCWRS estimates that, with continued decreases in watershed loading, the internal load will decrease approximately 1% per year.

8.3 Cost

The Clean Water Legacy Act requires that a TMDL study include an overall estimate of the cost to implement a TMDL (Minn. Stat. § 114D.25). A detailed analysis of the cost to implement the LoW TMDL study was not conducted, as the restoration efforts will be addressed through the development of the individual HUC-8 TMDL studies, WRAPS reports, and One Watershed, One Plan process local water plans. The WRAPS reports and TMDL studies have already been concluded for the LoW HUC-8 Watershed, Little Fork River Watershed, and Big Fork River Watershed. These watersheds are identified as large loading sources to the LoW. The LoW HUC-8 TMDL study provided a preliminary estimate of $2.5 to $3 million dollars to implement planned activities. The LoW HUC-8 1W1P provides approximately $620,000 in implementation funding, every two years for the life of the Clean Water Fund with 10-year updates to the 1W1P. No other cost estimates for implementation projects in the remaining HUC-8 watersheds exists. The Little Fork TMDL study has an estimated cost of $56.4 million for the 482 mi^2 of TSS impaired stream watersheds. This estimate is based on an interagency work group (BWSR, MDA, MPCA, Association of SWCDs, Association of Watershed Districts, National Oceanic and Atmospheric Administration) that assessed restoration costs for several TMDLs, with an average cost estimate of $117,000/square mile for a watershed-based treatment approach.

8.4 Adaptive Management

LoW is an international water that has been cooperatively managed by the U.S. and Canadian governments, through the IJC, since the Boundary Waters Treaty was signed in the early 1900s. Since that time, there has been a long history of cooperative water quality, water level, and fisheries management in the LoW and other upstream waters within the Rainy River Basin. Minnesota's TMDL follows in this convention.

The MPCA understands and respects the authorities of our international partners with regard to LoW water quality management. Although the water quality goals, jurisdictions, and authorities in the TMDL study apply to only the Minnesota waters of the LoW and upstream watersheds, as discussed in previous sections, the TMDL modeled conditions in some international waters are included due to natural water flow and circulation patterns. Additionally, the TMDL study has listed reductions from two sources within Canada: the idling of Abitibi's Fort Frances pulp and paper mill (which occurred after the TMDL study began) and the internal P reductions in the south basin prorated to Canadian waters. These findings were vetted by Canadian water management agencies through their participation on the TMDL TAC, and were only possible due to their cooperation and the rigorous datasets collected by our international partners and citizen scientists.

The TMDL process identified scientific findings that will advance the water quality management of the entire LoW and Rainy River Basin. By identifying, quantifying, and working to address "upstream" nutrient sources, Minnesota is striving to move in a positive direction to improve water quality in the LoW. It is recognized that Minnesota's impaired waters declaration in 2008 spurred additional research, monitoring, and government/public interest in eutrophication issues in the LoW. For example, in 2009 the IMA Working Arrangement (Arrangement) was signed by numerous federal, state, provincial, tribal, and county authorities to foster trans-jurisdictional coordination and collaboration to enhance and restore water quality in the LoW Watershed. The Arrangement defined a Work Group of management personnel who assigned a TAC to draft work-plans to carry out the objectives needed to advance key issues, such as the factors influencing algal bloom formation and advancing basin core monitoring and information sharing (e.g., the State of the Basin Reports). This advancement led to the formation of the IJC's International Rainy-Lake of the Woods Watershed Board, with the mandate to monitor ecosystem health in the LoW Basin. Soon after, the Board petitioned the development of a Water Quality POS and its priority water quality management issues. In 2016, Environment and Climate Change Canada allocated a multi-million dollar 4-year Science Plan for the watershed, designed to provide the science to support future multinational decisions and actions.

In summary, while the TMDL project only applies in Minnesota waters, the project will advance water quality management in the entire LoW Basin. Much cooperative progress has been made in the last decade in this regard. The IJC's recent recommendation that all international partners work together toward establishment of shared multinational P objectives is a testament to this outcome.

The restoration strategy will employ an adaptive management approach (Figure 8-1). The TMDL study implementation plan will be executed on an iterative cycle consisting of a series of five elements, each outlined below.

8.4.1 Design Strategy

The LoW Basin spans a number of jurisdictional boundaries, including a binational boundary. Each affected jurisdiction will be responsible for implementing the necessary strategies to reduce loading within the watershed. A coordinated effort is needed to obtain efficient and effective delivery of implementation programs. More detailed planning efforts will occur through existing programs, including local county water plans and 1W1P processes that are being developed for HUC-8 level watersheds in Minnesota. These plans will incorporate the LoW TMDL Study's restoration goals and include the detailed information regarding funding, responsible parties, priority subwatersheds, and

BMP targeting considerations. Each local plan also includes a detailed process for prioritizing and tracking implementation activities and reporting progress.

The design strategy will include additional studies or data acquisition needs in addition to the condition monitoring program. The purpose of these studies will be to provide the data necessary to evaluate progress or fill information gaps, particularly for the advancement and refinement of models that are used to determine success and predict future progress.

Finally, the design strategy will set measurable goal criteria that are based on expected outcomes and define the thresholds which will trigger adjustments to the adaptive management plan.

8.4.2 Implement

The activities outlined in the design strategy will be implemented by the responsible parties as funding and staff resources allow. Activities will be coordinated among the multiple local, state, federal, and provincial governments to leverage resources and streamline implementation efforts. Nongovernmental organizations, private companies, and citizen groups will develop partnerships to increase stewardship opportunities.

The majority of the TMDL Restoration Area is in LoW and Koochiching Counties. Therefore, tracking implementation efforts will primarily be led by LoW and Koochiching SWCDs, with other SWCDs within the basin supporting implementation efforts. These SWCDs will track and annually report implementation projects within their jurisdictions. This reporting includes using pollutant reduction calculators and inputting data into BWSR's web-based eLINK tracking system (Minnesota Board of Soils and Water Resources 2016). The BMPs effectiveness may be estimated by BWSR and MPCA calculators based on BMP designs, construction, and operation and maintenance considerations.

8.4.3 Monitor

The elements of the monitoring program are outlined in Section 7. The specific parameters, frequencies, and locations of the monitoring program will be developed as part of each adaptive management cycle in order to address data gaps and evaluate progress.

8.4.4 Evaluate

Data and information acquired through studies, monitoring, and implementation activities will be evaluated to ascertain progress towards goals. Modeling and statistical tools will be used for monitoring the performance of the implementation plan as well as to identify changes from expected results. The information obtained from this evaluation will be used in the assessment process.

8.4.5 Assess Progress

The results obtained from evaluating monitoring and data acquisition will be considered to determine the most appropriate strategy for attaining the water quality goals established in this TMDL study, and whether adjustments to the program elements should be made. Management activities will be changed or refined to efficiently meet the TMDL and lay the groundwork for de-listing the impaired waterbodies.

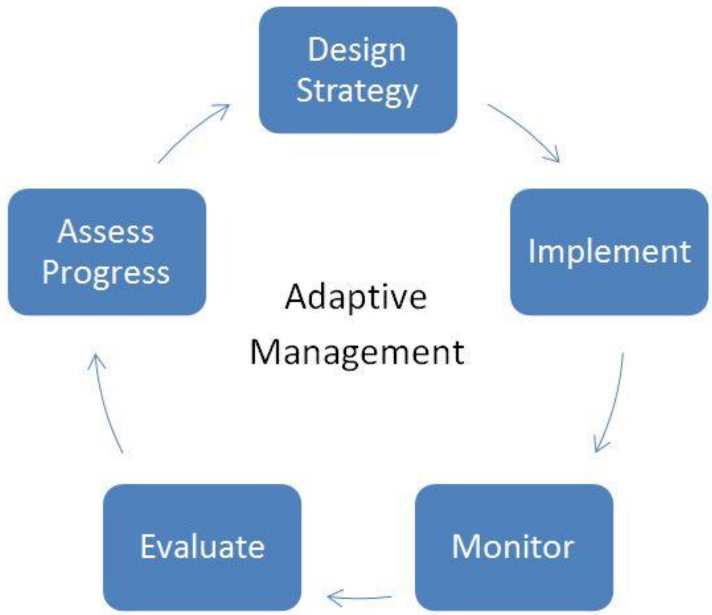


Figure 8-1. Adaptive Management

9. Public Participation

The project team built stakeholder participation into the TMDL study process from the start. The MPCA invited a representative group of individuals to an organizational meeting in October 2015 to determine level of interest in participating in the TAC.

The LoW TMDL Study TAC was comprised of representatives from stakeholder groups including:

- U.S. Geological Survey
- Red Lake Nation Department of Natural Resources
- LoW Sustainability Foundation
- Ontario Ministry of Environment and Climate Change (OMECC)
- Environment and Climate Change Canada
- Minnesota BWSR
- Minnesota Department of Health
- Minnesota Department of Natural Resources (DNR).

Modeling that was conducted for development of this TMDL was presented to the TAC at two presentations and in the form of background technical memoranda. The LoW SWCD promptly posted presentations and the video for each meeting on its web site.

In addition to the TAC, the MPCA has involved the broader public through annual forums and conferences. The MPCA and LoW SWCD staff members have given updates via presentations and newsletters to many organizations and audiences.

The MPCA informed and held meetings with point-source permit holders that were subject to WLAs. Multiple meetings were held with Boise Paper (International Falls), which was subject to the largest load reduction. There was not a permit in place that limited Boise Paper's P discharge prior to this TMDL study. The load reduction accounted for is based on actual discharge and the P load reductions will be specified in a new permit.

Efforts to facilitate public education, review, and comment with development of the LoW TMDL included meetings with local watershed groups to discuss the assessment findings, a 30-day public notice period for public review and comment of the draft TMDL study, and two virtual public meetings - held during the public notice period – to discuss the draft TMDL study and answer questions. All input, comments, responses, and suggestions from public meetings and the public notice period were addressed or were taken into consideration in developing the TMDL study. A complete list of public participation activities is included in Table 9-1.

Table 9-1. Public participation.

Date	Activity	Location	Target Group	No. of Participants
October 2, 2015	Organizational Meeting	Baudette, MN	Federal, state, local, and tribal agency partners	18
November 23, 2015	Project overview	Webinar	TAC	11
December 21, 2015	Watershed Model Review	Webinar	TAC	11
March 8, 2016	Study Update	International Falls, MN	IJC, IAG, and CAF groups	
March 8, 2016	Lake Model Review	International Falls, MN	TAC	14
March 10, 2016	Study Update	International Falls, MN	Annual Conference	
August 2016	Study Update		Mike H and Cary gave an update in Kenora (IJC?)	
October 24, 2016	Kick-off Meeting	International Falls, MN	General Public	9
October 25, 2016	Kick-off Meeting	Baudette, MN	General Public	8
October 25, 2016	Kick-off Meeting	Warroad, MN	General Public	1
October 31, 2016	Kick-off Meeting	Webinar	General Public	14
November 23, 2016	Preliminary Results	Webinar	TAC	16
March 8, 2017	Internal Loading	Webinar	TAC	17
March 9, 2017	Study Update	International Falls, MN	Annual Conference	
November 21, 2017	Internal loading	Webinar	TAC	18
February 28, 2018	Preliminary Load Allocations	Webinar	OME, ECCC	
March 6, 2018	Study review	International Falls, MN	TAC	9
March 8, 2018	Study Update	International Falls, MN	Annual Conference	
August 13, 2019	Study Update	Baudette, MN	IJC Board	
January 14, 2020	Study Update	Webinar	ECCC	
March 11, 2020	Study Update	International Falls, MN	Annual Conference	
August 17, 2020	Study Update	Webinar	IRLWWB Board	
October 2, 2020	Study Update	Webinar	IRLWWB Public Meeting	
March 4, 2021	Informational Meeting	Webinar	All Stakeholders	28

Public notice

An opportunity for public comment on the draft TMDL study was provided via a public notice in the State Register from February 22, 2021, through March 24, 2021. There were two comment letters received and responded to as a result of the public comment period.

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Appendix A. Detailed Climate Summary

This appendix includes a detailed overview of climate data for the LoW Basin.

A.1 TEMPERATURE

National Oceanic and Atmospheric Association (NOAA) temperature data (NOAA 2017 were obtained for Minnesota Climate Divisions 2 (North Central) and 3 (Northeast). Climate Division 2 includes the western portion of the Lake of the Woods Basin in Minnesota, while Climate Division 3 includes the eastern portion. Mean annual temperatures for 1895 through 2016 are presented in Figure A-1 and Figure A-2, while Figure A-3 and Figure A-4 show the mean temperature from June through September for each Climate Division. Figure A-1 and Figure A-2 show that mean annual temperatures have increased by approximately 0.3 degrees Fahrenheit (°F) per decade for both Climate Divisions. Figure A-3 and Figure A-4 show a mean temperature increase of 0.2°F per decade for both Climate Divisions.

A.2 GROWING SEASON LENGTH AND GROWING DEGREE DAYS

The duration of the frost-free period, which is the time between the last day below freezing in spring and the first day below freezing in the fall, can be used as a surrogate for growing season length. The length of the frost-free period was plotted by year for Warroad, Minnesota, (Figure A-5), Baudette, Minnesota, (Figure A-6), and Indian Bay, Manitoba (Figure A-7). A filter was applied to include only years with 200 or more minimum daily temperature values from April 1 to October 31 (the typical range of the frost-free period). Frost-free periods have increased over the past century at Warroad, Minnesota, and Baudette, Minnesota, where trend lines suggest an increase in the frost-free season of 30 to 35 days over the past century.

A growing degree analysis was carried out to further examine changes in temperature over the past century. Daily growing degree days (GDDs) are calculated as:

$$GDD = \frac{T_{\max} + T_{\min}}{2} - T_{base} \qquad \text{(A-1)}$$

where T_{max} is the daily maximum temperature, T_{min} is the daily minimum temperature, and T_{base} is the base temperature (10°C or 50°F). Mean daily temperature, taken as the average of T_{max} and T_{min}, must exceed T_{base} to generate GDDs; otherwise, the GDDs equal zero. Similarly, daily modified GDDs (MGDD) are calculated as:

$$MGDD = \frac{Minimum\left(T_{\max}, 30^{\circ}\mathrm{C}\right) + Maximum\left(T_{\min}, 30^{\circ}\mathrm{C}\right)}{2} - T_{base} \qquad \text{(A-2)}$$

MGDDs are based on the principle that plants neither receive additional benefit when the temperature rises above a certain threshold nor receive any usable energy when the temperature falls below a certain threshold. Threshold values of 10°C (50°F) and 30°C (86°F) are typically used for corn and soybeans. Using threshold temperatures reduces MGDDs on hot days by capping the maximum temperature and increases MGDDs on cooler days by setting a floor for the minimum temperature. MGDDs are typically greater than GDD values at higher latitudes because of a higher prevalence of cooler temperatures.

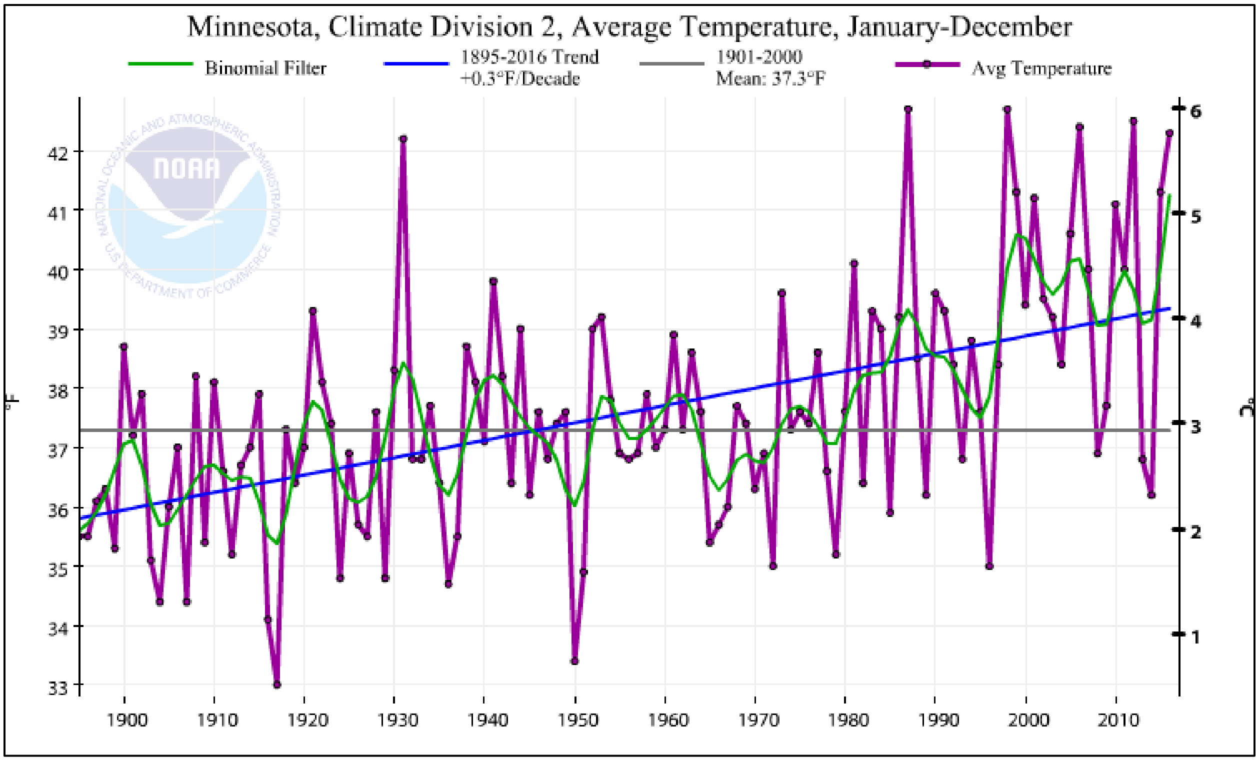


Figure A-1. Minnesota Climate Division 2 (North Central Minnesota) Average Annual Temperature, 1895–2016 (NOAA 2017)

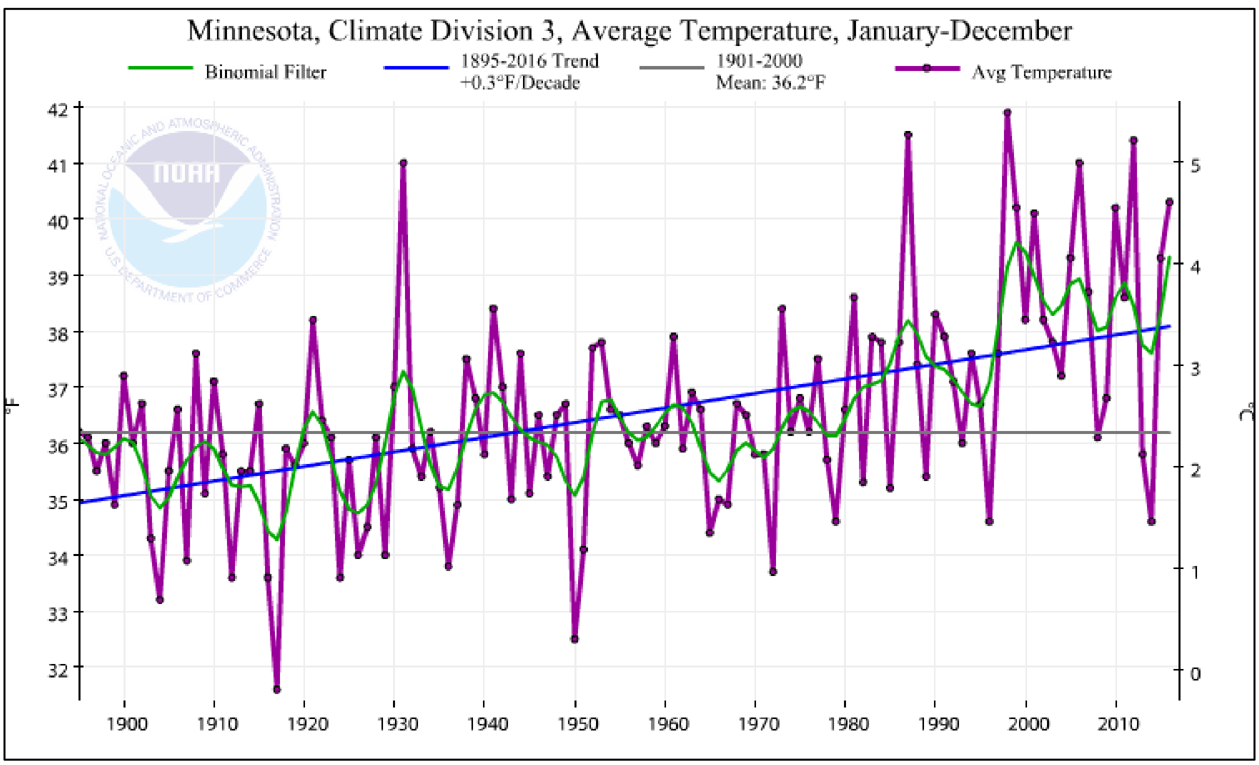


Figure A-2. Minnesota Climate Division 3 (Northeast Minnesota) Average Annual Temperature, 1895–2016 (NOAA 2017)

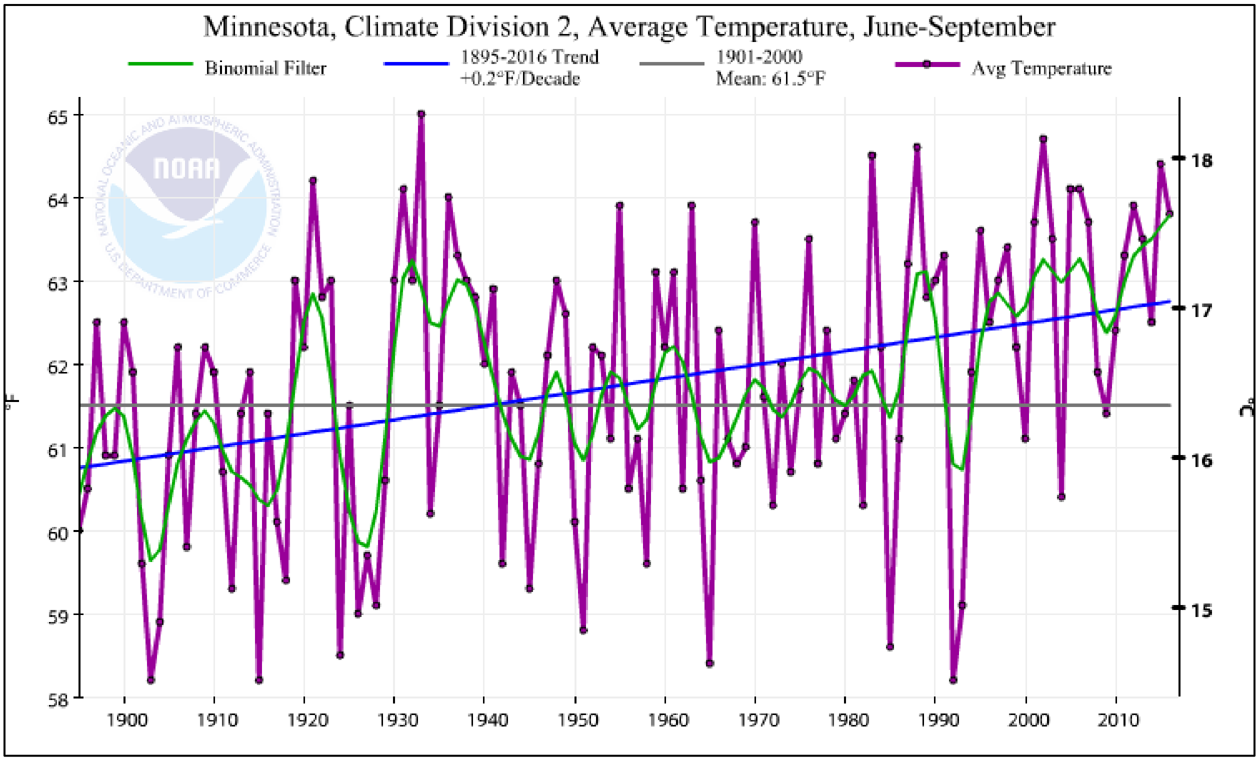


Figure A-3. Minnesota Climate Division 2 (North Central Minnesota) Average June–September Temperature, 1895–2016 (NOAA 2017)

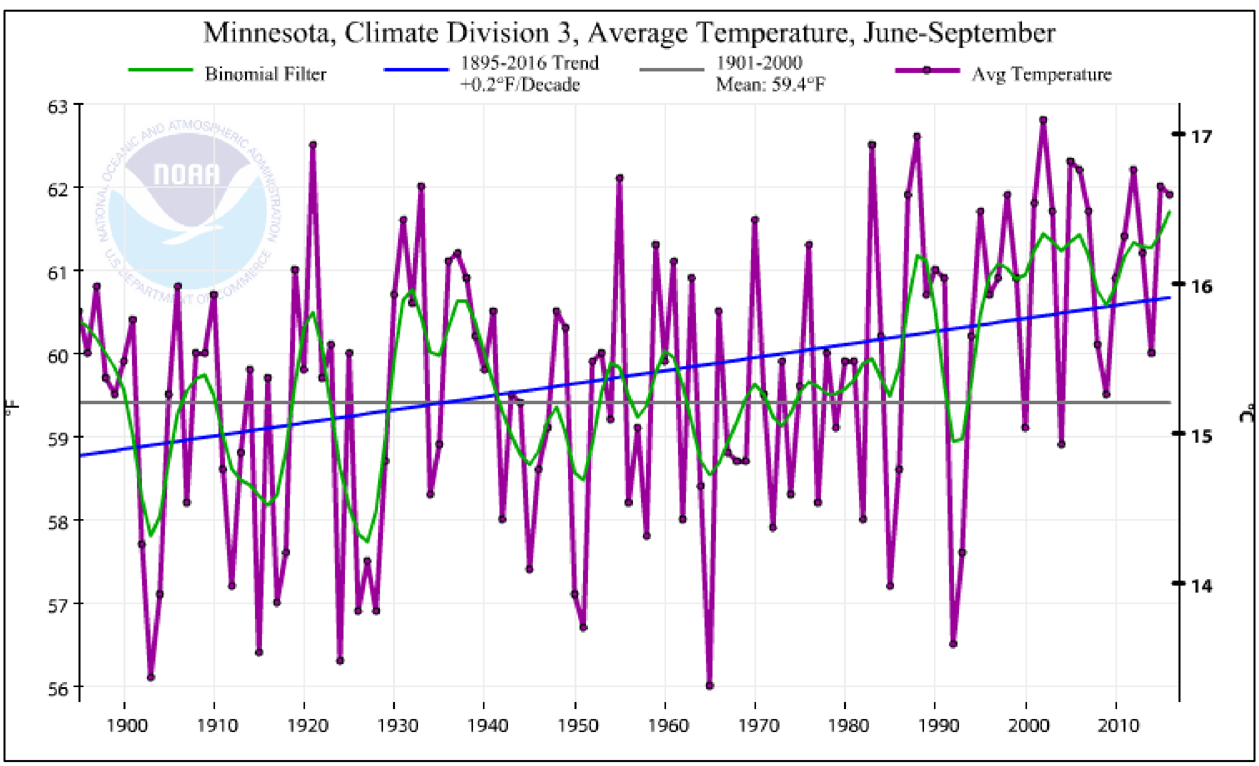


Figure A-4. Minnesota Climate Division 3 (Northeastern Minnesota) Average June–September Temperature, 1895–2016 (NOAA 2017)

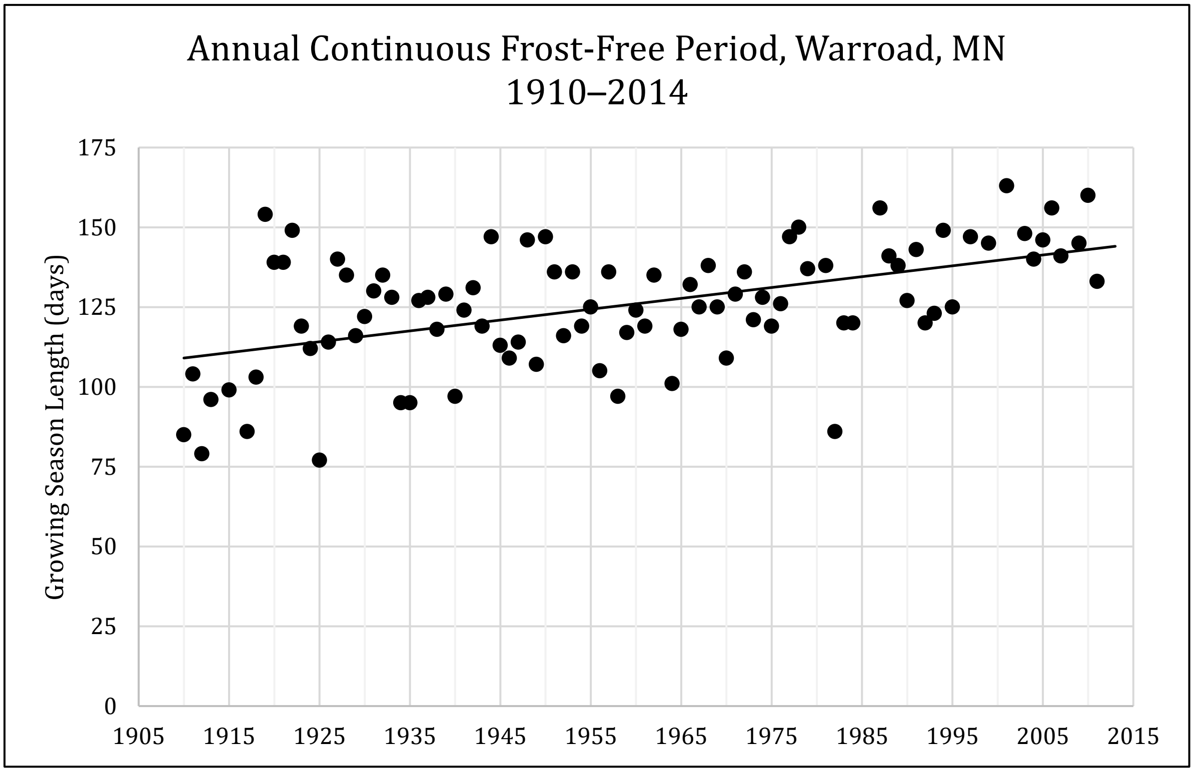


Figure A-5. Annual Continuous Frost-Free Period, Warroad, MN, 1910–2014 (Midwestern Regional Climate Center 2016)

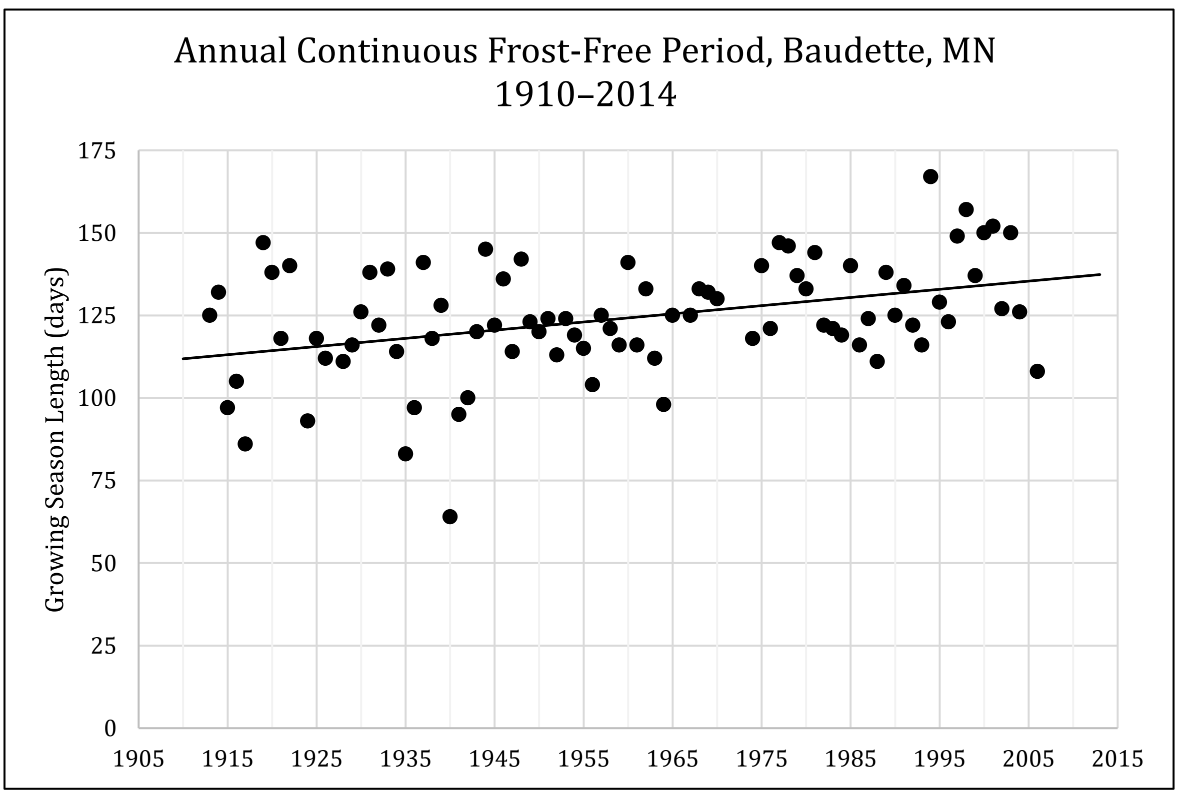


Figure A-6. Annual Continuous Frost-Free Period, Baudette, MN, 1910-2014 (Midwestern Regional Climate Center 2016)

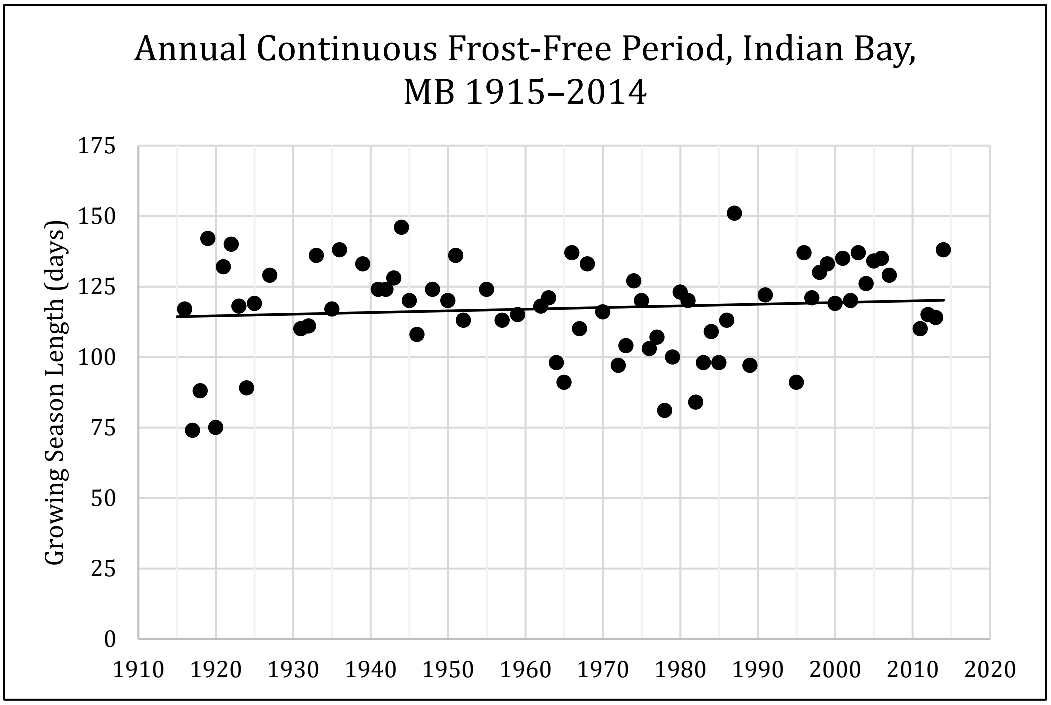


Figure A-7. Annual Continuous Frost-Free Period, Indian Bay, MB, 1915–2014 (Environment and Climate Change Canada 2016a)

The total annual GDDs and MGDDs for Warroad, Minnesota, from 1910 through 2007 are plotted in Figure A-8. Only years that have at least 200 data points for April through October were included. Annual MGDD values have remained flat over the past century, while the trendline suggests an increase in annual GDDs from approximately 1750 to 1900. The increase in GDDs is presumably caused by mean temperatures increasing over the past century. The slight increase in GDDs suggests that biological activity and overall ecosystem production may have increased slightly over the past century.

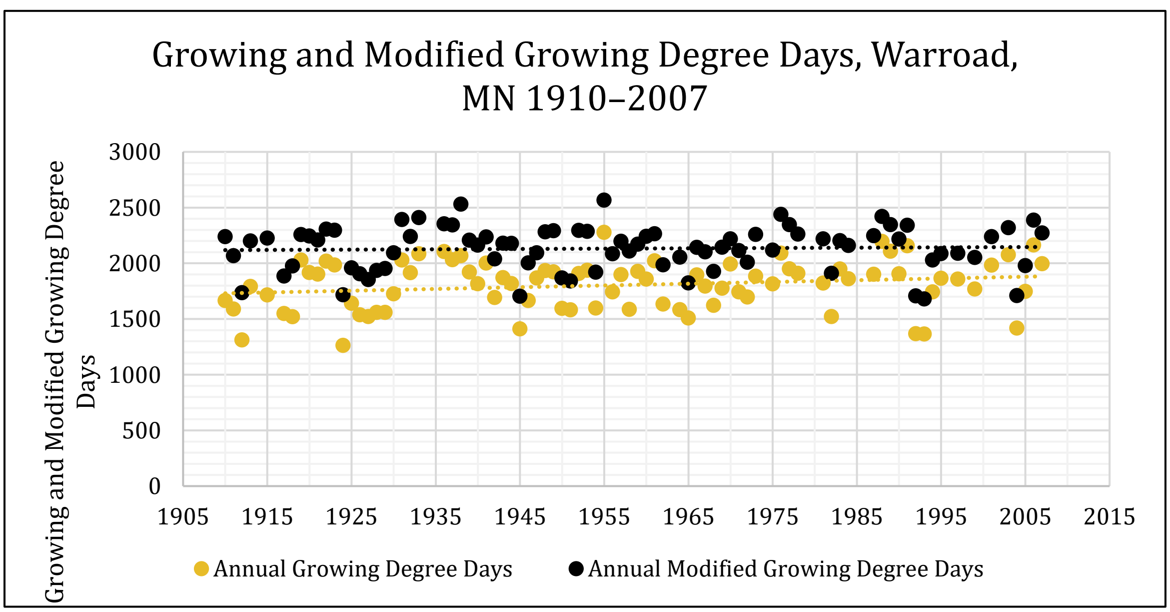


Figure A-8. Growing Season Data for Warroad, MN (USC00218679), 1910–2007 (Midwestern Regional Climate Center 2016)

A.3 PRECIPITATION

The NOAA precipitation data for Warroad, Minnesota, for 2005 through 2014 are summarized in Table A-1. Data were categorized by month and show the mean number of precipitation events exceeding specified thresholds. On average, 6.5 and 2.5 rainfall events occurred during the growing season (June through September) per year that exceed 0.5 and 1 inch (in), respectively.

Table A-1. 2005–2014: Number of precipitation events by month for Warroad, MN (Climate Station ID USC00218679) (Midwestern Regional Climate Center 2016).

Month	Mean Precipitation Events Exceeding Specified Depth			
	≥ 0.01 in	≥ 0.1 in	≥ 0.5 in	≥ 1 in
January	6.7	1.9	0	0
February	4.7	1.5	0.3	0
March	5.1	2.4	0.7	0
April	5.8	3.4	0.9	0.2
May	11.9	6.1	1.7	0.7
June	11.3	6.1	2.2	0.4
July	8.4	5.4	2.3	0.9
August	7.3	4	1.1	0.4
September	9.2	4.2	0.9	0.8
October	7.9	3.8	1.7	0.5
November	6.5	2.4	0.2	0
December	6.3	1.5	0.1	0
Growing Season (June–September)	36.2	19.7	6.5	2.5

The NOAA, in cooperation with the MPCA, DNR State Climatology Office, and Minnesota Department of Transportation, updated precipitation intensity and duration data for Minnesota, referred to as Atlas 14. Atlas 14 data for Warroad, Minnesota, (Site ID 21-8679) are given in Table A-2.

A.4 WIND

Wind patterns were evaluated with wind roses, which depict the distribution of wind speed and direction for a given site. Distribution of the wind direction is indicated by the length of each spoke, while wind speed distributions are indicated by the radial width of each color band along each spoke. Wind roses with 1996 through 2017 data for Flag Island, which is located in Little Traverse Bay near the U.S./Canada border, were obtained from the Iowa Environmental Mesonet (2017).

The annual wind rose for Flag Island is shown in Figure A-9. Annually, nearly 70% of wind comprises wind from the northwestern quadrant (32%), south-southeastern octant (between south and southeast, 24%), or calm (less than 2 miles per hour [mph] or 3.2 kilometers per hour [kph]; 12.7%). The most prevalent quadrant of the wind rose is the northwest, while the most prevalent octant is that between the south and southeast.

Table A-2. Atlas 14 precipitation frequency estimates for Warroad, MN, (21-8679) (NOAA 2016) (page 1 of 2).

Duration	Average Recurrence Interval (years)									
	1	2	5	10	25	50	100	200	500	1,000
PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[a]										
5-min	**0.32**	**0.38**	**0.47**	**0.56**	**0.69**	**0.79**	**0.89**	**1.00**	**1.15**	**1.27**
	(0.27–0.38)	(0.32–0.45)	(0.40–0.57)	(0.47–0.68)	(0.55–0.88)	(0.61–1.02)	(0.66–1.19)	(0.70–1.39)	(0.76–1.66)	(0.81–1.86)
10-min	**0.46**	**0.55**	**0.69**	**0.82**	**1**	**1.15**	**1.31**	**1.47**	**1.69**	**1.87**
	(0.39–0.56)	(0.47–0.66)	(0.59–0.84)	(0.69–1.00)	(0.80–1.28)	(0.89–1.50)	(0.96–1.75)	(1.02–2.03)	(1.11–2.42)	(1.19–2.72)
15-min	**0.57**	**0.67**	**0.85**	**1.00**	**1.23**	**1.41**	**1.59**	**1.79**	**2.06**	**2.27**
	(0.48–0.68)	(0.57–0.81)	(0.71–1.02)	(0.84–1.22)	(0.98–1.56)	(1.09–1.82)	(1.17–2.13)	(1.24–2.48)	(1.36–2.96)	(1.45–3.32)
30-min	**0.74**	**0.88**	**1.12**	**1.32**	**1.61**	**1.85**	**2.10**	**2.36**	**2.72**	**3.00**
	(0.63–0.90)	(0.75–1.06)	(0.94–1.35)	(1.10–1.60)	(1.29–2.06)	(1.43–2.40)	(1.55–2.81)	(1.64–3.27)	(1.79–3.90)	(1.91–4.38)
60-min	**0.93**	**1.11**	**1.41**	**1.67**	**2.03**	**2.32**	**2.61**	**2.92**	**3.33**	**3.66**
	(0.79–1.12)	(0.94–1.34)	(1.19–1.71)	(1.4–2.03)	(1.62–2.58)	(1.79–3.00)	(1.92–3.49)	(2.03–4.04)	(2.20–4.78)	(2.32–5.34)
2-hr	**1.12**	**1.34**	**1.71**	**2.01**	**2.44**	**2.78**	**3.12**	**3.48**	**3.95**	**4.31**
	(0.96–1.34)	(1.14–1.60)	(1.45–2.05)	(1.69–2.43)	(1.96–3.08)	(2.16–3.57)	(2.32–4.14)	(2.43–4.77)	(2.62–5.61)	(2.77–6.25)
3-hr	**1.25**	**1.49**	**1.89**	**2.23**	**2.71**	**3.08**	**3.45**	**3.83**	**4.35**	**4.74**
	(1.07–1.48)	(1.27–1.78)	(1.61–2.26)	(1.89–2.68)	(2.18–3.39)	(2.40–3.93)	(2.57–4.55)	(2.70–5.23)	(2.90–6.15)	(3.06–6.84)
6-hr	**1.48**	**1.75**	**2.19**	**2.58**	**3.14**	**3.6**	**4.06**	**4.56**	**5.24**	**5.77**
	(1.28–1.75)	(1.50–2.07)	(1.88–2.60)	(2.19–3.08)	(2.56–3.94)	(2.83–4.58)	(3.06–5.34)	(3.24–6.21)	(3.54–7.38)	(3.76–8.28)
12-hr	**1.75**	**2.00**	**2.47**	**2.91**	**3.59**	**4.17**	**4.80**	**5.49**	**6.48**	**7.29**
	(1.51–2.05)	(1.73–2.35)	(2.13–2.91)	(2.49–3.45)	(2.96–4.52)	(3.33–5.33)	(3.65–6.33)	(3.96–7.49)	(4.44–9.14)	(4.80–10.39)
24-hr	**1.99**	**2.28**	**2.83**	**3.37**	**4.21**	**4.96**	**5.78**	**6.70**	**8.03**	**9.13**
	(1.73–2.32)	(1.98–2.66)	(2.45–3.31)	(2.89–3.96)	(3.52–5.31)	(3.99–6.32)	(4.45–7.60)	(4.88–9.10)	(5.56–11.28)	(6.08–12.93)
2-day	**2.24**	**2.61**	**3.32**	**3.98**	**5.03**	**5.93**	**6.92**	**8.01**	**9.58**	**10.88**
	(1.96–2.59)	(2.28–3.03)	(2.88–3.85)	(3.44–4.66)	(4.21–6.27)	(4.80–7.50)	(5.36–9.02)	(5.88–10.8)	(6.70–13.36)	(7.31–15.3)
3-day	**2.46**	**2.84**	**3.56**	**4.25**	**5.34**	**6.29**	**7.33**	**8.48**	**10.15**	**11.53**
	(2.16–2.83)	(2.49–3.27)	(3.11–4.12)	(3.68–4.95)	(4.50–6.64)	(5.12–7.92)	(5.70–9.52)	(6.26–11.40)	(7.14–14.10)	(7.80–16.15)

Table A-2. Atlas 14 precipitation frequency estimates for Warroad, MN, (21-8679) (NOAA 2016) (page 2 of 2).

