Mississippi Headwaters Total Maximum Daily Loads for Little Turtle Lake and Lake Irving

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

RESPEC

CLEAN WATER LAND & LEGACY AMENDMENT

MINNESOTA POLLUTION CONTROL AGENCY

wq-iw8-57e

October 2018

Authors and Contributors:

Beltrami Soil and Water Conservation District

Bill Best
Brent Rudd

Bemidji State University

Steve Balmes
Pat Welle (Bemidji State University Emeritus))

Cass County Soil and Water Conservation District

John Ringle

City of Bemidji

Craig Gray
Nate Mathews
Shon Snopl

Clearwater Soil and Water Conservation District

Nathan Nordlund
Nick Phillips

Greater Bemidji Area Joint Planning Board

Josh Stearns

Headwaters Science Center

Susan Joy

Hubbard Soil and Water Conservation District

Jamin Carlson
Julie Kingsley

Itasca Soil and Water Conservation District

Kim Yankowiak

Leech Lake Band of Objibwe

Sam Malloy

Minnesota Board of Water and Soil Resources

Jeff Hrubes
Chad Severts

Minnesota Department of Health

Chris Parthun

Minnesota Department of Natural Resources

Dick Rossman
Andy Thompson
Dan Thul
Jaime Thibodeaux

Minnesota Department of Natural Resources (continued)
Rita Albrecht
Jennifer Corcoran
Michael Harris
Rian Reed
Tony Standera

Mississippi Headwaters Board
Tim Terrill

US Forest Service – Chippewa National Forest
David Morley

Turtle River Watershed Association
Carl Isaacson

Minnesota Pollution Control Agency
Kevin Stroom
Greg Van Eeckhout
Phil Votruba

RESPEC
Julie Blackburn
Cindie McCutcheon
Bruce Wilson

Table of Contents

List of Tables

List of Figures

List of Acronyms

AMA	Aquatic Management Area
BMP	best management practices
BOD	biochemical oxygen demand
BWSR	Board of Water and Soil Resources
Cfs	cubic feet per second
Chl-*a*	Chlorophyll-*a*
CWA	Clean Water Act
CWLA	Clean Water Legacy Act
DNR	Minnesota Department of Natural Resources
DO	dissolved oxygen
EIA	Effective impervious area
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
EQuIS	Environmental Quality Information System
GR	Geometry ratio
HSPF	Hydrologic Simulation Program–Fortran
Hm^3	Cubic hectometer
HSG	Hydrologic Soil Group
HUC	Hydrologic Unit Code
in/year	inches per year
kg/ha/year	kilogram per hectare per year
km^2	square kilometer
LA	Load allocation
LES	Lake eutrophication standard
LGU	Local governmental units
LID	low impact design
m	meter
m^2	square meter
m/year	meters per year
mg/L	milligrams per liter

$mg/m^2/day$	milligram per square meter per day
$mg/m^2/year$	milligram per square meter per year
MIDS	Minimal Impact Design Standards
MINLEAP	Minnesota Lake Eutrophication Analysis Procedure
mL	milliliter
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
MRCC	Midwestern Region Climate Center
MS4	Municipal Separate Storm Sewer System
NCHF	North Central Hardwood Forests
NHD	National Hydrography Dataset
NLCD	National Land Cover Database
NLF	Northern Lakes and Forests
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Services
P	Phosphorus
PDS	Partial duration series
PF	Precipitation frequency
PMP	Probable maximum precipitation
RC	Reserve capacity
RES	River Eutrophication Standards
SDS	State Disposal System
SSTS	Subsurface sewage treatment system
SWCD	Soil and Water Conservation District
SWPPP	Stormwater Pollution Prevention Plan
TMDL	Total Maximum Daily Load
TP	total phosphorus
TSI	Trophic State Index
TSS	Total suspended solids
µg/L	microgram per liter
USDA	U.S. Department of Agriculture

USGS	U.S. Geological Survey
WLA	Wasteload allocation
WRAPS	Watershed Restoration and Protection Strategy
WWTP	Wastewater Treatment Plant

Executive Summary

This report describes the impairments for Little Turtle Lake and Lake Irving, two impaired, natural lakes located in Beltrami County, Minnesota. The water quality of these two lakes does not meet state water quality standards, due to excess amounts of the plant nutrient phosphorus (P) that generates excess algae (small free-floating green plants) and reduces water clarity. Both of these lakes are part of a larger lake-river system: Lake Irving at Bemidji, Minnesota, receives the Mississippi River and discharges to Lake Bemidji; and Little Turtle Lake, north of Bemidji, is part of the Turtle River system that discharges to Turtle Lake and ultimately Cass Lake of the Mississippi River Headwaters. Cumulative river watershed P sources as well as legacy impacts that are generated from enriched lake sediments (referred to as internal P loading) affect the water quality of these impaired lakes. Both lakes are in the western basin of the Mississippi River Headwaters region above the large central basin lakes (Andrusia, Cass, and, Winnibigoshish). P quantity reductions that are required to attain water quality standards for Lake Irving and Little Turtle Lake were determined to be 57% and 33%, respectively.

Lake Bemidji was the subject of intense study in the late 1970s and 1980s; the city of Bemidji adopted stringent wastewater effluent P standards that resulted in improvement to the lake's water quality. The city of Bemidji has consistently maintained advanced wastewater treatment to achieve low P discharge. Additionally, the city of Bemidji was one of Minnesota's early adopters of stormwater best management practices (BMPs) beginning in the early 1990s with the installation of a network of stormwater detention basins and stormwater treatments as seen at Cameron Park, Diamond Point Park, the Bemidji State University campus, and the Chamber of Commerce park area (grit chambers).

Continued enrichment of the two impaired lakes will have negative consequences on immediately downstream lakes of the Turtle River system and Lake Bemidji of the Mississippi River system. In both cases, drier conditions with low flows create conditions that are most favorable for peak growing season sediment-released P. Growing season P concentrations that greatly exceeded standards were noted in 2006 through 2008, with corresponding algal concentrations noted to frequently exceed severe bloom levels in Lake Irving that discharges into Lake Bemidji's southern basin. Recent Lake Bemidji data from the upgradient north basin suggests near-impairment levels.

Lake Irving's loading goals appear particularly daunting; with a 37% reduction of Mississippi River P levels and 100% reduction of the excessive internal loading identified in this TMDL (see Section 4.2.9). Additionally, the city of Bemidji's regulated stormwater runoff P loads need to be reduced by 36%. Corresponding P reductions that were identified for Little Turtle Lake include 11% and 38% reductions of Turtle River and lakeshed sources, respectively. Various future watershed management scenarios developed in the Mississippi Headwaters Watershed Scenarios estimated potential P reductions to be approximately 3% to 34% from the widespread implementation of agricultural and riparian buffers. Similar levels of total suspended solids (TSS) reductions were defined that will reduce sediment and associated organic substance loading. Continued implementation of urban BMPs by the city of Bemidji and shoreland development that incorporates infiltration and filtration best practices with generally favorable sandy soils can reduce P loading substantially.