Duration	Average Recurrence Interval (years)									
	1	2	5	10	25	50	100	200	500	1,000
PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[a]										
4-day	**2.65**	**3.03**	**3.75**	**4.44**	**5.54**	**6.49**	**7.55**	**8.72**	**10.43**	**11.84**
	(2.33–3.05)	(2.66–3.48)	(3.28–4.32)	(3.85–5.15)	(4.68–6.86)	(5.30–8.16)	(5.90–9.78)	(6.47–11.69)	(7.36–14.45)	(8.04–16.53)
7-day	**3.14**	**3.54**	**4.28**	**4.99**	**6.09**	**7.05**	**8.10**	**9.25**	**10.92**	**12.30**
	(2.78–3.59)	(3.12–4.04)	(3.76–4.91)	(4.35–5.75)	(5.17–7.47)	(5.78–8.78)	(6.36–10.40)	(6.91–12.30)	(7.77–15.03)	(8.43–17.09)
10-day	**3.57**	**4.02**	**4.82**	**5.56**	**6.69**	**7.66**	**8.69**	**9.82**	**11.43**	**12.75**
	(3.17–4.06)	(3.55–4.57)	(4.25–5.51)	(4.87–6.39)	(5.68–8.14)	(6.29–9.46)	(6.85–11.08)	(7.35–12.97)	(8.17–15.63)	(8.78–17.65)
20-day	**4.82**	**5.44**	**6.48**	**7.38**	**8.65**	**9.67**	**10.72**	**11.81**	**13.31**	**14.47**
	(4.30–5.45)	(4.84–6.15)	(5.74–7.36)	(6.49–8.42)	(7.33–10.31)	(7.97–11.75)	(8.48–13.45)	(8.89–15.37)	(9.57–17.95)	(10.08–19.9)
30-day	**5.89**	**6.64**	**7.87**	**8.89**	**10.28**	**11.36**	**12.42**	**13.50**	**14.93**	**16.00**
	(5.26–6.62)	(5.93–7.48)	(7.00–8.89)	(7.85–10.10)	(8.72–12.13)	(9.38–13.67)	(9.86–15.45)	(10.20–17.42)	(10.78–19.98)	(11.21–21.91)
45-day	**7.26**	**8.16**	**9.59**	**10.73**	**12.26**	**13.39**	**14.48**	**15.55**	**16.90**	**17.88**
	(6.51–8.13)	(7.30–9.14)	(8.55–10.78)	(9.51–12.14)	(10.41–14.33)	(11.09–15.99)	(11.52–17.87)	(11.79–19.90)	(12.26–22.45)	(12.61–24.38)
60-day	**8.45**	**9.45**	**11.01**	**12.25**	**13.86**	**15.03**	**16.14**	**17.20**	**18.49**	**19.40**
	(7.59–9.43)	(8.48–10.55)	(9.85–12.35)	(10.88–13.82)	(11.79–16.12)	(12.48–17.86)	(12.88–19.82)	(13.08–21.90)	(13.46–24.46)	(13.74–26.39)

(a) Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Note: Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to the NOAA Atlas 14 document for more information.

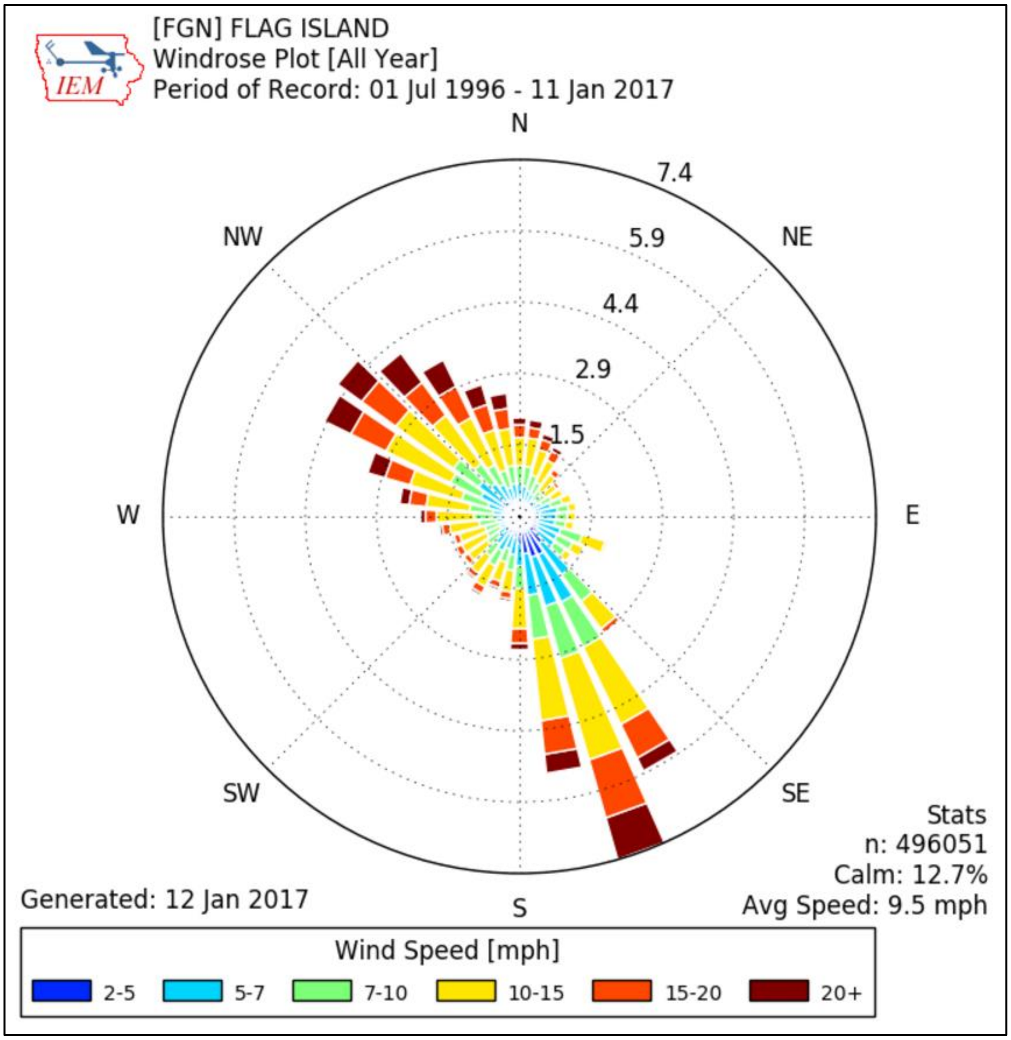


Figure A-9. Annual Wind Rose for Flag Island (Iowa Environmental Mesonet 2017)

Monthly wind roses for Flag Island (March through November) for 1996 through 2016 are shown in Figure A-10. Table A-3 lists mean wind speed, percent calm (less than 2 mph), and percent wind speed greater than 20 mph (32 kph) by month for 1996 through 2016. Winds from the north and northwest are more prevalent and stronger in the cooler and cold months (October through May), while winds from June through September tend to be split between northwest and south-southeast. These wind patterns suggest that both warm (from the south) and cool (from the north) wind affect the lake and lake mixing throughout the growing season. The cooler and cold months also show more prevalent high winds (greater than or equal to 20 mph) than during the warm months.

A.5 WIND AND LAKE DISSOLVED OXYGEN CONCENTRATION

Beginning in 2015, researchers from the Science Museum of Minnesota's SCWRS installed monitoring buoys at three locations in LoW to measure DO concentration 0.5 meters (m) (1.6 feet) above the lake bottom. Two locations were in Big Traverse Bay and one in Muskeg Bay. DO concentrations measured at the three sites in 2015 are shown in Figure A-11. Several events that showed sustained (one week or more) DO depletion were measured from June through September. Depletion rates of approximately 0.4 to 0.5 milligrams per liter per day (mg L^{-1} d^{-1}) were observed during extended depletion events, which suggests that approximately 16 to 20 days of continuous depletion would result in hypoxia (DO concentration < 2 milligrams per liter [mg L^{-1}]) assuming an initial DO concentration of 10 mg L^{-1}.

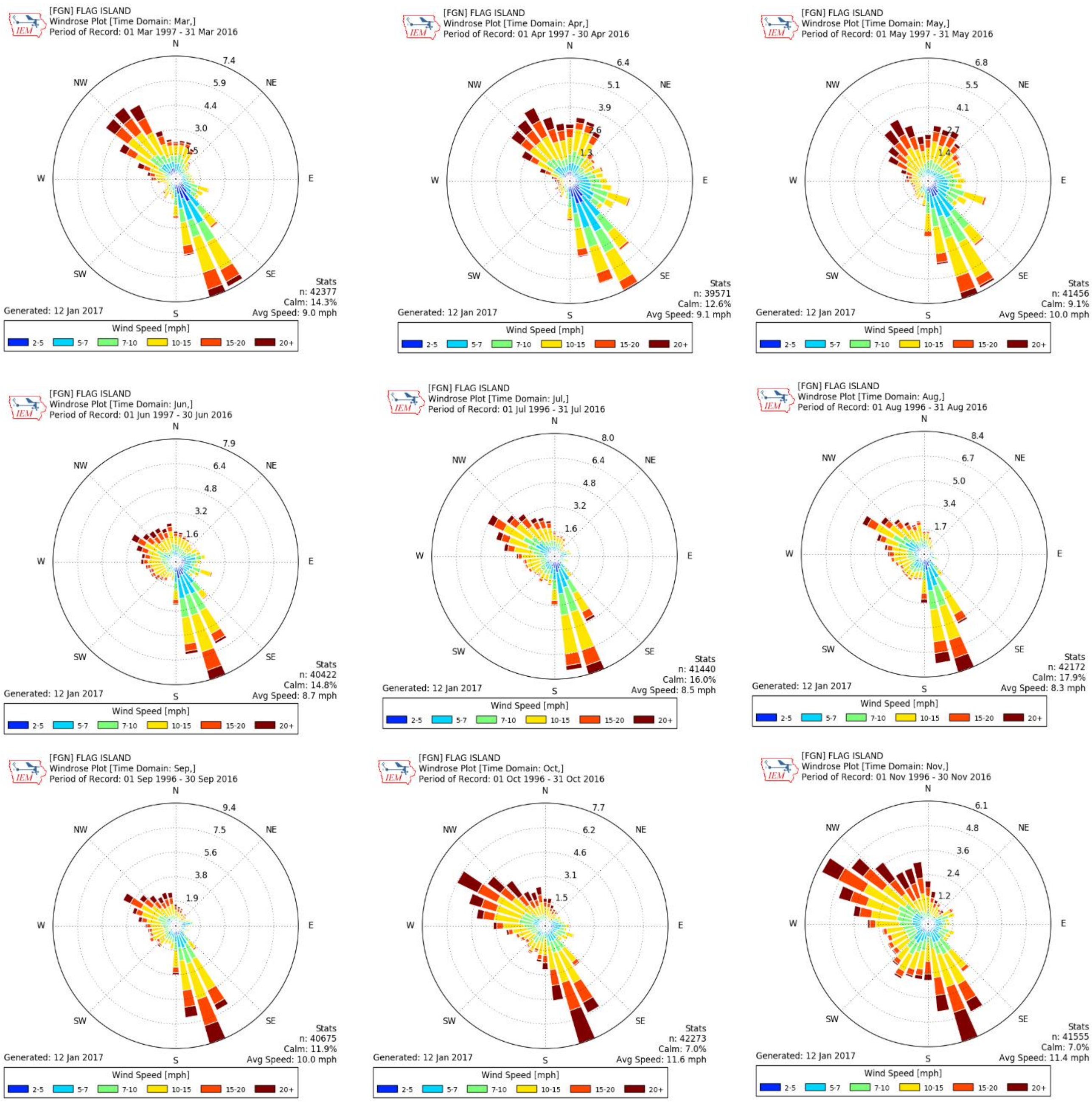


Figure A-10. Monthly wind roses for Flag Island for March through November, 1996–2016 (Iowa Environmental Mesonet 2017). Months are organized by row; March is on the top left, May is on the top right, and November is on the bottom right.

Table A-3. Flag Island monthly wind summary, 1996–2016 (Iowa Environmental Mesonet 2017).

Month	Mean Wind Speed (mph)	Percent Calm (< 2 mph)	Percent (> 20 mph)
January	9.3	14.4	6.4
February	8.8	14.3	5.2
March	9.0	14.3	5.6
April	9.1	12.6	5.7
May	10.0	9.1	7.0
June	8.7	14.8	4.9
July	8.5	16.0	4.3
August	8.3	17.9	4.5
September	10.0	11.9	7.6
October	11.6	7.0	12.7
November	11.4	7.0	11.1
December	9.5	13.0	6.3

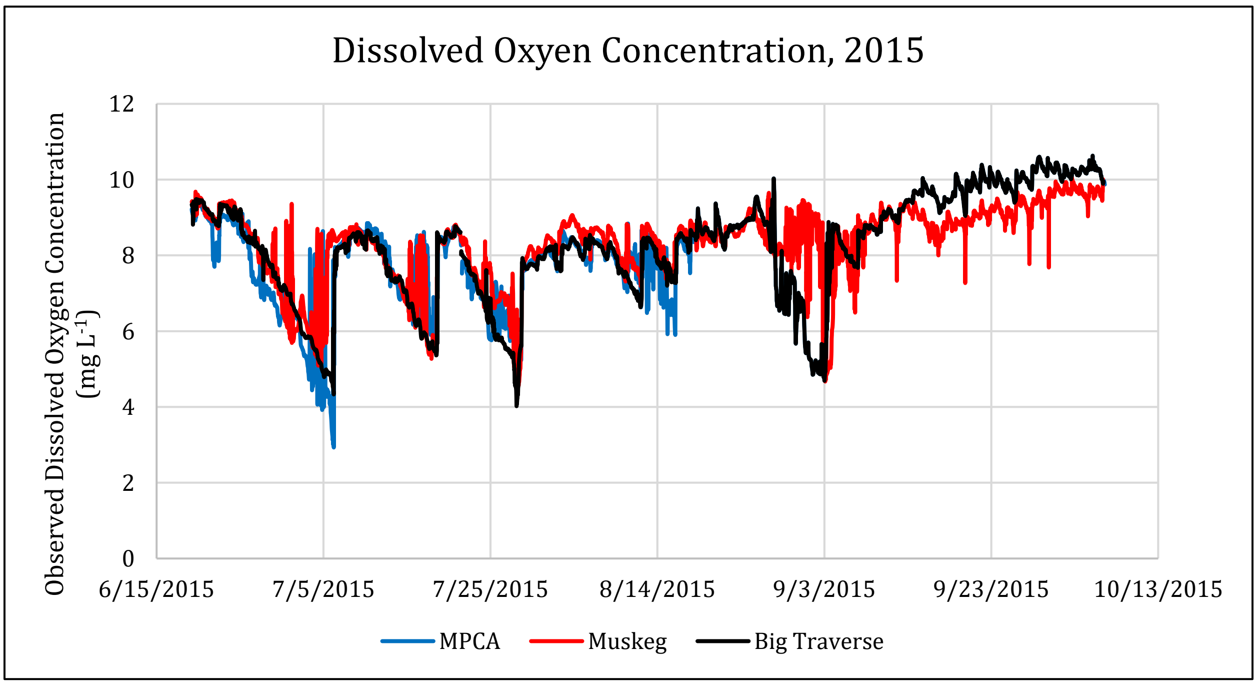


Figure A-11. Dissolved Oxygen Concentration at Three LoW Monitoring Locations 2015 (SCWRS 2015)

SCWRS DO concentration data were paired with wind speed data at Flag Island (Iowa Environmental Mesonet 2017) to investigate the link between wind speed and DO concentration in the LoW. Figure A-12 shows mean daily DO concentration and mean daily wind speed at Flag Island for the summer of 2015. The sustained periods of depletion are all coincident with daily mean wind speeds of approximately 5 meters per second ($m\ s^{-1}$) (11 mph) or less. The end of each of the extended depletion events coincided with at least one day of higher mean wind speed (typically 7 $m\ s^{-1}$ or greater). These data suggest the importance of wind speed as a control on lake mixing and internal loading, which is very sensitive to DO concentration at the water-sediment interface.

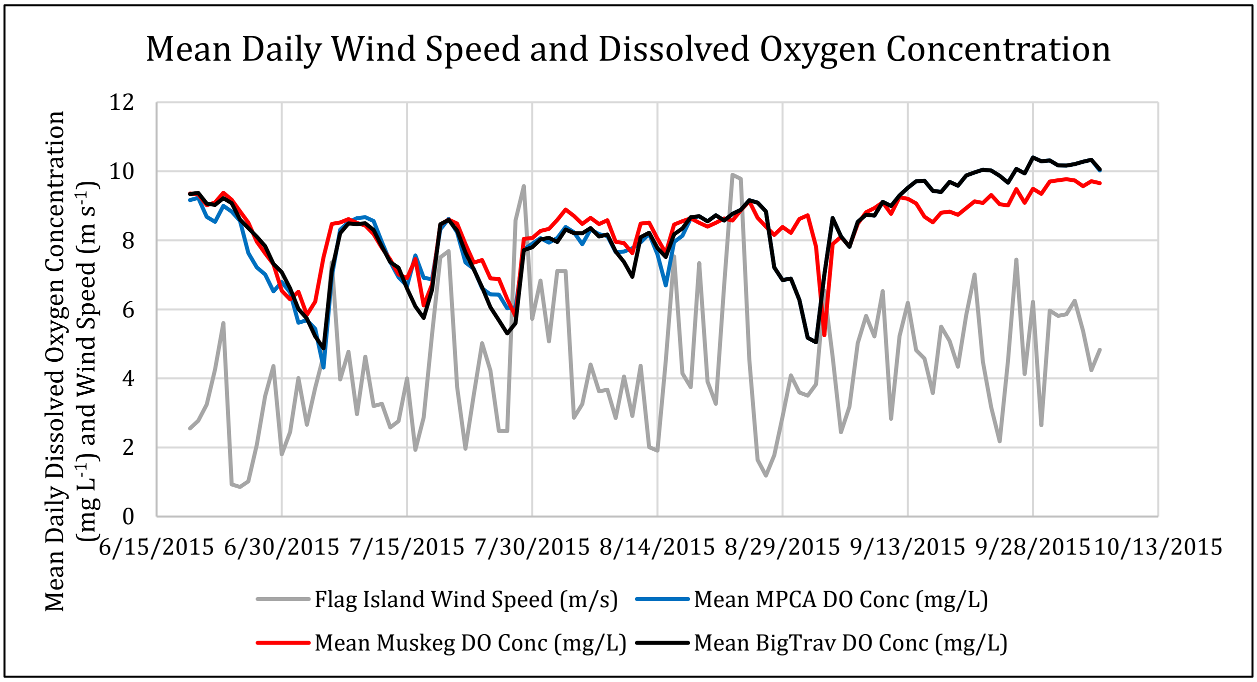


Figure A-12. Mean daily dissolved oxygen concentration measured at three LoW monitoring buoys and wind speed measured at Flag Island, 2015 (SCWRS 2015; Iowa Environmental Mesonet 2017)

Appendix B. Rainy River Summary

This appendix includes an overview of the Rainy River, which is the main tributary of the LoW.

B.1 HYDROLOGY

Because the Rainy River discharges to Four Mile Bay and, in turn, Big Traverse Bay, quantifying the effect of the Rainy River's discharge on Big Traverse Bay is useful. Estimates of the Big Traverse Bay growing-season flushing rates for the period 1996 to 2014 were made by year by dividing the volume of Big Traverse Bay by the Rainy River's growing-season discharge. Note that this analysis does not include inflow from other tributaries, upstream bays of the LoW, or rainfall on the lake. Low growing-season flushing rates can reduce dilution, increase water residence times, and influence internal lake processes during the peak growing season. The flushing rate and its inverse, water residence time, are important drivers of P dynamics, and sedimentation of incoming P loads is inversely proportional to the flushing rate. Annual flushing rates are presented in Table B-1. Estimated flushing rates varied from 0.13 to 0.98.

Table B-1. Estimated growing season flushing rates for Big Traverse Bay.

Year	Rainy River Growing Season Discharge (hm^3)	Growing Season Flushing Rate
1996	7,054	0.69
1997	2,655	0.26
1998	1,494	0.15
1999	6,886	0.68
2000	4,600	0.45
2001	8,592	0.85
2002	7,938	0.78
2003	1,283	0.13
2004	4,840	0.48
2005	6,719	0.66
2006	1,745	0.17
2007	2,600	0.26
2008	6,824	0.67
2009	5,483	0.54
2010	3,607	0.35
2011	2,937	0.29
2012	4,160	0.41
2013	6,137	0.60
2014	10,015	0.98
Mean	5,030	0.49

B.2 WATER QUALITY

Standards for the applicable North River Nutrient Region eutrophication and TSS are shown in Table B-2. The IJC also established a Rainy River TP concentration alert level of 30 micrograms per liter (µg L^{-1}) based on the potential for eutrophication of downstream receiving waters (Environment Canada 2014).

Table B-2. North River Nutrient Region eutrophication and TSS standards.

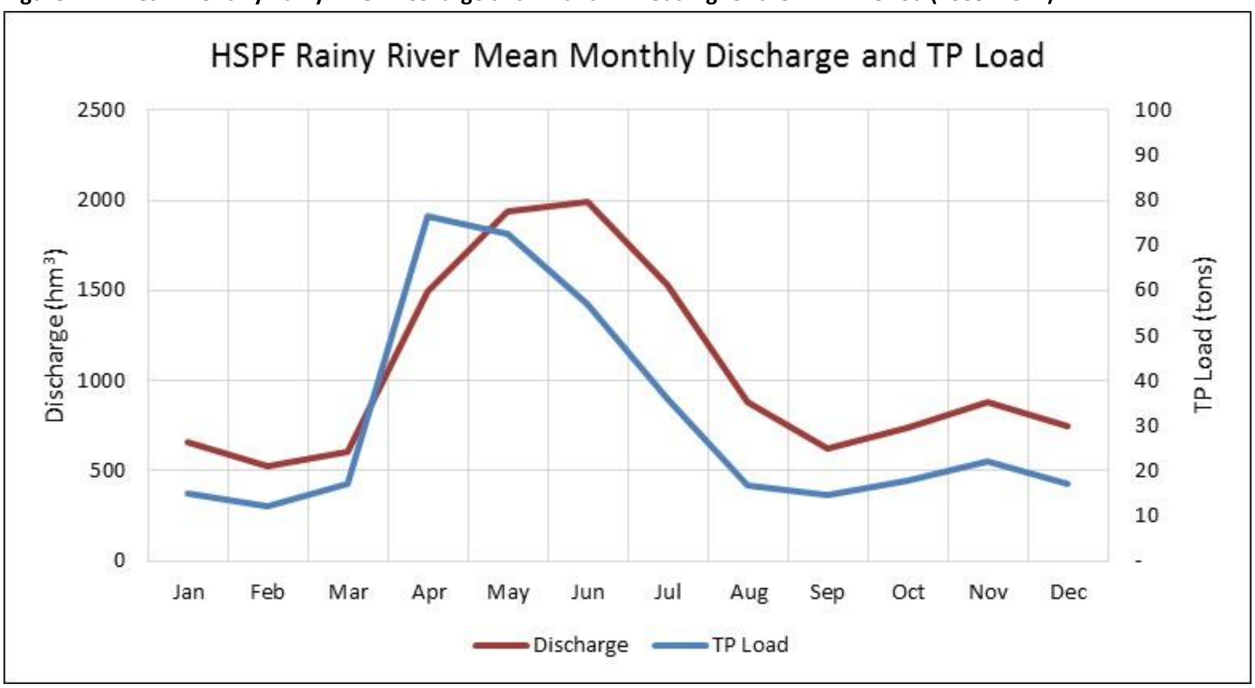
TP (ppb)	Chlorophyll-*a* (ppb)	Diel Dissolved Oxygen (ppm)	Biochemical Oxygen Demand (ppm)	TSS not to exceed 10% of time (ppm)
≤ 50	≤ 7	≤ 3.0	≤ 1.5	15

ppb = parts per billion
ppm = parts per million

B.3 PHOSPHORUS LOADING

Mean annual TP and OP loads of 357.8 t and 179.4 t, respectively, were estimated by HSPF modeling for the study period. Mean monthly TP and OP loading to the LoW are shown in Figure B-1. Monthly loads peaked in April and May, followed by a decline through the growing season. Approximately two-thirds of annual TP loading occurs from April to July. HSPF model-estimated, flow-weighted mean concentrations for TP (28 µg L^{-1}) and OP (14 µg L^{-1}) for the TMDL period are consistent with Environment Canada monitoring of total dissolved P from 2009 to 2011 for the Rainy River at Oak Groves, Ontario, (Environment Canada 2014) and recent MPCA monitoring data.

Figure B-1. Mean Monthly Rainy River Discharge and TP and DP Loading for the TMDL Period (2005–2014)



B.4 HISTORICAL WATER QUALITY

Historically, the pulp and paper industry of Fort Frances, Ontario, and International Falls, Minnesota, discharge organic wastes such as coarse (wood chips) and fine fiber particulate matter and dissolved organic compounds into the Rainy River. These pollutant loads were greatly reduced by the early 1980s as a result of wastewater treatment upgrades (Beak 1990) as shown in Figure B- 2. Five-day Biochemical oxygen demand (BOD_5) loads were reduced from more than 50 tons per day (t d^{-1}) in the 1960s and 1970s to just over 10 t d^{-1} by 1989.

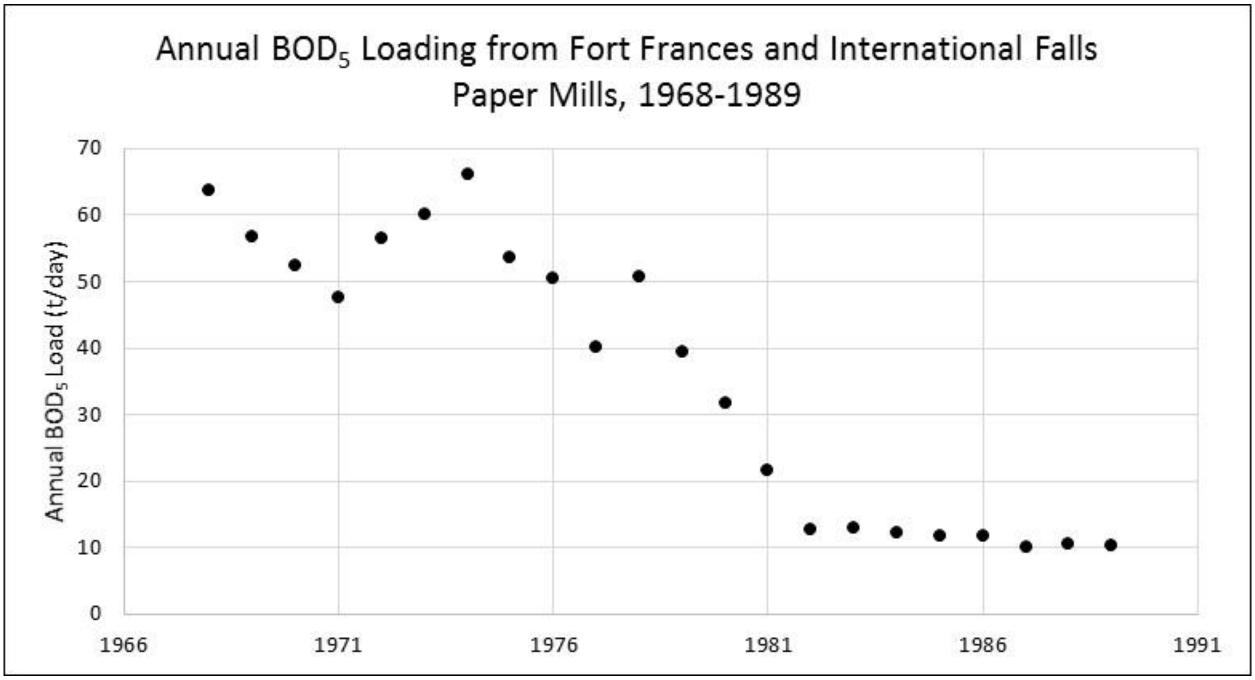


Figure B- 2. Daily BOD_5 Loading to the Rainy River from the Fort Frances and International Falls Paper Mills, 1968–1989 (Beak 1990)

Beak (1990) summarized shifts in benthic biology from 1969 to 1983 because of reduced wood solids deposition along the Rainy River and into the LoW as a result of paper and pulp industry wastewater treatment improvements. A degraded zone was identified well into Big Traverse Bay in 1969; wood fibers were noted in lake sediments, and benthic species included pollution-tolerant species such as the sludge worm (*Limnodrilus hoffmeisteri)*, midge larva (*Chironomus*) and the amphibod *Asellus*. By 1983, wood content in lake sediments was not noted; however, 15 of 20 stations that had been identified as degraded in 1969 remained so. Portions of degraded western Big Traverse Bay improved from degraded to impaired condition by 1983 (Beak 1990).

EPA STORET data for 1953 to 1986 were evaluated by Beak (1990) based on select pollutant (nitrogen, P, BOD_5, and iron) arithmetic mean concentrations at 14 stations along the Rainy River. Summaries of these data for the most downstream station, approximately two miles downstream of Baudette, Minnesota, are given in Table B-3. Note that these arithmetic means do not reflect the effects of flow variability as do flow-weighted mean concentrations. The table also includes historical TP concentrations estimated from historical BOD_5 concentrations, which were calculated by using an equation developed by Heiskary and Markus (2001):

$$BOD_5 = 0.019(TP) - 0.14 \quad \text{(B-1)}$$

Where BOD_5 is in milligrams per liter (mg L^{-1}), TP is the TP concentration in µg L^{-1}, and both BOD_5 and TP are growing season concentrations. Annual arithmetic BOD_5 values were used for this comparison.

Table B-3. Interpolated decadal arithmetic average values at a site two miles downstream of Baudette, MN (Beak 1990).

Analyte	Arithmetic Mean Concentration by Decade			
	1950s	1960s	1970s	1980s
TP (µg L^{-1})	130	110	80	45
TP Range (µg L^{-1})	110–150	50–120	30–130	25–60
TP calculated from BOD_5[(a)] (µg L^{-1})	*165*	*218*	*86*	*49*
OP (µg L^{-1})	ND	ND	12	8
TKN (µg L^{-1})	950	ND	600	650
NO_3 (µg L^{-1})	440	300	130	ND
BOD_5 (mg L^{-1})	3	4	1.5	0.8
Fe (µg L^{-1})	ND	550	200	25
TSS (mg L^{-1})	ND	18	15	10

ND = not data.

(a) Calculated from Equation B-1.

Data reported by Beak (1990) show decreased concentrations from the 1950s to the 1980s; 1980s TP and BOD_5 concentrations were approximately 35% and 25% of their respective 1950s values. Reductions were also reported for nitrogen (TKN and nitrate [NO_3]), TSS, and iron. Historical TP concentrations and ranges generally agreed with back-calculated TP values based on historical BOD_5 data. Present-day, flow-weighted mean concentrations at Wheelers Point vary from approximately one-fourth to one-third of 1950s to 1970s arithmetic means reported by Beak (1990) for the site near Baudette, Minnesota. Long-term trends for the Rainy River at Baudette (International Bridge) show statistically significant decreases in TP (86% decrease) and TSS (75% decrease) concentrations over the period of record (1953 to 2010) (MPCA 2014).

A total of 43 TP and 45 BOD_5 and TSS samples were reviewed from data collected from 1974 to 1977 by the MPCA at a Rainy River site west of International Falls, Minnesota, (off of Shorewood Drive) as part of the MPCA’s Routine River Monitoring program. The TP, BOD_5, and TSS arithmetic means of 150 µg L^{-1} (with removal of a value of 1.52 mg L^{-1}), 9.67 mg L^{-1}, and 21.5 mg L^{-1}, respectively, are higher than 1970s values reported by Beak (1990) for the site near Baudette, Minnesota. The 1979 through 1985 TP concentrations at Oak Groves, Ontario, reported by EC (2014) are consistent with 1980s concentrations reported by Beak (1990) for the site near Baudette, Minnesota.

The EC seasonal particulate and dissolved P monitoring data were interpolated graphically from the Lake of the Woods Science Initiative 2008 to 2011 (EC 2014) and are included in Table B-4. Data show that 50% to 60% of TP is present as dissolved P, which is consistent with HSPF modeling results at Wheelers Point for the TMDL period (50% dissolved P). EC (2014) summarized 2009 through 2011 water quality monitoring findings as follows:

We compared phosphorus and ammonia concentrations in our current samples to those from 1979–1985 collected during a previous Environment Canada monitoring program at the mouth of the Rainy River at Oak Groves… Overall TP concentrations were lower in our contemporary samples versus the period 1979-1985 (z = 6.54, p < 0.0001, Fig. 3.6). This was true for all seasons. The proportion of exceedances also declined; during the period from 1979–1985, 68% of the samples exceeded the Rainy River alert level for phosphorus while during the period from 2009–2011, only 19% of samples exceeded alert levels for phosphorus. Researchers at Trent University and MPCA estimated that phosphorus loads in the Rainy River have declined substantially since the mid- to early 1970s, while there has been no corresponding decrease in flows during that time (Hargan et al. 2011). While we cannot make a direct link between declining phosphorus concentrations and phosphorus loads, the decline in phosphorus concentrations between the 1979–1985 period in, and the contemporary sampling period for, Environment Canada data seems to correspond to the estimated decline in phosphorus loads from MPCA and Trent since the early 1970s.

Table B-4. Interpolated season mean P constituent concentrations at Oak Groves, Ontario (EC 2014).

Season	Phosphorus Constituent Concentration ($\mu g\ L^{-1}$)		
	Total	Particulate	Dissolved
Winter	20	8	12
Spring	29	14	15
Summer	28	14	14
Fall	25	12	14

EC (2014) also reported:

Total dissolved phosphorus (DP) was measured beginning in 2010 and ranged from 35% to 90% of TP. It is interesting to note that frequently during peaks in TP, 80 to 90% was in the dissolved phase at the upstream sites. Whether this is largely from waste water inputs is unclear. The high proportion of DP has implications for harmful algal growth as phosphorus in the dissolved phase is more biologically available. At the mouth of the Rainy River at Oak Groves, where it discharges into LOW, approximately 50% of phosphorus was in the dissolved phase. On average phosphorus concentrations increased downstream as several tributaries, (e.g., Little Fork and Big Fork Rivers) deliver phosphorus loads to the Rainy River, in addition to point sources including municipal waste water treatment and pulp and paper companies. Nonpoint sources of phosphorus, including agricultural and non-agricultural runoff and erosion of phosphorus-rich sediments, are considered to be the main source of phosphorus in the Rainy River basin (MPCA 2004). The two largest sources of TP to the Rainy River are Rainy Lake and the Little Fork River respectively (Hargan et al. 2011). Point sources to the Rainy River include seven municipal sewage treatment plants and two pulp and paper mill in Fort Frances and International Falls and account for approximately 98.2 tonnes/yr. The mills report their TP loads to the IRRWPB on an annual basis and are the largest anthropogenic source of TP to both LOW and the Rainy River, contributing an estimated 16% of TP loads to the river (Hargan et al. 2011).”

Sulphate (SO_4) is an important water quality constituent because its presence can inhibit iron's ability to retain P in lake bottom sediments. Mean annual SO_4 loading was estimated to be 70,000 tons/year based on the median SO_4 concentration at Oak Groves, Ontario, (EC 2014) and mean annual HSPF-modeled discharge at Wheelers Point, Minnesota. EC (2014) summarized the 2009 through 2011 SO_4 data as follows:

> *Sulphate (SO_4) concentrations in the Rainy River ranged from 2.6–12.9 mg/L at its outlet, with a median concentration of 5.6 mg/L, well within the normal range for this area. Substantial sulphide mineral deposits in the basin are currently under exploration for mine development. This has led to concerns from local residents regarding the impacts of increased levels of SO_4 to surface waters from acid mine drainage, particularly in regard to potential impacts on wild rice crops (Moyle 1944; DNR 2008). The current water quality guideline for SO_4 for the protection of wild rice in Minnesota is 10 mg/L, although this guideline is currently under review… There is also a concern that increased SO_4 concentrations would accelerate the microbial methylation of mercury to methyl mercury, its most biologically active form (Gilmour et al. 1992). Moreover, SO_4 has been implicated in enhancing the rate of phosphorus release from sediments, which may have implications for downstream receiving waters in LOW (Lamers et al. 1998; Zak et al. 2006).*
>
> *No Rainy River alert level or CWQG* (Canadian water quality guidelines) *concentration for the protection of aquatic life concentration has been developed for sulphate. For context, the British Columbia alert level for freshwater aquatic life is 50 mg/L, with a maximum acute concentration of 100 mg/L (Prov. British Columbia 2011). Currently, median concentrations of sulphate in the Rainy River are below the Minnesota standard for the protection of wild rice of 10 mg/L. However, concentrations of sulphates may increase substantially in the future as sulphide mineral mining initiatives in the basin become active.*

Appendix C. Load Allocation Table

This appendix includes the detailed LA table.

Lake of the Woods Load Allocation Table (May 20, 2021)

		Detailed Background Information and Source Loading Information used in TMDL Development														Final Allocations/Acknowledged Load		
		Existing Load (at Source)			Delivery to Lake of the Woods			Existing Load (at Lake of the Woods)			Proposed Load		Estimated Load Reduction					
		Total Load	Originating in Canada[1]	Originating in US	Delivery to Rainy River	Delivery along Rainy River to LoW	Total Delivery to LoW	Total Load	Originating in Canada[1]	Originating in US	Load at Source	Load to Lake	Load at Source	Load to Lake	Percent Change[2]	Total Allowable Load (US and Canada)	Load/Wasteload Allocation (US)	Acknowledged Load (Canada)[1]
		kg/yr	kg/yr	kg/yr				kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr		kg/yr	kg/yr	kg/yr
	Total Load	**885,951.9**	**326,453.3**	**559,498.6**				**814,914.9**	**294,886.8**	**520,028.2**	**723,385.1**	**673,914.3**	**162,566.8**	**141,000.6**	**-17.3%**	**673,914.3**	**432,467.3**	**241,447.0**
Wasteload	**Total WLA**	**89,189.0**	**44,681.2**	**44,507.7**				**72,297.9**	**36,079.1**	**36,218.9**	**45,747.6**	**45,747.6**	**43,441.4**	**26,550.4**	**-48.7%**	**45,747.6**	**39,400.0**	**6,347.5**
	Wastewater[3]	**88,900.5**	**44,681.2**	**44,219.3**				**72,009.5**	**36,079.1**	**35,930.4**	**45,230.5**	**45,230.5**	**43,670.0**	**26,779.0**	**-49.1%**	**45,230.5**	**38,883.0**	**6,347.5**
	Point Sources in Lake of the Woods HUC 8	**62.4**	**-**	**62.4**				**42.3**	**-**	**42.3**	**101.0**	**101.0**	**(38.6)**	**(58.7)**	**61.8%**	**101.0**	**101.0**	**-**
	Marvin Windows & Doors	*4.0*	-	*4.0*	*N/A*	*N/A*	*100%*	*4.0*	-	*4.0*	*4.0*	*4.0*	-	-	-	*4.0*	*4.0*	-
	Springsteel Island Sanitary District	*5.4*	-	*5.4*	*N/A*	*N/A*	*100%*	*5.4*	-	*5.4*	*10.0*	*10.0*	*(4.6)*	*(4.6)*	*84.0%*	*10.0*	*10.0*	-
	Williams WWTP	*53.0*	-	*53.0*	*N/A*	*N/A*	*62%*	*32.8*	-	*32.8*	*87.0*	*87.0*	*(34.0)*	*(54.2)*	*64.2%*	*87.0*	*87.0*	-
	Point Sources Discharging to Rainy River	**88,838.1**	**44,681.2**	**44,156.9**				**71,967.2**	**36,079.1**	**35,888.1**	**45,129.5**	**45,129.5**	**43,708.5**	**26,837.7**	**-49.2%**	**45,129.5**	**38,782.0**	**6,347.5**
	Point Sources Discharging to Big Fork River	**388.0**	**-**	**388.0**				**240.5**	**-**	**240.5**	**609.0**	**609.0**	**(221.0)**	**(368.5)**	**57.0%**	**609.0**	**609.0**	**-**
	Big Falls WWTP	*19.7*	-	*19.7*	*86%*	*85%*	*73%*	*14.5*	-	*14.5*	*119.0*	*119.0*	*(99.3)*	*(104.5)*	*504.5%*	*119.0*	*119.0*	-
	Bigfork WWTP	*251.5*	-	*251.5*	*69%*	*85%*	*59%*	*147.2*	-	*147.2*	*215.0*	*215.0*	*36.5*	*(67.8)*	*-14.5%*	*215.0*	*215.0*	-
	Effie WWTP	*33.8*	-	*33.8*	*75%*	*85%*	*64%*	*21.7*	-	*21.7*	*102.0*	*102.0*	*(68.2)*	*(80.3)*	*202.2%*	*102.0*	*102.0*	-
	MDNR Scenic State Park	*14.4*	-	*14.4*	*105%*	*85%*	*89%*	*12.9*	-	*12.9*	*21.0*	*21.0*	*(6.6)*	*(8.1)*	*46.0%*	*21.0*	*21.0*	-
	Northome WWTP	*68.7*	-	*68.7*	*76%*	*85%*	*65%*	*44.3*	-	*44.3*	*122.0*	*122.0*	*(53.3)*	*(77.7)*	*77.6%*	*122.0*	*122.0*	-
	Berger Horticultural Products - Pine Island Bog	-	-	-	*73%*	*85%*	*63%*	-	-	-	*30.0*	*30.0*	*(30.0)*	*(30.0)*	-	*30.0*	*30.0*	-
	Point Sources Discharging to Little Fork River	**924.5**	**-**	**924.5**				**528.7**	**-**	**528.7**	**1,310.0**	**1,310.0**	**(385.5)**	**(781.3)**	**41.7%**	**1,310.0**	**1,310.0**	**-**
	Cook WWTP	*398.4*	-	*398.4*	*82%*	*84%*	*69%*	*274.5*	-	*274.5*	*509.0*	*509.0*	*(110.6)*	*(234.5)*	*27.8%*	*509.0*	*509.0*	-
	ISD 2142 Pre-Kindergarten to Grade 12 N School	*11.8*	-	*11.8*	*66%*	*84%*	*55%*	*6.5*	-	*6.5*	*44.0*	*44.0*	*(32.2)*	*(37.5)*	*272.1%*	*44.0*	*44.0*	-
	Littlefork WWTP	*146.7*	-	*146.7*	*97%*	*84%*	*81%*	*118.6*	-	*118.6*	*229.0*	*229.0*	*(82.3)*	*(110.4)*	*56.1%*	*229.0*	*229.0*	-
	US Steel - Minntac Tailings Basin Area	*27.1*	-	*27.1*	*48%*	*84%*	*40%*	*10.9*	-	*10.9*	*30.0*	*30.0*	*(2.9)*	*(19.1)*	*10.7%*	*30.0*	*30.0*	-
	Hibbing Taconite Co - Tails Basin Area	*340.5*	-	*340.5*	*42%*	*84%*	*35%*	*118.2*	-	*118.2*	*498.0*	*498.0*	*(157.5)*	*(379.8)*	*46.3%*	*498.0*	*498.0*	-
	Point Sources Discharging Directly to Rainy River	**87,525.6**	**44,681.2**	**42,844.3**				**71,198.0**	**36,079.1**	**35,118.9**	**43,210.5**	**43,210.5**	**44,315.0**	**27,987.4**	**-50.6%**	**43,210.5**	**36,863.0**	**6,347.5**
	Anchor Bay Mobile Home Park	*68.7*	-	*68.7*	*100%*	*97%*	*97%*	*66.7*	-	*66.7*	*44.0*	*44.0*	*24.7*	*22.7*	*-35.9%*	*44.0*	*44.0*	-
	Barwick WWTP 🍁	*6.0*	*6.0*	-	*100%*	*90%*	*90%*	*5.4*	*5.4*	-	*6.0*	*6.0*	-	*(0.6)*	-	*6.0*	-	*6.0*
	Baudette WWTP	*3,244.5*	-	*3,244.5*	*100%*	*97%*	*97%*	*3,152.6*	-	*3,152.6*	*367.0*	*367.0*	*2,877.5*	*2,785.6*	*-88.7%*	*367.0*	*367.0*	-
	Boise White Paper LLC - Intl Falls	*35,541.2*	-	*35,541.2*	*100%*	*81%*	*81%*	*28,679.2*	-	*28,679.2*	*33,100.0*	*33,100.0*	*2,441.2*	*(4,420.8)*	*-6.9%*	*33,100.0*	*33,100.0*	-
	Emo WWTP 🍁	*353.9*	*353.9*	-	*100%*	*86%*	*86%*	*304.9*	*304.9*	-	*353.9*	*353.9*	-	*(49.0)*	-	*353.9*	-	*353.9*
	Fort Frances WWTP 🍁	*779.6*	*779.6*	-	*100%*	*81%*	*81%*	*629.1*	*629.1*	-	*779.6*	*779.6*	-	*(150.5)*	-	*779.6*	-	*779.6*
	ISD 363 - Indus School	*13.6*	-	*13.6*	*100%*	*86%*	*86%*	*11.7*	-	*11.7*	*34.0*	*34.0*	*(20.4)*	*(22.3)*	*149.6%*	*34.0*	*34.0*	-
	NKASD WWTP	*3,976.3*	-	*3,976.3*	*100%*	*81%*	*81%*	*3,208.6*	-	*3,208.6*	*3,318.0*	*3,318.0*	*658.3*	*(109.4)*	*-16.6%*	*3,318.0*	*3,318.0*	-
	Rainy River WWTP 🍁	*28.0*	*28.0*	-	*100%*	*97%*	*97%*	*27.2*	*27.2*	-	*28.0*	*28.0*	-	*(0.8)*	-	*28.0*	-	*28.0*
	Resolute (Abitibi) 🍁	*43,513.7*	*43,513.7*	-	*100%*	*81%*	*81%*	*35,112.5*	*35,112.5*	-	*5,180.0*	*5,180.0*	*38,333.7*	*29,932.5*	*-88.1%*	*5,180.0*	-	*5,180.0*
	MS4	**-**	**-**	**-**				**-**	**-**	**-**	**228.6**	**228.6**	**(228.6)**	**(228.6)**	**-**	**228.6**	**228.6**	**-**
	City of International Falls MS4 [4]	-	-	-	*100%*	*81%*	*81%*	-	-	-	*228.6*	*228.6*	*(228.6)*	*(228.6)*	-	*228.6*	*228.6*	-
	Industrial Stormwater	**193.9**	**-**	**193.9**	**N/A**	**N/A**	**100%**	**193.9**	**-**	**193.9**	**193.9**	**193.9**	**-**	**-**	**-**	**193.9**	**193.9**	**-**
	Construction Stormwater	**94.6**	**-**	**94.6**	**N/A**	**N/A**	**100%**	**94.6**	**-**	**94.6**	**94.6**	**94.6**	**-**	**-**	**-**	**94.6**	**94.6**	**-**
Load	**Total LA**	**796,763.0**	**281,772.1**	**514,990.9**				**742,617.0**	**258,807.7**	**483,809.3**	**676,750.5**	**627,279.7**	**120,012.5**	**115,337.3**	**-15.5%**	**627,279.7**	**392,900.2**	**234,379.5**
	Tributaries	**373,527.2**	**141,072.3**	**232,455.0**				**319,381.2**	**118,107.9**	**201,273.4**	**335,844.4**	**286,373.6**	**37,682.8**	**33,007.6**	**-10.3%**	**286,373.6**	**168,265.7**	**118,107.9**
	Rainy River Drainage	**344,838.9**	**131,209.7**	**213,629.2**				**290,692.9**	**108,245.3**	**182,447.6**	**314,394.1**	**264,923.3**	**30,444.8**	**25,769.6**	**-8.9%**	**264,923.3**	**156,678.0**	**108,245.3**
	Rainy Lake Drainage	**148,302.6**	**103,470.2**	**44,832.4**				**119,669.7**	**83,493.1**	**36,176.6**	**148,302.6**	**119,669.7**	**-**	**-**	**-**	**119,669.7**	**36,176.6**	**83,493.1**
	Rainy Lake 🍁	*148,302.6*	*103,470.2*	*44,832.4*	*100%*	*81%*	*81%*	*119,669.7*	*83,493.1*	*36,176.6*	*148,302.6*	*119,669.7*	-	-	-	*119,669.7*	*36,176.6*	*83,493.1*
	Little Fork River HUC8	**72,512.8**	**-**	**72,512.8**				**60,607.7**	**-**	**60,607.7**	**45,991.3**	**38,440.5**	**26,521.5**	**22,167.2**	**-36.6%**	**38,440.5**	**38,440.5**	**-**
	Little Fork River	*72,512.8*	-	*72,512.8*	*100%*	*84%*	*84%*	*60,607.7*	-	*60,607.7*	*45,991.3*	*38,440.5*	*26,521.5*	*22,167.2*	*-36.6%*	*38,440.5*	*38,440.5*	-
	Big Fork River HUC8	**48,120.8**	**-**	**48,120.8**				**41,002.4**	**-**	**41,002.4**	**46,555.8**	**39,668.9**	**1,565.0**	**1,333.5**	**-3.3%**	**39,668.9**	**39,668.9**	**-**
	Big Fork River	*48,120.8*	-	*48,120.8*	*100%*	*85%*	*85%*	*41,002.4*	-	*41,002.4*	*46,555.8*	*39,668.9*	*1,565.0*	*1,333.5*	*-3.3%*	*39,668.9*	*39,668.9*	-
	Rapid River HUC8	**20,876.0**	**-**	**20,876.0**				**19,986.1**	**-**	**19,986.1**	**20,876.0**	**19,986.1**	**-**	**-**	**-**	**19,986.1**	**19,986.1**	**-**
	Rapid River	*20,876.0*	-	*20,876.0*	*100%*	*96%*	*96%*	*19,986.1*	-	*19,986.1*	*20,876.0*	*19,986.1*	-	-	-	*19,986.1*	*19,986.1*	-
	Lower Rainy HUC8	**55,026.6**	**27,739.4**	**27,287.2**				**49,427.1**	**24,752.2**	**24,674.9**	**52,668.3**	**47,158.1**	**2,358.3**	**2,268.9**	**-4.6%**	**47,158.1**	**22,405.9**	**24,752.2**
	La Vallee River 🍁	*3,633.9*	*3,633.9*	-	*100%*	*84%*	*84%*	*3,037.3*	*3,037.3*	-	*3,633.9*	*3,037.3*	-	-	-	*3,037.3*	-	*3,037.3*
	Black River	*11,253.3*	-	*11,253.3*	*100%*	*86%*	*86%*	*9,695.9*	-	*9,695.9*	*11,253.3*	*9,695.9*	-	-	-	*9,695.9*	*9,695.9*	-
	Sturgeon River 🍁	*3,155.9*	*3,155.9*	-	*100%*	*90%*	*90%*	*2,838.4*	*2,838.4*	-	*3,155.9*	*2,838.4*	-	-	-	*2,838.4*	-	*2,838.4*
	McCloud Creek	*382.0*	-	*382.0*	*100%*	*92%*	*92%*	*352.9*	-	*352.9*	*239.8*	*221.6*	*142.2*	*131.4*	*-37.2%*	*221.6*	*221.6*	-
	Whitefish Creek	*569.0*	-	*569.0*	*100%*	*93%*	*93%*	*531.2*	-	*531.2*	*343.7*	*320.8*	*225.3*	*210.3*	*-39.6%*	*320.8*	*320.8*	-
	Pinewood River 🍁	*5,695.6*	*5,695.6*	-	*100%*	*93%*	*93%*	*5,316.7*	*5,316.7*	-	*5,695.6*	*5,316.7*	-	-	-	*5,316.7*	-	*5,316.7*
	Silver Creek	*1,163.8*	-	*1,163.8*	*100%*	*96%*	*96%*	*1,114.2*	-	*1,114.2*	*659.2*	*631.1*	*504.6*	*483.1*	*-43.4%*	*631.1*	*631.1*	-
	Unnamed (391)	*470.4*	-	*470.4*	*100%*	*97%*	*97%*	*457.1*	-	*457.1*	*362.3*	*352.0*	*108.2*	*105.1*	*-23.0%*	*352.0*	*352.0*	-
	Baudette River	*1,658.5*	-	*1,658.5*	*100%*	*97%*	*97%*	*1,611.5*	-	*1,611.5*	*1,324.5*	*1,287.0*	*334.0*	*324.5*	*-20.1%*	*1,287.0*	*1,287.0*	-
	Miller Creek	*432.6*	-	*432.6*	*100%*	*97%*	*97%*	*420.4*	-	*420.4*	*221.6*	*215.3*	*211.0*	*205.0*	*-48.8%*	*215.3*	*215.3*	-
	Winter Road River	*3,376.4*	-	*3,376.4*	*100%*	*97%*	*97%*	*3,280.7*	-	*3,280.7*	*3,231.4*	*3,139.9*	*145.0*	*140.9*	*-4.3%*	*3,139.9*	*3,139.9*	-
	Wabanica Creek	*1,404.6*	-	*1,404.6*	*100%*	*97%*	*97%*	*1,364.8*	-	*1,364.8*	*716.5*	*696.2*	*688.1*	*668.7*	*-49.0%*	*696.2*	*696.2*	-
	Direct Drainage 🍁	*21,830.6*	*15,254.1*	*6,576.5*	*100%*	*89%*	*89%*	*19,405.9*	*13,559.8*	*5,846.1*	*21,830.6*	*19,405.9*	-	-	-	*19,405.9*	*5,846.1*	*13,559.8*

Lake of the Woods Load Allocation Table (May 20, 2021)		Existing Load (at Source)			Delivery to Lake of the Woods			Existing Load (at Lake of the Woods)			Proposed Load		Estimated Load Reduction			Total Allowable Load (US and Canada)	Load/Wasteload Allocation (US)	Acknowledged Load (Canada)[1]
		Total Load	Originating in Canada[1]	Originating in US	Delivery to Rainy River	Delivery along Rainy River to LoW	Total Delivery to LoW	Total Load	Originating in Canada[1]	Originating in US	Load at Source	Load to Lake	Load at Source	Load to Lake	Percent Change[2]			
		kg/yr	kg/yr	kg/yr				kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr		kg/yr	kg/yr	kg/yr
Load	**Lake of the Woods HUC8**	**28,688.3**	**9,862.6**	**18,825.8**				**28,688.3**	**9,862.6**	**18,825.8**	**21,450.3**	**21,450.3**	**7,238.0**	**7,238.0**	**-25.2%**	**21,450.3**	**11,587.8**	**9,862.6**
	Sabaskong River 🍁	*2,232.6*	*2,232.6*	*-*	*N/A*	*N/A*	*100%*	*2,232.6*	*2,232.6*	*-*	*2,232.6*	*2,232.6*	*-*	*-*	*-*	*2,232.6*	*-*	*2,232.6*
	Splitrock River 🍁	*1,228.0*	*1,228.0*	*-*	*N/A*	*N/A*	*100%*	*1,228.0*	*1,228.0*	*-*	*1,228.0*	*1,228.0*	*-*	*-*	*-*	*1,228.0*	*-*	*1,228.0*
	Thompson Creek 🍁	*779.8*	*779.8*	*-*	*N/A*	*N/A*	*100%*	*779.8*	*779.8*	*-*	*779.8*	*779.8*	*-*	*-*	*-*	*779.8*	*-*	*779.8*
	Obabikon Lake 🍁	*457.7*	*457.7*	*-*	*N/A*	*N/A*	*100%*	*457.7*	*457.7*	*-*	*457.7*	*457.7*	*-*	*-*	*-*	*457.7*	*-*	*457.7*
	Big Grassy River 🍁	*1,108.2*	*1,108.2*	*-*	*N/A*	*N/A*	*100%*	*1,108.2*	*1,108.2*	*-*	*1,108.2*	*1,108.2*	*-*	*-*	*-*	*1,108.2*	*-*	*1,108.2*
	Little Grassy River 🍁	*2,333.7*	*2,333.7*	*-*	*N/A*	*N/A*	*100%*	*2,333.7*	*2,333.7*	*-*	*2,333.7*	*2,333.7*	*-*	*-*	*-*	*2,333.7*	*-*	*2,333.7*
	Bostic River (231)	*1,783.9*	*-*	*1,783.9*	*N/A*	*N/A*	*100%*	*1,783.9*	*-*	*1,783.9*	*1,283.8*	*1,283.8*	*500.1*	*500.1*	*-28.0%*	*1,283.8*	*1,283.8*	*-*
	Williams Creek (County Ditch 1; 211)	*1,101.8*	*-*	*1,101.8*	*N/A*	*N/A*	*100%*	*1,101.8*	*-*	*1,101.8*	*617.4*	*617.4*	*484.4*	*484.4*	*-44.0%*	*617.4*	*617.4*	*-*
	South Branch Zippel Creek (213)	*744.0*	*-*	*744.0*	*N/A*	*N/A*	*100%*	*744.0*	*-*	*744.0*	*214.9*	*214.9*	*529.1*	*529.1*	*-71.1%*	*214.9*	*214.9*	*-*
	West Branch Zippel Creek (203)	*1,887.6*	*-*	*1,887.6*	*N/A*	*N/A*	*100%*	*1,887.6*	*-*	*1,887.6*	*879.3*	*879.3*	*1,008.3*	*1,008.3*	*-53.4%*	*879.3*	*879.3*	*-*
	Judicial Ditch 24 (201)	*420.2*	*-*	*420.2*	*N/A*	*N/A*	*100%*	*420.2*	*-*	*420.2*	*259.4*	*259.4*	*160.8*	*160.8*	*-38.3%*	*259.4*	*259.4*	*-*
	Judicial Ditch 24 (191)	*1,256.2*	*-*	*1,256.2*	*N/A*	*N/A*	*100%*	*1,256.2*	*-*	*1,256.2*	*465.5*	*465.5*	*790.7*	*790.7*	*-62.9%*	*465.5*	*465.5*	*-*
	Judicial Ditch 22 (181)	*708.3*	*-*	*708.3*	*N/A*	*N/A*	*100%*	*708.3*	*-*	*708.3*	*333.3*	*333.3*	*375.1*	*375.1*	*-53.0%*	*333.3*	*333.3*	*-*
	Reach 171	*164.5*	*-*	*164.5*	*N/A*	*N/A*	*100%*	*164.5*	*-*	*164.5*	*52.5*	*52.5*	*112.0*	*112.0*	*-68.1%*	*52.5*	*52.5*	*-*
	Willow Creek (161)	*1,352.6*	*-*	*1,352.6*	*N/A*	*N/A*	*100%*	*1,352.6*	*-*	*1,352.6*	*641.7*	*641.7*	*711.0*	*711.0*	*-52.6%*	*641.7*	*641.7*	*-*
	County Ditch 26 (151)	*272.9*	*-*	*272.9*	*N/A*	*N/A*	*100%*	*272.9*	*-*	*272.9*	*102.7*	*102.7*	*170.2*	*170.2*	*-62.4%*	*102.7*	*102.7*	*-*
	County Ditch 26 (141)	*457.7*	*-*	*457.7*	*N/A*	*N/A*	*100%*	*457.7*	*-*	*457.7*	*193.3*	*193.3*	*264.4*	*264.4*	*-57.8%*	*193.3*	*193.3*	*-*
	County Ditch 26 (131)	*295.1*	*-*	*295.1*	*N/A*	*N/A*	*100%*	*295.1*	*-*	*295.1*	*83.8*	*83.8*	*211.3*	*211.3*	*-71.6%*	*83.8*	*83.8*	*-*
	County Ditch 20 (121)	*460.5*	*-*	*460.5*	*N/A*	*N/A*	*100%*	*460.5*	*-*	*460.5*	*193.4*	*193.4*	*267.1*	*267.1*	*-58.0%*	*193.4*	*193.4*	*-*
	County Ditch 25 (113)	*1,003.7*	*-*	*1,003.7*	*N/A*	*N/A*	*100%*	*1,003.7*	*-*	*1,003.7*	*341.7*	*341.7*	*662.0*	*662.0*	*-66.0%*	*341.7*	*341.7*	*-*
	Warroad River 🍁 †	*6,565.7*	*220.3*	*6,345.4*	*N/A*	*N/A*	*100%*	*6,565.7*	*220.3*	*6,345.4*	*5,574.2*	*5,574.2*	*991.5*	*991.5*	*-15.1%*	*5,574.2*	*5,353.9*	*220.3*
	Stony Creek 🍁	*746.0*	*438.7*	*307.3*	*N/A*	*N/A*	*100%*	*746.0*	*438.7*	*307.3*	*746.0*	*746.0*	*-*	*-*	*-*	*746.0*	*307.3*	*438.7*
	Northwest Angle Inlet 🍁	*1,327.7*	*1,063.7*	*264.0*	*N/A*	*N/A*	*100%*	*1,327.7*	*1,063.7*	*264.0*	*1,327.7*	*1,327.7*	*-*	*-*	*-*	*1,327.7*	*264.0*	*1,063.7*
	Lakeshed	**17,112.1**	**14,771.5**	**2,340.7**				**17,112.1**	**14,771.5**	**2,340.7**	**17,112.1**	**17,112.1**	**-**	**-**	**-**	**17,112.1**	**2,340.7**	**14,771.5**
	Sabaskong East 🍁	*2,058.1*	*2,058.1*	*-*	*N/A*	*N/A*	*100%*	*2,058.1*	*2,058.1*	*-*	*2,058.1*	*2,058.1*	*-*	*-*	*-*	*2,058.1*	*-*	*2,058.1*
	Sabaskong West 🍁	*1,824.3*	*1,824.3*	*-*	*N/A*	*N/A*	*100%*	*1,824.3*	*1,824.3*	*-*	*1,824.3*	*1,824.3*	*-*	*-*	*-*	*1,824.3*	*-*	*1,824.3*
	Four Mile 🍁	*1,988.5*	*1,988.5*	*-*	*N/A*	*N/A*	*100%*	*1,988.5*	*1,988.5*	*-*	*1,988.5*	*1,988.5*	*-*	*-*	*-*	*1,988.5*	*-*	*1,988.5*
	Big Traverse 🍁	*6,140.9*	*5,526.8*	*614.1*	*N/A*	*N/A*	*100%*	*6,140.9*	*5,526.8*	*614.1*	*6,140.9*	*6,140.9*	*-*	*-*	*-*	*6,140.9*	*614.1*	*5,526.8*
	Muskeg 🍁	*364.2*	*145.7*	*218.5*	*N/A*	*N/A*	*100%*	*364.2*	*145.7*	*218.5*	*364.2*	*364.2*	*-*	*-*	*-*	*364.2*	*218.5*	*145.7*
	Little Traverse South 🍁	*2,804.3*	*1,682.6*	*1,121.7*	*N/A*	*N/A*	*100%*	*2,804.3*	*1,682.6*	*1,121.7*	*2,804.3*	*2,804.3*	*-*	*-*	*-*	*2,804.3*	*1,121.7*	*1,682.6*
	Little Traverse North 🍁	*1,931.9*	*1,545.5*	*386.4*	*N/A*	*N/A*	*100%*	*1,931.9*	*1,545.5*	*386.4*	*1,931.9*	*1,931.9*	*-*	*-*	*-*	*1,931.9*	*386.4*	*1,545.5*
	Septic Systems	**721.7**	**410.7**	**311.0**				**721.7**	**410.7**	**311.0**	**410.7**	**410.7**	**311.0**	**311.0**	**-43.1%**	**410.7**	**-**	**410.7**
	Sabaskong East 🍁	*22.4*	*22.4*	*-*	*N/A*	*N/A*	*100%*	*22.4*	*22.4*	*-*	*22.4*	*22.4*	*-*	*-*	*-*	*22.4*	*-*	*22.4*
	Sabaskong West 🍁	*130.4*	*130.4*	*-*	*N/A*	*N/A*	*100%*	*130.4*	*130.4*	*-*	*130.4*	*130.4*	*-*	*-*	*-*	*130.4*	*-*	*130.4*
	Four Mile 🍁	*107.4*	*21.5*	*85.9*	*N/A*	*N/A*	*100%*	*107.4*	*21.5*	*85.9*	*21.5*	*21.5*	*85.9*	*85.9*	*-80.0%*	*21.5*	*-*	*21.5*
	Big Traverse 🍁	*331.8*	*165.9*	*165.9*	*N/A*	*N/A*	*100%*	*331.8*	*165.9*	*165.9*	*165.9*	*165.9*	*165.9*	*165.9*	*-50.0%*	*165.9*	*-*	*165.9*
	Muskeg	*19.7*	*-*	*19.7*	*N/A*	*N/A*	*100%*	*19.7*	*-*	*19.7*	*-*	*-*	*19.7*	*19.7*	*-100.0%*	*-*	*-*	*-*
	Little Traverse South 🍁	*87.4*	*52.4*	*34.9*	*N/A*	*N/A*	*100%*	*87.4*	*52.4*	*34.9*	*52.4*	*52.4*	*34.9*	*34.9*	*-40.0%*	*52.4*	*-*	*52.4*
	Little Traverse North 🍁	*22.6*	*18.1*	*4.5*	*N/A*	*N/A*	*100%*	*22.6*	*18.1*	*4.5*	*18.1*	*18.1*	*4.5*	*4.5*	*-20.0%*	*18.1*	*-*	*18.1*
	Shoreline Erosion	**72,000.0**	**-**	**72,000.0**				**72,000.0**	**-**	**72,000.0**	**60,480.0**	**60,480.0**	**11,520.0**	**11,520.0**	**-16.0%**	**60,480.0**	**60,480.0**	**-**
	Four Mile	*9,395.4*	*-*	*9,395.4*	*N/A*	*N/A*	*100%*	*9,395.4*	*-*	*9,395.4*	*7,892.2*	*7,892.2*	*1,503.3*	*1,503.3*	*-16.0%*	*7,892.2*	*7,892.2*	*-*
	Big Traverse	*36,000.0*	*-*	*36,000.0*	*N/A*	*N/A*	*100%*	*36,000.0*	*-*	*36,000.0*	*30,240.0*	*30,240.0*	*5,760.0*	*5,760.0*	*-16.0%*	*30,240.0*	*30,240.0*	*-*
	Muskeg	*26,604.6*	*-*	*26,604.6*	*N/A*	*N/A*	*100%*	*26,604.6*	*-*	*26,604.6*	*22,347.8*	*22,347.8*	*4,256.7*	*4,256.7*	*-16.0%*	*22,347.8*	*22,347.8*	*-*
	Atmospheric Deposition 🍁	**51,407.3**	**27,804.9**	**23,602.4**	**N/A**	**N/A**	**100%**	**51,407.3**	**27,804.9**	**23,602.4**	**51,407.3**	**51,407.3**	**-**	**-**	**-**	**51,407.3**	**23,602.4**	**27,804.9**
	Internal Load 🍁	**281,994.7**	**97,712.7**	**184,281.9**	**N/A**	**N/A**	**100%**	**281,994.7**	**97,712.7**	**184,281.9**	**211,496.0**	**211,496.0**	**70,498.7**	**70,498.7**	**-25.0%**	**211,496.0**	**138,211.4**	**73,284.6**
Reserve Capacity	**Total Reserve Capacity**	**-**	**-**	**-**				**-**	**-**	**-**	**887.0**	**887.0**	**(887.0)**	**(887.0)**	**-**	**887.0**	**167.0**	**720.0**
	Unsewered Communities	*-*	*-*	*-*	*N/A*	*N/A*	*100%*	*-*	*-*	*-*	*167.0*	*167.0*	*(167.0)*	*(167.0)*	*-*	*167.0*	*167.0*	*-*
	Fort Frances 🍁	*-*	*-*	*-*	*100%*	*81%*	*81%*	*-*	*-*	*-*	*300.0*	*300.0*	*(300.0)*	*(300.0)*	*-*	*300.0*	*-*	*300.0*
	New Gold Mine 🍁	*-*	*-*	*-*	*35%*	*93%*	*32%*	*-*	*-*	*-*	*420.0*	*420.0*	*(420.0)*	*(420.0)*	*-*	*420.0*	*-*	*420.0*
TOTAL		**885,951.9**	**326,453.3**	**559,498.6**	**-**	**-**	**-**	**814,914.9**	**294,886.8**	**520,028.2**	**723,385.1**	**673,914.3**	**162,566.8**	**141,000.6**	**-17.3%**	**673,914.3**	**432,467.3**	**241,447.0**
MOS (5%)												**35,608.1**				**35,608**		
LOADING CAPACITY												**709,522.4**				**709,522**		

1: Loads originating in Canada are assigned neither load allocations nor wasteload allocations, but are instead considered acknowledged loads, which are included to provide a full accounting of loads to Lake of the Woods.

2: For all wasteload allocations, percent change is calculated from end of pipe loads (at source) for consistency with permitting; percent change for all other items is based on the existing load at Lake of the Woods and thte proposed load at Lake of the Woods

3: Point source loads for First Nations wastewater treatment plants in Canada are not reflected in the wasteload allocation due to insufficient discharge information. Loads from these populations are reflected in septic system loading, which was developed based on populations not served by modeled WWTPs.

4: Not currently permitted but expected to come under permit coverage in the future.

† HSPF modeling boundaries show that a portion of the Warroad River Subwatershed extends into Canada and the runoff from that portion of the subwatershed drains directly to the lake

🍁 denotes that all or a portion of the designated load originates in Canada

Appendix D. Detailed Water Quality Summary

Water quality data were obtained from the EPA STORET, MPCA Environmental Quality Information System (EQuIS), and the OMECC databases. Data were collected by the Red Lake Department of Natural Resources, MPCA, and OMECC. Data from Canadian sources were obtained for Sabaskong Bay only.

Water quality constituent summaries (based on growing season data for the study period) are given for each bay in Table D-1. More detailed summaries for each bay in the TMDL Study Area (Sabaskong, Four Mile, Muskeg, Big Traverse, and Little Traverse) are included in Table D-2, Table D-3, Table D-4, Table D-5, and Table D-6.

Annual growing-season mean values by bay are shown in Figure D-1, Figure D-2, and Figure D-3. Mean TP concentrations show little change except increasing concentrations in Big Traverse Bay. Insufficient data were available to perform a statistical trend test. Nearly all annual mean values show exceedances for TP, Chl-*a*, and Secchi Disk depth, with the exception of annual growing-season mean Chl-*a* concentrations in Four Mile Bay.

D.1 TEMPERATURE AND DISSOLVED OXYGEN

Temperature and DO data were examined to understand lake mixing patterns, which affect biological responses and lake P dynamics. Lake-bottom water temperature and DO concentration impact internal loading of P and are, therefore, important parameters for characterizing in-lake nutrient dynamics. Available data from 1999 to 2010 are shown in Figure D-4, Figure D-5, Figure D-6, Figure D-7, Figure D-8, Figure D-9, Figure D-10, Figure D-11, Figure D-12, and Figure D-13. Data that predate the study period (2005 through 2014) were included to allow a more complete review of lake characteristics. Temperature and DO data were noted to have been collected concurrently. Sport fisheries generally require DO concentrations of at least 5 mg L^{-1}. Only one of the 1,467 DO measurements was below 5 mg L^{-1}. Data are lacking for values at or near the sediment surfaces.

D.2 FOUR MILE BAY

Temperature and DO profiles (collected from April through October) indicate that the bay is well mixed (polymictic) throughout the warm months of the year. Temperatures vary from 10 degrees Celsius (°C) during cool months to more than 20°C during warm months. DO concentrations were generally 7 milligrams per liter (mg L^{-1}) or greater, with minimum values measured in July 2006.

D.3 MUSKEG BAY

Muskeg Bay profiles show that the bay is generally well mixed, with a few instances of temperature gradients or oxygen depletion. Temperature measurements ranged from approximately 5° to 25°C, while DO concentrations were generally greater than 8 mg L^{-1}.

D.4 BIG TRAVERSE BAY

Because of the large number of samples for Big Traverse Bay, data were split by monitoring site (39-0002-01-105 in the middle of Big Traverse Bay and 39-0002-01-101 along the Canadian border just north of Four Mile Bay). Data suggest that Big Traverse Bay is well mixed, with few observations of temperature gradients or oxygen depletion. Temperatures ranged from below 5°C to nearly 25°C, while DO concentrations were generally above 7 mg L^{-1}.

Table D-1. Study period (2005–2014) summer-average water quality summary by bay.

Bay	Total Phosphorus			Chl-*a*			Secchi Disk			Turbidity (FNU)			TSS
	Mean Concentration (µg L^{-1})	n	CV mean	Mean Concentration (µg L^{-1})	n	CV mean	Mean Depth (m)	n	CV mean	Mean Value (FNU)	n	CV mean	Mean Value (mg L^{-1})
Sabaskong	26.9	–	0.35	6.4	–	1.7	1.3	–	0.4	No data available; limited TP, Chl-*a*, and Secchi data available for Sabaskong Bay; data taken from the 2012 Lake of the Woods BATHTUB model (Anderson et al. 2013).			
4-Mile	32.95	20	0.051	5.21	18	0.151	1.34	16	0.142	2.82	27	0.19	10.5
Muskeg	37.65	20	0.071	12.24	19	0.285	1.07	29	0.058	2.89	24	0.19	9.3
Big Traverse	35.71	41	0.049	9.34	36	0.202	1.17	50	0.056	3.67	45	0.17	7.8
Little Traverse	33.59	41	0.043	9.48	40	0.112	1.39	15	0.172	3.52	113	0.11	8.7

Table D-2. Sabaskong Bay water quality monitoring data summary.

Constituent	Minimum	Mean	Maximum	Standard Deviation	No. of samples
TP (µg L^{-1})	16.3	31.68	61.3	11.44	11
Chl-*a* (µg L^{-1})					
Secchi disk depth (m)	0.42	1.35	2.46	0.54	33

Table D-3. 4-Mile Bay water quality monitoring data summary.

Constituent	Minimum	Mean	Maximum	Standard Deviation	No. of samples
TP (µg L^{-1})	20	33	45	8	20
Dissolved Phosphorus (µg L^{-1})	11	16	24	6	5
Total Ortho Phosphorus (µg L^{-1})	5	6	10	2	5
Dissolved Ortho Phosphorus (µg L^{-1})	6	9	14	4	5
TKN (mg L^{-1})	0.41	0.607	1.00	0.146	18
Total NO_2+NO_3 (mg L^{-1})	0.05	0.054	0.06	0.005	5
Total NO_2 (mg L^{-1})	0.01	0.01	0.01	-	1
Total NH_3 (mg L^{-1})	0.05	0.05	0.05	0	4
Dissolved NH_3 (mg L^{-1})	0.014	0.019	0.025	0.004	5
Total Ammonia (mg L^{-1})	0.05	0.05	0.05	-	1

Constituent	Minimum	Mean	Maximum	Standard Deviation	No. of samples
Secchi disk depth (m)	0.7	1.34	4.0	0.765	16
Chl-*a* ($\mu g\ L^{-1}$)	1.2	5.214	15.5	3.340	18
TSS ($mg\ L^{-1}$)	1.6	10.459	30.0	10.165	17
Total Volatile Suspended Solids ($mg\ L^{-1}$)	1.0	6.129	20.0	7.938	17
Turbidity (FNU)	0	2.819	8.2	2.758	27

Table D-4. Muskeg Bay water quality monitoring data summary.

Constituent	Minimum	Mean	Maximum	Standard Deviation	No. of samples
TP ($\mu g\ L^{-1}$)	24	38	68	12	20
Dissolved P ($\mu g\ L^{-1}$)	7	11	14	3	7
Total Ortho P ($\mu g\ L^{-1}$)	5	8	12	3	4
Dissolved Ortho P ($\mu g\ L^{-1}$)	4	7	9	2	7
Total Kjeldahl N ($mg\ L^{-1}$)	0.39	0.633	1.18	0.172	19
Total NO_2+NO_3 ($mg\ L^{-1}$)	0.05	0.05	0.05	0	4
Total NH_3 ($mg\ L^{-1}$)	0.05	0.05	0.05	0	4
Dissolved NH_3 ($mg\ L^{-1}$)	0.01	0.014	0.02	0.004	7
Secchi disk depth (m)	0.46	1.070	1.8	0.334	29
Chl-*a* ($\mu g\ L^{-1}$)	1.2	12.239	64.6	15.195	19
TSS ($mg\ L^{-1}$)	2.0	9.316	30.0	7.235	19
Total Volatile Suspended Solids ($mg\ L^{-1}$)	1.0	6.484	28.0	7.144	19
Turbidity (FNU)	0.0	2.892	9.9	2.671	24

Table D-5. Big Traverse Bay water quality monitoring data summary.

Constituent	Minimum	Mean	Maximum	Standard Deviation	No. of samples
TP ($\mu g\ L^{-1}$)	11	36	63	11	41
Dissolved P ($\mu g\ L^{-1}$)	9	20	28	7	10
Total Ortho P ($\mu g\ L^{-1}$)	5	9	19	5	10
Dissolved Ortho P ($\mu g\ L^{-1}$)	4	12	20	6	10
Total Kjeldahl N ($mg\ L^{-1}$)	0.41	0.633	0.98	0.107	36
Total NO_2+NO_3 ($mg\ L^{-1}$)	0.05	0.050	0.05	0	10
Total NO_2 ($mg\ L^{-1}$)	0.01	0.01	0.01	0	2
Total NH_3 ($mg\ L^{-1}$)	0.05	0.05	0.05	0	9
Dissolved NH_3 ($mg\ L^{-1}$)	0.016	0.020	0.03	0.004	10
Total Ammonia as N ($mg\ L^{-1}$)	0.05	0.05	0.05		1
Secchi disk depth (m)	0.3	1.171	2.4	0.461	50
Chl-*a* ($\mu g\ L^{-1}$)	0.9	9.337	55.3	11.312	36
TSS ($mg\ L^{-1}$)	1.0	7.800	27.0	6.647	35
Total Volatile Suspended Solids ($mg\ L^{-1}$)	1.0	4.474	18.0	4.739	35
Turbidity (FNU)	0.0	3.670	16.8	4.070	45

Table D-6. Little Traverse Bay water quality monitoring data summary.

Constituent	Minimum	Mean	Maximum	Standard Deviation	No. of samples
TP (µg L^{-1})	20	34	62	9	41
Dissolved P (µg L^{-1})	5	10	16	4	11
Total Ortho P (µg L^{-1})	5	8	21	3	27
Dissolved Ortho P (µg L^{-1})	4	8	12	3	11
Total Kjeldahl N (mg L^{-1})	0.52	0.662	1.06	0.123	41
Total NO_2+NO_3 (mg L^{-1})	0.05	0.05	0.05	0	30
Total NO_2 (mg L^{-1})	0.01	0.01	0.01	0	4
Total NH_3 (mg L^{-1})	0.05	0.05	0.05	0	21
Dissolved NH_3 (mg L^{-1})	0.011	0.022	0.037	0.007	11
Total Ammonia (mg L^{-1})	0.05	0.05	0.05	0	6
Secchi disk depth (m)	0.7	1.389	4.5	0.926	15
Chl-*a* (µg L^{-1})	2.2	9.477	30.6	6.690	40
TSS (mg L^{-1})	2.0	8.668	29.0	6.245	41
Total Solids (mg L^{-1})	92.0	95.0	98.0	3.000	3
Total Volatile Solids (mg L^{-1})	34.0	39.0	45.0	5.568	3
Total Volatile Suspended Solids (mg L^{-1})	1.0	5.068	24.0	5.147	38
Turbidity (FNU)	0.0	3.521	15.0	4.240	113

Figure D-1. Annual Summer-Average TP Concentrations, 2005–2014

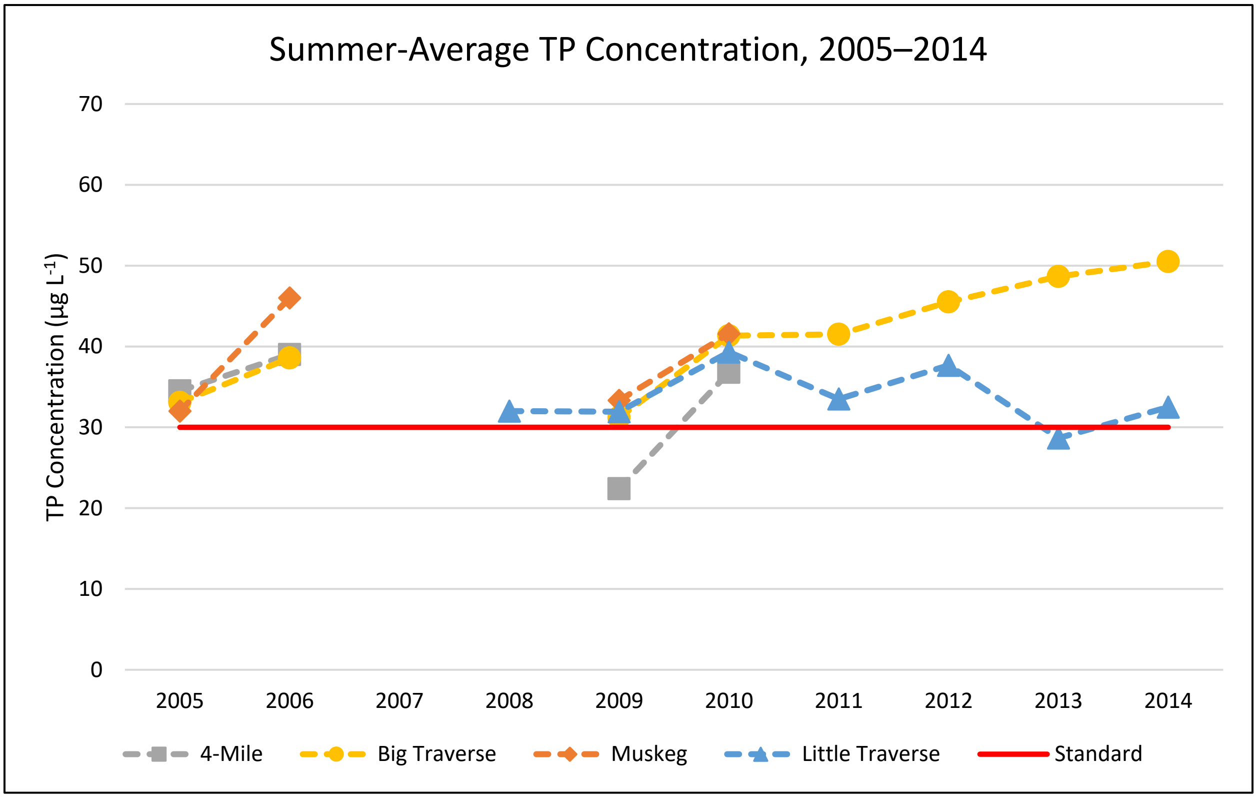


Figure D-2. Annual Summer-Average Chl-*a* Concentrations, 2005–2014

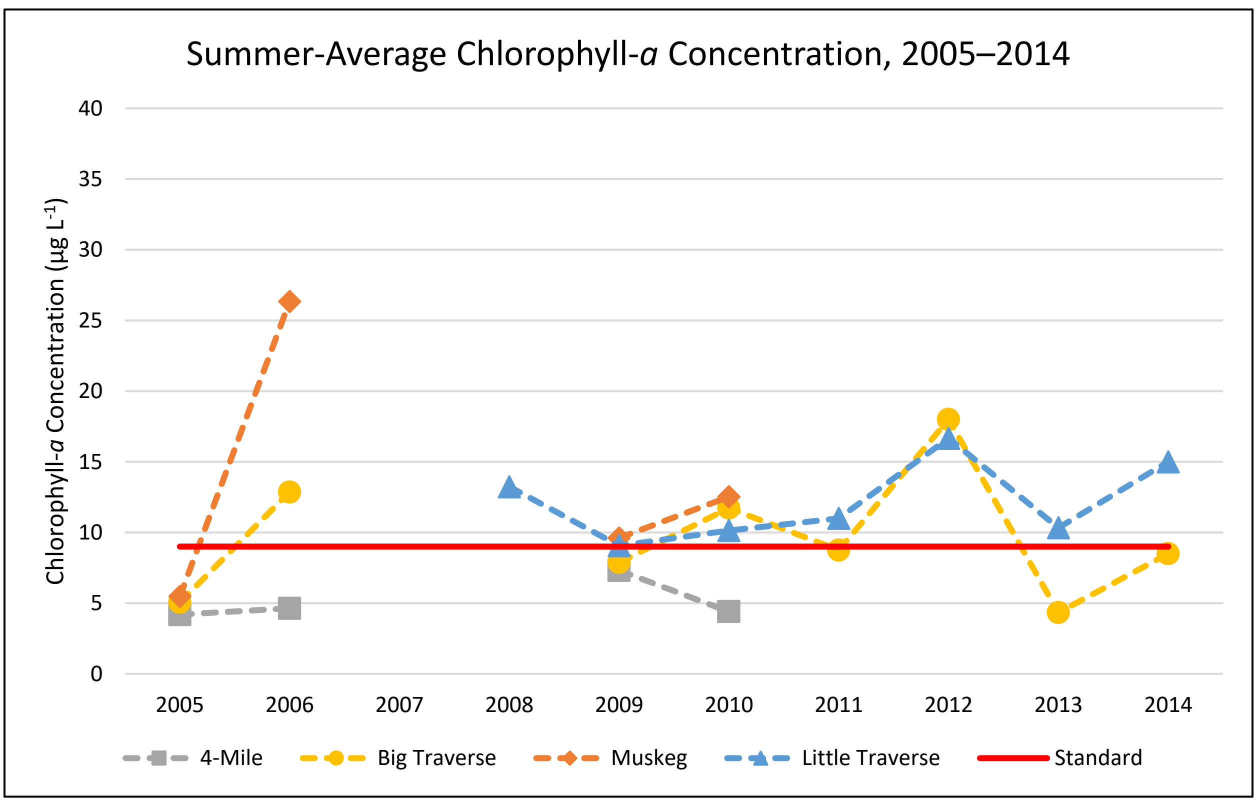
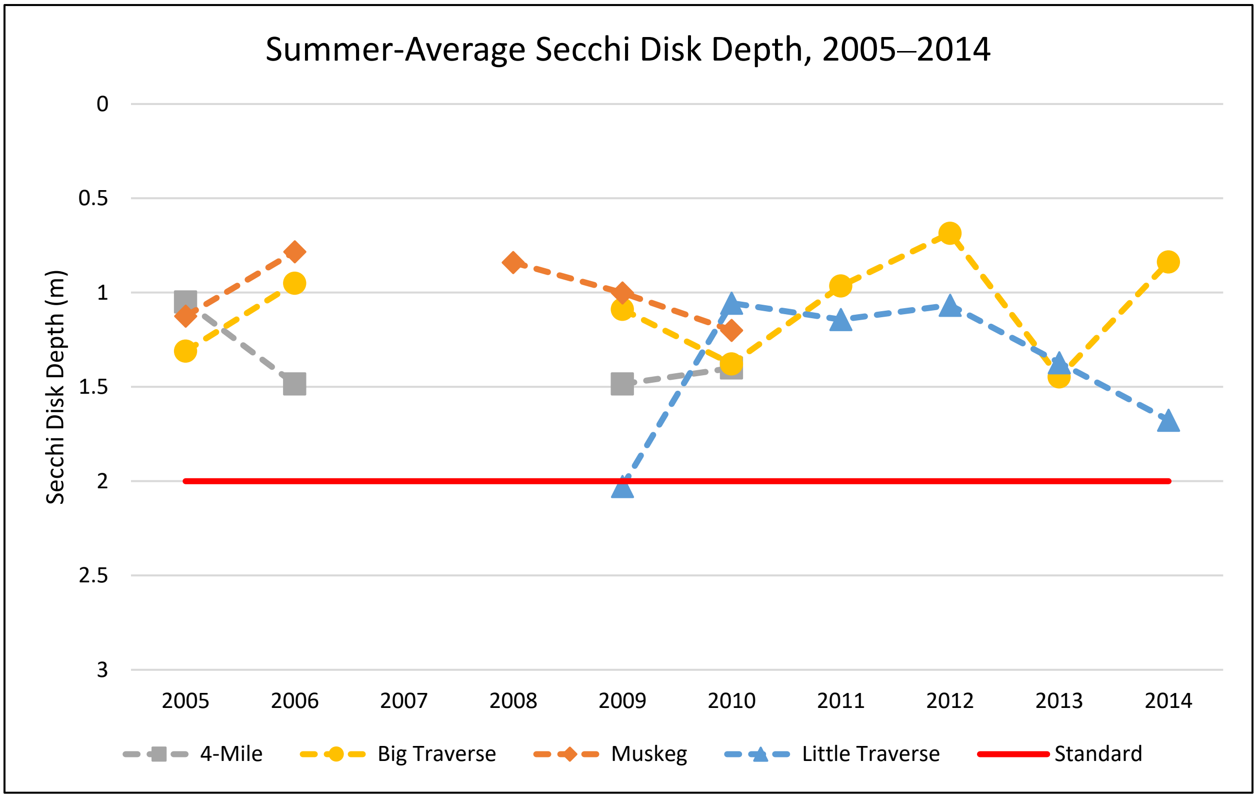


Figure D-3. Annual Summer-Average Secchi Disk Depths, 2005–2014



D.5 LITTLE TRAVERSE BAY

Little Traverse Bay data suggest that this bay is the least well mixed of the four bays. Water temperature profiles show several instances of temperature gradients and even increasing temperatures with depth. DO profiles show several dates with oxygen depletion (loss) of 2 mg L^{-1} over the profile depth, with a peak depletion of 3.9 mg L^{-1} in July 2010.