Both lakes experience loss of oxygen concentrations with depth during the peak months of the growing season. A collective weight of evidence analysis strongly suggests that the sediments of both lakes release P that is mixed into lake waters that induces higher P and algal responses with lower summer transparencies. Seasonal chemical and oxygenation/aeration techniques may help to control excess Lake Irving growing-season P and directly improve Lake Bemidji. To a lesser degree, internal loading also occurs in Little Turtle Lake. However, reducing watershed sources is recommended before considering chemically treating Little Turtle Lake’s sediment P accumulations.

1 Project Overview

1.1 Purpose

Section 303(d) of the Federal Clean Water Act (CWA) requires the Minnesota Pollution Control Agency (MPCA) to identify waterbodies that do not meet water quality standards, and to develop pollutant Total Maximum Daily Loads (TMDLs), or in the case of this report nutrient reduction goals, for those waterbodies. Little Turtle Lake was listed on the 303(d) impaired waterbody list in 2008, and Lake Irving was listed on the 303(d) impaired waterbody list in 2010. A TMDL is the amount of a pollutant that a waterbody can assimilate without exceeding the established water quality standard for that pollutant. Through a TMDL, pollutant loads are allocated to permitted (regulated) and non-permitted (nonregulated) sources within the watershed that discharge to the waterbody. The purpose of this TMDL is to quantify the pollutant reductions needed to meet state water quality standards and the appropriate endpoint for nutrients in the lake. This TMDL defines loading capacity and allocates P loads to sources for Lake Irving and Little Turtle Lake. This TMDL's endpoints are based on Minnesota's ecoregion-based standards of 30 micrograms per liter (μg/L) total phosphorus (TP), 9 μg/L Chlorophyll-*a* (Chl-*a*), and not less than 2.0 meters (m) for Secchi transparency expressed as summer (June through September) averages.

1.2 Identification of Waterbodies

The Mississippi Headwaters Watershed of north-central Minnesota has aquatic-recreation use impairments from eutrophication (P) in two lakes (Lake Irving and Little Turtle Lake), which are shown in Figure 1-1.

The state of Minnesota classifies streams and lakes into categories that are protected for specific, designated uses. All impairments addressed in this TMDL are Class 2B and Class 3C waters.

> *The quality of Class 2B surface waters shall be such as to permit the propagation and maintenance of a health community of cool or warm water sport or commercial fish and associated aquatic life, and their habitats. These waters shall be suitable for aquatic recreation of all kinds including bathing, for which the waters may be usable. This class of surface water is not protected as a source of drinking water.*
>
> *The quality of Class 3C waters of the state shall be such as to permit their use for industrial cooling and materials transport without a high degree of treatment being necessary to avoid sever fouling, corrosion, scaling or other unsatisfactory conditions.*

Applicable standards for Class 2B waters are summarized in Chapter 2.0. Class 3C-related water quality standards (chlorides, hardness, and pH) are not impaired or addressed in this TMDL.

1.3 Priority Ranking

The MPCA's schedule for TMDL completions, as indicated on the 303(d) impaired waters list, reflects Minnesota's priority ranking of this TMDL. The MPCA has aligned our TMDL priorities with the watershed approach and our Watershed Restoration and Protection Strategy (WRAPS) cycle. The schedule for TMDL completion corresponds to the WRAPS report completion on the 10-year cycle. The

MPCA developed a state plan, Minnesota's TMDL Priority Framework Report, to meet the needs of Environmental Protection Agency's (EPA's) national measure (WQ-27) under EPA's Long-Term Vision for Assessment, Restoration and Protection under the CWA Section 303(d) Program. As part of these efforts, the MPCA identified water quality impaired segments, which will be addressed by TMDLs by 2022. The surface waters addressed by this TMDL are part of that MPCA prioritization plan to meet EPA's national measure.

Table 1-1. Water Quality Impairments Addressed by This Report

Lake Name	Lake ID	Use Classification	Year Listed	Impairment
Irving	04-0140-00	2B, 3C	2010	Nutrient/eutrophication biological indicators
Little Turtle	04-0155-00	2B, 3C	2008	Nutrient/eutrophication biological indicators

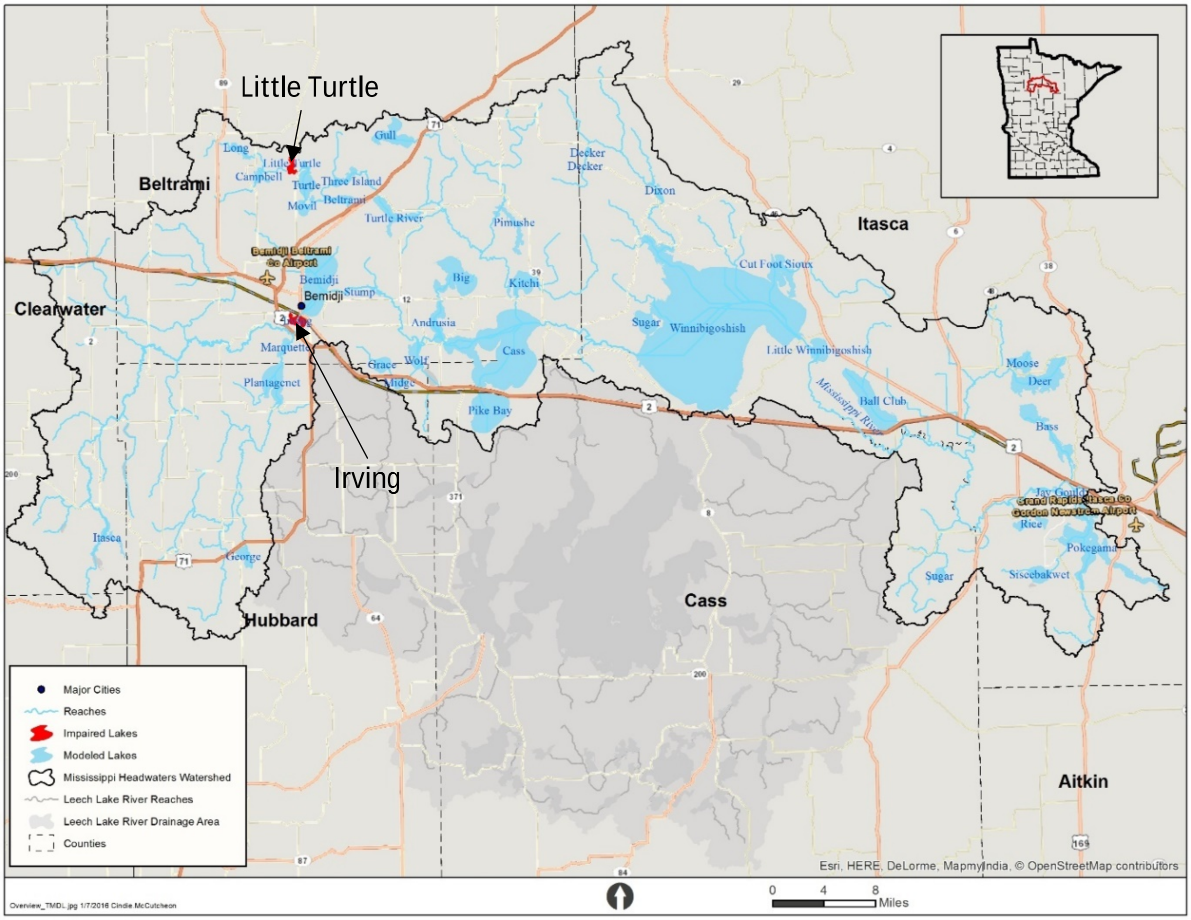


Figure 1-1. Impaired Lakes.