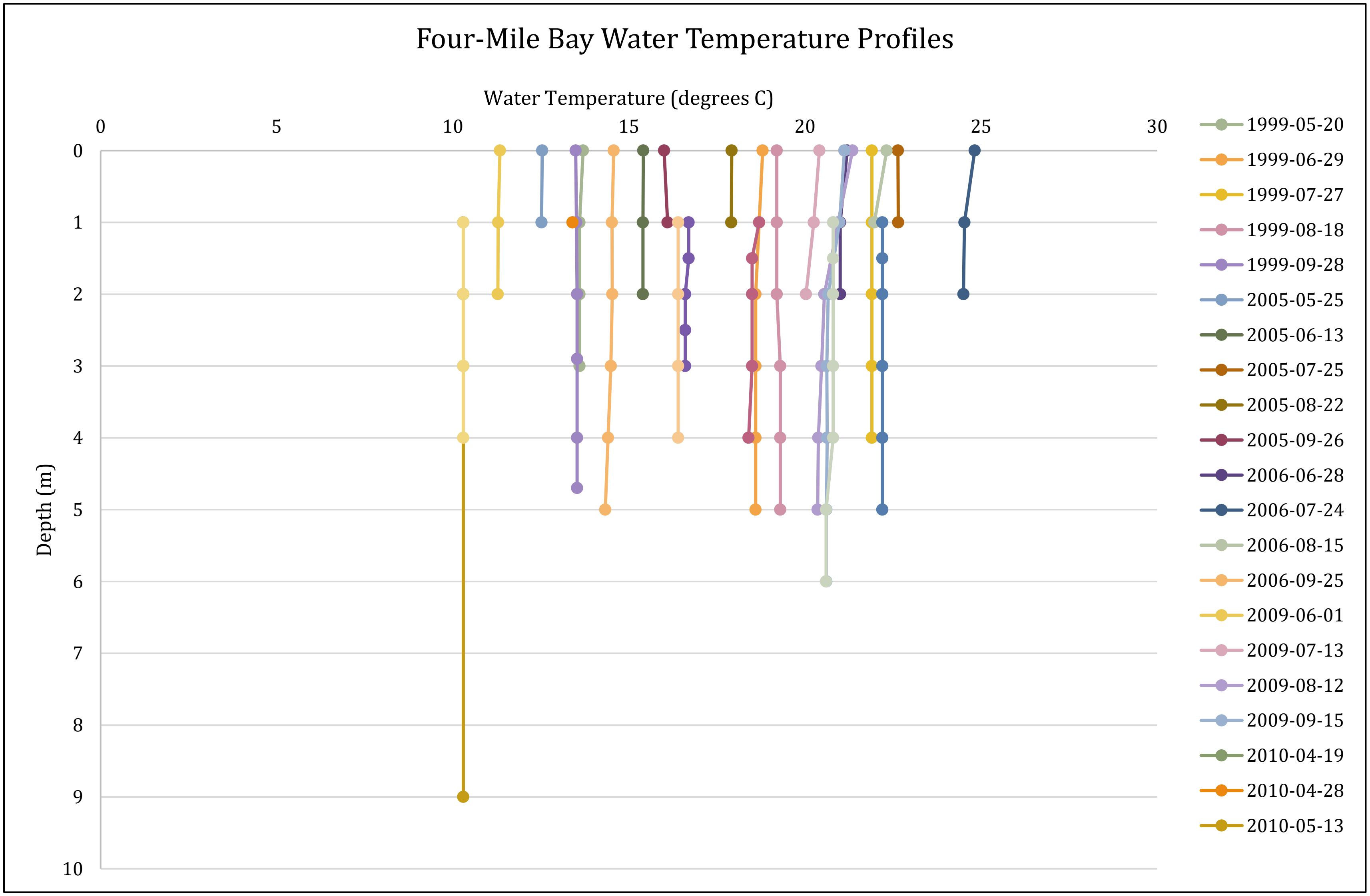


Figure D-4. Four Mile Bay Temperature Profiles

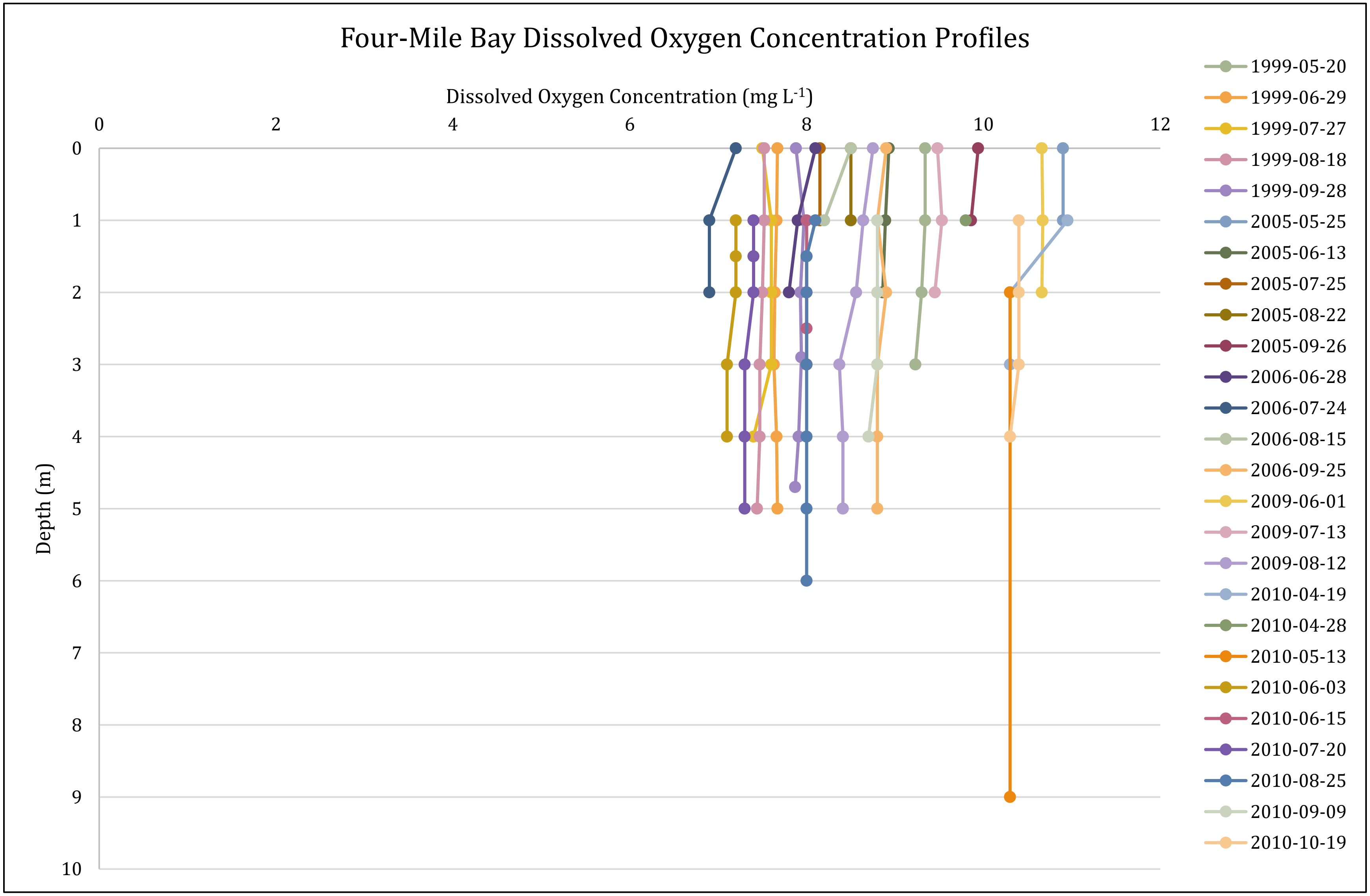


Figure D-5. Four Mile Bay DO Profiles

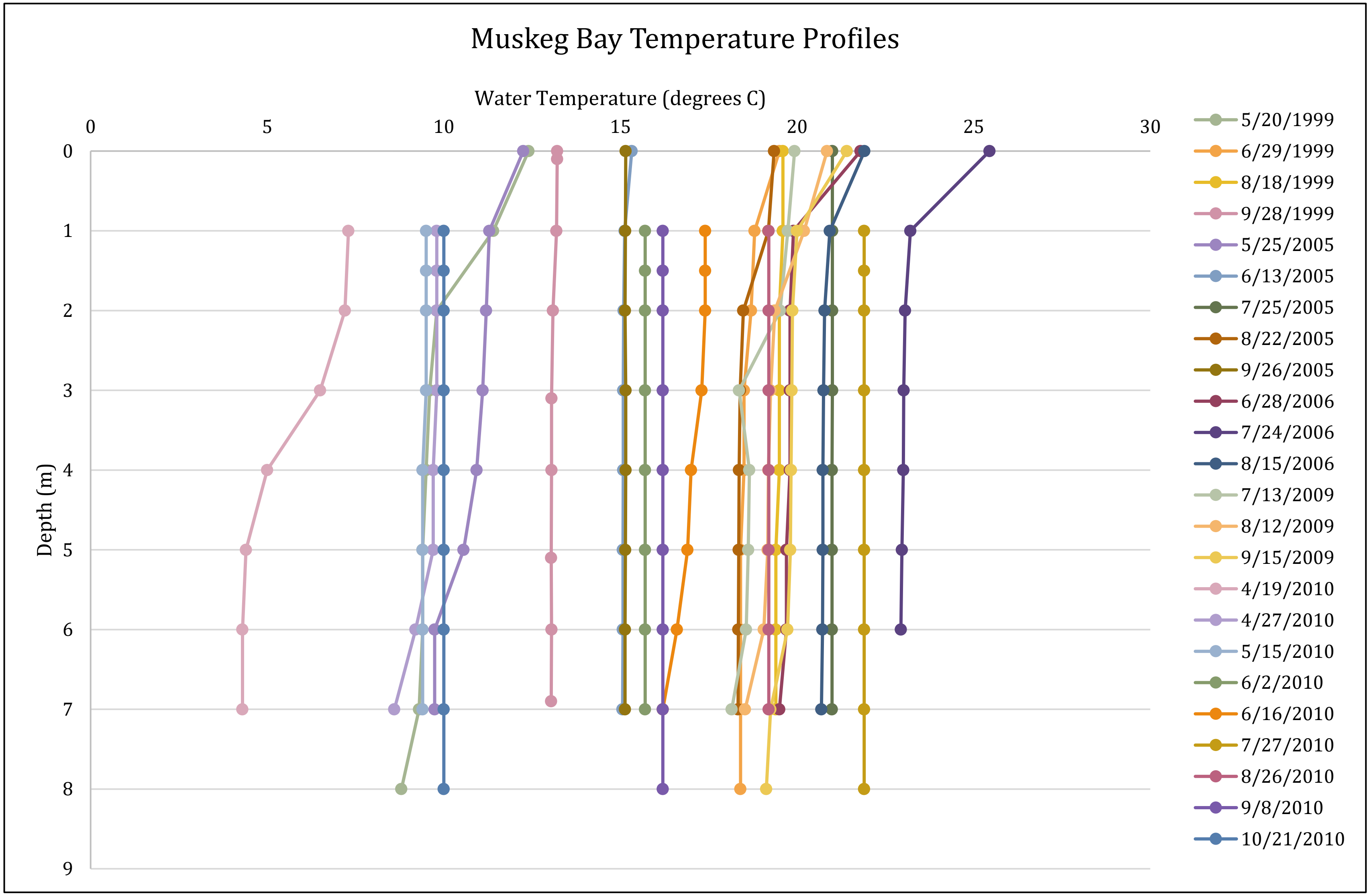


Figure D-6. Muskeg Bay Temperature Profiles

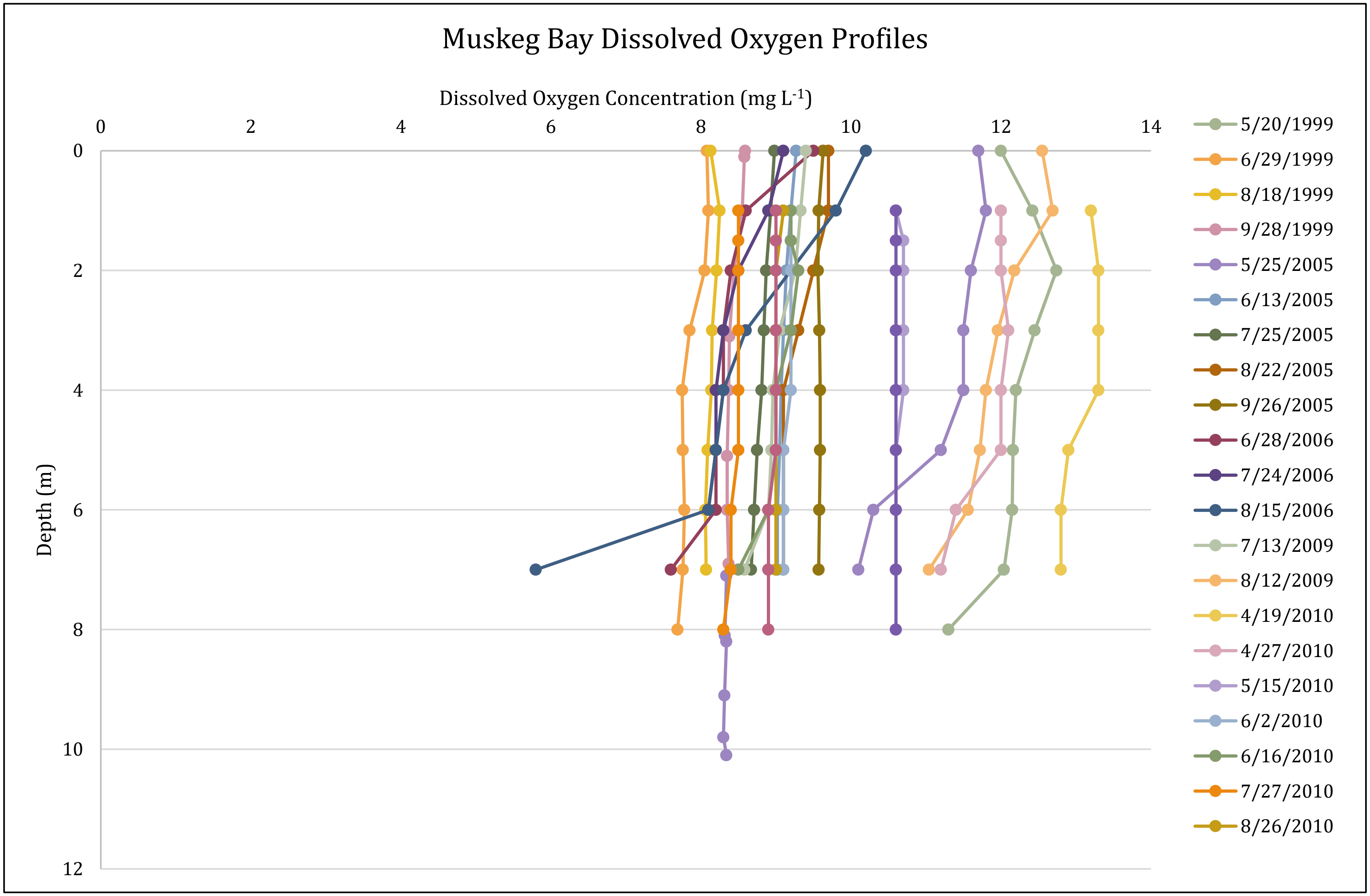


Figure D-7. Muskeg Bay DO Profiles

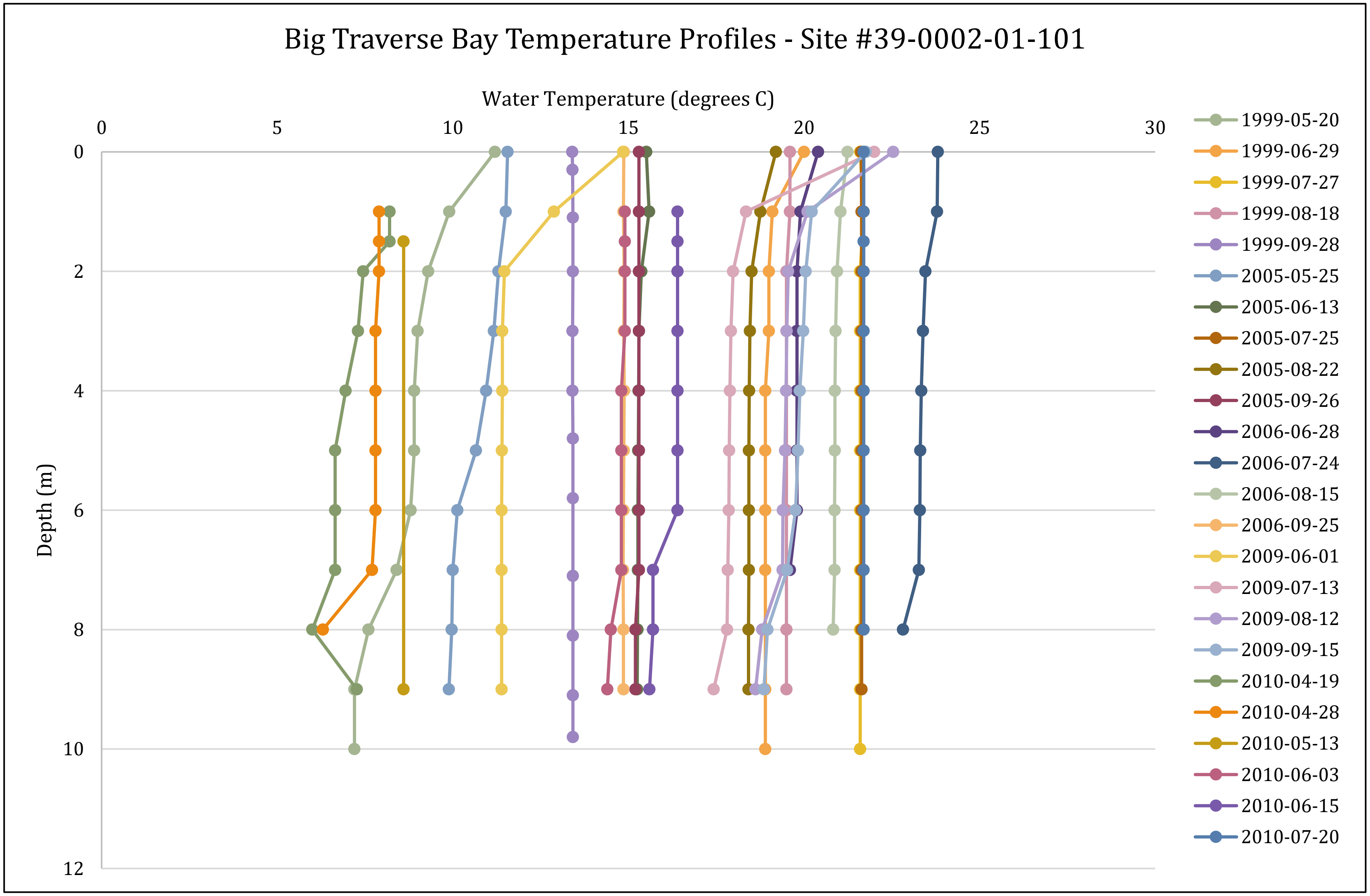


Figure D-8. Big Traverse Bay Temperature Profiles at Site 39-0002-01-101

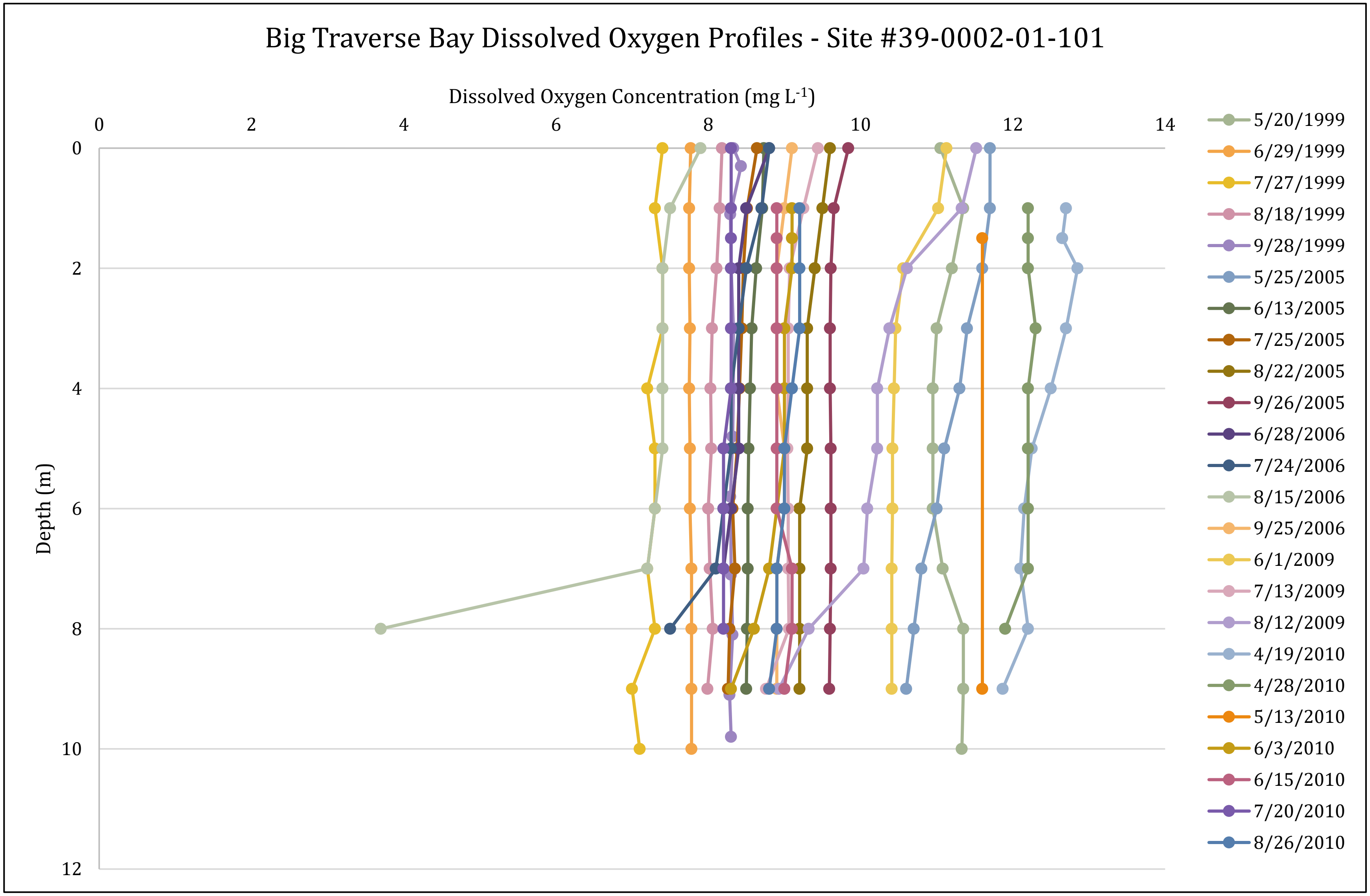


Figure D-9. Big Traverse Bay DO Profiles at Site 39-0002-01-101

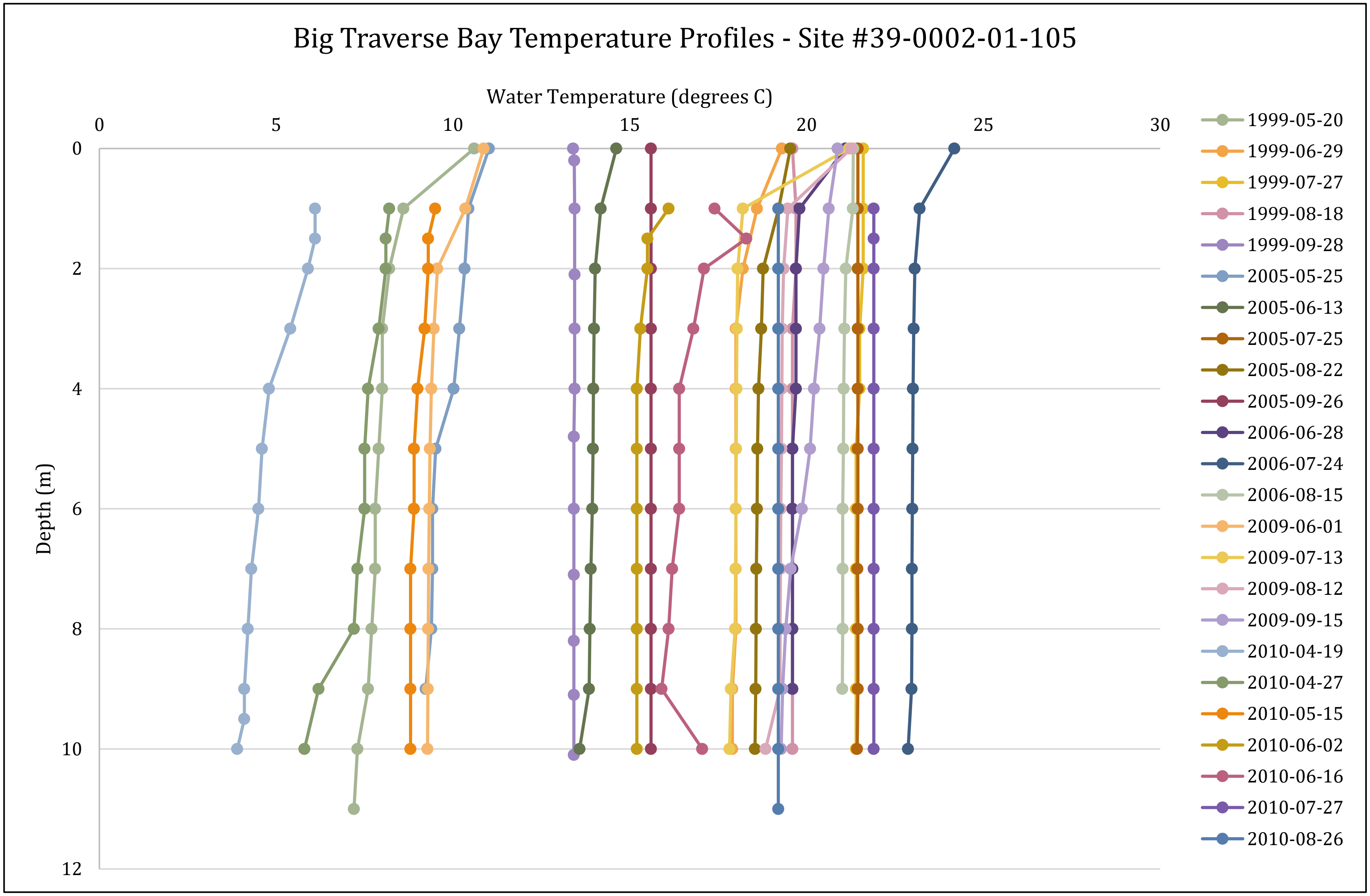


Figure D-10. Big Traverse Bay Temperature Profiles at Site 39-0002-01-105

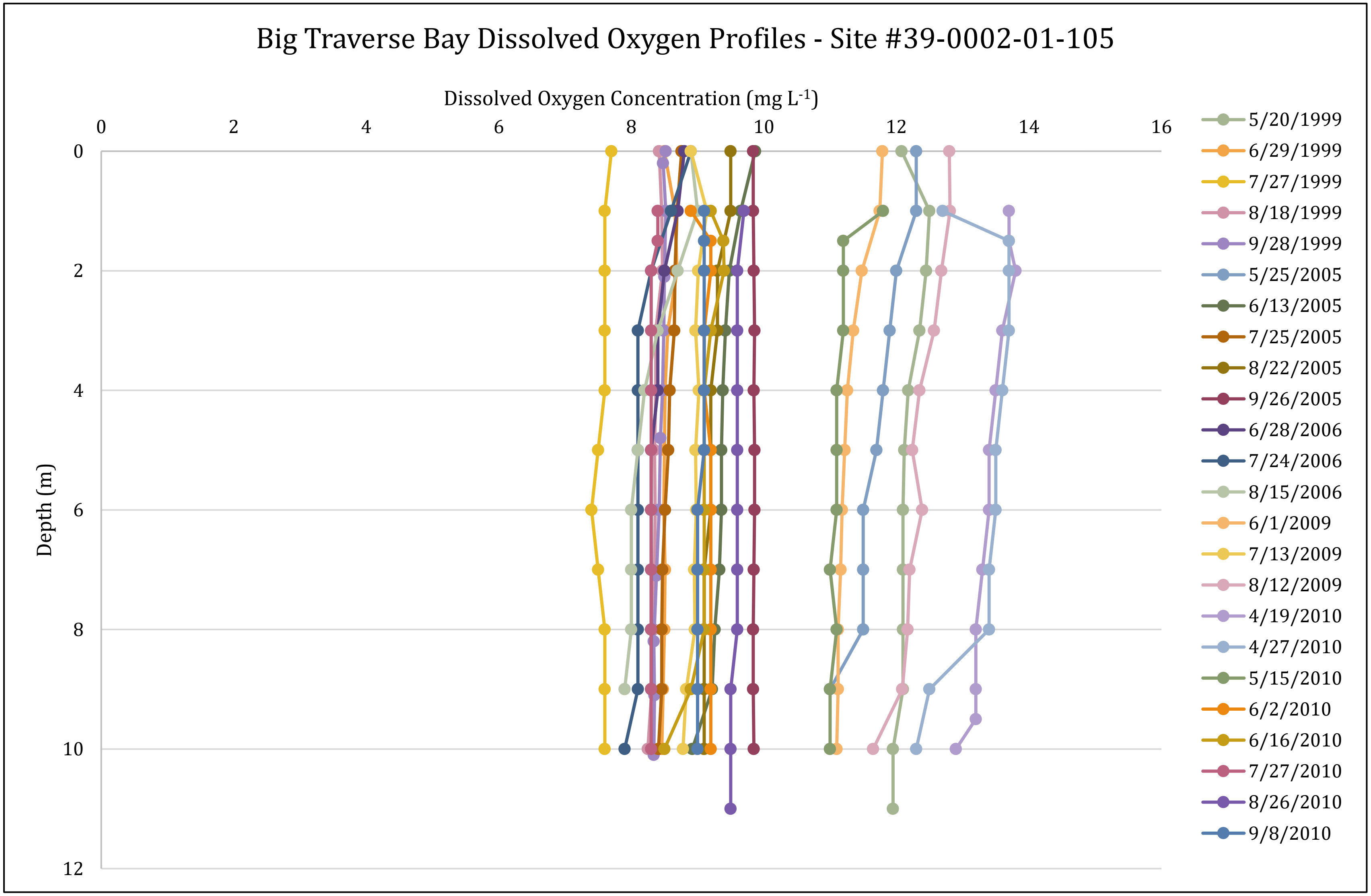


Figure D-11. Big Traverse Bay DO Profiles at Site 39-0002-01-105

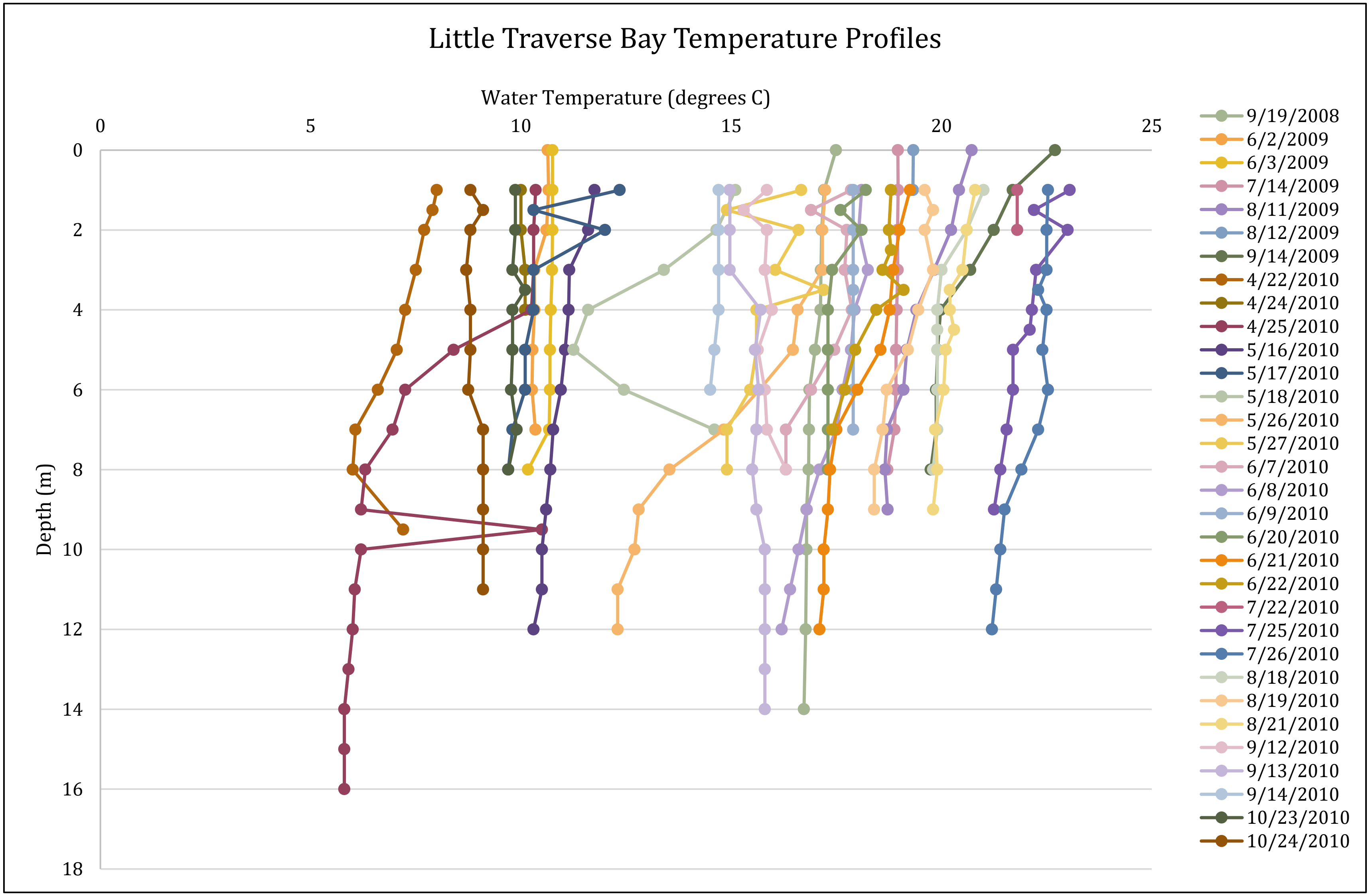


Figure D-12. Little Traverse Bay Temperature Profiles

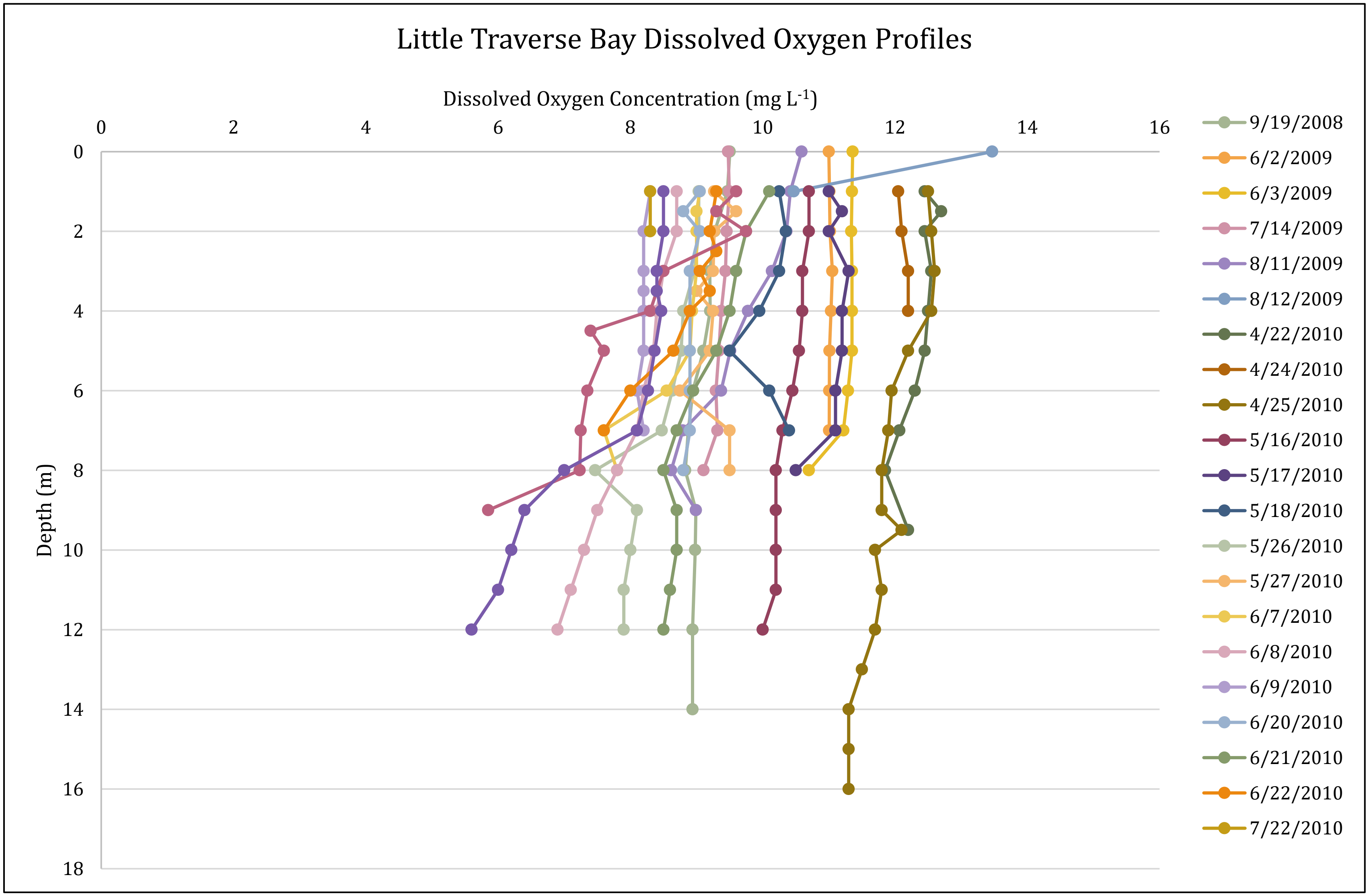


Figure D-13. Little Traverse Bay Dissolved Oxygen Profile

Appendix E. Detailed Phosphorus Source Summary

This appendix provides a detailed summary of P sources and the methods used to estimate study period mean annual P loads, LAs, and proposed reductions. Sources are categorized as permitted and nonpermitted sources in this appendix. A summary of study period LoW loading is provided in Figure E-1.

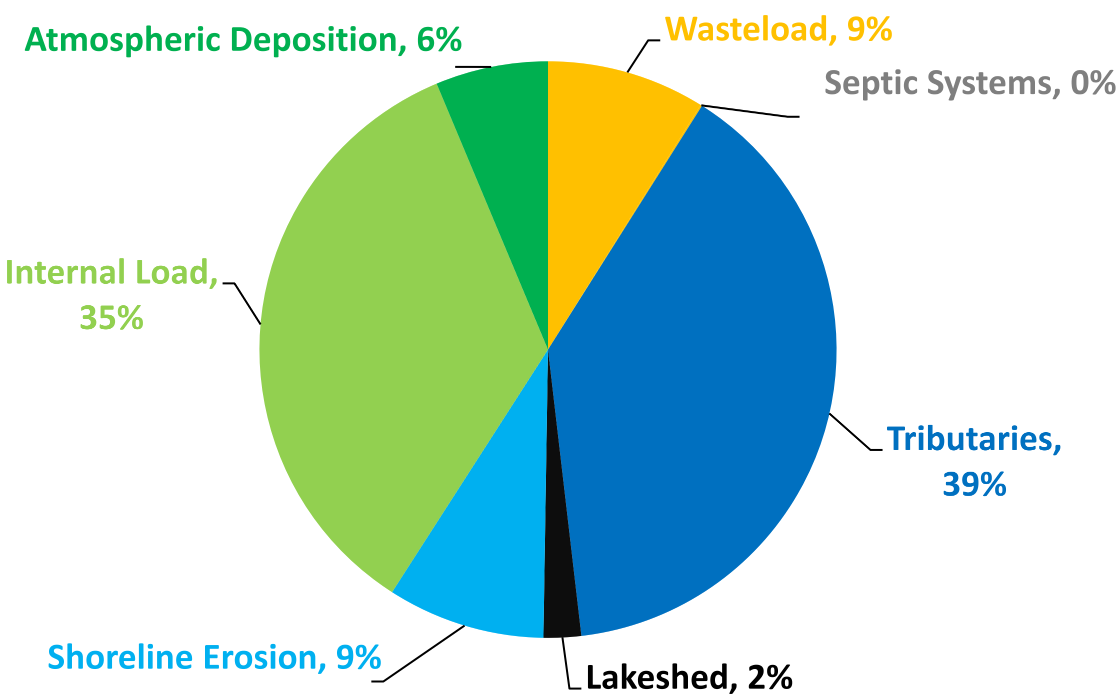


Figure E-1. Summary of Lake of the Woods Phosphorus Loading Sources.

Loads presented in this appendix may be quantified at the source (i.e., the discharge point from a WWTP or at the mouth of a tributary) or at the point where that source's runoff enters the LoW. The load delivered to the LoW from a particular source is less than the load at the source because of nutrient attenuation (i.e., settling of particle-bound P or plant uptake). Load at the LoW is germane to this TMDL study because the goal is to quantify the total load that the LoW can receive while still meeting its water quality standards. Loads at the source may be of interest for purposes such as managing a WWTP or future implementation work focusing on reducing nonpoint source loading from a LoW tributary. Note that while attenuation was applied to all of the applicable loads (those not discharging directly to LoW) for the existing conditions (study period) loading analysis and existing conditions BATHTUB model, attenuation was not used in developing any proposed WLAs or in the septic system LA. As such, proposed loads for wasteload sources and septic systems loads are equal to the corresponding WLA or LA for each specific source. The exclusion of attenuation causes these loads to have higher than expected P delivery to LoW, which provides an implicit MOS.

E.1 Rainy River Phosphorus Delivery Analysis

The concept of attenuation and delivery ratios was briefly introduced in Section 4.2.2.1 and is expanded upon here. Consideration of attenuation was necessary to accurately account for the total load entering LoW during the study period and to establish a calibrated existing conditions BATHTUB model. Incorporating load attenuation provides the best representation of study period loading to LoW by accounting for P settling and uptake of particulate and dissolved P within upstream tributaries. Without attenuation, the total of all of the loads (at the source) to LoW would exceed the actual load entering LoW for the study period and would lead to an inaccurate representation of LoW's nutrient loading and in-lake response. Note that attenuation was not accounted for in developing all of the WLAs (and acknowledged loads in Canada from sources that would receive WLAs, were they located in the US), the septic system LA, and RC loads. Not including attenuation in these loads provides an additional implicit MOS (beyond the explicit 5% MOS) because of the higher than average dissolved P loads from these sources. Exclusion of attenuation also provides consistency between load and WLAs from these sources and the assumed load that will be delivered to LoW; this provides consistency between the TMDL study and permitted loads to be enforced as part of the TMDL.

Attenuation is observed in monitoring data within the Rainy River, as well as in HSPF-modeled loads along the Rainy River that are calibrated to the monitoring data. Attenuation can be caused by physical and biological processes such as particle settling and burial of sediment-bound P or nutrient uptake. The attenuation analysis was undertaken for two areas in the TMDL Study Area:

1. All sources drained by Rainy River
2. Williams WWTP and Williams Creek (County Ditch 1).

Attenuation of sources draining to Rainy River is necessary to properly account for the contribution of existing (study period) point and nonpoint sources to LoW. Attenuation of Williams WWTP loads is necessary as the Williams WWTP discharges to Williams Creek (County Ditch 1), not directly to LoW. All of the other loads, as modeled in HSPF, discharge directly to LoW and are not attenuated before discharging to LoW.

Attenuation is implemented mathematically using a delivery ratio. The delivery ratio is the ratio of the mean annual study period load leaving a reach to the total mean annual study period load entering a reach. A delivery ratio of 94% means that 94% of the total load entering a reach is discharged from that reach and the remainder, 6%, is attenuated or stored within the reach.

Study period HSPF loads were analyzed to determine the delivery ratio for each of the nine HSPF reaches along the Rainy River between Rainy Lake and LoW. These reaches are shown in bold black outline in Figure E-2, beginning upstream with reach 10 and discharging to LoW from reach 430. The delivery ratio for each reach was calculated as the ratio of study period mean annual discharge of P to the study period total mean annual inflow of P. Cumulative delivery ratios by reach were then calculated as the product of all downstream reaches. Because each of the Rainy River reaches has a delivery ratio of less than 1 (e.g., on average, attenuation is observed in every reach of Rainy River), delivery ratios are lower for sources further upstream from LoW (e.g. the TP delivery ratio for discharge from the Little Fork River is 0.84, while the delivery ratio for discharge from the Rapid River is 0.96). Separate delivery ratios for both TP and orthophosphate (OP) due to the sensitivity of the BATHTUB to OP loading.

The following sections detail the attenuation analysis and results within the Rainy River system

E.1.1 Rainy River Hydrology Analysis

Rainy River tributaries and local drainage to Rainy River within the Rainy River model reaches (shown with bold black borders) are shown in Figure E-2. Study period mean annual discharge from the HSPF model is listed for each tributary to Rainy River in Table E-1. Total discharge to LoW at Wheelers Point is 12,739 hm^3. Inflow by tributary (blue bars) and cumulative discharge (gray line) to the Rainy River are shown in Figure E-3; upstream (Rainy Lake) is shown on the right end of the x-axis and the downstream end at the mouth of Rainy River (Four Mile Bay) is shown on the left end of the x-axis. Spacing along the x-axis is in 1 km increments. Rainy Lake outflow dominates inputs to Rainy River (72% of discharge), while approximately 8% of discharge at Wheelers Point originates from both the Big Fork and Little Fork Watersheds.

Table E-1. Summary of subwatershed characteristics and study period mean annual discharge (Lupo 2015b) in the Rainy River drainage area.

Subwatershed	River Above 4-Mile Bay (km)	Drainage Area (km^2)	Discharge (hm^3)	Runoff (cm)
Rainy Lake	132	38,178	9,096	24
Little Fork River	112	4,853	946	19
La Vallee River	107	298	67	22
Big Fork River	100	5,326	943	18
Black River	95	1,033	271	26
Sturgeon River	65	220	49	22
McCloud Creek	54	24	5	20
Whitefish Creek	48	34	7	20
Pinewood River	40	569	109	19
Rapid River	30	2,445	520	21
Silver Creek	25	76	13	17
Unnamed (391)	19	43	7	17
Baudette River	17	154	26	17
Miller Creek	13	23	4	19
Winter Road River	10	384	65	17
Wabanica Creek	7	75	14	19
Direct Drainage	–	951	207	22
Total (4-Mile Bay)	**0**	**54,686**	**12,739**	**23**

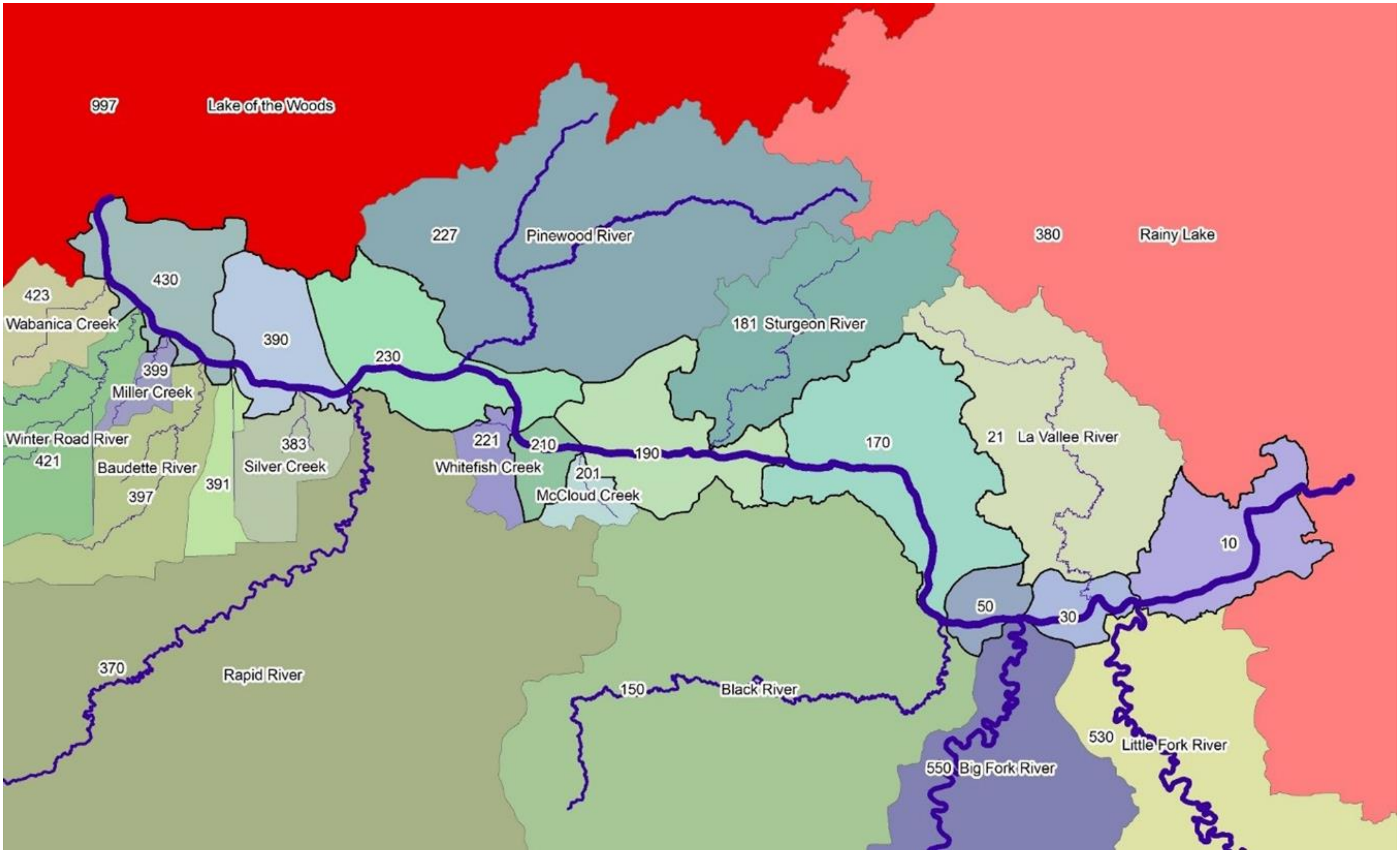


Figure E-2. Rainy River HSPF Reaches (black outline) with tributary reaches. Note that reaches 380 (Rainy Lake), 530 (Little Fork River), and 550 (Big Fork River) are separate HSPF models that discharge to Rainy River.

E.1.2 Phosphorus

Study period FWMCs and mean annual loads for TP and OP are listed by Rainy River tributary in Table E-2. The tributary loads listed are as delivered to Rainy River and do not account for attenuation in Rainy River. More than one-third of the TP and one-half of the OP that enters the Rainy River comes from Rainy Lake. The second- and third-largest tributary loads come from the Little Fork River and the Big Fork River, respectively, and all HSPF model tributaries have higher FWMCs than Rainy Lake outflow. Note that point source loads presented in the table only include point sources that enter the Rainy River directly. Point sources within the Little Fork and Big Fork River watersheds are not explicitly listed in Table E-2 but are embedded in their associated tributary loads in this table. The point source load listed in Table E-2 reflects the point sources discharging directly to Rainy River; the load from these sources accounts for approximately 20% of TP and OP loads to Rainy River.

Table E-2. Summary of mean annual HSPF-modeled phosphorus (TP and OP) loads in the Rainy River drainage area for the study period (Lupo 2015b).

Subwatershed	River km Above Four Mile Bay	Drainage Area (km^2)	Study Period FWMCs ($\mu g\ L^{-1}$)		2005-2014 Mean Annual Loads (t)		OP/TP Ratio
			TP	OP	TP	OP	
Rainy Lake	132	38,178	16	14	148.3	123.7	83%
Little Fork River	112	4,853	77	30	73.1	28.5	39%
La Vallee River	107	298	55	20	3.6	1.3	36%
Big Fork River	100	5,326	51	17	48.4	15.6	32%
Black River	95	1,033	41	13	11.3	3.4	30%
Sturgeon River	65	220	65	22	3.2	1.0	33%
McCloud Creek	54	24	80	30	0.4	0.1	38%
Whitefish Creek	48	34	83	28	0.6	0.2	33%
Pinewood River	40	569	52	19	5.7	2.0	36%
Rapid River	30	2,445	40	14	20.9	7.1	34%
Silver Creek	25	76	88	34	1.2	0.5	39%
Unnamed (391)	19	43	65	21	0.5	0.2	32%
Baudette River	17	154	63	24	1.7	0.6	39%
Miller Creek	13	23	98	48	0.4	0.2	49%
Winter Road River	10	384	52	20	3.4	1.3	38%
Wabanica Creek	7	75	98	41	1.4	0.6	42%
Direct Drainage	–	951	–	–	21.8	6.9	32%
Point Sources to Rainy	–	–	–	–	81.5	49.7	61%
Cumulative Load	–	–	–	–	427.3	242.9	57%
Export to Four Mile Bay	**0**	**54,686**	**28**	**14**	**357.8**	**179.4**	**50%**
Rainy River Attenuation	**–**	**–**	**–**	**–**	**69.5**	**63.5**	

Figure E-4 and Figure E-5 show the inflows of TP and OP, respectively, to Rainy River. Loads from each of the sources in Table E-2 were assigned to the river location (km above Wheelers Point) at which they entered the Rainy River and show tributary inflow as a blue bar at the tributary's corresponding river km. Figure E-4 and Figure E-5 show cumulative loading as a gray line and show actual HSPF model-estimated loads as an orange line. The difference between these two lines represents P attenuation in Rainy River.

An additional figure (Figure E-6) shows discharge and TP load as a function of river km. Flow-weighted mean TP concentrations are labeled in this figure as well. The figure illustrates that, although outflow from Rainy Lake represents more than 70% of discharge from the Rainy River to the LoW, Rainy Lake outflow represents less than half of the TP load delivered to the LoW. This is due to FWMCs increasing from approximately 16 to 28 µg L^{-1} between Rainy Lake and the LoW.

Individual (within reach) and cumulative (multi-reach) delivery ratios are presented in Table E-3 and Table E-4 for TP and OP, respectively. The HSPF reach IDs correspond to those shown in Figure E-2. Reach delivery ratios represent the delivery within each reach and cumulative delivery ratios represent delivery ratios for transport from the reach to LoW. Cumulative delivery ratios vary from 81% to 97% for TP and 70% to 97% for OP.

E.1.3 Additional Analysis: Williams WWTP and Upstream Point Sources

Additional attenuation analysis was required to quantify the load delivered to LoW from point sources within the Little Fork and Big Fork River watersheds. As previously mentioned, the loads from these point sources were reflected in the total discharges to Rainy River from the Little Fork and Big Fork Rivers in Table E-2. Additional analysis was performed to calculate delivery ratios for each of these point sources between the point source outfall and Rainy River. This allows for the loads from Little Fork and Big Fork Rivers to be split between the portion of the loads attributable to point sources and those attributable to nonpoint sources. An analysis of HSPF study period mean annual loads resulted in the delivery ratios for these sources as shown in Table E-5 (TP) and Table E-6 (OP).

A similar analysis was completed for Williams WWTP to properly account for the load delivered from the point source to LoW. Resulting TP and OP delivery ratios to LoW of 62% and 65%, respectively, were determined based on study period mean annual discharge.

E.1.4 Attenuation Discussion

The HSPF model results for the study period suggest that attenuation occurs within the Lower Rainy River between Rainy Lake and LoW. The HSPF modeling processes reflect complex fluvial processes that occur in conjunction with more straightforward mass balance (both in terms of water and pollutants) processes as a result of rainfall and runoff. Those complex processes in the HSPF model were calibrated to a relatively robust set of monitoring data based on streamflow and water quality data sampling locations throughout the Lower Rainy River Watershed. The HSPF model results for the study period show an attenuation of 69.4 and 63.3 t y^{-1} of TP and OP, respectively. These attenuation results are consistent with approximate mass balances based on total inflow to Rainy River from the four largest sources of water and P to Rainy River: Rainy Lake, Little Fork River, Big Fork River, and point sources discharging directly to Rainy River. These four sources constitute 86% of streamflow and 82% and 90% of TP and

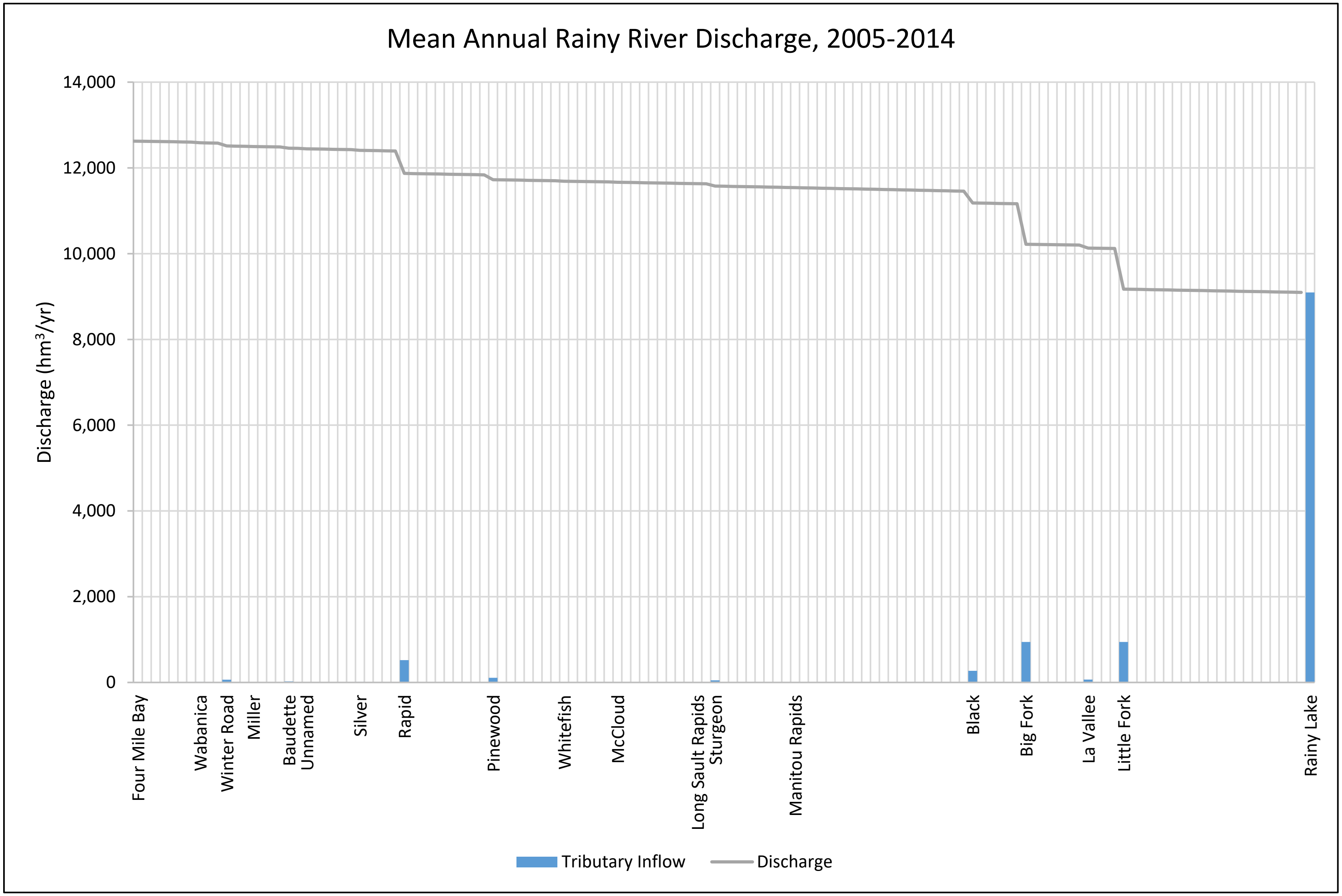


Figure E-3. Cumulative Rainy River Discharge from Rainy Lake to Wheelers Point (Four Mile Bay). Tributary inflows are shown in blue and spacing along the horizontal axis is 1 km

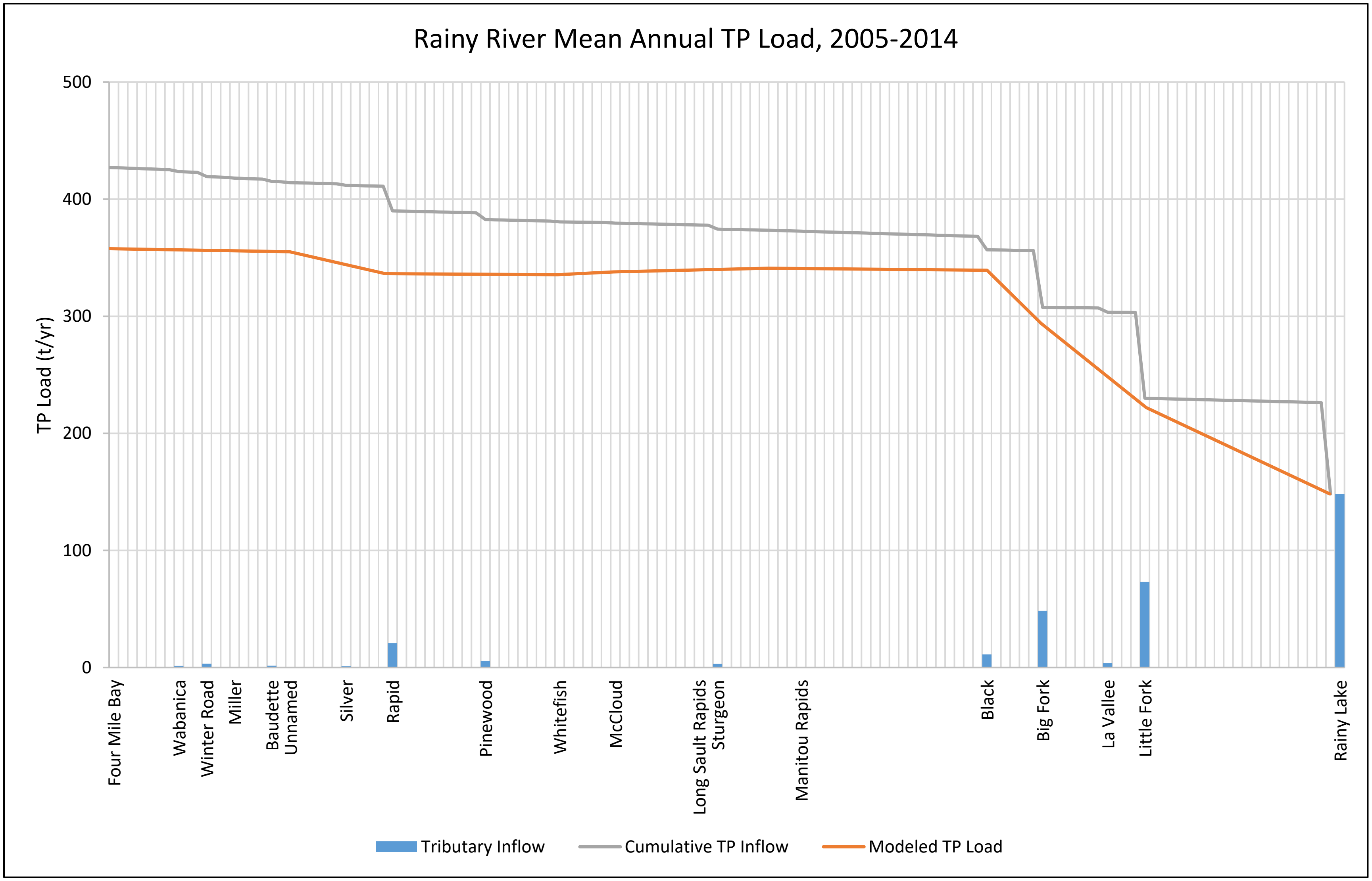


Figure E-4. Cumulative Rainy River TP Load from Rainy Lake to Wheelers Point (Four Mile Bay). Tributary inflows are shown in blue and spacing along the horizontal axis is 1 km. The gray line shows cumulative TP inflow and the orange line is in-stream TP load by river km

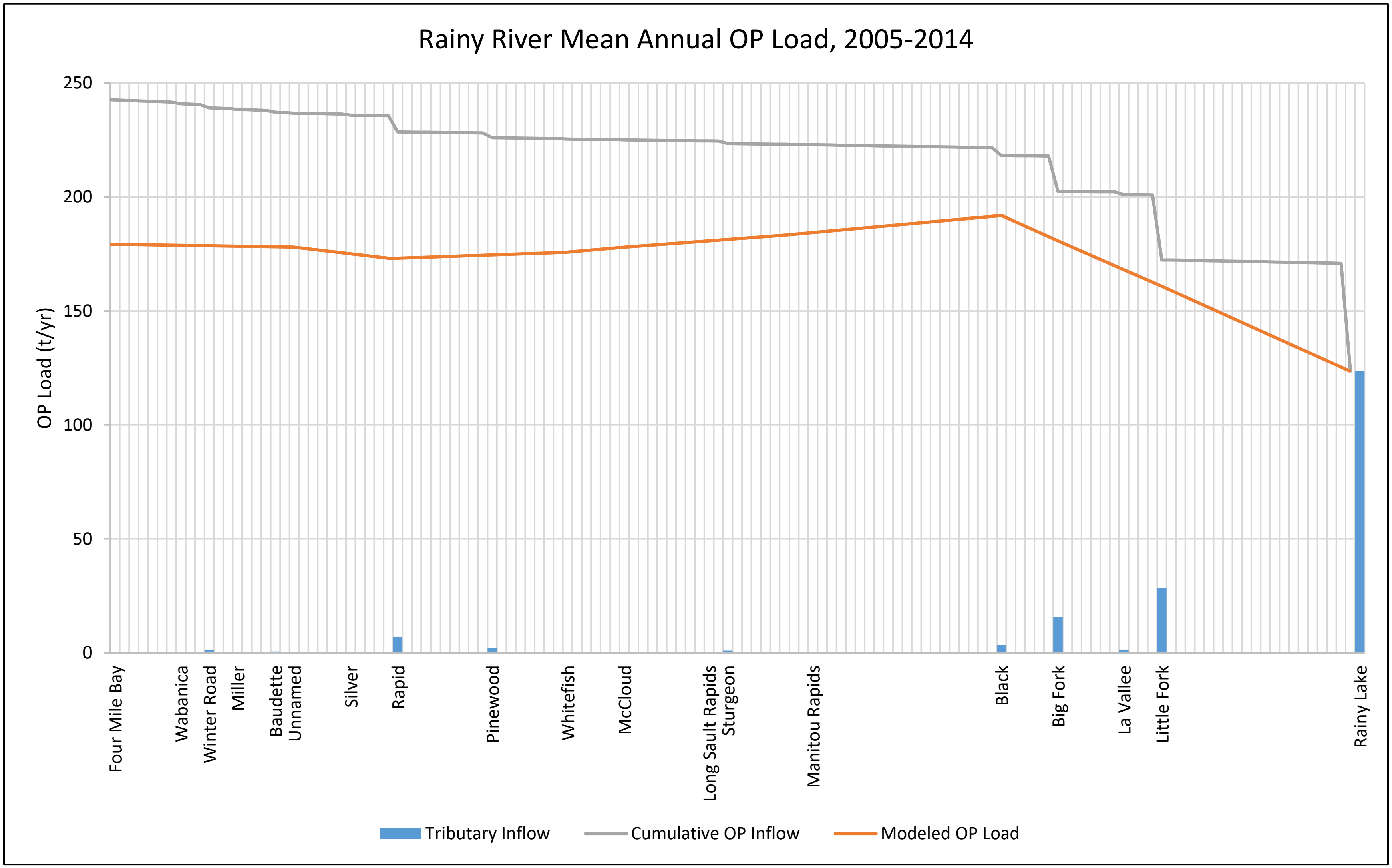


Figure E-5. Cumulative Rainy River OP Load from Rainy Lake to Wheelers Point (Four Mile Bay). Tributary inflows are shown in blue and spacing along the horizontal axis is 1 km. The gray line shows cumulative OP inflow and the orange line is in-stream OP load by river km

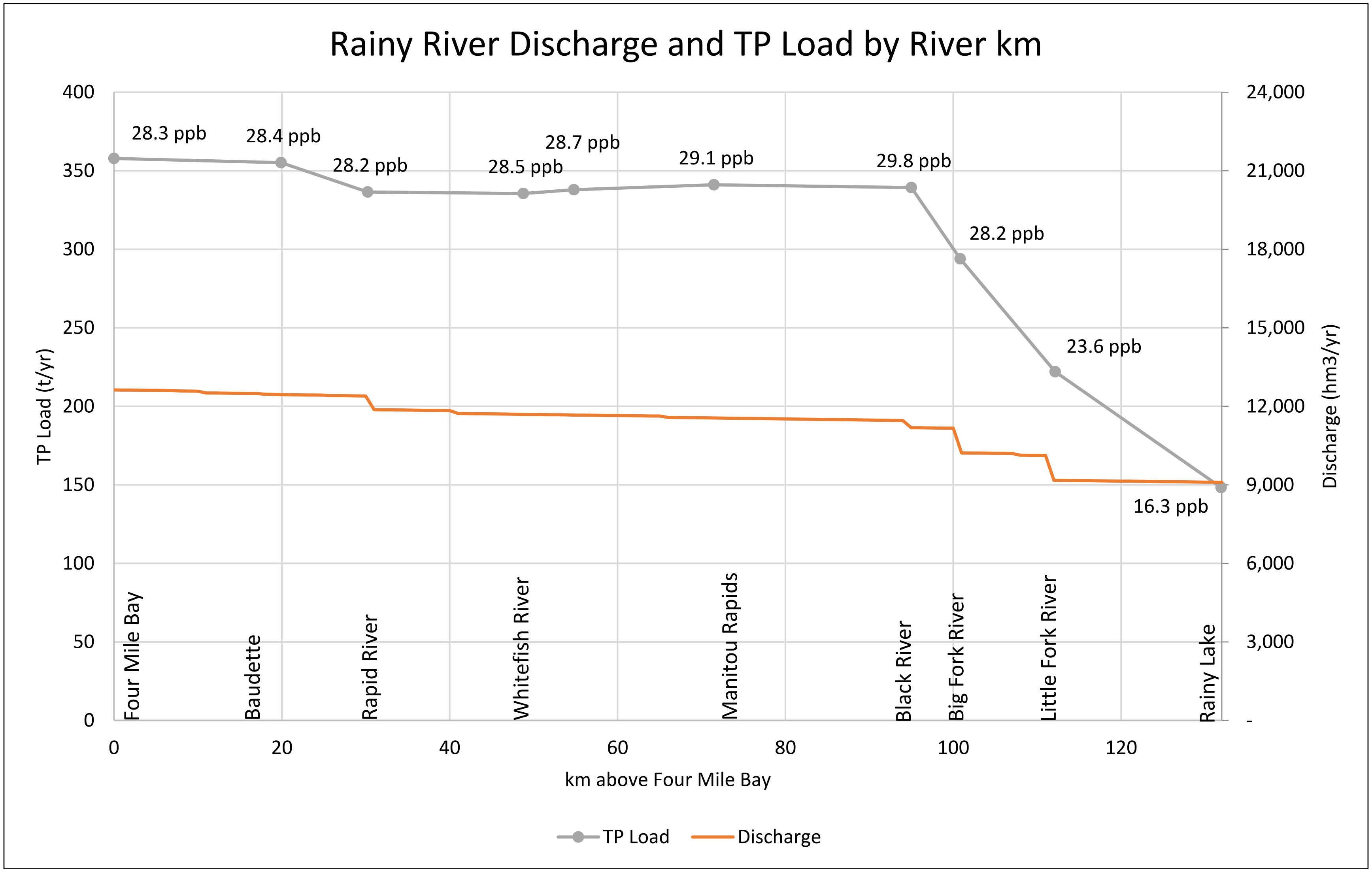


Figure E-6. Summary of the Rainy River's Discharge and TP Load by River km. TP load data points are labeled with corresponding flow-weighted mean TP concentrations

OP inflow, respectively to Rainy River. The inflow to Rainy River from these four sources alone constitutes 98% of the outflow of TP and 121% of the outflow of OP to LoW from Rainy River. These four sources have relatively robust monitoring datasets to draw from and the HSPF model is calibrated to closely match those monitoring data. An additional 76 t y^{-1} and 25.4 t y^{-1} of TP and OP, respectively, enters Rainy River from smaller tributaries. While some of these tributaries may not be gauged, applying loading rates based on land use and soils data helps ensure that these spatial extrapolations are as representative of the watershed as possible.

Table E-3. TP Attenuation and Delivery Ratio by Rainy River Reach.

HSPF Reach ID	Reach Length (km)	TP Inflow (t/yr)	TP Export (t/yr)	TP Attenuation (t/yr)	Delivery Ratio (%)	Cumulative Delivery Ratio (%)	TP Load to LOTW (t/yr)
10	19.8	230.0	222.0	7.9	97	81	185.6
30	11.4	299.7	294.0	5.7	98	84	64.9
50	5.8	343.1	339.3	3.8	99	85	41.9
170	23.5	356.0	341.1	15.0	96	86	14.4
190	16.7	347.2	337.9	9.3	97	90	5.5
210	6.0	338.9	335.5	3.4	99	92	0.9
230	18.5	345.0	336.4	8.6	98	93	8.9
390	10.3	360.4	355.1	5.3	99	96	23.0
430	19.9	368.2	357.8	10.4	97	97	12.7
Total	-	-	-	69.4	-	-	357.8

Table E-4. OP Attenuation and Delivery Ratio by Rainy River Reach.

HSPF Reach ID	Reach Length (km)	OP Inflow (t/yr)	OP Export (t/yr)	OP Attenuation (t/yr)	Delivery Ratio	Cumulative Delivery Ratio	OP Load to LOTW (t/yr)
10	19.8	172.5	160.6	11.9	93	70	121.4
30	11.4	190.6	181.1	9.5	95	76	22.7
50	5.8	196.9	191.9	5.0	97	80	12.6
170	23.5	196.9	183.1	13.8	93	82	4.1
190	16.7	185.1	177.9	7.1	96	88	1.7
210	6.0	178.3	175.8	2.5	99	91	0.3
230	18.5	179.0	173.1	5.9	97	93	3.0
390	10.3	181.2	178.1	3.2	98	96	7.8
430	19.9	184.1	179.4	4.7	97	97	5.8
Total	-	-	-	63.6	-	-	179.4

Additional analysis of the HSPF model's output showed that there is a corresponding increase in the storage of P within the lower reaches of the Rainy River system. Table E-7 shows the total change in P storage within the lower reaches of the Rainy River over the HSPF modeling period (1996 through 2014; note this is longer than the study period of 2005 through 2014). There was a mean annual TP storage increase of 75.7 t y^{-1} for all reaches from 1996-2014, the majority of which, 66.2 t y^{-1}, was dissolved PO_4. There was also a small increase of 16.7 t y^{-1} of phytoplanktonic and biochemical oxygen demand (BOD) associated organic P. This suggests that the dominant attenuation process in the HSPF model was settling of dissolved PO_4.

Table E-5. TP attenuation and delivery ratio for point sources within the Little Fork and Big Fork River watersheds.

HSPF Reach ID	HUC-8	Rainy River HSPF Reach	Delivery Ratio to Rainy River (%)	Rainy River Delivery Ratio to LoW (%)	Cumulative Delivery Ratio (%)
Big Falls WWTP	Big Fork River	50	86	85	73
Bigfork WWTP			69	85	59
Effie WWTP			75	85	64
DNR Scenic State Park			105	85	89
Northome WWTP			76	85	65
Berger Horticultural Products - Pine Island Bog			73	85	63
Cook WWTP	Little Fork River	30	82	84	69
ISD 2142 Pre-Kindergarten to Grade 12 N School			66	84	55
Littlefork WWTP			97	84	81
US Steel - Minntac Tailings Basin Area			48	84	40
Hibbing Taconite Co - Tails Basin Area			42	84	35

Table E-6. OP attenuation and delivery ratio for point sources within the Little Fork and Big Fork River watersheds.

HSPF Reach ID	HUC-8	Rainy River HSPF Reach	Delivery Ratio to Rainy River (%)	Rainy River Delivery Ratio to LoW (%)	Cumulative Delivery Ratio (%)
Big Falls WWTP	Big Fork River	50	17	80	13
Bigfork WWTP			35	80	28
Effie WWTP			8	80	6
DNR Scenic State Park			17	80	13
Northome WWTP			41	80	33
Berger Horticultural Products - Pine Island Bog			-52	80	-41
Cook WWTP	Little Fork River	30	58	76	44
ISD 2142 Pre-Kindergarten to Grade 12 N School			36	76	27
Littlefork WWTP			20	76	15
US Steel - Minntac Tailings Basin Area			35	76	26
Hibbing Taconite Co - Tails Basin Area			88	76	67

Table E-7. Change in P Storage by HSPF Reach and P Species for 1996-2014 (Lupo 2015b).

Phosphorus Species Change in Storage (t/yr)	HSPF Reach									Total (all reaches)
	10	30	50	170	190	210	230	390	430	
Total Phosphorus	+8.2	+6.4	+4.2	+16.3	+10.1	+3.7	+9.5	+5.9	+11.4	+75.7
Total PO_4	+11.8	+9.4	+4.9	+14.2	+7.7	+2.7	+6.9	+4	+5.9	+67.5
Dissolved PO_4	+11.9	+8.8	+4.7	+14	+7.6	+2.6	+6.8	+3.9	+5.9	+66.2
Particulate PO_4	-0.2	+0.6	+0.2	+0.2	+0.1	0	+0.1	+0.1	0	+1.1
Total Organic P	-3.5	-3	-0.7	+2.1	+2.4	+1.1	+2.6	+1.9	+5.5	+8.4
Refractory Organic P	-1.4	-1.9	-0.9	-2	-0.9	-0.2	-0.8	-0.4	+0.3	-8.2
Phyto & BOD Organic P	-2.1	-1	+0.2	+4.1	+3.3	+1.3	+3.4	+2.3	+5.2	+16.7

E.2 Permitted Sources

Background on permitted sources is included in the following sections. This information includes identification of unique point sources and individual point source loads (where appropriate), the methodology used to determine study period mean annual loads and LAs for each permitted source or category, and information regarding proposed reductions (if any).

E.2.1 Domestic Wastewater

Domestic wastewater discharged from WWTPs to waters of Minnesota is regulated by NPDES/SDS permits, which are administered by the MPCA. There are 14 regulated WWTPs within the U.S. portion of the TMDL Study Area and are listed in Table E-8 with study period mean annual loads and WLAs. Study period mean annual loads were taken from HSPF-modeled output or information provided by the MPCA. The WLAs were provided by the MPCA staff and were determined as the product of each facility's design discharge and permitted P concentration. The large reduction in the loading from the Baudette WWTP is a result of the difference between the mean annual study period loading and the new 367 kg/yr^{-1} TP load limit resulting from a permit issued in November 2010. Before the November 2010 permit, the facility was subject to a calendar year average intervention limit of 4 mg/l^{-1} and was not subject to an annual loading limit. Baudette WWTP's annual loads have fallen below the permit limit of 367 kg/yr^{-1} in the years since the permit was issued and thus, the reduction required as a result of the WLA has already been achieved.

Canadian domestic WWTPs within the TMDL Study Area are listed in Table E-9 with associated study period mean annual loads and acknowledged loads (in lieu of WLAs as they are not within MPCA's jurisdiction). No changes are proposed for these sources because they are outside the MPCA's jurisdiction under the CWA. Additional WWTPs in Canada that serve First Nations communities are not listed explicitly due to incomplete data. Loads from First Nations communities are, however, reflected implicitly in estimates of septic system loading from communities not treated by WWTPs or treated by WWTPs with insufficient data to include explicitly.

All of the WLAs and acknowledged loads from domestic wastewater sources assume no P attenuation between the source and LoW, which provides an implicit MOS.

E.2.2 Industrial Wastewater

Industrial wastewater discharges to waters of Minnesota are also subject to NPDES/SDS permits. There are five industrial wastewater sources exist in the U.S. within the TMDL Study Area, as listed in Table E-10. Study period mean annual industrial wastewater loads were estimated from monitoring data. Industrial wastewater WLAs were provided by the MPCA staff and determined as the product of each facility's design discharge and permitted P concentration. All of the WLAs and acknowledged loads from industrial wastewater sources assume no P attenuation between the source and LoW, which provides an implicit MOS.

Table E-8. U.S. Domestic WWTPs in the TMDL Study Area.

WWTP	Receiving Water	Study Period Mean Annual TP Load (kg y^{-1})		Wasteload Allocation TP Load (kg y^{-1})		Percent Change (at LoW)
		At Source	At LoW	At Source	At LoW	
Springsteel Island Sanitary District	Lake of the Woods	5.4	5.4	10.0	10.0	92.6
Williams WWTP	Lake of the Woods	53.0	32.8	87.0	87.0	165.2
Big Falls WWTP	Big Fork River	19.7	14.5	119.0	119.0	720.7
Bigfork WWTP	Big Fork River	251.5	147.2	216.0	216.0	46.7
Effie WWTP	Big Fork River	33.8	21.7	102.0	102.0	370.0
DNR Scenic State Park	Big Fork River	14.4	12.9	21.0	21.0	62.8
Northome WWTP	Big Fork River	68.7	44.3	122.0	122.0	175.4
Cook WWTP	Little Fork River	398.4	274.5	509.0	509.0	85.4
ISD 2142 Pre-Kindergarten to Grade 12 N School	Little Fork River	11.8	6.5	44.0	44.0	576.9
Littlefork WWTP	Little Fork River	146.7	118.6	229.0	229.0	93.1
Anchor Bay Mobile Home Park	Lower Rainy River	68.7	66.7	44.0	44.0	-34.0
Baudette WWTP	Lower Rainy River	3,244.5	3,152.6	367.0	367.0	-88.4
ISD 363 – Indus School	Lower Rainy River	13.6	11.7	34.0	34.0	190.6
North Koochiching Area Sanitary District WWTP	Lower Rainy River	3,976.3	3,208.6	3,318.0	3,318.0	3.4
Total		–	**7,118.1**	–	**5,221.0**	**-26.7**

Table E-9. Canadian Domestic WWTPs in the TMDL Study Area.

WWTP	Receiving Water	Study Period Mean Annual TP Load (kg y^{-1})		Acknowledged TP Load (kg y^{-1})		Percent Change (at LoW)
		At Source	At LoW	At Source	At LoW	
Township of Chapple Lagoon (Barwick)	Lower Rainy River	6.0	5.4	6.0	6.0	11.1
Emo WWTP	Lower Rainy River	353.9	304.9	353.9	353.9	16.1
Fort Frances WWTP	Lower Rainy River	779.6	629.1	779.6	779.6	23.9
Rainy River WWTP	Lower Rainy River	28.0	27.2	28.0	28.0	2.9
Total		–	**966.6**	–	**1,167.5**	**20.8**

The only Canadian industrial wastewater discharger in the TMDL Study Area is the Abitibi paper plant in Fort Frances, Ontario, which has been idle for several years. The study period mean annual load from this facility was 43,513.7 kg y^{-1} (at source) and 35,112.5 kg y^{-1} (at LoW). The acknowledged load (in lieu of a WLA, as it is not within MPCA's jurisdiction) for this site in the TMDL is 5,180.0 kg y^{-1}, which was determined by MPCA based on reported discharge levels following idling of the plant.