2 Applicable Water Quality Standards and Numeric Water Quality Targets

All of the impaired lakes that are addressed in this TMDL are located in the Northern Lakes and Forests (NLF) Region of Minnesota. A very small portion of the area that drains to Little Turtle Lake is in the North Central Hardwood Forests (NCHF) Ecoregion. For a lake to be determined impaired, the summer-average TP concentrations that are measured in the waterbody must show exceedances of the TP standard. Table 2-1 shows the applicable lake standards (Minn. R. 7050.0150, subp. 5a), along with one or both of the eutrophication response standards for Chl-*a* and Secchi transparency. 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. Summer season is subsequently 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 [MPCA 2005]. Clear relationships were established between the causal factor TP and the response variables Chl-*a* and Secchi transparency. Based on these relationships, the Chl-*a* and Secchi standards are expected to be met. Table 2-2 shows the applicable stream standards.

Table 2-1. Lake Nutrient/Eutrophication Standards for Lakes, Shallow Lakes, and Reservoirs in the Northern Lakes and Forest Ecoregion [Minnesota State Legislature 2008]

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

ppb = parts per billion

Table 2-2. Northern River Nutrient Region Standards and Total Suspended Solids Standards

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

ppb = parts per billion, ppm = parts per million

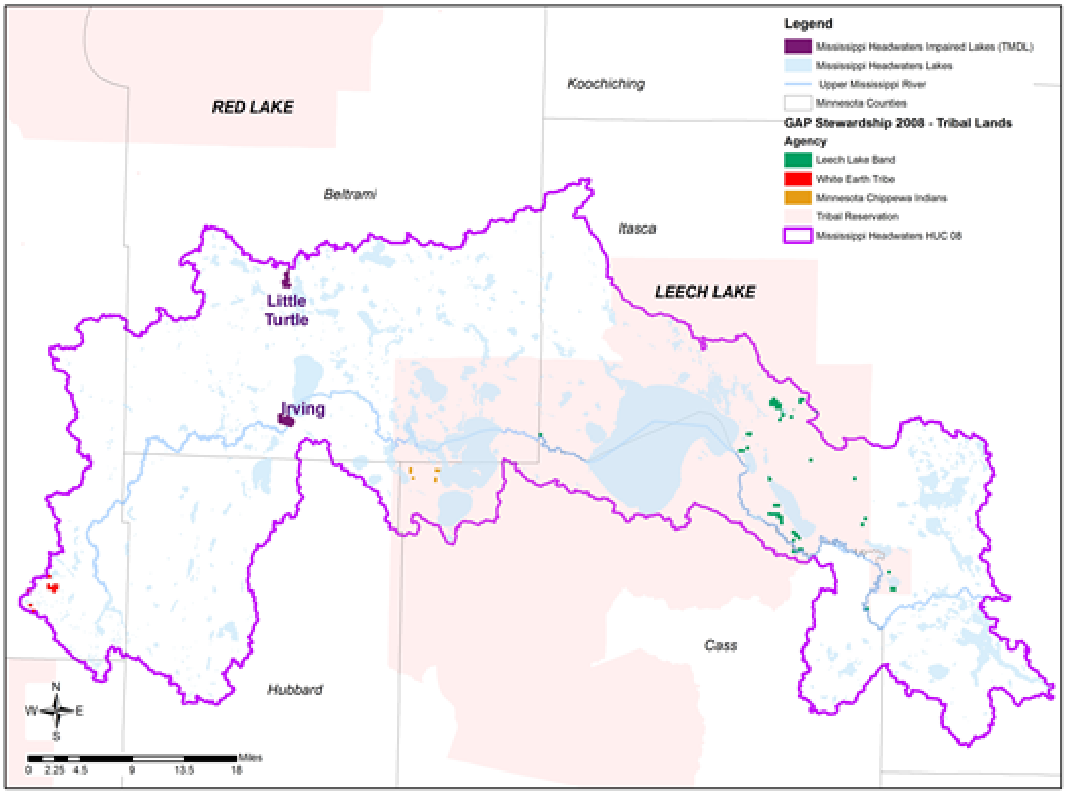
3 Watershed and Waterbody Characterization

3.1 Headwaters Context

The Mississippi River Headwaters Watershed (Hydrologic Unit Code [HUC] 07010101) is located in parts of Clearwater, Beltrami, Itasca, Becker, Hubbard, and Cass Counties in north-central Minnesota. The watershed drains approximately 1,229,440 acres. The contributing area to Little Turtle Lake is 26,293 acres (Beltrami County), and the contributing area to Lake Irving is 355,306 acres (primarily in Beltrami, Clearwater, and Hubbard Counties).

Lake Irving and Little Turtle Lake lie outside of tribal lands; however, the receiving waters of these lakes (Mississippi River and the Turtle River, respectively) flow through the Leech Lake Indian Reservation situated to the east of Bemidji via the Mississippi River Headwaters Watershed. No impairments downstream along the main stem of the upper Mississippi River drainage were documented (other than mercury) within the Leech Lake Reservation boundary and within the Mississippi River Headwaters Watershed as a whole. See Figure 3-1 below for location of tribal lands within the Mississippi River Headwaters Watershed.

Figure 3-1. Mississippi River Headwaters Watershed – Impaired Lakes and Tribal Lands



3.2 Historical View

Beltrami County was named after Giacomo Constantino Beltrami, the Italian who explored most of the northern sources of the Mississippi River in 1823 [Upham 2001]. He was the first explorer to also supply descriptions of the Turtle Lake system. By 1866, Beltrami County was formally established, and the city of Bemidji was incorporated in 1896. The city of Bemidji was named for an Ojibwe leader whose band lived on the shores of Lake Bemidji and Lake Irving. His name was translated as “the lake where the current flows directly across the water,” which referred to the Mississippi River flowing from Lake Irving across the lake’s east side, cutting Lake Bemidji into two portions [Upham 2001]. Portions of the Ojibwe site became part of the city of Bemidji. The city’s early settlement years included the establishment of the Carson Trading Post, three sawmills, two planing mills, four churches, three schools, and the Bemidji Opera House. The post office was spelled “Bermidji” from 1894 to 1898 when it was changed to its present spelling and incorporated. In the early 1900s, logging was the primary industry that attracted railroads and road development and remains an important part of the region’s economy.