Table E-10. U.S. Industrial Wastewater Discharges in the TMDL Study Area.

Industrial Wastewater Source	Receiving Water	Study Period Mean Annual TPLoad (kg y^{-1})		Wasteload Allocation TP Load (kg y^{-1})		Percent Change
		At Source	At LoW	At Source	At LoW	
Marvin Windows and Doors	Lake of the Woods	4.0	4.0	4.0	4.0	0
Berger Horticultural Products Pine Island Bog (not yet operational)	Big Fork River	0	0	30.0	30.0	–
US Steel – Minntac Tailings Basin Area	Little Fork River	27.1	10.9	30.0	30.0	175.2
Hibbing Taconite Co. – Tailings Basin Area	Little Fork River	340.5	118.2	498.0	498.0	321.3
Boise White Paper LLC – Intl Falls	Lower Rainy River	35,541.2	28,679.2	33,100.0	33,100.0	15.4
Total		–	**28,812.3**	–	**33,662.0**	**16.8**

E.2.3 Industrial Stormwater

Industrial stormwater runoff is a regulated source as defined by the MPCA's reissued Multi-Sector Industrial Stormwater NPDES/SDS General Permit (MNR050000), which applies to facilities with Standard Industrial Classification Codes in ten categories of industrial activities with the potential for significant materials and activities exposed to stormwater and that may leak, leach, or decompose and be carried offsite. Facilities can obtain a No Exposure exclusion if the site's operations occur under-roof. The permittee is required to develop and implement a SWPPP) that details stormwater BMP implemented to manage stormwater at the facility. Permitted facilities are also required to perform runoff sampling.

The MPCA's records (MCPA 2017a) identified 14 permitted facilities not covered under a no exposure exclusion within the TMDL Study Area. These 14 facilities are listed in Table E-11. These areas total 798 ha (1,972 ac). The industrial stormwater WLA was determined as the TMDL loading capacity multiplied by the portion of the watershed lying within permitted industrial stormwater sites, which results in an estimated existing (study period) load and a WLA of 193.9 kg yr^{-1}. No change in loading is proposed for industrial stormwater. The industrial stormwater WLA included in this TMDL study is categorical (i.e., all industrial stormwater locations are included as a single WLA in the LA table). The industrial stormwater WLA assumes no P attenuation between the source and LoW, which provides an implicit MOS.

E.2.4 Construction Stormwater

Runoff from construction sites is a regulated source as defined by the MPCA's General Permit Authorization to Discharge Stormwater Associated with Construction Activity under the NPDES/SDS Program (Permit MNR100001). Exposed soil surfaces from construction sites can be eroded and particle-bound P can be carried away from construction sites. Permits are required for construction activities that disturb the following:

1. One acre or more of soil; or
2. less than one acre if:
    a. the acre is part of a larger common plan of development or sale larger than one acre or
    b. the MPCA determines that the activity poses a risk to water resources.

Table E-11. Permitted Industrial Stormwater Locations in the TMDL Study Area.

Facility Name	Area (ac)	Area (ha)
Marvin Windows and Doors	33	13
Warroad International Memorial Airport	9	4
Erickson Timber Products	15	6
Baudette/Lake of the Woods International Airport	374	151
Hasbargen Logging Inc	2	1
Falls International Airport	760	308
Einarson Flying Service Inc.	10	4
Green Forest Inc	17	7
Boise White Paper LLC - International Falls	342	138
Boise White Paper LLC - Remote Site 17 Landfill	20	8
Hancock Fabrication Inc.	1	0
Cook Transfer Station	5	2
Cook Municipal Airport	375	152
Hill Wood Products Inc.	9	4
Total	**1,972**	**798**

Construction site data from the study period (MPCA 2015d) were used to estimate the area of construction activity within the LoW Basin. The mean annual area subject to construction stormwater permits was determined by county and is listed in Table E-12. The mean annual total area under construction across the 8 counties in the LoW Basin was 925.1 ha (2,285.9 ac), but these counties are not entirely within the LoW Basin. The portion of each county within the LoW Basin was determined and used to estimate the construction area within each county that was also within the LoW Basin. As shown in Table E-12, the mean annual total construction (permitted) area is 389.4 ha (962.2 ac).

The study period construction stormwater load and construction stormwater WLA were determined as the TMDL loading capacity multiplied by the ratio of the mean annual total permitted construction area to the total watershed area. No load reduction is proposed for construction stormwater and thus, the WLA is equal to the estimated study period mean annual load of 94.6 kg yr. The construction stormwater WLA included in this TMDL study is categorical (i.e., all of the construction stormwater locations are included as a single WLA in the TMDL LAs table). The construction stormwater WLA assumes no P attenuation between the source and LoW, which provides an implicit MOS.

Table E-12. Construction Stormwater Locations in the TMDL Study Area.

County	Mean Annual Permitted Area		Fraction of County in LoW Basin	Mean Annual Permitted Area Within the LoW Basin (ha)
	ac	ha		
Beltrami	212.1	85.8	0.0710	6.1
Cook	55.8	22.6	0.2025	4.6
Itasca	682.3	276.1	0.4221	116.6
Koochiching	102.8	41.6	0.9041	37.6
Lake	92.6	37.5	0.5898	22.1
Lake of the Woods	84.4	34.2	0.9764	33.4
Roseau	298.6	120.8	0.1354	16.4
Saint Louis	757.3	306.5	0.4983	152.7
Total	**2285.9**	**925.1**		**389.4**

E.2.5 Confined Animal Feeding Operations

Feedlot data for the TMDL Study Area obtained from the MPCA (2017) showed that no feedlots exceeded thresholds that would require NPDES or SDS permits according to MPCA guidance (2015c). The total numbers of feedlots and animal counts in the TMDL Study Area (adapted from MPCA [2017b]) are included in Table E-13. Because of the absence of CAFOs that meet NPDES/SDS permit thresholds, no CAFO load was included in this TMDL study.

Table E-13. Feedlots and Animal Units in the TMDL Study Area.

Primary Stock	Total Number of Feedlots	Total Animal Count
Beef Cattle – Cow and Calf Pair	44	3,971
Dairy Cattle > 1,000 pounds	6	1,149
Beef Cattle – Slaughter/Stock	6	779
Horses	3	133
Turkeys > 5 pounds	1	10

E.2.6 Municipal Separate Storm Sewer Systems

Municipal stormwater permits are required for specified Phase II cities defined as MS4 by permit (General Permit Authorization to Discharge Stormwater Associated with Small MS4 Under the NPDES/SDS) (MNR040000). All MS4s are defined by the MPCA as conveyance systems (e.g., roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, and storm drains) that are owned or operated by a public entity such as a state, city, town, county, district, or other public body. Runoff from rainfall and snowmelt carries pollutants to storm sewer conveyances. Loading is largely influenced by the amounts and distribution of impervious areas such as roof tops, sidewalks, driveways/parking lots, streets, and other compacted surfaces. Lawns, soils, grass clippings, organic debris, road surface particles, vehicular debris, eroded soil particles, pet and wildlife wastes, and atmospheric deposition are all potential P-containing substances.

The Hibbing, Minnesota, MS4 is the only regulated MS4 located in the TMDL Study Area and is located in the headwaters of the Little Fork River. The city of Hibbing covers an area of 482 km^2 (186 mi^2), and approximately 41 km^2 (16 mi^2) of that area are located within the TMDL Study Area. Approximately 30 km^2 (11 mi^2) of the area within the basin is covered by the Hibbing Taconite Company Tails Basin Area, which is a regulated point source. As such, the load from the tails basin area has already been accounted for in this study explicitly as a point source that discharges to the Little Fork River through its tributaries. The remaining 11 km^2 (5 mi^2) outside the tails basin, but still within the TMDL Study Area, is largely forested and undeveloped. There are no discharges to the city of Hibbing's stormwater conveyance system that are within the 11 km^2 area. Thus, no MS4 WLA was given to the city of Hibbing MS4.

The city of International Falls is expected to be subject to an MS4 permit as it is a city with a population greater than 5,000 people that drains to an impaired water (LoW). The city of International Falls MS4 was determined as the portion of LoW loading capacity equal to the ratio of the area of the city of International Falls to the total TMDL Study Area. In other words, if the city of International Falls MS4 occupied 1% of the TMDL Study Area, it would be assigned a WLA equal to 1% of the LoW loading capacity. The city of International Falls covers 16.2 km^2 (6.3 mi^2) within the 62,654 km^2 (24,191 mi^2) TMDL Study Area and was thus assigned a WLA of 228.6 kg y^{-1} The MS4 WLA assumes no P attenuation between the source and LoW, which provides an implicit MOS.

E.3 Nonpermitted Sources

The following nonpermitted sources of P were considered as part of this study:

1. Tributary loading;
2. Direct lakeshed loading;
3. Shoreline erosion loading;
4. SSTS;
5. Atmospheric deposition; and
6. Internal P loading.

The sections below describe the quantification of study period mean annual loads, LAs, and levels of reduction proposed as part of this TMDL study.

E.3.1 Tributary Loading

While tributaries carry P from both nonpoint sources (i.e., watershed runoff) and upstream point sources (permitted sources) to the LoW, tributary loading as discussed in this section is only the nonpoint portion of that load (i.e., excluding loads that originate from permitted sources). Nonpoint loading occurs as a result of rainfall-runoff processes that can detach and transport sediment and associated P and transport dissolved P to downstream waters. Susceptibility to detachment and erosion by rainfall-runoff processes dependent on land use because of more disturbed land uses (e.g., agriculture) will generally produce more runoff and P loads than more natural land uses (e.g., forest). Soil types also play a role in the amount of runoff and P delivered to a stream and carried downstream. Tributary loading can also include P loading associated with channel bed and bank sediment loads.

Tributary loading is the largest source of P to the LoW, with the Rainy River accounting for approximately 90% of the tributary load. Study period mean annual tributary loading was taken from HSPF-modeled output. Table E-14 lists the HSPF-modeled tributaries that discharge directly to the LoW along with study period mean annual loads, LAs, and proposed reductions for each tributary. Loads in Table E-14 are presented at the mouth of the tributary and, thus, correspond directly to the loading entering the LoW from tributaries.

Table E-14. Study period mean annual loads (Lupo 2015b) and LAs to the LoW. Note that these tributary loads only include that portion of discharge attributable to nonpoint sources (LA) and thus do not include loads attributable to point sources (WLAs).

Tributary	Study Period Mean Annual TP Load (kg y^{-1})	Load Allocation (Acknowledged Load for Canadian Sources) TP Load to LoW (kg y^{-1})	Proposed Reduction (kg y^{-1})
Rainy River 🍁	290,692.9	264,923.3	25,769.6
Sabaskong River 🍁	2,232.6	2,232.6	0
Splitrock River 🍁	1,228.0	1,228.0	0
Thompson Creek 🍁	779.8	779.8	0
Obabikon Lake 🍁	457.7	457.7	0
Big Grassy River 🍁	1,108.2	1,108.2	0
Little Grassy River 🍁	2,333.7	2,333.7	0
Bostic River (231)	1,783.9	1,283.8	500.1
Williams Creek (County Ditch 1; 211)	1,101.8	617.4	484.4
South Branch Zippel Creek (213)	744.0	214.9	529.1
West Branch Zippel Creek (203)	1,887.6	879.3	1,008.3
Judicial Ditch 24 (201)	420.2	259.4	160.8
Judicial Ditch 24 (191)	1,256.2	465.5	790.7
Judicial Ditch 22 (181)	708.3	333.3	375.1
Reach 171	164.5	52.5	112.0
Willow Creek (161)	1,352.6	641.7	711.0
County Ditch 26 (151)	272.9	102.7	170.2
County Ditch 26 (141)	457.7	193.3	264.4
County Ditch 26 (131)	295.1	83.8	211.3
County Ditch 20 (121)	460.5	193.4	267.1
County Ditch 25 (113)	1,003.7	341.7	662.0
Warroad River 🍁 †	6,565.7	5,574.2	991.5
Stony Creek 🍁	746.0	746.0	0
Northwest Angle Inlet 🍁	1,327.7	1,327.7	0
Total	**319,381.2**	**286,373.6**	**33,007.60**

🍁 denotes that all or part of the load from this source originates in Canada

† HSPF model boundaries show that a portion of the modeled Warroad River Subwatershed extends into Canada and the runoff from that portion of the subwatershed drains directly to the lake

Tributary LAs were developed with the assumption that all of the upstream tributaries meet the northern river eutrophication standard of 50 µg L^{-1} TP. This assumes that tributaries will meet the northern river eutrophication standard even after accounting for any WLAs that are also carried by each tributary. Because the Rainy River constitutes such a large portion of the tributary inflow, a detailed account of the tributaries that drain to the Rainy River is presented in Table E-15. Because these upstream tributaries do not drain to the LoW directly, further detail regarding source load (tributary mouth) and load delivered to the LoW is provided.

Table E-15. Detailed tributary loading above the lower boundary condition at Wheelers Point. Note that these tributary loads only include that portion of discharge attributable to nonpoint sources (LA) and thus do not include loads attributable to point sources (WLAs).

Tributary	Study Period Mean Annual TP Load (kg y^{-1})		Load Allocation (Acknowledged Load for Canadian Sources) TP Load to LoW (kg y^{-1})		Proposed Reduction (kg y^{-1})	
	At Source	At LoW	At Source	At LoW	At Source	At LoW
Rainy Lake 🍁	148,302.6	119,669.7	148,302.6	119,669.7	0	0
Little Fork River	72,512.8	60,607.7	45,991.3	38,440.5	26,521.5	22,167.2
Big Fork River	48,120.8	41,002.4	46,555.8	39,668.9	1,565.0	1,333.5
Rapid River	20,876.0	19,986.1	20,876.0	19,986.1	0	0
La Vallee River 🍁	3,633.9	3,037.3	3,633.9	3,037.3	0	0
Black River	11,253.3	9,695.9	11,253.3	9,695.9	0	0
Sturgeon River 🍁	3,155.9	2,838.4	3,155.9	2,838.4	0	0
McCloud Creek	382.0	352.9	239.8	221.6	142.2	131.4
Whitefish Creek	569.0	531.2	343.7	320.8	225.3	210.3
Pinewood River 🍁	5,695.6	5,316.7	5,695.6	5,316.7	0	0
Silver Creek	1,163.8	1,114.2	659.2	631.1	504.6	483.1
Unnamed (391)	470.4	457.1	362.3	352.0	108.2	105.1
Baudette River	1,658.5	1,611.5	1,324.5	1,287.0	334.0	324.5
Miller Creek	432.6	420.4	221.6	215.3	211.0	205.0
Winter Road River	3,376.4	3,280.7	3,231.4	3,139.9	145.0	140.9
Wabanica Creek	1,404.6	1,364.8	716.5	696.2	688.1	668.7
Direct Drainage 🍁	21,830.6	19,405.9	21,830.6	19,405.9	0	0
Total (Rainy River)	**344,838.9**	**290,692.9**	**314,394.1**	**264,923.3**	**30,444.8**	**25,769.6**

🍁 denotes that all or part of the load from this source originates in Canada

E.3.2 Direct Lakeshed Loading

Direct lakeshed loading is similar to tributary loading but occurs at a smaller scale and closer to the lakeshore than much of the tributary loading. Direct lakeshed loading is typically carried either over land to the lake or through streams smaller than those included in the tributary loading category, which were explicitly modeled in HSPF. Direct lakeshed loading is similar in nature to tributary loading in that it depends on land use and soil types. Direct lakeshed loading was taken from HSPF-modeled output and averaged over the study period (Table E-16). Because of HSPF model reach (subwatershed) boundaries, both Sabaskong and Little Traverse direct lakeshed loading are split into two loads, one for each HSPF model reach in its direct lakeshed loading area. No direct lakeshed loading reductions are proposed.

Table E-16. Direct lakeshed loading to the LoW.

Direct Lakeshed Drainage Area by Bay	Study Period Mean Annual TP Load ($kg\ y^{-1}$)	Load Allocation (Acknowledged Load for Canadian Sources) TP Load to LoW ($kg\ y^{-1}$)	Proposed Reduction ($kg\ y^{-1}$)
Sabaskong East	2,058.1	2,058.1	0
Sabaskong West	1,824.3	1,824.3	0
Four Mile	1,988.5	1,988.5	0
Big Traverse	6,140.9	6,140.9	0
Muskeg	364.2	364.2	0
Little Traverse South	2,804.3	2,804.3	0
Little Traverse North	1,931.9	1,931.9	0
Total	**17,112.1**	**17,112.1**	**0**

E.3.3 Shoreline Erosion Loading

Shoreline erosion loading is P loading associated with shoreline erosion. A study of shoreline erosion loading was performed by Houston Engineering and the LoW SWCD (2013) for the southern portion of the LoW that extends east from Warroad, Minnesota, to Four Mile Bay. The mean annual load of 72,000 kg was apportioned to the three bays (Four Mile, Big Traverse, and Muskeg) between Warroad, Minnesota, and the Rainy River based on shoreline length. Load by bay is shown in Table E-17. This study only evaluated shoreline erosion for this particular area of shoreline. Erosion in other areas of the lake are implicitly included in the BATHTUB model.

Table E-17. Shoreline erosion phosphorus loading to the LoW.

Shoreline Erosion by Bay	Study Period Mean Annual TP Load ($kg\ y^{-1}$)	Load Allocation (Acknowledged Load for Canadian Sources) TP Load to LoW ($kg\ y^{-1}$)	Proposed Reduction ($kg\ y^{-1}$)
Four Mile	9,395.4	7,892.2	1,503.3
Big Traverse	36,000.0	30,240.0	5,760.0
Muskeg	26,604.6	22,347.8	4,256.7
Total	**72,000.0**	**60,480.0**	**11,520.0**

E.3.4 Subsurface Sewage Treatment Systems

SSTS, or septic systems, treat sewage from homes and businesses not served by domestic WWTPs. SSTS loading was taken from HSPF-modeled output. The loading methodology used in the HSPF model was based on the estimated population served by SSTSs, loading from individual SSTSs, and SSTS failure rate data to determine total load from failing SSTSs. Residences that have properly functioning SSTSs were assumed to have an effluent indistinguishable from background groundwater concentrations.

The number of SSTSs in each subwatershed was estimated by using a Geographic Information System (GIS). Residences that were served by SSTSs were allocated evenly across the county and subwatershed. The MPCA (2004) report estimates the percentage of failing SSTSs by county, and those values were multiplied by the number of residences to estimate the total load from failing SSTSs.

Canadian Census data were used to estimate the total number of people living in the Canadian portion of the LoW Watershed (Ackerman 2015). The population that is served by SSTSs was estimated as the total Basin population in Canada minus the population within city boundaries. The number of SSTSs in each subwatershed was estimated by using a GIS.

An assumption of 2.5 persons per SSTS was made, with an assumed discharge of 50 gallons per day per person (MPCA 2004). Nutrient concentrations for phosphate (20 mg L^{-1}) and total nitrogen (TN; 53 mg L^{-1}, evenly divided between ammonia and nitrate) were based on literature values (Ackerman 2015) and were assumed to be reduced by 57% and 28%, respectively (Ackerman 2015). Loads from failing SSTSs were included in the models as a constant point source based on information from the MPCA (2004). Septic system loading to the LoW is summarized in Table E-18.

Table E-18. Study period SSTS loading and LAs by direct lakeshed drainage area and country.

Bay/ Lakeshed	Study Period Mean TP Load to LoW (kg y^{-1})		Load Allocation (Acknowledged Load for Canadian Sources) TP Load to LoW (kg y^{-1})		Proposed Reduction (kg y^{-1})
	Load Originating in Canada	Load Originating in US	Load Originating in Canada	Load Originating in US	
Sabaskong East	22.4	0.0	22.4	0.0	0
Sabaskong West	130.4	0.0	130.4	0.0	0
Four Mile	21.5	85.9	21.5	0.0	85.9
Muskeg	0.0	19.7	0.0	0.0	19.7
Big Traverse	165.9	165.9	165.9	0.0	165.9
Little Traverse South	52.4	34.9	52.4	0.0	34.9
Little Traverse North	18.1	4.5	18.1	0.0	4.5
Total	**410.7**	**311.0**	**410.7**	**0.0**	**311.0**

E.3.5 Atmospheric Deposition

Atmospheric deposition of P on the lake surface is an important part of the LoW P budget. Atmospheric deposition occurs in both wet (carried by precipitation) and dry (dry particles carried as dust) forms.

Unlike other nonpoint sources, such as watershed runoff or septic loading, atmospheric P deposition originates outside of the watershed and cannot be controlled. An atmospheric P deposition rate of 19.3 mg $m^{-2}y^{-1}$ (reported by Twarowski et al. [2007] for the Rainy River Basin) for average precipitation years was used in this TMDL study. The total atmospheric P load to the LoW within the TMDL Study Area is 51,407.3 kg y^{-1}.

E.3.6 Internal Phosphorus Loading

Lake nutrient cycling (or internal loading) refers to several processes that can result in P release into the water column where it can be available for algal growth. Internal loading is caused by natural sources and enhanced over time from accumulated sediment P that results from anthropogenic activity. The P is released from lake sediments in both aerobic and anaerobic conditions as moderated by amounts of available iron and other factors such as legacy loading (natural background and accumulation of anthropogenic effects). Resuspension of sediments that results from wind mixing may cause resuspension of particulate and loosely associated P. A more thorough discussion of internal P loading and calculation of internal P loading for this TMDL study is included in Appendix F. Table E-19 shows the existing mean annual internal P loading within the LoW as calculated and used in this TMDL study.

Table E-19. Mean Annual Internal P Load to the LoW.

	Four Mile	Muskeg	Big Traverse	Little Traverse	Total
Mean Annual Internal P Load (kg)	48,615	11,601	220,317	1,129	**281,995**

A 25% reduction in internal P loading is proposed for this TMDL, which will reduce the load to 211,496 kg y^{-1}. A 25% reduction is estimated to occur based on continued declines in in-lake P available to internal loading processes as a result of both past and future declines in external P loading to the LoW.

Appendix F. Internal Phosphorus Loading

This appendix provides background information regarding internal P loading in the LoW Basin. An overview of existing studies is provided and is followed with a detailed description of internal loading estimates made as part of this TMDL study.

F.1 Background and Existing Studies

Lake nutrient cycling (or internal loading) refers to several processes that can result in P release into the water column where it can be available for algal growth. Internal loading is caused by natural sources and enhanced over time from accumulated sediment P that results from anthropogenic activity. The P is released from lake sediments in both aerobic and anaerobic conditions as moderated by amounts of available iron and other factors, such as legacy loading (natural background and accumulation of anthropogenic effects). Sediment resuspension that is caused by wind mixing may cause resuspension of particulate and loosely associated P. Small particles (clay and silt) that dominate Big Traverse Bay's sediments (James 2012) are most vulnerable to resuspension. Specific area (surface area per unit mass) increases with decreasing particle size; thus, clay and silt can have a higher P-holding capacity than sand. Tributary discharges of total P (TP) and dissolved P (DP) can contribute to elevated in-lake concentrations and increased algal growth. Environment Canada (2014) noted that DP accounted for approximately 50% of TP at the Oak Groves, Ontario, Rainy River site in 2010 and 2011. Elevated DP discharge to the LoW may result in increased biological growth, decay, and deposition, which can influence the pool of soluble/DP, shallow in-lake sediments, and may contribute to enrichment of the sediment surface (sometimes referred to as P bulge). Internal loading has been investigated for the LoW, and while many questions remain, these investigations arrived at converging estimates of internal loading.

Internal P loading RRs were determined from LoW sediment cores by James (2012, 2015, 2017a, 2017b). Sediment sample cores were obtained from Big Traverse, Muskeg, and Four Mile Bays and examined for sediment particle sizes, chemical composition, and P release (James 2012). Big Traverse sediments contained the highest clay content (50% compared to less than 25% in Muskeg and Four Mile Bays). Laboratory measurements of sediment P release ranged from 0.2 to 0.6 mg m^{-2} d^{-1} under aerobic conditions to 8.3 to 12.5 mg m-2d-1 (an increase of approximately 20-fold) under anaerobic conditions.

James (2015) studied additional sediment cores obtained from Big Traverse Bay and performed laboratory tests to determine the impact of temperature on sediment P release. Test results showed mean diffusive P release increases exponentially with temperature under both aerobic and anaerobic conditions. The P RRs measured from aerobic sediments ranged from 0.05 mg $m^{-2}d^{-1}$ at 5°C to 0.36 mg $m^{-2}d^{-1}$ at 25°C. Sediment P release was found to be greater under anaerobic conditions, with values that range from 0.8 mg $m^{-2}d^{-1}$ at 5°C to 16.8 mg $m^{-2}d^{-1}$ at 25°C. Because anaerobic RRs were more than 10 times higher than aerobic RRs, even short periods of anaerobic conditions along the sediment-water interface could generate substantial loss of P from the lake sediments. The monitoring data have not provided any indication of anaerobic conditions in the well-mixed (or polymictic) Big Traverse Bay.

Anaerobic P RRs were in the upper range of values for other Minnesota lakes, while the aerobic P RRs were near the median of values (James 2015).

James (2017b) estimated mean annual P RRs of 38 and 1,172 mg $m^{-2}y^{-1}$ in Big Traverse Bay for aerobic and anaerobic conditions, respectively, based on laboratory-measured, temperature moderated diffusive P flux, and in-lake, monthly, bottom water temperatures measured in 2015. These P RRs correspond to annual loads of 47.5 and 1,463.8 t y^{-1} for purely aerobic and purely anaerobic release, respectively. These loads set approximate minimum and maximum constraints on annual internal loading within Big Traverse Bay based on two extreme conditions. However, uncertainty remains regarding the presence or prevalence of anaerobic conditions within Big Traverse Bay because DO monitoring data have not shown anaerobic conditions (DO concentration less than 2 mg L^{-1}).

James (2017b) also estimated annual internal P loading values based on sediment P concentrations in the upper 6 cm of lake bottom sediment cores that were collected in Big Traverse Bay. The annual loading estimates that used this methodology range from 193 to 291 mg $m^{-2}y^{-1}$, corresponding to a mean annual load of 241.1 to 363.5 t y^{-1}. James noted that a P bulge (high P concentrations) in the upper 6 cm of the lake bottom sediment was observed even though external loading to the lake has been reduced over the past several decades. James suggested that the low rate of sediment P burial may be caused by cyanobacterial-mediated direct biological uptake of sediment P or other recycling causes. The range of internal P loads estimated from sediment P concentrations (i.e., approximately 302 ± 61 t y^{-1}) provides a narrower range of possible loads than the laboratory-measured P RR data discussed above. This tighter range of annual loads from 241.1 to 363.5 t y^{-1} also suggests that anaerobic conditions play a role in Big Traverse Bay because these loads are approximately five to eight times greater than the mean, annual, aerobic internal P loading (47.5 t y^{-1}) that would be expected if no anaerobic conditions developed at the sediment-water interface.

The Science Museum of Minnesota's SCWRS sampled sediment cores from seven LoW bays and performed a range of assessments including radioisotopic dating, P fractions, silicon, diatoms, and pigments (Edlund et al. 2014). The authors found that although lake P loading has declined, sediment P accumulation has increased in modern times, which serves as a pool of legacy P that may fuel internal P loading. Additional analyses (Edlund et al. 2017) modeled sediment P and estimated an active sediment pool of 10,000 tons (t) P. Edlund et al. further estimated that 2.5% of the active pool is available for exchange with the water on a mean annual basis, which corresponds to an annual internal load of approximately 250 t P.

F.2 Internal Phosphorus Loading Estimation

As part of this TMDL study, an analysis was performed to develop an estimate of mean, annual internal P loading to the LoW. The analysis merged HSPF model results with observed in-lake data to assess bay-by-bay water and TP budgets, as well as monthly water balance, inter-bay flow, and advective TP exchange between bays. Unless otherwise noted, input data were consistent with BATHTUB input data described in Appendix G. Unlike the TMDL Study Area and BATHTUB model boundaries, this analysis included the entire LoW surface area, which allowed for a full mass balance of LoW accounting for outflow from the lake at Kenora.

F.2.1 Hydrologic Analysis and Water Balance

A monthly water balance of the LoW was constructed and used as the basis for the subsequent P balance. The HSPF-modeled tributary inflows to the LoW for the TMDL period (2005 through 2014) were summarized and mean monthly inflows (hm^3) were determined for each tributary. Mean monthly lakeshed inflows (direct runoff to the LoW) for the southern LoW (Sabaskong, Four Mile, Muskeg, Big Traverse, and southern Little Traverse Bay) Watershed were determined by distributing mean annual inflows (2005 through 2014) with the same distribution as monthly tributary inflows (i.e., if 10% of inflow volume from tributaries occurs in April, 10% of inflow from the lakeshed was assumed to also occur in April). The HSPF model-estimated, mean annual lakeshed inflow values for the portion of the LoW outside the TMDL TMDL Study Area were not available because of time constraints; therefore, runoff was estimated by assuming a runoff depth equal to that from tributaries that enter that portion of the lake.

Rainfall on the lake itself was calculated on a bay-by-bay basis. Values for each bay were taken as the mean annual precipitation (2005 through 2014) from HSPF. Values ranged from 60 cm for the southwestern portion of the lake to 75 cm for the northeastern portion of the lake; the area-weighted mean value was 63 cm. Monthly rainfall for each bay was estimated by applying the monthly rainfall distribution from Warroad, Minnesota, from 2005 to 2014.

Evaporation was estimated on a bay-by-bay basis from the Hydrologic Atlas of Canada (Canadian National Committee for the International Hydrologic Decade 1978. "Hydrologic Atlas of Canada." Fisheries and Environment of Canada, Ottawa, Ontario, Canada). Mean annual evaporation ranged from 62 cm for the northeastern portion of the lake to 68 cm for the southwestern portion of the lake; the area-weighted mean value was 65 cm. Monthly evaporation was determined by applying the monthly HSPF model-estimated pan evaporation distribution to mean annual evaporation for each of the bays.

Outflow from the LoW was estimated from approximately weekly (4 times per month) LWCB data from 1981 to 2010 (LWCB 2014). Mean monthly outflow values were calculated as the mean of the four values reported for each month.

Surface areas and volumes for the portions of the LoW within the TMDL Study Area (Sabaskong, Four Mile, Muskeg, Big Traverse, and southern Little Traverse Bays) were developed from Environment Canada bathymetry data as received from MPCA (MPCA 2015a). The surface area and volume for the portion of the LoW outside the TMDL Study Area were calculated by difference from published data (Environment Canada 2014). The overall monthly inflow and outflow balance was used to determine changes in lake volume and lake water surface elevation. Net inflow/outflow by bay was then determined as the difference of in-lake volume change and the sums of all other components of the water budget. Flows between bays were determined according to the magnitude and direction of discharge to/from upstream/downstream bays. Headwater bays, such as Sabaskong and Muskeg, generally flow out to downstream bays (Big and Little Traverse) during fall and winter months when the lake level is generally decreasing. Those same headwater bays show net inflow from Big Traverse Bay during spring and summer months when the lake receives high discharges from the Rainy River.
Table F-1 shows a summary of hydrologic and TP loading pathways.

Table F-1. Summary of hydrologic and TP pathways.

Pathway	Hydrologic Component	TP Transport Component
Tributary Inflow	✓	✓
Precipitation	✓	✓ (Wet atmospheric deposition)
Atmospheric Deposition		✓ (Dry)
Evaporation	✓	
Flow between Bays	✓	✓
Outflow	✓	✓
Groundwater	Not considered	

F.2.2 Phosphorus Analysis and Budget

The HSPF-modeled tributary TP loads to the LoW for the study period (2005 through 2014) were summarized and TP loads were determined for each tributary. Mean monthly lakeshed TP loads for the southern LoW (Sabaskong, Four Mile, Muskeg, Big Traverse, and southern Little Traverse Bays) bays were estimated by applying the same distribution as monthly tributary TP loads (i.e., if 12% of TP load from tributaries occurs in April, 12% of TP loads from the lakeshed were assumed to also occur in April). The HSPF model-estimated mean annual lakeshed loading values for the area outside of the TMDL Study Area were not available because of time constraints. Therefore, loads were estimated by assuming a TP load equal to that from tributaries that enter that portion of the lake, on a per-area basis.

In-lake TP mass was calculated by bay and by month as the product of mean observed TP concentration (2005 to 2014) and estimated bay volume. The TP concentration data were obtained from the EPA's STORET and the OMECC. In-lake TP concentrations outside the TMDL Study Area were assumed equal to concentrations observed in the Winnipeg River immediately (< 10 km) downstream of Kenora, Ontario.

Estimates of atmospheric P deposition were based on values reported by Twarowski, Czoschke, and Anderson (2007) for the Rainy River Basin. The mean annual atmospheric deposition of 0.193 kg ha^{-1} yr^{-1} comprised 0.073 kg ha^{-1} yr^{-1} of wet deposition and 0.12 kg ha^{-1} yr^{-1} of dry deposition. The wet deposition value reported for an average (not wet or dry) year was used in this analysis. The 0.12 kg ha^{-1} yr^{-1} of dry deposition was assumed to fall on the LoW at a constant rate throughout the year and monthly rates are, therefore, a function only of number of days per month. Wet deposition rates were assumed to occur at a constant concentration and are, therefore, directly correlated to precipitation (i.e., the monthly wet deposition distribution is the same as the precipitation distribution).

The TP export from the LoW was calculated as the product of discharge at Kenora, Ontario, and observed TP concentrations immediately (less than 10 km) downstream of Kenora. Data were not available for November through March; concentrations for those months were assumed equal to 20 micrograms per liter (µg L^{-1}) (mean monthly concentrations for April to October ranged from 20 to 26 µg L^{-1}).

Interbay advective TP flow was estimated as the product of in-bay TP concentration (by month) and the net outflow to other bays. As discussed earlier, the direction of flow between bays varies throughout the year and may change direction multiple times throughout the year.

F.3 Results

F.3.1 Lake of the Woods as a Whole

The overall water budget for the LoW shows an estimate of water surface fluctuation of approximately 75 cm throughout the year, as illustrated in Figure F-1. The predicted ending relative water surface elevation at the end of the year was 3 cm above the starting value in January. This error is caused by cumulative effects of uncertainties in parameter estimation and simplicity of the simulation (i.e., groundwater is neglected). The difference in volume that corresponds to 3 cm of elevation change is approximately 122 hm^3, while the annual total inflow to the LoW was estimated to be approximately 17,000 hm^3.

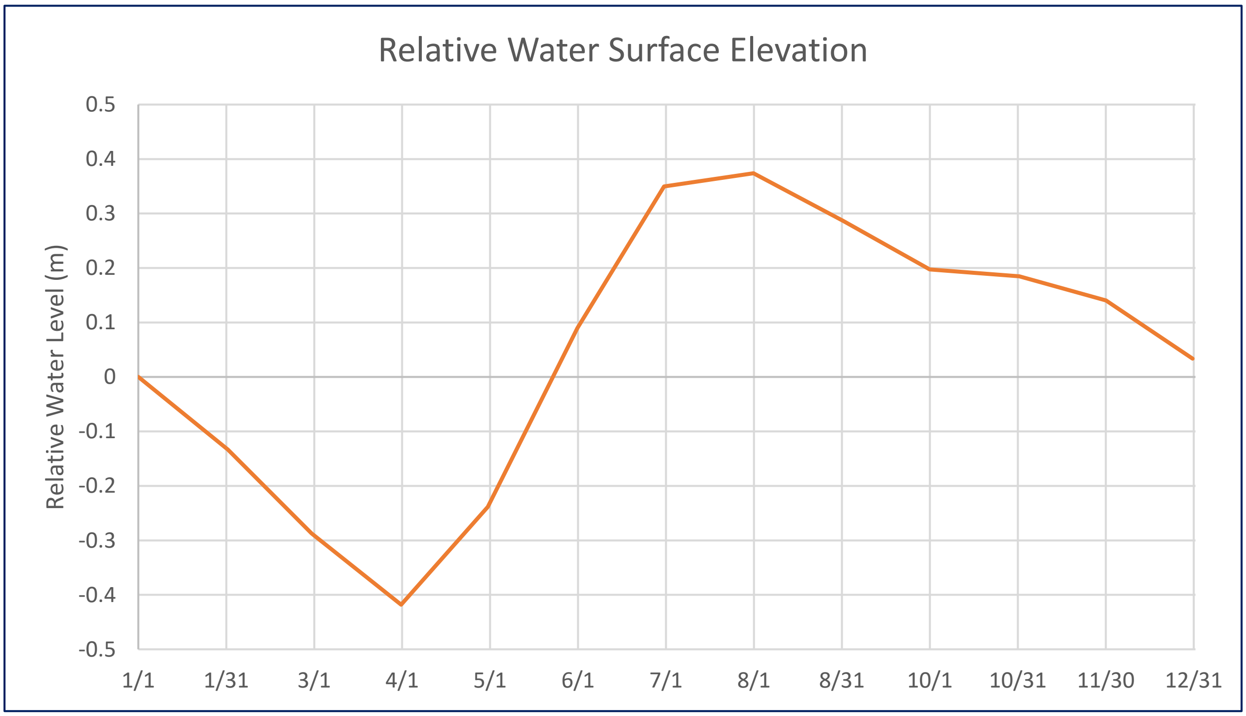


Figure F-1. Mean Relative Water Surface Elevation throughout the Year

Mean monthly total inflow and outflow (at Kenora, Ontario) are shown with mean monthly change in volume in Table F-2. Because outflow at Kenora is controlled by a dam, outflow from the LoW generally varies less throughout the year than inflow to the lake. Mean monthly inflow varies from approximately 600 to 3,000 hm^3, while mean monthly total outflow (outflow at Kenora plus evaporation) varies from approximately 1,200 to 2,000 hm^3.

Table F-3 shows the mean monthly TP inflow and outflow from the LoW. Mean monthly TP inflow follows a similar pattern as monthly water inflow, with large fluxes from April to July. More than half of the mean annual load occurs from April to June, which corresponds to the beginning of the growing season. Mean annual inflow (583 tons per year [t y^{-1}]) exceeds mean annual outflow (320 t y^{-1}), which suggests that approximately 45% of TP that enters the LoW every year is trapped within the lake.

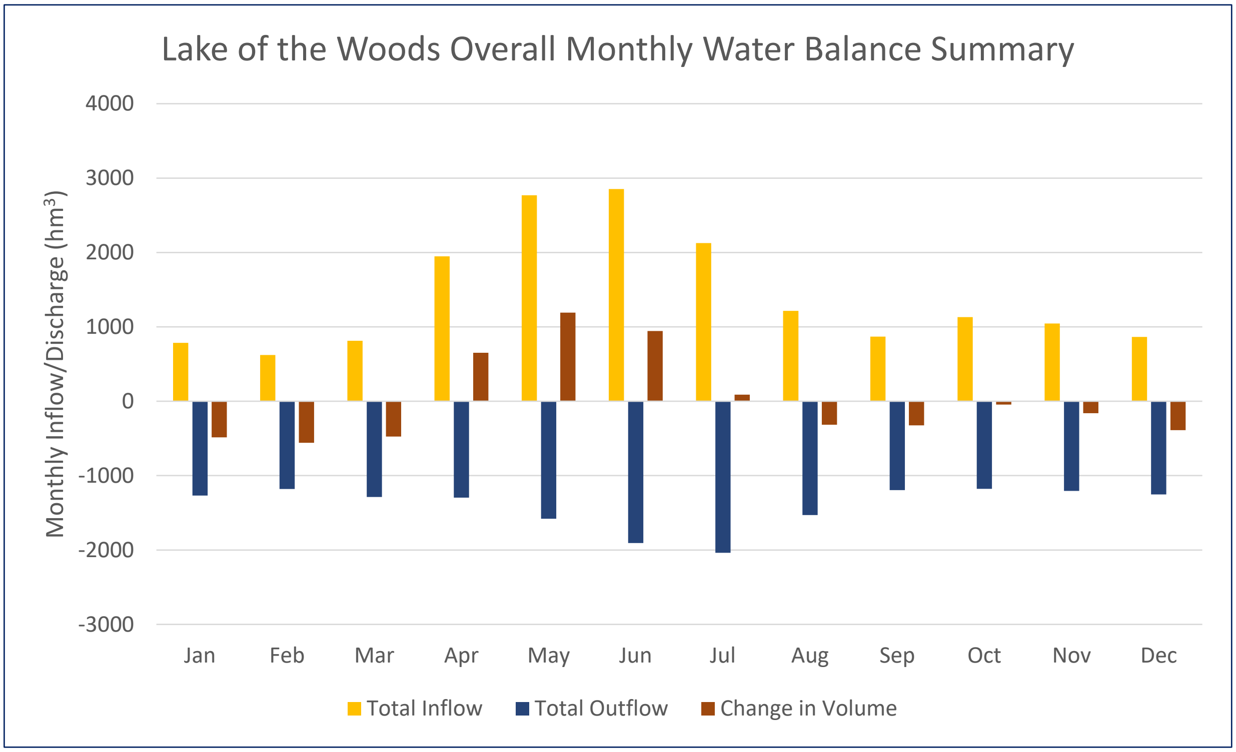


Figure F-2. Mean Monthly Inflow and Outflow

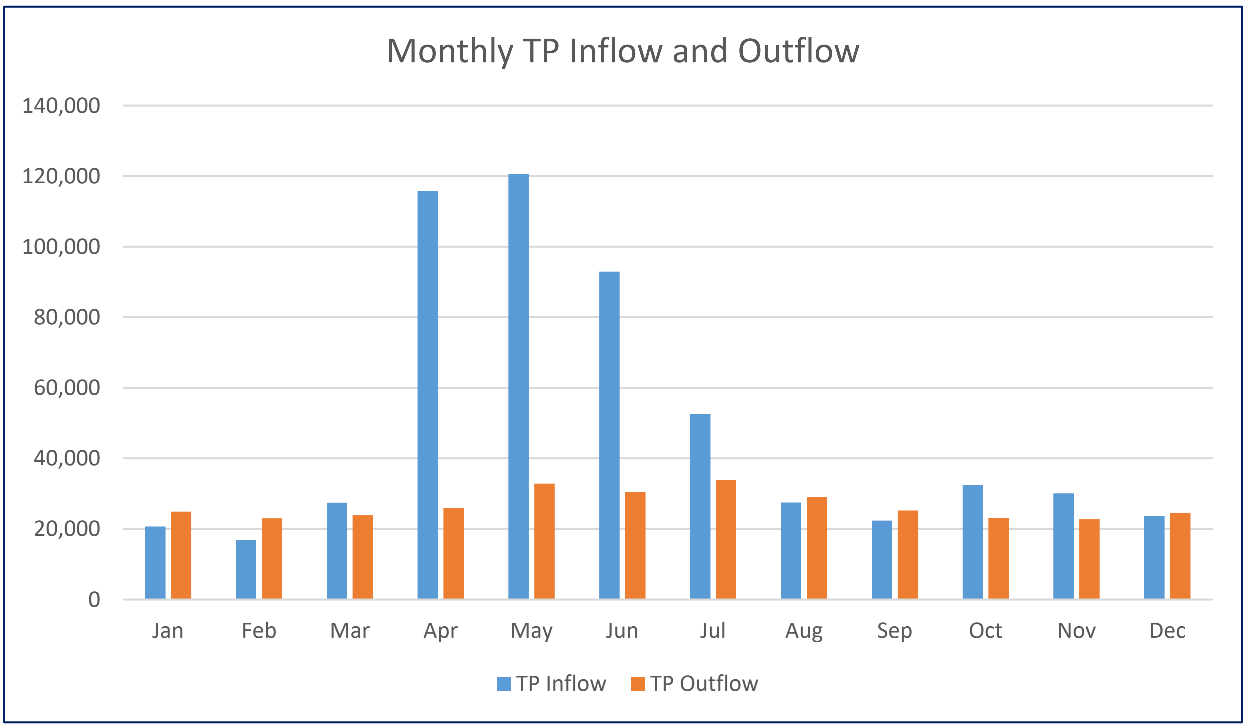


Figure F-3. Monthly TP Inflow and Outflow

F.3.2 Results by Bay

This analysis also affords the ability to determine monthly water and TP fluxes on a bay-by-bay basis, which is useful because of the uncertainty in estimating internal TP loading within the lake. Using observed TP concentrations, we can also estimate changes in TP mass on a month-by-month and bay-by-bay basis (discussed here as Method A). An alternative method to estimating change in TP mass on a month-by-month and bay-by-bay basis was developed by estimating water inflow (tributaries, lakeshed, precipitation) and outflow (evaporation, flow through the lake and between bays) and associated, advective TP fluxes (discussed here as Method B).

Method A is considered the known (measured) change in TP mass, while Method B is considered an incomplete mass balance approach to the TP budget that does not account for the unknown magnitude of internal loading that occurs within the lake. The difference between Methods A and B is termed unexplained residual and is assumed to be the net sum of internal loading processes. Unexplained residual is positive (net flux into the water column) when the change in in-bay TP mass estimated using Method A is greater than that estimated with Method B. When unexplained residual is positive, sediment P release, algal activity, P translocation, and resuspension exceed sedimentation. Conversely, when the change in in-bay TP mass that was estimated with Method A is less than with Method B, sedimentation dominates internal TP processes.

Lake TP concentration data are generally only available for April to November. Little data were available for Sabaskong Bay and the area outside the TMDL Study Area. Therefore, the focus of the monthly TP analysis is on Four Mile, Muskeg, Big Traverse, and Little Traverse Bays. Because of the relative abundance of data for these bays and the coarse nature of the analysis (mean annual and monthly values for a 10-year period), a 60-day moving average (± 30 days) was applied to observed in-lake TP concentrations measured in these four bays, shown in Figure F-4. A 60-day window was determined to provide the best balance between smoothing and maintaining the approximate shape of the scatter data (observed concentration versus day of year).

The 60-day rolling mean values allow a more accurate estimation of the in-bay TP concentration at the beginning and end of each month. Unexplained residual values by month for Muskeg, Big Traverse, and Little Traverse Bays are presented in Figure F-6. Results for Big Traverse Bay show that the unexplained residual is negative (sedimentation dominates) in May and October but that sediment P release and resuspension dominate from June to September. Figure F-5 shows a more detailed summary of TP fluxes by month for Big Traverse Bay. Net inflow shown is the sum of net inflow and net outflow (negative inflow). The unexplained residual is the difference between the observed change in TP mass (Method A) and the net inflow (Method B).

Unexplained residual loads are summarized by bay in Table F-2. Because the growing season (June through September) is the relevant time period for water quality regulation and for biological activity that can lead to Chl-*a* impairment, only the total unexplained residual for those four months is considered for developing the total annual internal loading rate. Note that the unexplained residual may underestimate sediment P release and resuspension because we are unable to separate sedimentation in our analysis. Unexplained residual loading rates are presented in Table F-3, along with the equivalent annual RR (total flux to water column from June through September divided by days per year and area of each bay). The annual rate is required as an input in the BATHTUB model. The mean unexplained residual (internal load in BATHTUB) is therefore estimated to be 282 t y^{-1}, as seen in Table F-4 for the portion of LoW in the TMDL Study Area.

Figure F-4. 60-Day Mean Observed TP Concentration by Ordinal Day

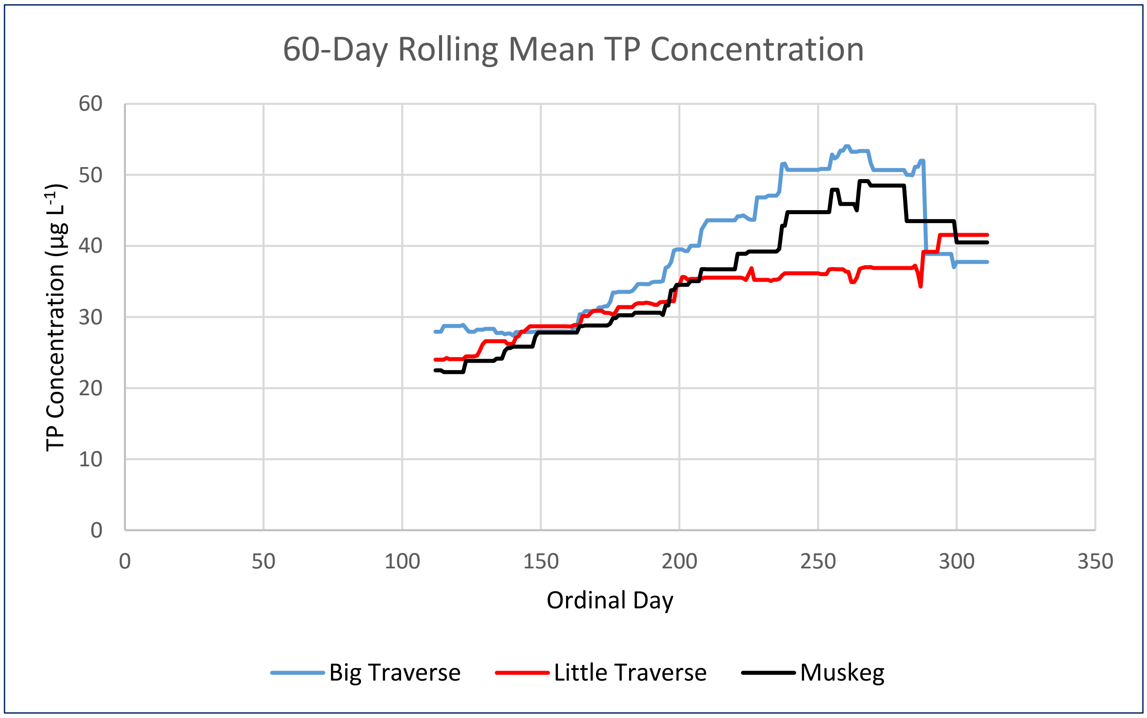


Figure F-5. Monthly TP Inflow and Outflow

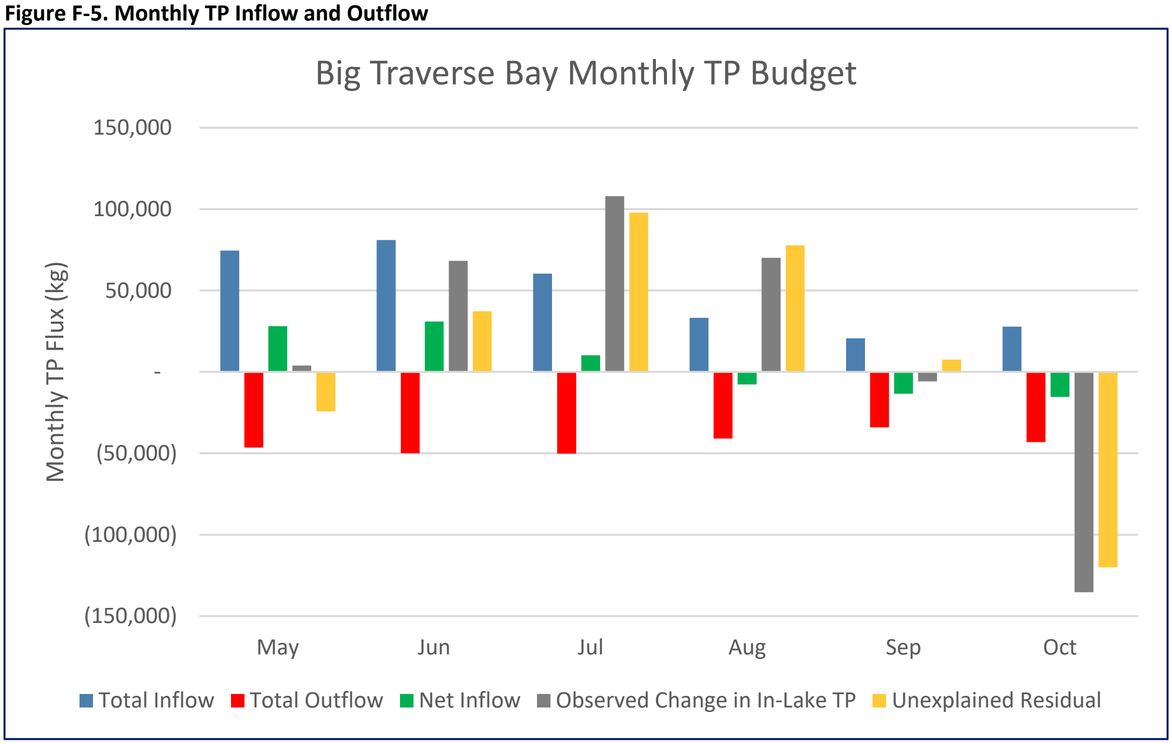


Figure F-6. Big Traverse Bay TP Budget by Month

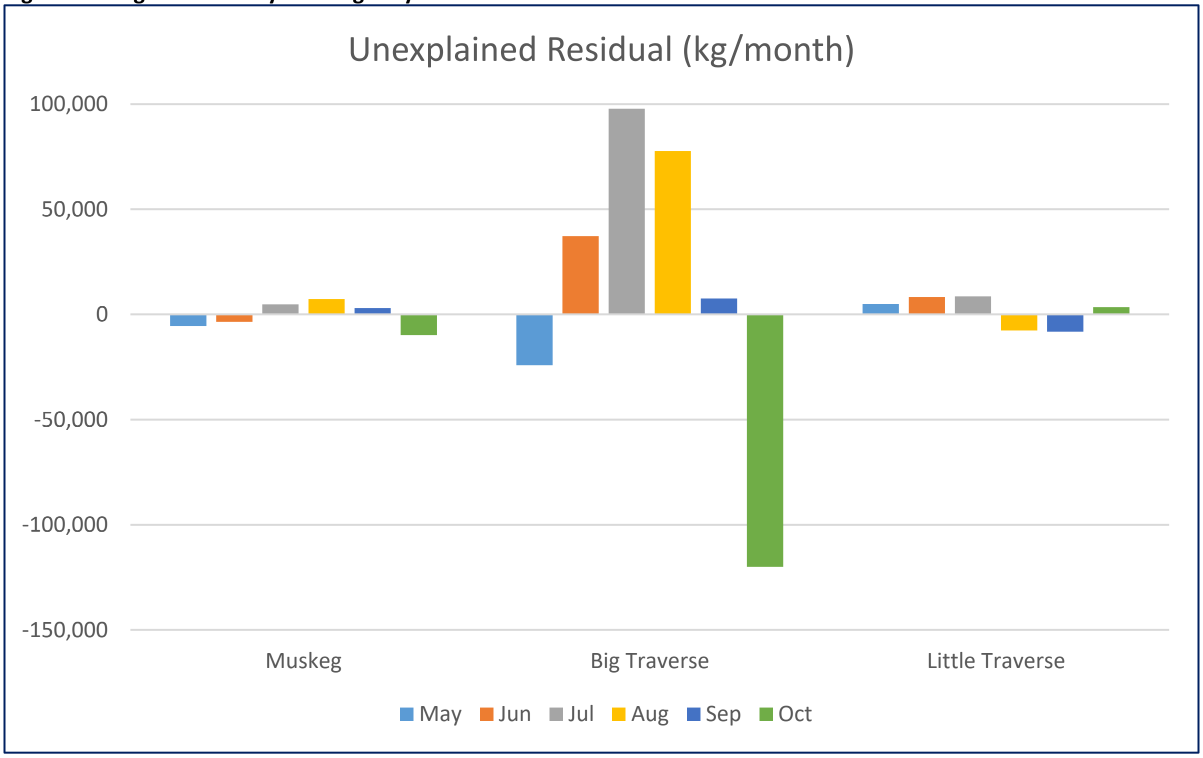


Table F-2. May through October unexplained residual by bay.

Unexplained Residual Load (kg)	Four Mile	Muskeg	Big Traverse	Little Traverse
May	(17,272)	(5,505)	(24,205)	5,067
June	10,111	(3,429)	37,237	8,321
July	20,940	4,723	97,785	8,565
August	13,346	7,313	77,717	(7,607)
September	4,218	2,994	7,578	(8,150)
October	2,291	(9,908)	(119,993)	3,409

Table F-3. June through September and mean annual monthly net unexplained residual release rate.

Unexplained Residual Release Rate (mg m^{-1} d^{-1})	Four Mile	Muskeg	Big Traverse	Little Traverse
June	11.17	–0.60	1.00	0.40
July	22.38	0.81	2.54	0.40
August	14.27	1.25	2.02	–0.36
September	4.66	0.53	0.20	–0.39
Mean annual rate (based on June–September loading)	**4.41**	**0.168**	**0.486**	**0.0045**

Table F-4. Estimated annual unexplained residual by bay.

Unexplained Residual (kg)	Four Mile	Muskeg	Big Traverse	Little Traverse	Total
Growing Season (June–September)	48,615	11,601	220,317	1,129	**281,661**

F.3.3 Comparison of Results

Table F-5 compares internal loads estimated in this study and those reported by James (2017b) and Edlund et al. (2017). This study's internal loading estimates for the portion of the LoW in the TMDL Study Area (282 t y^{-1}) compares well with the estimate for the entire LoW (250 t y^{-1}) from Edlund et al. (2017). Likewise, this study's estimate of Big Traverse Bay's internal loading (220 t y^{-1}) falls below the range of expected values (241.1–363.5 t y^{-1}) estimated from sediment P concentration data by James (2017b).

Table F-5. June through September mean annual monthly net unexplained residual release rate.

Mean Annual Internal Load (t y^{-1})	Minimum	Mean	Maximum	Notes
This study		282		TMDL Study Area only
Edlund [2017]		250		Entire LoW
This study		220		Big Traverse Bay only
James [2017b]	241.1		363.5	Big Traverse Bay only

Twarowski, Czoschke, and Anderson (2007)

Appendix G. BATHTUB Modeling and Calibration Summary

This appendix provides a description of the development of the existing conditions BATHTUB model corresponding to the study period (2005 through 2014), model calibration, and development of the proposed conditions BATHTUB model reflecting loads in the TMDL LA table.

G.1 Model Development

G.1.1 Lake Segmentation and Physical Characterization

The LoW Basin was separated into five segments in the BATHTUB model as shown in Figure G-1: Sabaskong, Four Mile, Muskeg, Big Traverse, and Little Traverse Bays. Segmentation of the LoW loosely followed previously established BATHTUB segmentation (Anderson et al. 2013), and exact boundaries were taken from HSPF model boundaries (Lupo 2016), which are shown in Figure G-2. Sabaskong Bay is included in the LoW Canada HSPF model, while the remaining four bays are included in the LoW (US) HSPF model.

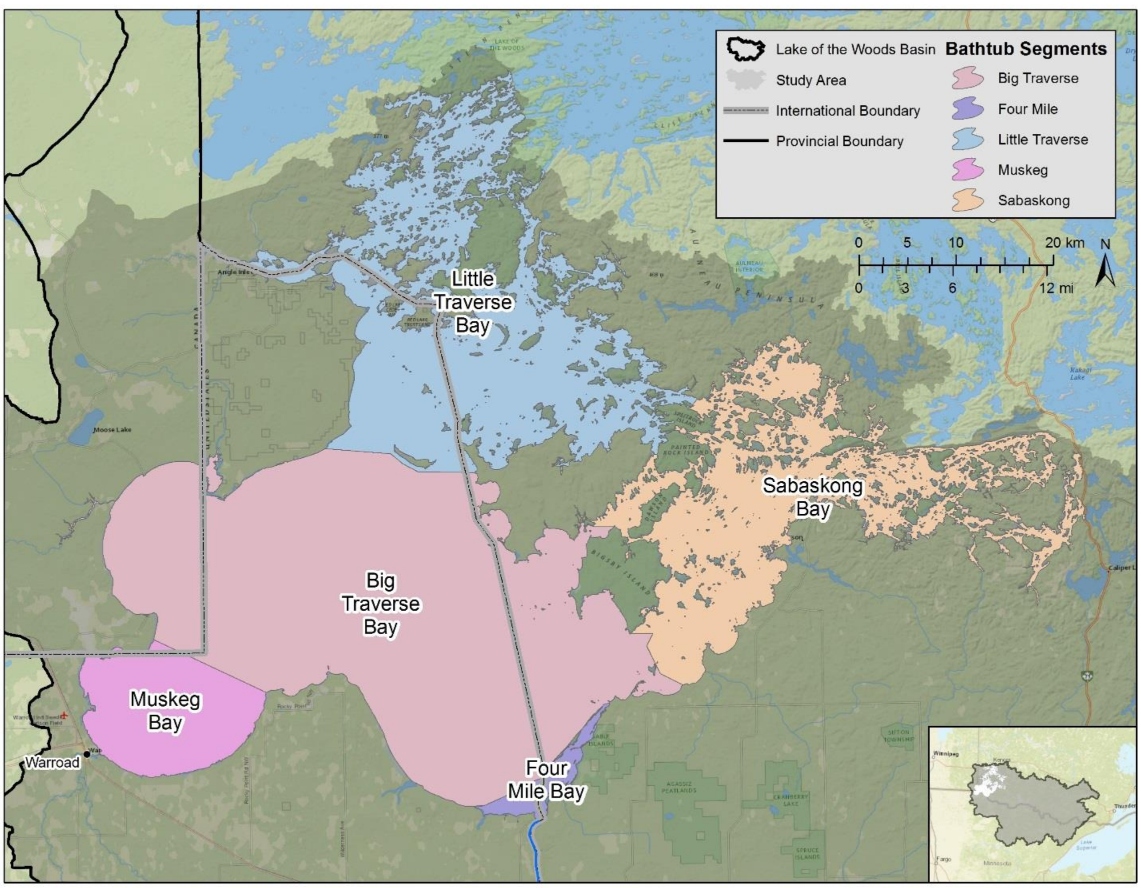


Figure G-1. The Lake of the Woods BATHTUB Model Lake Segmentation

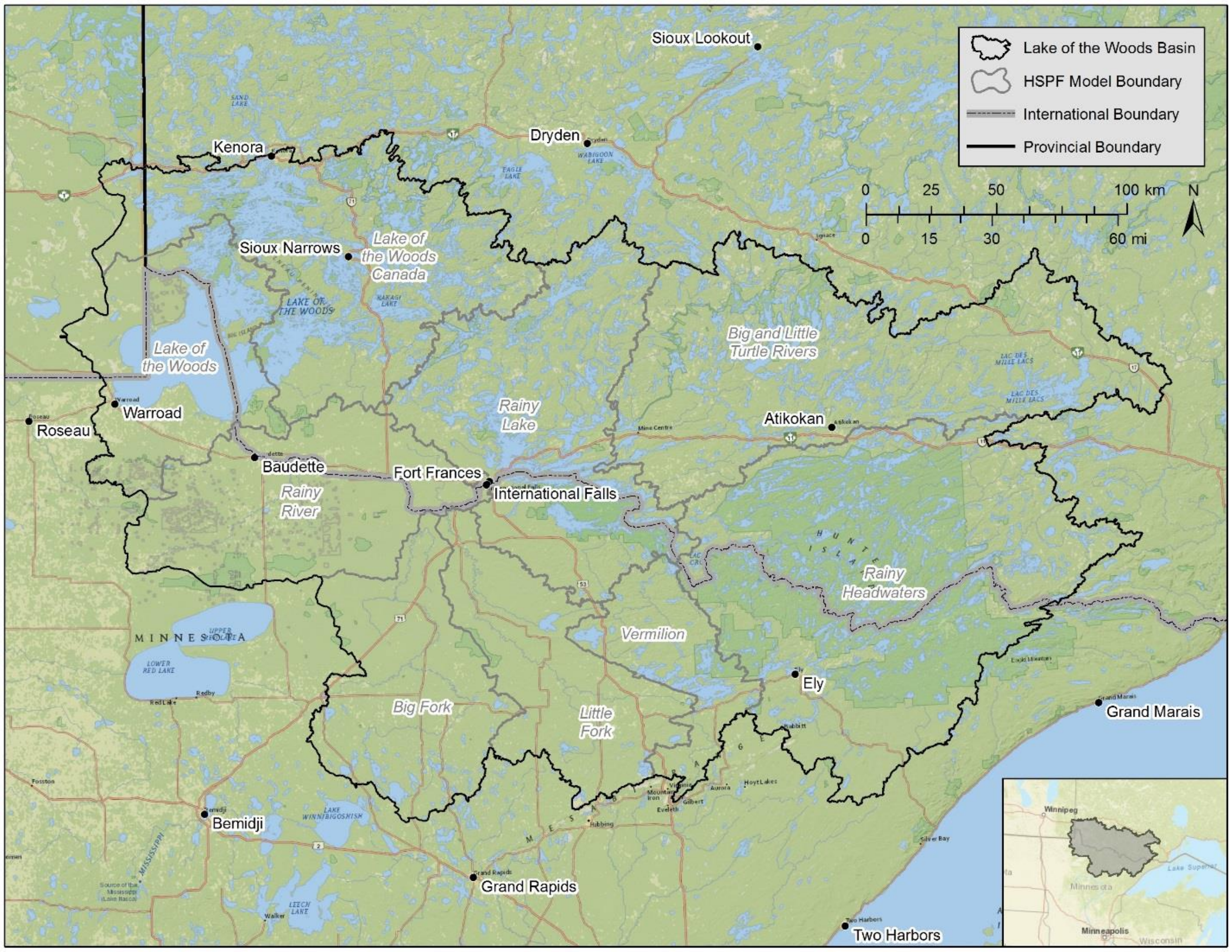


Figure G-2. HSPF Model Boundaries within the Lake of the Woods Basin (Lupo 2016)

The boundaries between Sabaskong and Little Traverse and Big Traverse Bays are based on the boundary between the Lake of the Woods and Lake of the Woods Canada HSPF models (two separate HSPF models as shown in Figure G-2). The boundary between Big Traverse Bay and Four Mile Bay is based on the physical barrier at islands such as Pine Island and Currys Island. The boundary between Big Traverse Bay and Muskeg Bay was determined as the shortest line between Buffalo Point on the west and Rocky Point on the east. The boundary between Big and Little Traverse Bays was based on an HSPF model subwatershed boundary and corresponded to the area near Garden Island where Big Traverse Bay narrows as it transitions to Little Traverse Bay. The northern boundary of Little Traverse Bay was set as the boundary between the Lake of the Woods and Lake of the Woods Canada HSPF models. The remainder of LoW was not modeled in BATHTUB.

Surface areas of each lake segment were determined using ArcMap. Environment Canada bathymetry data as received from MPCA were used to determine the total volume of each segment and mean depths were calculated from the volume and surface area. Each segment's physical characteristics are summarized in Table G-1. Flow routing between segments in the TMDL Study Area is shown in Table G-2, which lists the downstream receiving segment for each of the five lake segments. The outflow from Sabaskong Bay is split between Big Traverse and Little Traverse Bays, with 75% of the outflow routed to

Little Traverse Bay. The linkage between Sabaskong and Little Traverse Bays is represented as a channel in BATHTUB.

Table G-1. TMDL Study Area lake segment characteristics.

Segment	Area (km^2) (mi^2)	Maximum Depth (m) (ft)	Mean Depth (m) (ft)
Sabaskong	518 (200)	17.6 (57.9)	3.6 (11.9)
Four Mile	31 (12)	4.5 (14.7)	1.0 (3.3)
Muskeg	190 (73)	10.0 (32.8)	5.6 (18.3)
Big Traverse	1249 (482)	12.1 (39.6)	8.2 (26.9)
Little Traverse	697 (269)	28.3 (92.8)	4.6 (15.1)

Table G-2. Bay connectivity and flow routing.

Segment	Downstream Receiving Segment
Sabaskong	Big Traverse and Little Traverse
Four Mile	Big Traverse
Muskeg	Big Traverse
Big Traverse	Little Traverse
Little Traverse	Outflow at TMDL Study Area boundary

G.1.2 In-Lake Water Quality Data

Summer-average TP and Chl-*a* concentrations and Secchi disk depths were calculated from monitoring data for the TMDL study period (2005 through 2014); these values are summarized in Table G-3. Summer-average concentrations that apply for Minnesota lake water quality standards are based on representative samples from June through September. Summer-average values for the TMDL study period are used to calibrate the existing conditions BATHTUB model.

Table G-3. Summer-average eutrophication parameter values by bay for the study period.

Segment	TP Concentration ($\mu g\ L^{-1}$)	Chl-*a* Concentration ($\mu g\ L^{-1}$)	Secchi Disk Depth (m)
Sabaskong	26.9	6.4	1.3
Four Mile	32.95	5.21	1.34
Muskeg	37.65	12.24	1.07
Big Traverse	35.71	9.34	1.17
Little Traverse	33.59	9.48	1.39

G.1.3 Internal Loading

Internal P loading rates were determined by bay and input to the BATHTUB model as a loading rate in mg m^{-2} d^{-1}. A detailed explanation of the internal loading estimation methodology is included in Appendix F. Internal loading rates used in the BATHTUB model are listed in Table G-4. Note that an internal loading rate was not developed for Sabaskong Bay due to lack of applicable data and thus an assumed internal load of zero was applied to Sabaskong Bay.

Table G-4. BATHTUB calibration statistics.

Segment	TP Internal Loading Rate ($mg\ m^{-2}\ d^{-1}$)
Sabaskong	0 (no data available)
Four Mile	0.486
Muskeg	4.41
Big Traverse	0.168
Little Traverse	0.0045

G.1.4 Tributaries

External inflows to the LoW were entered in BATHTUB as tributaries. BATHTUB tributaries are not limited to river or streams, but can also include point sources or any other sources that contributes water and nutrients to the lake. Due to limitations within BATHTUB on the number of tributaries available, it was not possible to explicitly include every source from the LoW LA table in the LoW BATHTUB model. Thus, all sources (all nonpoint and point sources) draining through the Rainy River were included as a single tributary (Rainy River) in the LoW BATHTUB model. The BATHTUB TP loads for Rainy River are therefore larger than the LAs assigned to Rainy River and its tributaries because it also includes all WLAs for sources within the Lower Rainy River Watershed.

The Rainy River tributary includes all discharge from the seven HSPF models above the lower boundary condition at Wheelers Point:

1. Rainy Lake Watershed HSPF models
    a. Rainy Headwaters
    b. Big and Little Turtle Rivers
    c. Vermilion River
    d. Rainy Lake
2. Lower Rainy River HSPF models
    a. Little Fork River
    b. Big Fork River
    c. Lower Rainy River

BATHTUB tributaries were taken from the nine HSPF models for the LoW Basin (Figure G-2). The area above the upper boundary condition at International Falls, Minnesota/Fort Frances, Ontario, comprises four HSPF models (Rainy Headwaters, Big and Little Turtle Rivers, Vermilion River, and Rainy Lake); these models constitute the Rainy Lake Watershed (pink area) in Figure G-3. Outflow from Rainy Lake to Rainy River at International Falls, Minnesota/Fort Frances, Ontario, and is carried by the Rainy River to the LoW. The Lower Rainy River Watershed (the green area in Figure G-3) comprises three HSPF models: Little Fork River, Big Fork River, and Rainy River drains. The Lower Rainy River Watershed is drained by the Rainy River, which carries runoff from both the Lower Rainy River and Rainy Lake Watersheds to LoW, where it discharges to to the lower boundary condition at Four Mile Bay. The remainder of the TMDL Study Area lies within the LoW Direct Watershed (yellow area in Figure G-3), which includes the entirety of the Lake of the Woods HSPF model and a portion of the Lake of the Woods Canada HSPF model. Note that a portion of the basin is not included in the TMDL Study Area as shown in Figure G-3.

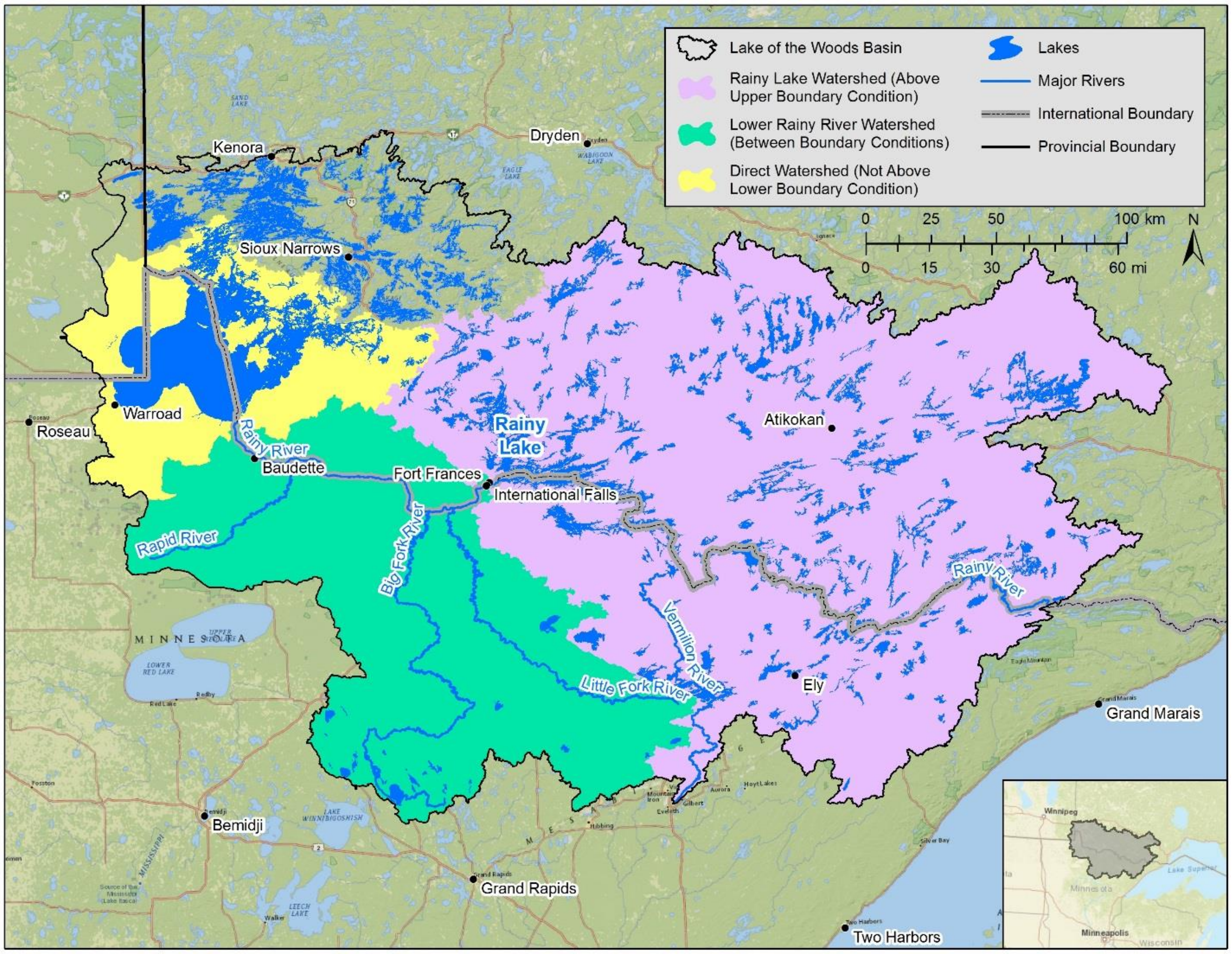


Figure G-3. Lake of the Woods Basin Map Showing the Lake of the Woods Basin With Drainage Areas at the Upper and Lower Boundary Conditions and the Direct Watershed not Above the Lower Boundary Condition

Due to limitations on the number of sources in BATHTUB, the entire Rainy River All other modeled reaches within the remainder of the TMDL Study Area (yellow area in Figure G-3) were included as tributaries. A total of 24 tributaries were created in the BATHTUB model. Tributary discharge and loading for the existing conditions model were taken from the calibrated HSPF models. Mean annual discharge and flow-weighted mean concentrations of TP, OP, TN, and inorganic nitrogen were determined for each of the 24 tributaries and entered into BATHTUB. Tributary drainage area, mean annual discharge, flow-weighted mean TP concentration, and mean annual TP load are included in Table G-5.

G.1.5 Lakeshed

Lakeshed loading was determined for the areas within the direct watershed (Figure G-4) that do not drain to an HSPF-modeled reach. Runoff from these areas is carried to the LoW through small tributaries that were not represented in HSPF models or through overland flowpaths. The area that corresponds to the lakeshed loading area is shown in Figure G-4. Seven distinct lakeshed loading areas were created in the BATHTUB model: one each for Four Mile, Muskeg, and Big Traverse Bays and two each for Sabaskong and Little Traverse Bays. The Sabaskong and Little Traverse Bay lakeshed areas were each split into two areas to correspond with HSPF-modeled reach boundaries for ease of input into the BATHTUB model. Mean annual lakeshed discharge and water quality constituent loads were taken from the HSPF models and entered into BATHTUB using the methodology explained above for tributary loading.

Table G-5. BATHTUB tributary characteristics for the existing conditions BATHTUB model.

Tributary	HSPF Reach	Drainage Area (km^2)	Study Period Mean Annual Discharge (hm^3)	Study Period Flow-weighted Mean TP Concentration ($\mu g\ L^{-1}$)	Study Period Mean Annual TP Load (t)
Sabaskong River 🍁	45	483.0	69.5	32.1	2.23
Splitrock River 🍁	49	176.0	23.3	52.7	1.23
Thompson Creek 🍁	17	110.9	21.8	35.8	0.78
Obabikon Lake 🍁	14	96.1	20.5	22.4	0.46
Big Grassy River 🍁	13	153.9	21.4	51.8	1.11
Little Grassy River 🍁	11	307.5	37.5	62.3	2.33
Rainy River 🍁	430	54,686.1	12,738.7	28.5	362.68
Bostick River	231	142.0	25.7	69.5	1.78
Williams Creek (County Ditch 1; 211)	211	80.2	14.1	80.5	1.13
S. Branch Zippel Creek	213	21.2	4.3	173.1	0.74
W. Branch Zippel Creek	203	99.7	17.6	107.3	1.89
Judicial Ditch 24 (201)	201	33.2	5.2	81.0	0.42
Judicial Ditch 24 (191)	191	57.4	9.3	134.9	1.26
Judicial Ditch 22	181	40.4	6.7	106.3	0.71
Reach 171	171	5.9	1.1	156.7	0.16
Willow Creek	161	71.6	12.8	105.4	1.35
County Ditch 26 (151)	151	12.1	2.1	132.8	0.27
County Ditch 26 (141)	141	24.8	3.9	118.4	0.46
County Ditch 26 (131)	131	10.0	1.7	176.1	0.30
County Ditch 20	121	24.7	3.9	119.0	0.46
County Ditch 25	113	38.4	6.8	146.9	1.00
Warroad River 🍁 †	70	716.3	111.5	58.9	6.57
Stony Creek 🍁	301	176.3	24.1	31.0	0.75
Northwest Angle Inlet 🍁	312	378.9	46.4	28.6	1.33

🍁 denotes that all or part of the load from this source originates in Canada

† HSPF model boundaries show that a portion of the modeled Warroad River Subwatershed extends into Canada and the runoff from that portion of the subwatershed drains directly to the lake

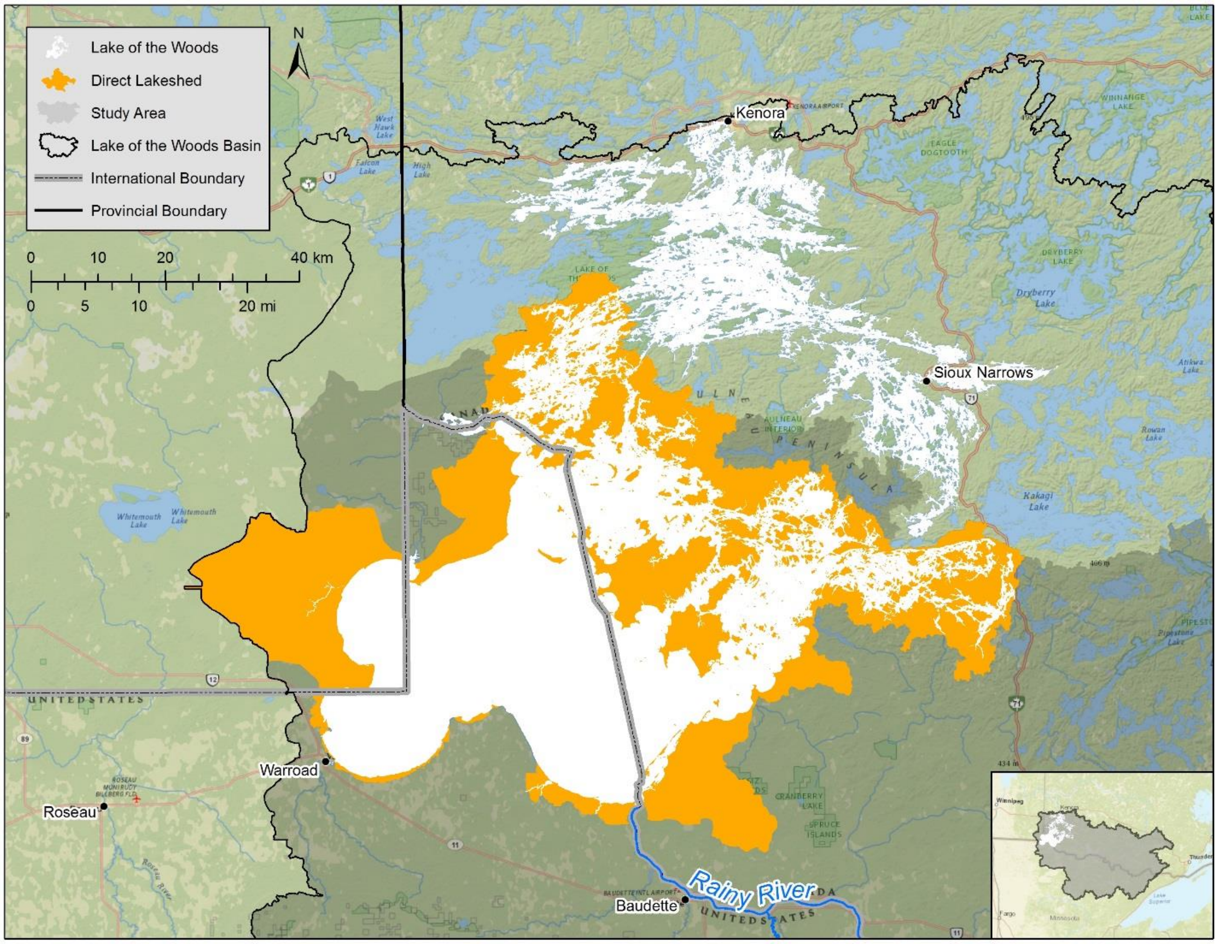


Figure G-4. The Lake of the Woods Lakeshed Loading Area

G.1.6 Septic Loading

SSTS, or septic system, loading to the LoW was taken from HSPF model output. Septic loading was only included for the lakeshed areas that do not drain to HSPF-modeled reaches. As with lakeshed loading, septic loading was reported by bay, with Sabaskong and Little Traverse Bays each having two separate lakeshed areas that correspond with HSPF-modeled reaches.

G.1.7 Point-Source Loading

Point sources that discharge directly to the LoW were also represented explicitly in the existing conditions BATHTUB model because their loads were not reflected in tributary or lakeshed loads within BATHTUB. Point sources upstream of the lower boundary condition were reflected in the existing Rainy River discharge and loading from the HSPF model. Only two point sources not above the lower boundary condition (Springsteel Island and Marvin Windows and Doors) discharge to the lake without traveling through an HSPF-modeled reach. Study period mean annual discharge and load from these two point sources was taken from HSPF output and entered explicitly into BATHTUB.

G.1.8 Global Variables

G.1.8.1 Precipitation

The mean annual precipitation for each of the BATHTUB lake segments was determined from HSPF-modeled inputs for the study period. An area-weighted mean annual precipitation was developed by using the areas of each of the BATHTUB lake segments. This information is summarized in Table G-6. Sabaskong Bay was split into east and west portions due to its being split across two HSPF hydrozones.

Table G-6. Bay-by-bay and area-weighted surface area and precipitation for the study period.

Segment	HSPF Hydrozone	Surface Area (km^2)	Mean Annual Precipitation (m)
Sabaskong (East)	7	142.3	0.6479
Sabaskong (West)	5	370.5	0.6223
Four Mile	11	30.2	0.6034
Muskeg	11	189.2	0.6034
Big Traverse	11	1,243.0	0.6034
Little Traverse	11	688.5	0.6034
Area-weighted	**–**	**2,663.6**	**0.6084**

G.1.8.2 Evaporation

Annual evaporation for the TMDL Study Area was estimated as the area-weighted mean of bays in the TMDL Study Area. Mean annual evaporation for each BATHTUB segment was estimated visually from a map from den Hartog and Ferguson (1978). This information is summarized in Table G-7.

Table G-7. Bay-by-bay and area-weighted mean surface area and mean annual evaporation for the study period.

Segment	Surface Area (km^2)	Mean Annual Evaporation (m)
Sabaskong (East)	142.3	0.63
Sabaskong (West)	370.5	0.64
Four Mile	30.2	0.67
Muskeg	189.2	0.68
Big Traverse	1,243.0	0.66
Little Traverse	688.5	0.64
Area-weighted	**2,663.6**	**0.652**

G.1.8.3 Change in Water Level

An assumption of no change in water level over the 10-year study period was made for the BATHTUB model.

G.1.8.4 BATHTUB Model Selections

BATHTUB model selections are presented in Table G-8.

Table G-8. TMDL Study Area lake segment characteristics.

Parameter	Numerical Model Selection	Model Selection Description
Total Phosphorus	2	2nd Order, Decay
Total Nitrogen	2	2nd Order, Decay
Chl-*a*	4	P, Linear
Transparency	1	Vs. Chl-a and Turbidity
Longitudinal Dispersion	1	Fischer-Numeric
Phosphorus Calibration	2	Concentrations
Nitrogen Calibration	2	Concentrations

G.2 Model Calibration

The existing conditions BATHTUB model was calibrated to reflect the in-lake response to external and internal loads; calibration statistics are shown in Table G-9.

Table G-9. BATHTUB calibration statistics.

Segment	TP Calibration Factor	Total Nitrogen Calibration Factor	Chl-*a* Calibration Factor
Sabaskong	0.94	No total nitrogen data	0.85
Four Mile	1.14	1.20	0.57
Muskeg	1.29	1.20	1.16
Big Traverse	1.24	1.24	0.93
Little Traverse	1.17	1.29	1.01

G.3 Model Calibration

The calibrated BATHTUB model was used to determine the loading capacity (TMDL) for the LoW in the TMDL Study Area, which is the maximum P load that allows the LoW to achieve its summer-average TP standard of 30 µg L^{-1}. Loading capacity was developed iteratively as load-reduction scenarios were developed. This iterative process was necessary because of varying TP/dissolved P ratios from sources in the TMDL Study Area. In-lake water quality is more sensitive to dissolved P loading than particulate P because of its higher bioavailability and thus different combinations of load reductions result in different loading capacities. The loading capacity for the LoW in the TMDL Study Area is 712,000 kg y^{-1}.

G.4 Proposed Conditions BATHTUB Model

The calibrated existing conditions BATHTUB model was updated to reflect the TMDL LA table. The P sources included in the proposed conditions BATHTUB model generally match line items in the LA table. However, items shown in Table G-10 were lumped as shown in the BATHTUB model (i.e., one BATHTUB tributary represents many sources from the LA table). Items not listed in this table are represented as expected in the proposed conditions BATHTUB model (i.e., the LA for the Warroad River is represented in both the TMDL LA table and in the proposed conditions BATHTUB model as Warroad River, with no adjustments for loads such as point sources).

The majority of sources listed in Table G-10 drain to the Rainy River. As in the existing conditions BATHTUB model, the loads for all sources that drain through the Rainy River are represented as a single load and input (Rainy River) in the proposed conditions BATHTUB model. Note that several LA sources that may drain partially to the Rainy River are not listed here and are, therefore, not reflected in the Rainy River load in the proposed conditions BATHTUB model. These sources include both construction and industrial stormwater, which are distributed throughout the portion of the basin below the upper boundary condition. While both of these sources may include sites that drain to the Rainy River, difficulty in accurately representing the effect of each individual site necessitated including these loads with an assumption of 100% delivery to the LoW. This assumption provides an additional (implicit) MOS by over-representing the contribution of these loads to the LoW. Because of the assumption of 100% delivery, these loads are represented explicitly in the proposed conditions BATHTUB model.