Turtle River Township was named for Turtle Lake River, which is the northern-most tributary of the Mississippi River. The township was a booming lumber village in the late 1890s when the Minnesota and International Railway was extended into the area and brought merchants and residents to the area. Lake Irving was named by explorer Henry R. Schoolcraft in approximately 1832, in honor of Washington Irving, an eminent American author.

In the early 1980s, the Bemidji Wastewater Treatment System was the subject of controversy that required an Environmental Impact Statement (EIS) [U.S. EPA 1981]. As a result of the EIS, the Bemidji Wastewater Treatment Plant’s (WWTP) P effluent limit was established at 0.300 milligrams per liter (mg/L) to protect Lake Bemidji and downstream headwaters lakes. At that time, water-based recreation industries occupancy was estimated to be approximately 536,000 visitor days per year with travel and tourism generating (including local multipliers) approximately $11.5 to $21.6 million of income annually to the region. Since the new wastewater effluent limits were adopted, the city of Bemidji has maintained and often surpassed those limits to protect Lake Bemidji’s water quality, which has responded as predicted by the EIS modeling. Additionally, the city of Bemidji was one of Minnesota’s early adopters of stormwater BMPs, beginning in the early 1990s with the installation of stormwater network BMPs, such as detention basins and stormwater treatments as seen at Cameron Park, Diamond Point Park, the Bemidji State University campus, and the Chamber of Commerce parking lot’s grit chambers. The Bemidji area of today has a diversified economy that still depends on the area’s forests, lakes, and streams for travel, tourism and related services.

3.3 Lake Eutrophication

Developing Minnesota’s lake nutrient standards occurred in phases over three decades of monitoring and assessment of a large cross section of lakes and lake types of Minnesota’s aquatic ecoregions [Heiskary and Wilson 2005]. Distinct relationships were established between the causal factor (TP) and the response variables (Chl-*a* and Secchi transparency). TP has often been found to be the limiting factor in freshwater lakes. As lake P concentrations increase, algal abundance increases, which results in higher Chl-*a* concentrations and reduced lake transparency. Based on these relationships, the Chl-*a* and Secchi standards are expected to be met by meeting the P target in each lake. Supporting these standards are definitions described by Minn. R. 7050.0150, subp. 4, including the following definitions that are pertinent to the Mississippi Headwaters Basin Lake TMDLs:

- *“Lake" means an enclosed basin filled or partially filled with standing fresh water with a maximum depth greater than 15 feet. Lakes may have no inlet or outlet, an inlet or outlet, or both an inlet and outlet.*

- *"Reservoir" means a body of water in a natural or artificial basin or watercourse where the outlet or flow is artificially controlled by a structure such as a dam. Reservoirs are distinguished from river systems by having a hydraulic residence time of at least 14 days. For purposes of this item, residence time is determined using a flow equal to the 122Q10 for the months of June through September.*
- *"Shallow lake" means an enclosed basin filled or partially filled with standing fresh water with a maximum depth of 15 feet or less or with 80% or more of the lake area shallow enough to support emergent and submerged rooted aquatic plants (the littoral zone). It is further defined in Minn. R. 7050.0150, subp.4.CC. Shallow lakes are differentiated from wetlands and lakes on a case-by-case basis. Wetlands are defined in Minn. R. 7050.0186, subp. 1a.*

Minnesota's lake eutrophication standards (LES) for the NLF ecoregion are currently considered as a single class of lakes, with the potential for future changes that would address shallow lakes separately. Deep lakes that remain thermally stratified can be expected to have stable or declining surface water P concentrations over the summer growing season. While deep-lake sediments may go anoxic, sediment-generated P (e.g., internal loading) can be less susceptible to mixing into surface waters because of thermal stratification. Conversely, shallow lakes are more prone to wind mixing events, and may have widely fluctuating TP concentrations as inflow P is mixed with resuspended organic matter and lake sediment-generated P quantities.

For a lake to be determined impaired, measured summer-average lake TP concentrations must show exceedances of the TP standard shown in Table 2-1 along with one or both of the eutrophication response standards for Chl-*a* and Secchi transparency. 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; "summer season" is subsequently defined as a period annually from June 1 through September 30. River Eutrophication Standards (RES) similarly require exceedance of the P standard with one or more eutrophication responses. In this instance, the North River Nutrient Region standard for TP is 50 µg/L with a Chl-*a* of 7 µg/L applies to the Mississippi River, while the NLF lake standard of 30 µg/L for TP and 9 µg/L for Chl-*a* applies to Lakes Irving and Bemidji. The LES is more restrictive and takes precedent over the RES. In practical terms the inflowing river needs to be reduced to near the LES in order for Lake Irving to achieve the LES 30 µg/L. Lake Bemidji immediately downstream is also facing increased TP levels. Multi-year Lake Bemidji monitoring data suggest that this lake is nearing LES values with recent years' TP and Chl-*a* exceeding LES values. Hence, Lake Irving is an important water quality gateway for the Mississippi River Headwaters.

Internal loading of P may be an important P source for lakes with temporary thermal stratification, such as Little Turtle Lake and Lake Irving, that may form an anoxic (very low or no dissolved oxygen (DO)) layer near the sediments. This layer may allow a P release from the lake's sediments that can be periodically mixed into the surface waters and provide nutrients and light for algal growth. However, shallow, well-mixed or well-flushed lakes that maintain oxic conditions near the sediment-water interface over most of the summer may have lower internal loading rates [Nürnberg 1995]. These important concepts will aid in future management of both of these impaired lakes.

3.4 Lake Physical Characteristics

Little Turtle Lake is located 10 miles north of Bemidji in Beltrami County, and approximately midway in the chain of eleven lakes known as the Turtle River Chain. Little Turtle Lake is located approximately 2.4 stream miles downstream of Campbell Lake, and about 0.3 mile upstream from Big Turtle/Movil Lakes. Public access to Little Turtle Lake is available via a carry-on location at the Aquatic Management Area (AMA) and by river channel from Big Turtle Lake's public boat ramp. Little Turtle Lake has a surface area of approximately 465 acres with a contributing watershed, including the lake surface, of approximately 26,273 acres, and a corresponding large watershed to lake area ratio of approximately 56.5:1. Heiskary and Wilson [2005] reported typical northern lake watershed area to lake area ratios of less than 10:1 to 15:1, with an average watershed area to lake area ratio of 2.6 noted for identified minimally impacted NLF lakes. Little Turtle Lake has approximately 28 homes and cabins along its shore. With a mean depth of 11 feet and a maximum depth of 25 feet, Little Turtle Lake is relatively shallow and subject to wind mixing and Turtle River flows from its large contributing watershed.

Lake Irving is located in the city of Bemidji and is a shallow, natural lake with a surface area of 661 acres. Its somewhat elliptical basin is oriented with the main axis in an east-west direction. Water entering from the Mississippi River at the south-central shore flows approximately 90 degrees to the main axis, north to Lake Bemidji. Irving Lake's Mississippi River contributing watershed area covers approximately 355,306 acres, which results in an extremely large watershed to lake-surface area ratio of approximately 537.5:1. As such, Lake Irving's water quality is strongly influenced by the Mississippi River's characteristics. Lake Irving has a mean depth of approximately 7 feet and a maximum depth of approximately 19 feet, according to the Minnesota Department of Natural Resources (DNR).