Table G-10. Load allocation table items and their representation in the proposed conditions BATHTUB model.

BATHTUB Tributary	Load Allocation Line Item	Load Allocation Load Type
Rainy River (430)	Big Falls WWTP	Wasteload
	Bigfork WWTP	
	Effie WWTP	
	DNR Scenic State Park	
	Northome WWTP	
	Berger Horticultural Products – Pine Island Bog	
	Cook WWTP	
	ISD 2142 Pre-Kindergarten to Grade 12 N School	
	Littlefork WWTP	
	US Steel – Minntac Tailings Basin Area	
	Hibbing Taconite Co – Tails Basin Area	
	Anchor Bay Mobile Home Park	
	Barwick WWTP	
	Baudette WWTP	
	Boise White Paper LLC – Intl Falls	
	Emo WWTP	
	Fort Frances WWTP	
	ISD 363 – Indus School	
	North Koochiching Area Sanitary District WWTP	
	Rainy River WWTP	
	Abitibi	
	Rainy Lake	Load
	Little Fork River	
	Big Fork River	
	Rapid River	
	Lower Rainy HUC-8 Tributaries (numerous)	
	Fort Frances	Reserve Capacity
	New Gold Mine	
Williams Creek (County Ditch 1; 211)	Williams WWTP	Wasteload
	Reach 211	Load

Appendix H. BATHTUB Model Input: .btb Files

This appendix includes the text files that correspond to the calibrated existing conditions and proposed conditions BATHTUB models. A text editor can be used to save the text from this appendix as two separate .btb files, which can then be read by BATHTUB.

H.1 Calibrated Existing Conditions BATHTUB Model

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16,"TOTAL P",80.542,.054
16,"TOTAL N",1115.996,49.162
16,"ORTHO P",37.73,.067
16,"INORGANIC N",251.659,96.732
16,"LandUses",0,0,0,0,0,0,0,0
17,"South Branch Zippel Creek (213)",2,1,21.2,4.298,.102,0
17,"CONSERVATIVE SUBST.",0,0
17,"TOTAL P",173.095,.077
17,"TOTAL N",1815.229,64.194
17,"ORTHO P",103.51,.086
17,"INORGANIC N",464.733,56.379
17,"LandUses",0,0,0,0,0,0,0,0
18,"West Branch Zippel Creek (203)",2,1,99.7,17.586,.11,0
18,"CONSERVATIVE SUBST.",0,0
18,"TOTAL P",107.338,.053
18,"TOTAL N",1463.498,40.149
18,"ORTHO P",47.532,.07
18,"INORGANIC N",224.18,41.011
18,"LandUses",0,0,0,0,0,0,0,0
19,"Reach 201",2,1,33.2,5.188,.15,0

19,"CONSERVATIVE SUBST.",0,0
19,"TOTAL P",81.002,.054
19,"TOTAL N",1161.704,49.58
19,"ORTHO P",31.942,.062
19,"INORGANIC N",148.341,43.765
19,"LandUses",0,0,0,0,0,0,0,0
20,"Reach 191",2,1,57.4,9.31,.145,0
20,"CONSERVATIVE SUBST.",0,0
20,"TOTAL P",134.927,.031
20,"TOTAL N",1853.924,21.385
20,"ORTHO P",59.24,.044
20,"INORGANIC N",283.743,26.352
20,"LandUses",0,0,0,0,0,0,0,0
21,"Reach 181",4,1,40.4,6.665,.143,0
21,"CONSERVATIVE SUBST.",0,0
21,"TOTAL P",106.278,.065
21,"TOTAL N",1270.704,60.514
21,"ORTHO P",55.872,.071
21,"INORGANIC N",238.173,55.908
21,"LandUses",0,0,0,0,0,0,0,0
22,"Reach 171",4,1,5.9,1.05,.134,0
22,"CONSERVATIVE SUBST.",0,0
22,"TOTAL P",156.699,.057
22,"TOTAL N",1895.572,49.786
22,"ORTHO P",83.354,.062
22,"INORGANIC N",380.896,38.184
22,"LandUses",0,0,0,0,0,0,0,0
23,"Willow Creek (161)",4,1,71.6,12.833,.108,0
23,"CONSERVATIVE SUBST.",0,0
23,"TOTAL P",105.403,.057
23,"TOTAL N",1534.985,26.162
23,"ORTHO P",62.208,.06
23,"INORGANIC N",233.039,25.875
23,"LandUses",0,0,0,0,0,0,0,0
24,"Reach 151",4,1,12.1,2.054,.134,0
24,"CONSERVATIVE SUBST.",0,0
24,"TOTAL P",132.843,.091
24,"TOTAL N",1400.36,73.876
24,"ORTHO P",80.078,.105
24,"INORGANIC N",331.294,71.513
24,"LandUses",0,0,0,0,0,0,0,0
25,"Reach 141",4,1,24.8,3.866,.142,0
25,"CONSERVATIVE SUBST.",0,0
25,"TOTAL P",118.379,.064
25,"TOTAL N",1474.602,49.556
25,"ORTHO P",59.52,.081
25,"INORGANIC N",267.285,47.548
25,"LandUses",0,0,0,0,0,0,0,0
26,"Reach 131",4,1,10,1.676,.136,0
26,"CONSERVATIVE SUBST.",0,0
26,"TOTAL P",176.094,.079
26,"TOTAL N",1983.201,57.149
26,"ORTHO P",103.846,.094
26,"INORGANIC N",497.753,50.43
26,"LandUses",0,0,0,0,0,0,0,0
27,"Reach 121",4,1,24.7,3.868,.141,0
27,"CONSERVATIVE SUBST.",0,0
27,"TOTAL P",119.044,.056
27,"TOTAL N",1528.4,41.774
27,"ORTHO P",57.166,.073
27,"INORGANIC N",255.931,42.187
27,"LandUses",0,0,0,0,0,0,0,0
28,"Reach 113",4,1,38.4,6.834,.126,0
28,"CONSERVATIVE SUBST.",0,0
28,"TOTAL P",146.872,.059
28,"TOTAL N",1751.19,41.748
28,"ORTHO P",77.404,.078
28,"INORGANIC N",320.13,49.723
28,"LandUses",0,0,0,0,0,0,0,0
29,"Warroad River (70)",4,1,716.3,111.483,.123,0
29,"CONSERVATIVE SUBST.",0,0
29,"TOTAL P",58.894,.086
29,"TOTAL N",710.137,80.072
29,"ORTHO P",27.493,.094
29,"INORGANIC N",116.19,53.51
29,"LandUses",0,0,0,0,0,0,0,0
30,"Stony Creek (301)",2,1,176.3,24.097,.171,0
30,"CONSERVATIVE SUBST.",0,0
30,"TOTAL P",30.957,.103
30,"TOTAL N",578.29,76.175
30,"ORTHO P",6.867,.106
30,"INORGANIC N",78.415,117.602
30,"LandUses",0,0,0,0,0,0,0,0
31,"Northwest Angle Inlet (312)",5,1,378.9,46.435,.196,0
31,"CONSERVATIVE SUBST.",0,0
31,"TOTAL P",28.593,.054
31,"TOTAL N",179.639,115.826
31,"ORTHO P",25.559,.068
31,"INORGANIC N",82.774,99.531
31,"LandUses",0,0,0,0,0,0,0,0
32,"Sabaskong East Septics (988)",1,3,0,.0070445,0,0
32,"CONSERVATIVE SUBST.",0,0
32,"TOTAL P",3180.852,0
32,"TOTAL N",46186.74,0
32,"ORTHO P",1738.522,0
32,"INORGANIC N",35768.48,0
32,"LandUses",0,0,0,0,0,0,0,0
33,"Sabaskong West Septics (989)",1,3,0,.0409705,0,0
33,"CONSERVATIVE SUBST.",0,0
33,"TOTAL P",3182.966,0
33,"TOTAL N",46217.77,0
33,"ORTHO P",1740.39,0
33,"INORGANIC N",35790.93,0
33,"LandUses",0,0,0,0,0,0,0,0
34,"Four Mile Septics (997)",3,3,0,.0337573,0,0
34,"CONSERVATIVE SUBST.",0,0
34,"TOTAL P",3182.562,0
34,"TOTAL N",46211.16,0
34,"ORTHO P",1739.918,0
34,"INORGANIC N",35786.13,0
34,"LandUses",0,0,0,0,0,0,0,0
35,"Big Traverse Septics (997)",2,3,0,.1042519,0,0
35,"CONSERVATIVE SUBST.",0,0
35,"TOTAL P",3182.562,0
35,"TOTAL N",46211.16,0
35,"ORTHO P",1739.918,0
35,"INORGANIC N",35786.13,0
35,"LandUses",0,0,0,0,0,0,0,0
36,"Muskeg Septics (997)",4,3,0,.0061825,0,0
36,"CONSERVATIVE SUBST.",0,0
36,"TOTAL P",3182.562,0
36,"TOTAL N",46211.16,0
36,"ORTHO P",1739.918,0
36,"INORGANIC N",35786.13,0
36,"LandUses",0,0,0,0,0,0,0,0
37,"Muskeg Springsteel PS (997)",4,3,0,.0042126,0,0
37,"CONSERVATIVE SUBST.",0,0
37,"TOTAL P",1290.09,0
37,"TOTAL N",16542.99,0
37,"ORTHO P",854.856,0
37,"INORGANIC N",15123.38,0
37,"LandUses",0,0,0,0,0,0,0,0
38,"Little Traverse South Septics (998)",5,3,0,.0273952,0,0
38,"CONSERVATIVE SUBST.",0,0

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38,"TOTAL P",3188.946,0
38,"TOTAL N",46292.7,0
38,"ORTHO P",1743.489,0
38,"INORGANIC N",35849.98,0
38,"LandUses",0,0,0,0,0,0,0,0
39,"Little Traverse North Septics (999)",5,3,0,.0070934,0,0
39,"CONSERVATIVE SUBST.",0,0
39,"TOTAL P",3184.493,0
39,"TOTAL N",46226.3,0
39,"ORTHO P",1739.321,0
39,"INORGANIC N",35803.16,0
39,"LandUses",0,0,0,0,0,0,0,0
40,"Four Mile Shoreline Erosion (997)",3,3,0,.0001305,0,0
40,"CONSERVATIVE SUBST.",0,0
40,"TOTAL P",7.2E+07,0
40,"TOTAL N",1.223E+09,0
40,"ORTHO P",0,0
40,"INORGANIC N",0,0
40,"LandUses",0,0,0,0,0,0,0,0
41,"Big Traverse Shoreline Erosion (997)",2,3,0,.0005,0,0
41,"CONSERVATIVE SUBST.",0,0
41,"TOTAL P",7.2E+07,0
41,"TOTAL N",1.223E+09,0
41,"ORTHO P",0,0
41,"INORGANIC N",0,0
41,"LandUses",0,0,0,0,0,0,0,0
42,"Muskeg Shoreline Erosion (997)",4,3,0,.0003695,0,0
42,"CONSERVATIVE SUBST.",0,0
42,"TOTAL P",7.2E+07,0
42,"TOTAL N",1.223E+09,0
42,"ORTHO P",0,0
42,"INORGANIC N",0,0
42,"LandUses",0,0,0,0,0,0,0,0
1,"Channels"
1,"Sabaskong-Big Traverse",1,2,58.242,0,0,0
8,"Land Use Export Categories"
1,"landuse1"
1,"Runoff",0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",0,0
1,"TOTAL N",0,0
1,"ORTHO P",0,0
1,"INORGANIC N",0,0
2,"landuse2"
2,"Runoff",0,0
2,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",0,0
2,"TOTAL N",0,0
2,"ORTHO P",0,0
2,"INORGANIC N",0,0
3,"landuse3"
3,"Runoff",0,0
3,"CONSERVATIVE SUBST.",0,0
3,"TOTAL P",0,0
3,"TOTAL N",0,0
3,"ORTHO P",0,0
3,"INORGANIC N",0,0
4,"landuse4"
4,"Runoff",0,0
4,"CONSERVATIVE SUBST.",0,0
4,"TOTAL P",0,0
4,"TOTAL N",0,0
4,"ORTHO P",0,0
4,"INORGANIC N",0,0
5,""
5,"Runoff",0,0
5,"CONSERVATIVE SUBST.",0,0
5,"TOTAL P",0,0
5,"TOTAL N",0,0
5,"ORTHO P",0,0
5,"INORGANIC N",0,0
6,""
6,"Runoff",0,0
6,"CONSERVATIVE SUBST.",0,0
6,"TOTAL P",0,0
6,"TOTAL N",0,0
6,"ORTHO P",0,0
6,"INORGANIC N",0,0
7,""
7,"Runoff",0,0
7,"CONSERVATIVE SUBST.",0,0
7,"TOTAL P",0,0
7,"TOTAL N",0,0
7,"ORTHO P",0,0
7,"INORGANIC N",0,0
8,""
8,"Runoff",0,0
8,"CONSERVATIVE SUBST.",0,0
8,"TOTAL P",0,0
8,"TOTAL N",0,0
8,"ORTHO P",0,0
8,"INORGANIC N",0,0
"Notes"
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End of BATHTUB file – do not include this line in the .btb file. The “Notes” line near the end of the .btb file should be Line 465, and 11 empty lines should follow Line 465 (466–476) at the end of the file. Tests showed that removing these lines from the .btb file resulted in an “Input File Error” from BATHTUB.

H.2 Proposed Conditions BATHTUB Model

Vers 6.14f (04/28/2015)
Default Case
4,"Global Parameters"
1,"AVERAGING PERIOD (YRS)",1,0
2,"PRECIPITATION (METERS)",.6084,.2
3,"EVAPORATION (METERS)",.652,.3
4,"INCREASE IN STORAGE (METERS)",0,0
12,"Model Options"
1,"CONSERVATIVE SUBSTANCE",0
2,"PHOSPHORUS BALANCE",2
3,"NITROGEN BALANCE",2
4,"CHLOROPHYLL-A",4
5,"SECCHI DEPTH",1
6,"DISPERSION",1
7,"PHOSPHORUS CALIBRATION",2
8,"NITROGEN CALIBRATION",2
9,"ERROR ANALYSIS",1
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",1,.45
3,"N DECAY RATE",1,.55
4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",.33,0
15,"Avail Factor - Ortho P",1.93,0
16,"Avail Factor - TN",.59,0
17,"Avail Factor - Inorganic N",.79,0
5,"Atmospheric Loads"
1,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",19.3,.5
3,"TOTAL N",532.4,.5
4,"ORTHO P",19.3,.5
5,"INORGANIC N",532.4,.5
5,"Segments"
1,"Sabaskong",5,1,512.77,3.638,23,3.638,0,0,0,.61,.2,0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",0,0
1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,1,0
1,"TOTAL P MG/M3",26.9,.35,.9405578,0
1,"TOTAL N MG/M3",0,0,1,0
1,"CHL-A MG/M3",6.4,1.7,.8498427,0
1,"SECCHI M",1.3,.4,1,0
1,"ORGANIC N MG/M3",0,0,1,0
1,"TP-ORTHO-P MG/M3",0,0,1,0
1,"HOD-V MG/M3-DAY",0,0,1,0
1,"MOD-V MG/M3-DAY",0,0,1,0
2,"Big Traverse",5,1,1242.97,8.18,40,8.18,0,0,0,.69,.07,0,0
2,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",.3645,0
2,"TOTAL N",0,0
2,"CONSERVATIVE SUB",0,0,1,0
2,"TOTAL P MG/M3",35.707,.049,1.239632,0
2,"TOTAL N MG/M3",683.056,0,1.240826,0
2,"CHL-A MG/M3",9.337,.202,.933816,0
2,"SECCHI M",1.171,.056,1,0
2,"ORGANIC N MG/M3",633.056,.028,1,0
2,"TP-ORTHO-P MG/M3",24.007,0,1,0
2,"HOD-V MG/M3-DAY",0,0,1,0
2,"MOD-V MG/M3-DAY",0,0,1,0
3,"Four Mile",2,1,30.18,1,3,1,0,0,0,.66,.15,0,0
3,"CONSERVATIVE SUBST.",0,0
3,"TOTAL P",3.3075,0
3,"TOTAL N",0,0
3,"CONSERVATIVE SUB",0,0,1,0
3,"TOTAL P MG/M3",32.95,.051,1.143646,0
3,"TOTAL N MG/M3",660.667,0,1.19993,0
3,"CHL-A MG/M3",5.214,.151,.5651953,0
3,"SECCHI M",1.344,.142,1,0
3,"ORGANIC N MG/M3",606.667,.057,1,0
3,"TP-ORTHO-P MG/M3",23.75,0,1,0
3,"HOD-V MG/M3-DAY",0,0,1,0
3,"MOD-V MG/M3-DAY",0,0,1,0
4,"Muskeg",2,1,189.19,5.59,13.5,5.59,0,0,0,.67,.13,0,0
4,"CONSERVATIVE SUBST.",0,0
4,"TOTAL P",.126,0
4,"TOTAL N",0,0
4,"CONSERVATIVE SUB",0,0,1,0
4,"TOTAL P MG/M3",37.65,.071,1.288107,0
4,"TOTAL N MG/M3",683.158,0,1.202299,0
4,"CHL-A MG/M3",12.239,.285,1.161725,0
4,"SECCHI M",1.06,.054,1,0
4,"ORGANIC N MG/M3",633.158,.062,1,0
4,"TP-ORTHO-P MG/M3",30.507,0,1,0
4,"HOD-V MG/M3-DAY",0,0,1,0
4,"MOD-V MG/M3-DAY",0,0,1,0
5,"Little Traverse",0,1,688.48,4.61,20,4.61,0,0,0,.59,.11,0,0
5,"CONSERVATIVE SUBST.",0,0
5,"TOTAL P",.003375,0
5,"TOTAL N",0,0
5,"CONSERVATIVE SUB",0,0,1,0
5,"TOTAL P MG/M3",33.585,.043,1.166192,0
5,"TOTAL N MG/M3",711.951,0,1.294252,0
5,"CHL-A MG/M3",9.477,.112,1.008158,0
5,"SECCHI M",1.389,.112,1,0
5,"ORGANIC N MG/M3",661.951,.029,1,0
5,"TP-ORTHO-P MG/M3",26.04,0,1,0
5,"HOD-V MG/M3-DAY",0,0,1,0
5,"MOD-V MG/M3-DAY",0,0,1,0
47,"Tributaries"
1,"Sabaskong East Lakeshed Loading
(988)",1,1,265.1,33.337,0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",61.736,0
1,"TOTAL N",1157.477,0
1,"ORTHO P",9.726,0
1,"INORGANIC N",77.317,0
1,"LandUses",0,0,0,0,0,0,0,0
2,"Sabaskong West Lakeshed Loading
(989)",1,1,259.3,28.069,0,0
2,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",64.995,0
2,"TOTAL N",1192.249,0
2,"ORTHO P",12.482,0
2,"INORGANIC N",104.122,0

2,"LandUses",0,0,0,0,0,0,0,0
3,"Four Mile Lakeshed Loading (997)",3,1,207.3,28.695,0,0
3,"CONSERVATIVE SUBST.",0,0
3,"TOTAL P",69.297,0
3,"TOTAL N",1329.903,0
3,"ORTHO P",9.379,0
3,"INORGANIC N",82.027,0
3,"LandUses",0,0,0,0,0,0,0,0
4,"Big Traverse Lakeshed Loading (997)",2,1,640.2,88.617,0,0
4,"CONSERVATIVE SUBST.",0,0
4,"TOTAL P",69.297,0
4,"TOTAL N",1329.903,0
4,"ORTHO P",9.379,0
4,"INORGANIC N",82.027,0
4,"LandUses",0,0,0,0,0,0,0,0
5,"Muskeg Lakeshed Loading (997)",4,1,38,5.255,0,0
5,"CONSERVATIVE SUBST.",0,0
5,"TOTAL P",69.297,0
5,"TOTAL N",1329.903,0
5,"ORTHO P",9.379,0
5,"INORGANIC N",82.027,0
5,"LandUses",0,0,0,0,0,0,0,0
6,"Little Traverse South Lakeshed Loading
(998)",5,1,366,45.471,0,0
6,"CONSERVATIVE SUBST.",0,0
6,"TOTAL P",61.672,0
6,"TOTAL N",1268.598,0
6,"ORTHO P",4.07,0
6,"INORGANIC N",68.98,0
6,"LandUses",0,0,0,0,0,0,0,0
7,"Little Traverse North Lakeshed Loading
(999)",5,1,263.5,30.547,0,0
7,"CONSERVATIVE SUBST.",0,0
7,"TOTAL P",63.243,0
7,"TOTAL N",1285.735,0
7,"ORTHO P",4.97,0
7,"INORGANIC N",73.315,0
7,"LandUses",0,0,0,0,0,0,0,0
8,"Sabaskong River (45)",1,1,483,69.507,.184,0
8,"CONSERVATIVE SUBST.",0,0
8,"TOTAL P",32.121,.061
8,"TOTAL N",753.357,49.196
8,"ORTHO P",14.452,.058
8,"INORGANIC N",290.656,63.537
8,"LandUses",0,0,0,0,0,0,0,0
9,"Splitrock River (49)",1,1,176,23.289,.169,0
9,"CONSERVATIVE SUBST.",0,0
9,"TOTAL P",52.727,.068
9,"TOTAL N",1026.136,46.324
9,"ORTHO P",12.121,.08
9,"INORGANIC N",100.999,27.727
9,"LandUses",0,0,0,0,0,0,0,0
10,"Thompson Creek (17)",1,1,110.9,21.768,.192,0
10,"CONSERVATIVE SUBST.",0,0
10,"TOTAL P",35.821,.03
10,"TOTAL N",528.402,42.415
10,"ORTHO P",15.875,.019
10,"INORGANIC N",92.178,38.693
10,"LandUses",0,0,0,0,0,0,0,0
11,"Obabikon Lake (14)",1,1,96.1,20.455,.13,0
11,"CONSERVATIVE SUBST.",0,0
11,"TOTAL P",22.376,.006
11,"TOTAL N",207.822,29.232
11,"ORTHO P",17.827,.007
11,"INORGANIC N",114.601,44.934
11,"LandUses",0,0,0,0,0,0,0,0
12,"Big Grassy River (13)",1,1,153.9,21.384,.159,0
12,"CONSERVATIVE SUBST.",0,0
12,"TOTAL P",51.824,.064
12,"TOTAL N",1005.457,42.865
12,"ORTHO P",12.38,.085
12,"INORGANIC N",99.716,25.625
12,"LandUses",0,0,0,0,0,0,0,0
13,"Little Grassy River (11)",1,1,307.5,37.468,.269,0
13,"CONSERVATIVE SUBST.",0,0
13,"TOTAL P",62.284,.06
13,"TOTAL N",1134.405,39.285
13,"ORTHO P",17.688,.077
13,"INORGANIC N",140.491,52.629
13,"LandUses",0,0,0,0,0,0,0,0
14,"Rainy River (430)",3,1,54686.1,12738.66,.092,0
14,"CONSERVATIVE SUBST.",0,0
14,"TOTAL P",24.41398,.036
14,"TOTAL N",559.635,34.79
14,"ORTHO P",12.2176,.045
14,"INORGANIC N",291.744,51.906
14,"LandUses",0,0,0,0,0,0,0,0
15,"Bostick River (231)",3,1,142,25.676,.107,0
15,"CONSERVATIVE SUBST.",0,0
15,"TOTAL P",50,.048
15,"TOTAL N",870.087,32.57
15,"ORTHO P",32.1,.068
15,"INORGANIC N",108.803,48.287
15,"LandUses",0,0,0,0,0,0,0,0
16,"Reach 211",2,1,80.2,14.088,.111,0
16,"CONSERVATIVE SUBST.",0,0
16,"TOTAL P",50,.054
16,"TOTAL N",1115.996,49.162
16,"ORTHO P",37.73,.067
16,"INORGANIC N",251.659,96.732
16,"LandUses",0,0,0,0,0,0,0,0
17,"South Branch Zippel Creek (213)",2,1,21.2,4.298,.102,0
17,"CONSERVATIVE SUBST.",0,0
17,"TOTAL P",50,.077
17,"TOTAL N",1815.229,64.194
17,"ORTHO P",50,.086
17,"INORGANIC N",464.733,56.379
17,"LandUses",0,0,0,0,0,0,0,0
18,"West Branch Zippel Creek (203)",2,1,99.7,17.586,.11,0
18,"CONSERVATIVE SUBST.",0,0
18,"TOTAL P",50,.053
18,"TOTAL N",1463.498,40.149
18,"ORTHO P",47.532,.07
18,"INORGANIC N",224.18,41.011
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19,"Reach 201",2,1,33.2,5.188,.15,0
19,"CONSERVATIVE SUBST.",0,0
19,"TOTAL P",50,.054
19,"TOTAL N",1161.704,49.58
19,"ORTHO P",31.942,.062
19,"INORGANIC N",148.341,43.765
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20,"TOTAL N",1853.924,21.385
20,"ORTHO P",50,.044
20,"INORGANIC N",283.743,26.352
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21,"TOTAL N",1270.704,60.514
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21,"INORGANIC N",238.173,55.908
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22,"TOTAL N",1895.572,49.786
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29,"TOTAL N",710.137,80.072
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34,"TOTAL N",46211.16,0
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43,"ORTHO P",5.34123E+09,0
43,"INORGANIC N",1.01543E-04,0
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Notes"
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file. The “Notes” line near the end of the .btb file should be Line 500, and 11 empty lines should follow Line 500 (501-511) at the end of the file. Tests showed that removing these lines from the .btb file resulted in an “Input File Error” from BATHTUB.

Appendix I. BATHTUB Output

This appendix includes output from the existing conditions and proposed BATHTUB models. Output includes the water balances and TP mass balances.

I.1 Calibrated Existing Conditions Model Output

Filename: 20180115 - Existing Conditions.btb

Tributary	Segment	Name	Area (km^2)	Water Balance: Flow ($hm^3\ y^{-1}$)	Water Balance: Variance ($(hm^3\ y^{-1})^2$)	Water Balance: Coefficient of Variation	Water Balance: Runoff ($m\ y^{-1}$)	Phosphorus Balance: Load: kg yr^{-1}	Phosphorus Balance: Load: % of total	Phosphorus Balance: Load Variance: $(kg\ yr^{-1})^2$	Phosphorus Balance: Load Variance: % of total	Phosphorus Balance: Load Variance: CV	Phosphorus Balance: Concentration ($mg\ m^{-3}$)	Phosphorus Balance: Export ($kg\ km^{-2}\ yr^{-1}$)
1	1	Sabaskong East Lakeshed Loading (988)	265.1	33.3	0.00E+00	0.00	0.13	2058.1	0.3	0		0	61.7	7.8
2	1	Sabaskong West Lakeshed Loading (989)	259.3	28.1	0.00E+00	0.00	0.11	1824.3	0.2	0		0	65.0	7.0
3	3	Four Mile Lakeshed Loading (997)	207.3	28.7	0.00E+00	0.00	0.14	1988.5	0.2	0		0	69.3	9.6
4	2	Big Traverse Lakeshed Loading (997)	640.2	88.6	0.00E+00	0.00	0.14	6140.9	0.8	0		0	69.3	9.6
5	4	Muskeg Lakeshed Loading (997)	38.0	5.3	0.00E+00	0.00	0.14	364.2	0.0	0		0	69.3	9.6
6	5	Little Traverse South Lakeshed Loading (998)	366.0	45.5	0.00E+00	0.00	0.12	2804.3	0.3	0		0	61.7	7.7
7	5	Little Traverse North Lakeshed Loading (999)	263.5	30.5	0.00E+00	0.00	0.12	1931.9	0.2	0		0	63.2	7.3
8	1	Sabaskong River (45)	483.0	69.5	1.64E+02	0.18	0.14	2232.6	0.3	1.9E+05	0.0	0.19	32.1	4.6
9	1	Splitrock River (49)	176.0	23.3	1.55E+01	0.17	0.13	1228.0	0.2	5.0E+04	0.0	0.18	52.7	7.0
10	1	Thompson Creek (17)	110.9	21.8	1.75E+01	0.19	0.20	779.8	0.1	2.3E+04	0.0	0.19	35.8	7.0
11	1	Obabikon Lake (14)	96.1	20.5	7.07E+00	0.13	0.21	457.7	0.1	3.6E+03	0.0	0.13	22.4	4.8
12	1	Big Grassy River (13)	153.9	21.4	1.16E+01	0.16	0.14	1108.2	0.1	3.6E+04	0.0	0.17	51.8	7.2
13	1	Little Grassy River (11)	307.5	37.5	1.02E+02	0.27	0.12	2333.7	0.3	4.1E+05	0.0	0.28	62.3	7.6
14	3	Rainy River (430)	54686.1	12738.7	1.37E+06	0.09	0.23	362681	44.5	1.3E+09	66.0	0.10	28.5	6.6
15	3	Bostick River (231)	142.0	25.7	7.55E+00	0.11	0.18	1783.9	0.2	4.4E+04	0.0	0.12	69.5	12.6
16	2	Reach 211	80.2	14.1	2.45E+00	0.11	0.18	1134.7	0.1	2.0E+04	0.0	0.12	80.5	14.1
17	2	South Branch Zippel Creek (213)	21.2	4.3	1.92E-01	0.10	0.20	744.0	0.1	9.0E+03	0.0	0.13	173.1	35.1
18	2	West Branch Zippel Creek (203)	99.7	17.6	3.74E+00	0.11	0.18	1887.6	0.2	5.3E+04	0.0	0.12	107.3	18.9
19	2	Reach 201	33.2	5.2	6.06E-01	0.15	0.16	420.2	0.1	4.5E+03	0.0	0.16	81.0	12.7
20	2	Reach 191	57.4	9.3	1.82E+00	0.14	0.16	1256.2	0.2	3.5E+04	0.0	0.15	134.9	21.9
21	4	Reach 181	40.4	6.7	9.08E-01	0.14	0.16	708.3	0.1	1.2E+04	0.0	0.16	106.3	17.5
22	4	Reach 171	5.9	1.0	1.98E-02	0.13	0.18	164.5	0.0	5.7E+02	0.0	0.15	156.7	27.9
23	4	Willow Creek (161)	71.6	12.8	1.92E+00	0.11	0.18	1352.6	0.2	2.7E+04	0.0	0.12	105.4	18.9
24	4	Reach 151	12.1	2.1	7.58E-02	0.13	0.17	272.9	0.0	2.0E+03	0.0	0.16	132.8	22.6
25	4	Reach 141	24.8	3.9	3.01E-01	0.14	0.16	457.7	0.1	5.1E+03	0.0	0.16	118.4	18.5
26	4	Reach 131	10.0	1.7	5.20E-02	0.14	0.17	295.1	0.0	2.2E+03	0.0	0.16	176.1	29.5
27	4	Reach 121	24.7	3.9	2.97E-01	0.14	0.16	460.5	0.1	4.9E+03	0.0	0.15	119.0	18.6
28	4	Reach 113	38.4	6.8	7.41E-01	0.13	0.18	1003.7	0.1	2.0E+04	0.0	0.14	146.9	26.1
29	4	Warroad River (70)	716.3	111.5	1.88E+02	0.12	0.16	6565.7	0.8	9.7E+05	0.0	0.15	58.9	9.2
30	2	Stony Creek (301)	176.3	24.1	1.70E+01	0.17	0.14	746.0	0.1	2.2E+04	0.0	0.20	31.0	4.2
31	5	Northwest Angle Inlet (312)	378.9	46.4	8.28E+01	0.20	0.12	1327.7	0.2	7.3E+04	0.0	0.20	28.6	3.5
32	1	Sabaskong East Septics (988)		0.0	0.00E+00	0.00		22.4	0.0	0		0.00	3180.9	
33	1	Sabaskong West Septics (989)		0.0	0.00E+00	0.00		130.4	0.0	0		0.00	3183.0	
34	3	Four Mile Septics (997)		0.0	0.00E+00	0.00		107.4	0.0	0		0.00	3182.6	
35	2	Big Traverse Septics (997)		0.1	0.00E+00	0.00		331.8	0.0	0		0.00	3182.6	
36	4	Muskeg Septics (997)		0.0	0.00E+00	0.00		19.7	0.0	0		0.00	3182.6	
37	4	Muskeg Springsteel PS (997)		0.0	0.00E+00	0.00		5.4	0.0	0		0.00	1290.1	
38	5	Little Traverse South Septics (998)		0.0	0.00E+00	0.00		87.4	0.0	0		0.00	3188.9	

Tributary	Segment	Name	Area (km²)	Water Balance				Phosphorus Balance							
				Flow ($hm^3\ y^{-1}$)	Variance ($(hm^3\ y^{-1})^2$)	Coefficient of Variation	Runoff ($m\ y^{-1}$)	Load		Load Variance			Concentration ($mg\ m^{-3}$)	Export ($kg\ km^{-2}\ yr^{-1}$)
								$kg\ yr^{-1}$	% of total	$(kg\ yr^{-1})^2$	% of total	CV		
39	5	Little Traverse North Septics (999)		0.0	0.00E+00	0.00		22.6	0.0	0		0.00	3184.5	
40	3	Four Mile Shoreline Erosion (997)		0.0	0.00E+00	0.00		9396.0	1.2	0		0.00	72000000.0	
41	2	Big Traverse Shoreline Erosion (997)		0.0	0.00E+00	0.00		36000	4.4	0		0.00	72000000.0	
42	4	Muskeg Shoreline Erosion (997)		0.0	0.00E+00	0.00		26604	3.3	0		0.00	72000000.0	
Precipitation			2663.6	1620.5	1.05E+05	0.20	0.61	51407	6.3	6.6E+08	33.9	0.50	31.7	19.3
Internal Load								281994.6	34.6	0		0.00		
Tributary Load			59986.0	13489.5	1.37E+06	0.09	0.22	408514.3	50.1	1.3E+09	66.1	0.09	30.3	6.8
Point-Source Inflow				0.2	0.00E+00	0.00		72727.1	8.9	0		0.00	313603.4	
TOTAL INFLOW			62649.6	15110.3	1.48E+06	0.08	0.24	814643.4	100.0	2.0E+09	100.0	0.05	53.9	13.0
Advective Outflow			62649.6	13373.6	1.75E+06	0.10	0.21	448971.2	55.1	2.2E+11		1.05	33.6	7.2
TOTAL OUTFLOW			62649.6	13373.6	1.75E+06	0.10	0.21	448971.2	55.1	2.2E+11		1.05	33.6	7.2
Retention				1736.7	2.71E+05	0.30		365672.2	44.9	2.2E+11		1.29		

I.2 Proposed Conditions Model Output

Filename: 20200215 - Proposed Reductions - Draft LA Table v8.btb

Tributary	Segment	Name	Area (km^2)	Water Balance				Phosphorus Balance						
				Flow (hm^3 y^{-1})	Variance (hm^3 y^{-1})^2	Coefficient of Variation	Runoff (m y^{-1})	Load		Load Variance			Concentration (mg m^{-3})	Export (kg km^{-2} yr^{-1})
								kg yr^{-1}	% of total	(kg yr^{-1})^2	% of total	CV		
1	1	Sabaskong East Lakeshed Loading (988)	265.1	33.3	0.00E+00	0.00	0.13	2058.1	0.3%	0.00E+00		0.00	61.7	7.8
2	1	Sabaskong West Lakeshed Loading (989)	259.3	28.1	0.00E+00	0.00	0.11	1824.3	0.3%	0.00E+00		0.00	65.0	7.0
3	3	Four Mile Lakeshed Loading (997)	207.3	28.7	0.00E+00	0.00	0.14	1988.5	0.3%	0.00E+00		0.00	69.3	9.6
4	2	Big Traverse Lakeshed Loading (997)	640.2	88.6	0.00E+00	0.00	0.14	6140.9	0.9%	0.00E+00		0.00	69.3	9.6
5	4	Muskeg Lakeshed Loading (997)	38.0	5.3	0.00E+00	0.00	0.14	364.2	0.1%	0.00E+00		0.00	69.3	9.6
6	5	Little Traverse South Lakeshed Loading (998)	366.0	45.5	0.00E+00	0.00	0.12	2804.3	0.4%	0.00E+00		0.00	61.7	7.7
7	5	Little Traverse North Lakeshed Loading (999)	263.5	30.5	0.00E+00	0.00	0.12	1931.9	0.3%	0.00E+00		0.00	63.2	7.3
8	1	Sabaskong River (45)	483.0	69.5	1.64E+02	0.18	0.14	2232.6	0.3%	1.87E+05	0.0	0.19	32.1	4.6
9	1	Splitrock River (49)	176.0	23.3	1.55E+01	0.17	0.13	1228.0	0.2%	5.00E+04	0.0	0.18	52.7	7.0
10	1	Thompson Creek (17)	110.9	21.8	1.75E+01	0.19	0.20	779.8	0.1%	2.30E+04	0.0	0.19	35.8	7.0
11	1	Obabikon Lake (14)	96.1	20.5	7.07E+00	0.13	0.21	457.7	0.1%	3.55E+03	0.0	0.13	22.4	4.8
12	1	Big Grassy River (13)	153.9	21.4	1.16E+01	0.16	0.14	1108.2	0.2%	3.61E+04	0.0	0.17	51.8	7.2
13	1	Little Grassy River (11)	307.5	37.5	1.02E+02	0.27	0.12	2333.7	0.3%	4.14E+05	0.0	0.28	62.3	7.6
14	3	Rainy River (430)	54686.1	12738.7	1.37E+06	0.09	0.23	311001.4	43.8%	9.44E+08	58.8	0.10	24.4	5.7
15	3	Bostick River (231)	142.0	25.7	7.55E+00	0.11	0.18	1283.8	0.2%	2.27E+04	0.0	0.12	50.0	9.0
16	2	Reach 211	80.2	14.1	2.45E+00	0.11	0.18	704.4	0.1%	7.56E+03	0.0	0.12	50.0	8.8
17	2	South Branch Zippel Creek (213)	21.2	4.3	1.92E-01	0.10	0.20	214.9	0.0%	7.54E+02	0.0	0.13	50.0	10.1
18	2	West Branch Zippel Creek (203)	99.7	17.6	3.74E+00	0.11	0.18	879.3	0.1%	1.15E+04	0.0	0.12	50.0	8.8
19	2	Reach 201	33.2	5.2	6.06E-01	0.15	0.16	259.4	0.0%	1.71E+03	0.0	0.16	50.0	7.8
20	2	Reach 191	57.4	9.3	1.82E+00	0.14	0.16	465.5	0.1%	4.76E+03	0.0	0.15	50.0	8.1
21	4	Reach 181	40.4	6.7	9.08E-01	0.14	0.16	333.3	0.0%	2.74E+03	0.0	0.16	50.0	8.2
22	4	Reach 171	5.9	1.0	1.98E-02	0.13	0.18	52.5	0.0%	5.84E+01	0.0	0.15	50.0	8.9
23	4	Willow Creek (161)	71.6	12.8	1.92E+00	0.11	0.18	641.7	0.1%	6.14E+03	0.0	0.12	50.0	9.0
24	4	Reach 151	12.1	2.1	7.58E-02	0.13	0.17	102.7	0.0%	2.77E+02	0.0	0.16	50.0	8.5
25	4	Reach 141	24.8	3.9	3.01E-01	0.14	0.16	193.3	0.0%	9.06E+02	0.0	0.16	50.0	7.8
26	4	Reach 131	10.0	1.7	5.20E-02	0.14	0.17	83.8	0.0%	1.74E+02	0.0	0.16	50.0	8.4
27	4	Reach 121	24.7	3.9	2.97E-01	0.14	0.16	193.4	0.0%	8.61E+02	0.0	0.15	50.0	7.8
28	4	Reach 113	38.4	6.8	7.41E-01	0.13	0.18	341.7	0.0%	2.26E+03	0.0	0.14	50.0	8.9
29	4	Warroad River (70)	716.3	111.5	1.88E+02	0.12	0.16	5574.1	0.8%	7.00E+05	0.0	0.15	50.0	7.8
30	2	Stony Creek (301)	176.3	24.1	1.70E+01	0.17	0.14	746.0	0.1%	2.22E+04	0.0	0.20	31.0	4.2
31	5	Northwest Angle Inlet (312)	378.9	46.4	8.28E+01	0.20	0.12	1327.7	0.2%	7.29E+04	0.0	0.20	28.6	3.5
32	1	Sabaskong East Septics (988)		0.0	0.00E+00	0.00		22.4	0.0%	0.00E+00		0.00	3180.9	
33	1	Sabaskong West Septics (989)		0.0	0.00E+00	0.00		130.4	0.0%	0.00E+00		0.00	3183.0	
34	3	Four Mile Septics (997)		0.0	0.00E+00	0.00		21.5	0.0%	0.00E+00		0.00	636.5	
35	2	Big Traverse Septics (997)		0.1	0.00E+00	0.00		165.9	0.0%	0.00E+00		0.00	1591.3	
36	4	Muskeg Septics (997)		0.0	0.00E+00	0.00		0.0	0.0%	0.00E+00		0.00	0.0	
37	4	Muskeg Springsteel PS (997)		0.0	0.00E+00	0.00		10.4	0.0%	0.00E+00		0.00	2373.8	
38	5	Little Traverse South Septics (998)		0.0	0.00E+00	0.00		52.4	0.0%	0.00E+00		0.00	1913.4	

Tributary	Segment	Name	Area (km^2)	Water Balance				Phosphorus Balance						
				Flow ($hm^3\ y^{-1}$)	Variance ($(hm^3\ y^{-1})^2$)	Coefficient of Variation	Runoff ($m\ y^{-1}$)	Load		Load Variance			Concentration ($mg\ m^{-3}$)	Export ($kg\ km^{-2}\ yr^{-1}$)
								kg yr^{-1}	% of total	($(kg\ yr^{-1})^2$)	% of total	CV		
39	5	Little Traverse North Septics (999)		0.0	0.00E+00	0.00		18.1	0.0	0.00E+00		0.00	2547.6	
40	3	Four Mile Shoreline Erosion (997)		0.0	0.00E+00	0.00		7892.2	1.1	0.00E+00		0.00	60480000.0	
41	2	Big Traverse Shoreline Erosion (997)		0.0	0.00E+00	0.00		30240.0	4.3	0.00E+00		0.00	60480000.0	
42	4	Muskeg Shoreline Erosion (997)		0.0	0.00E+00	0.00		22347.8	3.1	0.00E+00		0.00	60480000.0	
43	3	Margin of Safety		0.0	0.00E+00	0.00		35608.1	5.0	0.00E+00		0.00	35608100864.0	
44	4	Marvin Windows & Doors		0.0	0.00E+00	0.00		4.0	0.0	0.00E+00		0.00	2468.8	
45	3	Industrial Stormwater		0.0	0.00E+00	0.00		193.9	0.0	0.00E+00		0.00	193850.0	
46	3	Construction Stormwater		0.0	0.00E+00	0.00		94.6	0.0	0.00E+00		0.00	94590.0	
47	3	Unsewered Communities		0.0	0.00E+00	0.00		167.0	0.0	0.00E+00		0.00	167000.0	
Precipitation			2663.6	1620.5	1.05E+05	0.20	0.61	51407.3	7.2	6.61E+08	41.1	0.50	31.7	19.3
Internal Load								211496.0	29.8	0.00E+00		0.00		
Tributary Load			59986.0	13489.5	1.37E+06	0.09	0.22	385452.9	54.3	6.61E+08	58.9	0.08	28.6	6.4
Point-Source Inflow				0.2	0.00E+00	0.00		61166.3	8.6	0.00E+00		0.00	259698.4	
TOTAL INFLOW			62649.6	15110.3	1.48E+06	0.08	0.24	709522.4	100.0	9.46E+08	100.0	0.06	47.0	11.3
Advective Outflow			62649.6	13373.6	1.75E+06	0.10	0.21	401911.6	56.6	1.22E+11		0.87	30.1	6.4
TOTAL OUTFLOW			62649.6	13373.6	1.75E+06	0.10	0.21	401911.6	56.6	1.22E+11		0.87	30.1	6.4
Retention				1736.7	2.71E+05	0.30		307610.8	43.4	1.22E+11		1.14		