Summary lake morphometric and watershed characteristics for the impaired lakes are tabulated in Table 3-1 and for Lake Bemidji are tabulated in Table 3-2. Although not impaired, morphometric data for Lake Bemidji is included in Table 3-2 that was used to develop the BATHTUB model that links Lake Irving discharges with eutrophication responses of Lake Bemidji. Lake bathymetry is shown in Figure 3-1 for Little Turtle Lake and Figure 3-2 for Lake Irving.

Minn. R. 7050.0150, subp. 4 defines a shallow lake as an enclosed basin filled or partially filled with standing fresh water, with a maximum depth of 15 feet or less or with 80% or more of the lake area shallow enough to support emergent and submerged rooted aquatic plants (the littoral zone). "It is uncommon for shallow lakes to thermally stratify during the summer". Two additional metrics (lake geometry ratio (GR) and Osgood Index) have been used to help define lake mixing.

Hondzo and Stefan [1996] evaluated lake thermal stratification by evaluating the use of a lake GR based on Equation 3-1. Lake GRs are used to classify lakes as (1) shallow (greater than 5.3); (2) medium (1.6 to 5.3); and deep (less than 0.9) [Hondzo and Stefan 1996].

$$\text{Lake Goemetry ratio} = \frac{A^{0.25}}{D_{max}} \qquad (3.1)$$

Where: A = lake surface area (M^2)

Dmax = maximum depth(M)

Osgood [1998] developed the Osgood Index shown in Equation 3-2 to categorize lakes as polymictic (values < 4 units), intermediate (values 4–9 units) or dimictic (values > 9 units):

$$\text{Osgood Index} = \frac{D_{mean}}{\sqrt{A_{surface}}} \qquad (3.2)$$

Where: D^{mean} = lake mean depth (M)
$\sqrt{A_{surface}}$ = Surface area (M)

Table 3-1. Summary of Little Turtle Lake and Irving Lake Morphometric and Select Watershed Characteristics

Characteristic	Little Turtle	Irving	Source
Lake-Surface Area (acres)	465	661	DNR LakeFinder
Lake Littoral Surface Area (acres)	302	546	DNR LakeFinder
Lake Littoral Surface Area (percent)	64	83	DNR LakeFinder
Drainage Area (km^2)	106.4	1,437.9	Model subwatersheds
Watershed Area to Lake Area Ratio	56.4	537.5	Calculated
Wetland Area (% of watershed)	15.6	16.5	Model land use
Number of Upland Lakes	> 10	Many	U.S. Geological Survey (USGS) topographic maps
Number of Perennial Inlet Streams	1	Mississippi River	National Hydrology Dataset (NHD) Flowlines
Number of Ephemeral Inlet Streams	0	Storm sewers + 2	USGS topographic maps
Lake Volume (acre-feet)	5,332	4,914	DNR LakeFinder
Mean Depth (feet/m)	11/3.4	7/2.1	DNR LakeFinder
Annual Lake-Level Fluctuations (feet): typical, maximum	0.75–1.5	No data	DNR LakeFinder lake levels
Maximum Depth (feet)	25	19	DNR LakeFinder
Maximum Fetch Length (miles)	1.74	1.49	Measured
Lake Geometry Ratio (GR)	7.6	12.1	Calculated
Osgood Index	2.5	1.3	Calculated
Estimated Water Residence Time (days)	209 days	20 days at 10th percentile growing-season flows	Calculated
Public Access	1 DNR	1 City	
Shore land Properties	54	158	Counted from topographic maps

Lake Irving has: (1) a maximum depth of 19 feet; (2) a littoral area of 83%; (3) a GR of 12.1; and (4) an Osgood Index of 1.3. It is therefore considered a shallow lake. Little Turtle Lake has: (1) a maximum depth of 25 feet; (2) a littoral area of 65%; (3) a GR of 7.6; and (4) an Osgood Index of 2.5. It therefore shares a combination of shallow and deep-lake characteristics.

Lake levels for Little Turtle Lake are illustrated in Figure 3-3. Little Turtle Lake-level data indicate that typical annual water level fluctuations are approximately 1 foot, with a maximum of approximately 1.5 feet noted in the wet year of 2014. With a mean depth of 11 feet, lake-level fluctuations of 1 to

1.5 feet may closely represent lake volume increases or decreases of 10% and 15%, respectively. Lake-level data were not available for Lake Irving.

Table 3-2. Select Lake Bemidji Morphometric and Watershed Characteristics

Characteristic	Lake Bemidji			
	Whole Lake	North Basin	South Basin	Source
Lake-Surface Area (acres)	6,420	4,924	1,496	EPA [1981]
Lake Littoral Surface Area (acres)	1,960	1,484	475	EPA [1981]
Drainage Area (m^2)	610.1			Model Subwatersheds
Watershed Area to Lake Area Ratio	60.8			Calculated
Mississippi Inlet 340 (m^2)	555.2			USGS topographic maps
Lakeshed (km^2)	63.71			Model Subwatersheds
Lake Volume (acre-feet)	200,600	158,899	41,760	EPA [1981]
Mean Depth (feet)	31.3	32.3	27.9	EPA [1981]
Maximum Depth (feet)	76	76	28	EPA [1981]
Maximum Fetch Length (miles)	5.4	3.5	1.9	Google Earth
Estimated Water Residence Time (years)	1.3	9.5	0.3	Calculated
Public Access	6	4	2	City of Bemidji/DNR

Figure 3-2. Bathymetric Map for Little Turtle Lake.

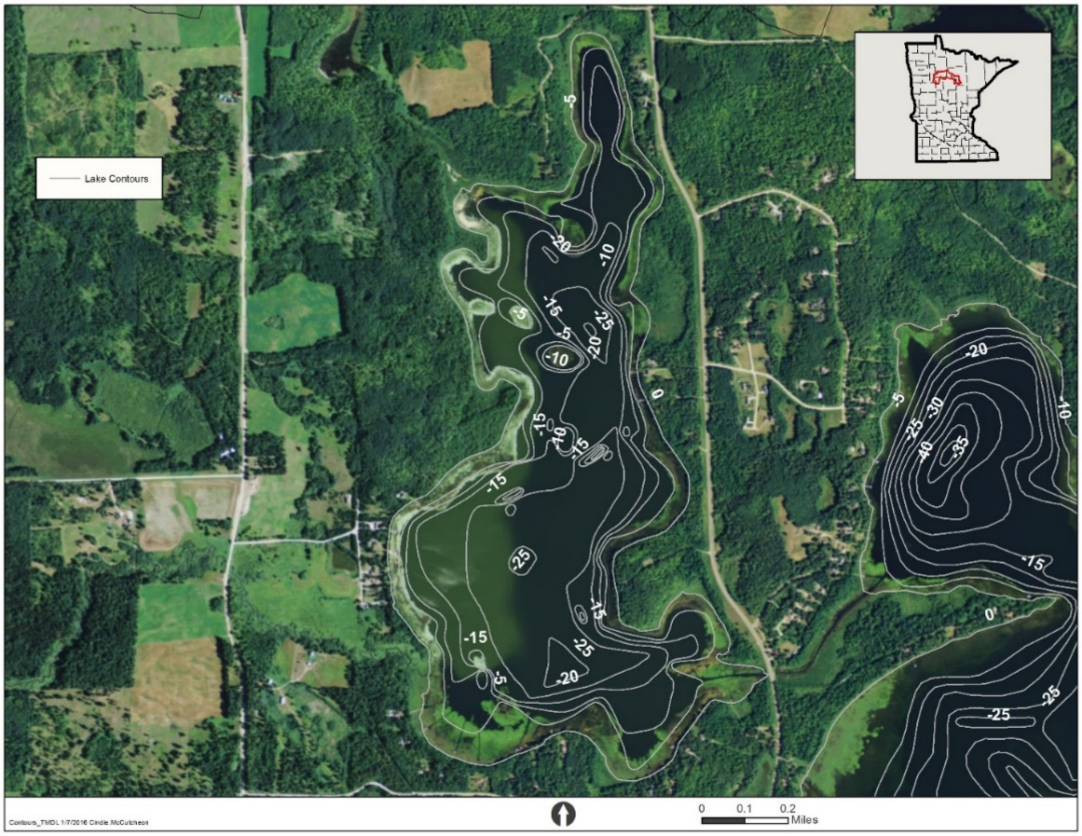
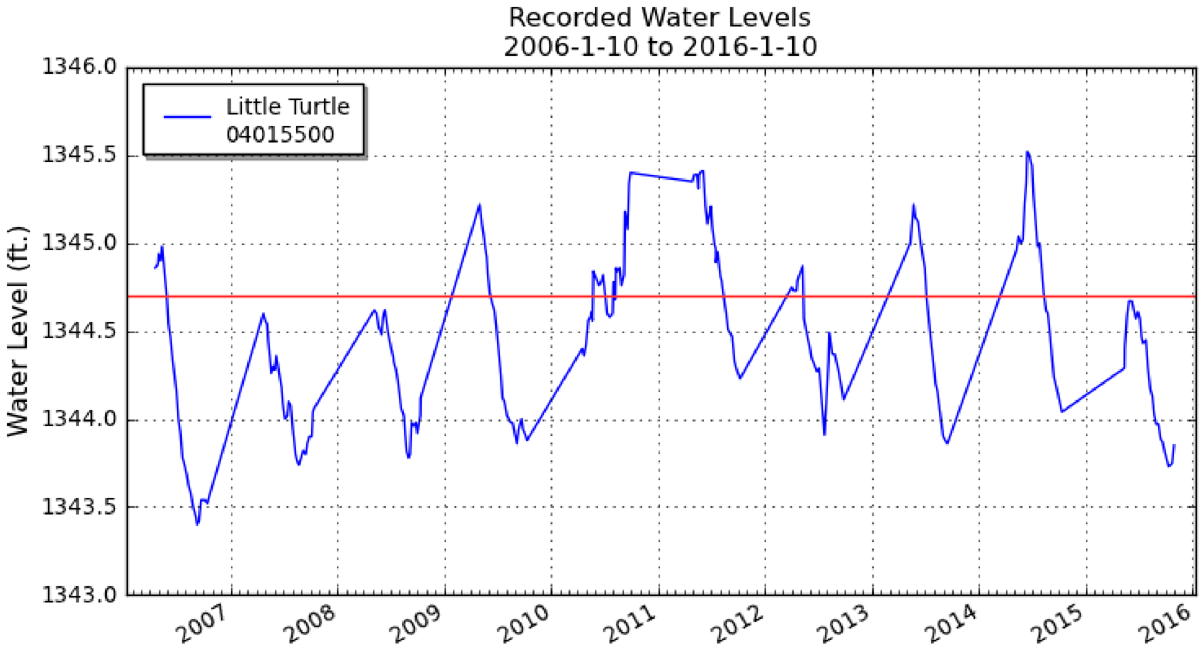


Figure 3-3. Bathymetric Map for Lake Irving.

Figure 3-4. Lake-Level Recordings for Little Turtle Lake [DNR 2015].



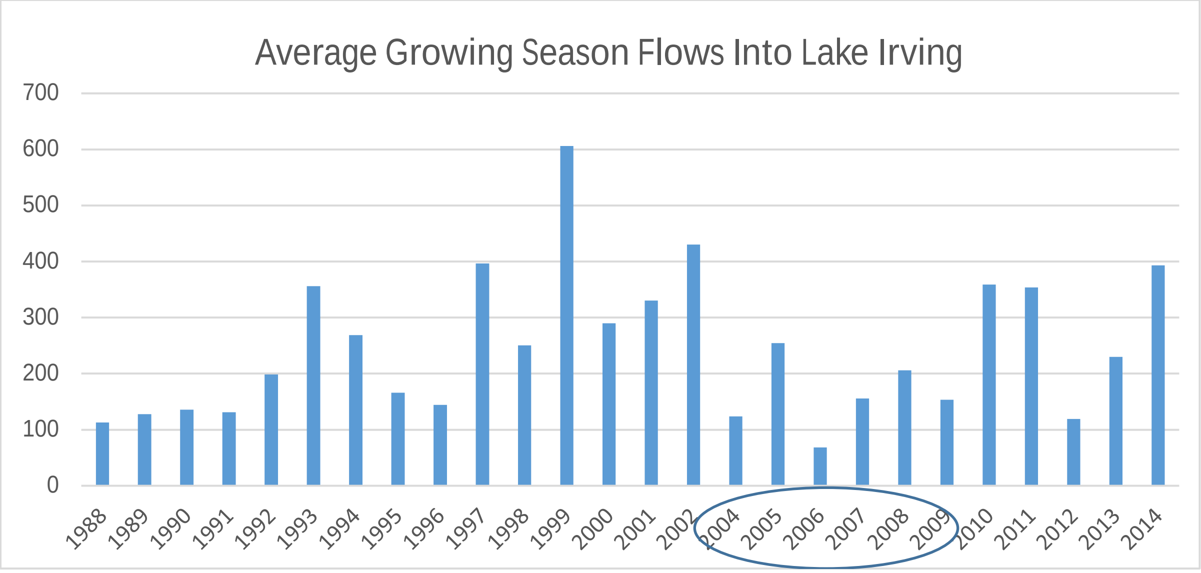


Figure 3-5. Average Growing-Season Flows (cfs) for Mississippi River Adjusted to Lake Irving From Stump Lake Flows (USGS 05200510). The TMDL time period is 2000–2009, and the circle highlights the lower flow years.

3.5 Mississippi River Flows and Water Residence Times

Water residence time is an important aspect in nutrient dynamics. Period of record growing season flow data was compiled from the USGS monitoring system for the Mississippi River below Lake Bemidji at the Stump Lake dam (USGS 05222510). Comparable gaged flow data were not available for the Turtle River system.

3.5.1 Lake Irving Residence Times

The Mississippi River flows into and out of Lake Irving and, as such, is the dominant water and P source to the lake. To better characterize the nature of these flows, USGS flow data from the Stump Lake discharge were tabulated for its period of record and summarized by growing season year in Figure 3-4, with summary of residence times presented in Table 3-3. Flows for Lake Irving were adjusted based on prorating by drainage areas and expressed as cubic feet per second (cfs).

Table 3-3. Estimated Lake Irving Water Residence Times Based on Growing-Season Flows at USGS Site 05200510 for the Period of Record (1988–2015)

1988–2015	Growing Season	
	cfs	Tw (days)
10th Percentile	122	20
25th Percentile	140	18
50th Percentile	230	11
75th Percentile	342	7
90th Percentile	395	6
2000–2009 Mean	224	11

Growing-season average flows plotted in Figure 3-4 varied from the low of 68 cfs in 2006 to a high of 606 cfs in 1999, with 10th and 25th percentile 122 day flows being approximately 122 cfs and 140 cfs, respectively as shown in Table 3-3. These values translate into Lake Irving growing-season water residence times of 20 days and 18 days, respectively. Flows noted for 10th and 25th percentile growing-season flows exceed 14 days. Mean growing-season flows for the TMDL period averaged about 230 cfs, or close to the period of record median flow of 224 cfs, and corresponds to a water residence time of 11 days.

The low growing-season flow conditions of 2006 averaged 68 cfs (with corresponding prorated growing-season water residence time of about 37 days), with monthly mean flows as low as approximately 45 cfs during August and September. Hence, the directional nature of flows between Lakes Irving and Bemidji during dry conditions should include consideration of potential backwatering from Lake Bemidji. If advective flows from Lake Bemidji into Lake Irving occur during lower flows or because of wind-mixing events, loading from Lake Bemidji and potentially Bemidji's WWTPs channel discharge between the lakes could be influencing Lake Irving's P dynamics.

The relationship between average growing-season inflows and Lake Irving's average growing-season TP values is depicted in Figure 3-5, which shows that higher TP occurred during lower flows and lower lake TP with higher flows. The NLF lake standard of 30 µg/L (blue line) and the North River Nutrient Region standard of 50 µg/L (orange line) are superimposed on Figure 3-6, showing that Lake Irving approaches the lake standard during higher flows. A further parsing of average growing-season monthly flows and average lake TP is depicted in Figure 3-7, which indicates that lower flows of the late growing season are strongly related to TP concentrations in Lake Irving.

3.5.2 Little Turtle Lake Residence Times

Based on Hydrologic Simulation Program—Fortran (HSPF) modeled output, the estimated average annual water residence time for Little Turtle Lake is approximately 215 days. No other residence time information is available for Little Turtle Lake.

3.6 Watershed Characteristics

Little Turtle Lake sits on the easternmost edge of the middle Turtle River Watershed with more than 10 upland lakes, one perennial stream (Turtle River), and no noted ephemeral streams. Watershed slopes for Little Turtle range from 0% to 27%, with an average of 2%. Little Turtle Lake Watershed relief is shown in Figure 3-7. Lake Irving is located on the east edge of its much larger Mississippi River Watershed. Lake Irving's watershed slopes range from 0% to 42% with an average of 3%. Irving watershed relief is shown in Figure 3-8.

Land cover within the Little Turtle Lake Watershed and the Lake Irving Watershed is summarized in Table 3-4 based on the National Land Cover Database (NLCD) [Homer et al. 2015]. Approximately 44% of the Little Turtle Watershed is deciduous forest, 15% is pasture/hay, 10% is open water, 9% is evergreen forest, and 11% is wetlands (7% woody wetlands and 4% emergent herbaceous wetlands). The remainder of the lands include low-intensity developed lands, shrub/scrub, row crops, and grasslands. Approximately 1,437 animal units were estimated to be in Little Turtle Watershed. Approximately 49% of the Lake Irving Watershed is deciduous forest, 14% is evergreen forest, 10% is pasture/hay and 11% is wetlands (6% woody wetlands and 5% emergent herbaceous wetlands). The remainder of the lands include open water, low-intensity developed lands, shrub/scrub, row crops, and grasslands. Approximately 4,334 animal units were estimated to be in the Lake Irving Watershed. The animal count data layer MPCA Feedlots with Animal Counts and Animal Units was obtained from the Minnesota Geospatial Commons. The spatial distribution of land covers of both watersheds is depicted in Figures 3-9 and 3-10.

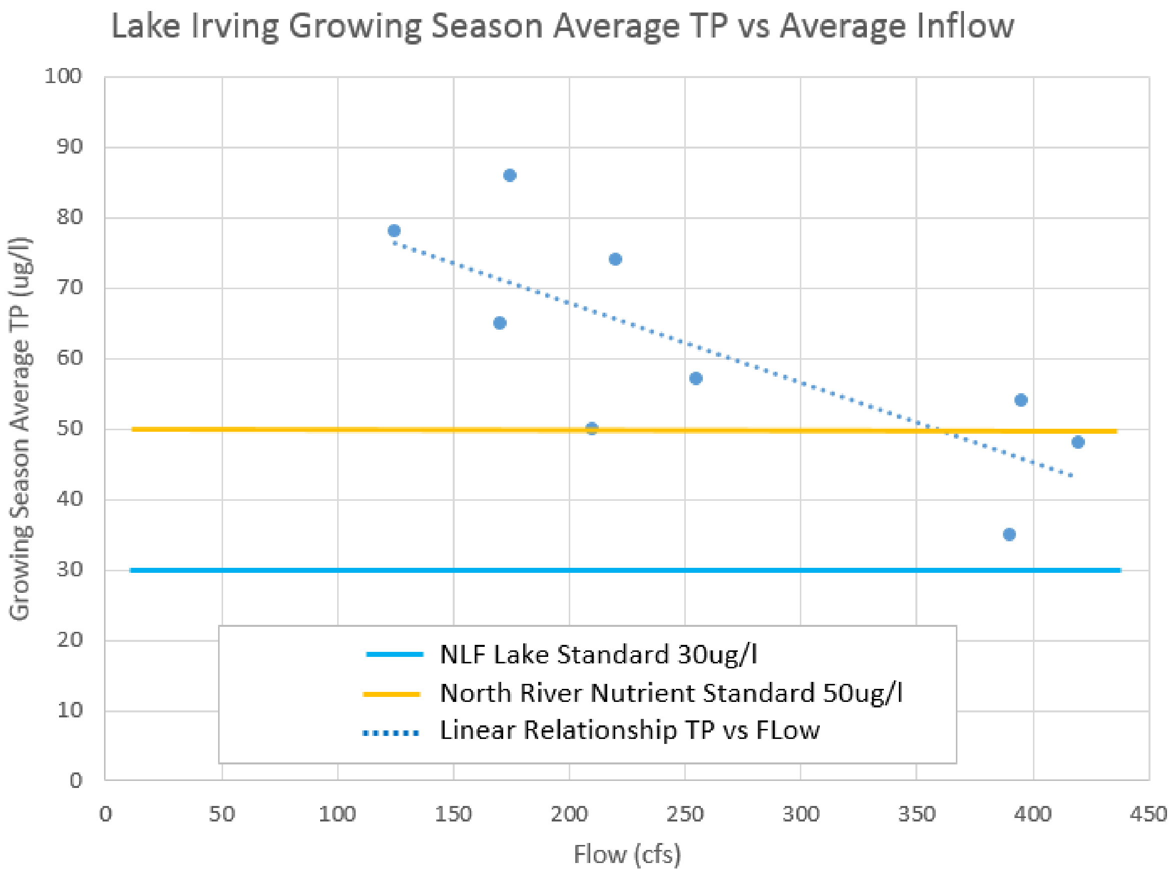


Figure 3-6. Lake Irving Growing-Season Flows (cfs) Versus Average Growing-Season TP.

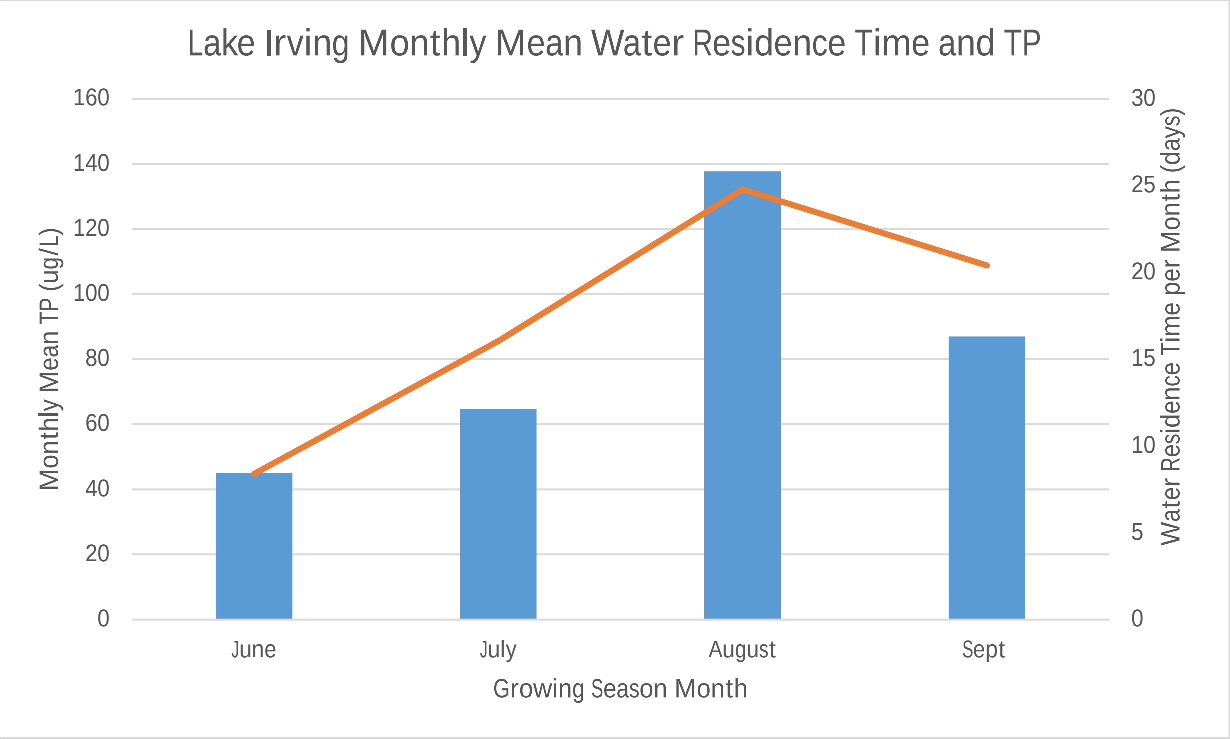
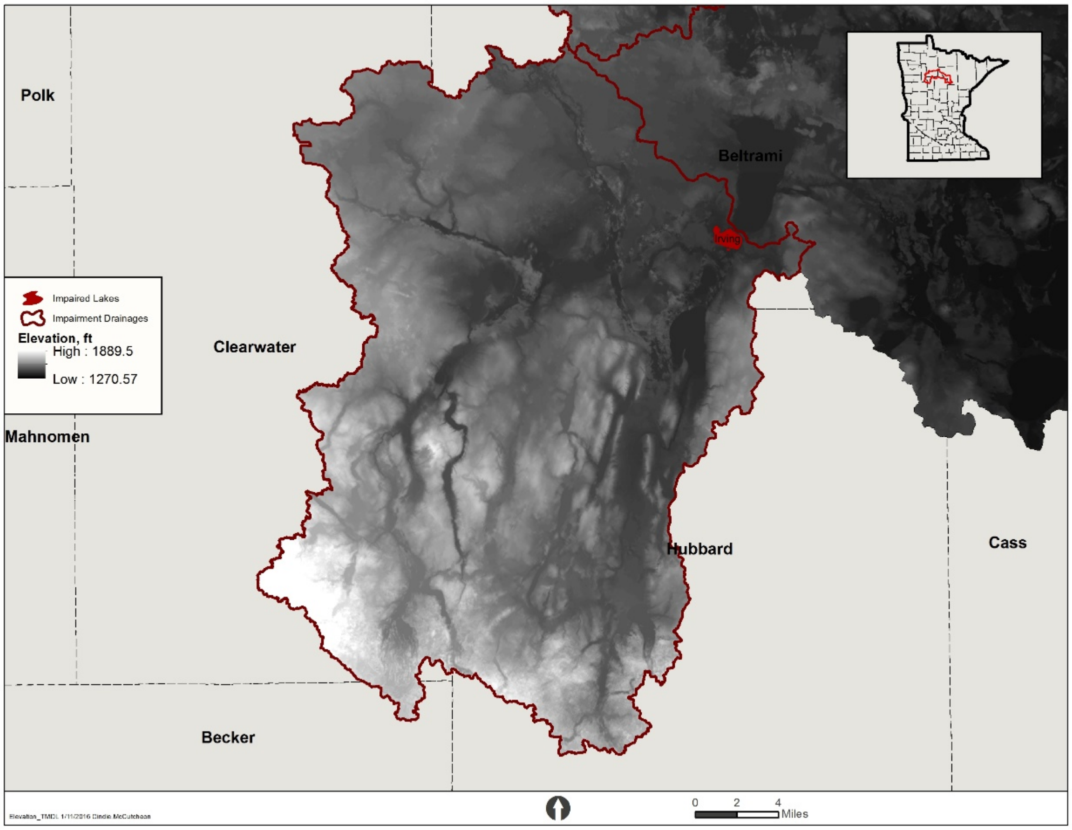


Figure 3-7. Lake Irving Average Growing-Season Monthly Residence Time and Average Monthly TP. Blue bars for residence time are based on the right vertical axis, and the red line for TP is based on the left vertical axis.

Figure 3-8. Lake Irving Watershed Relief.



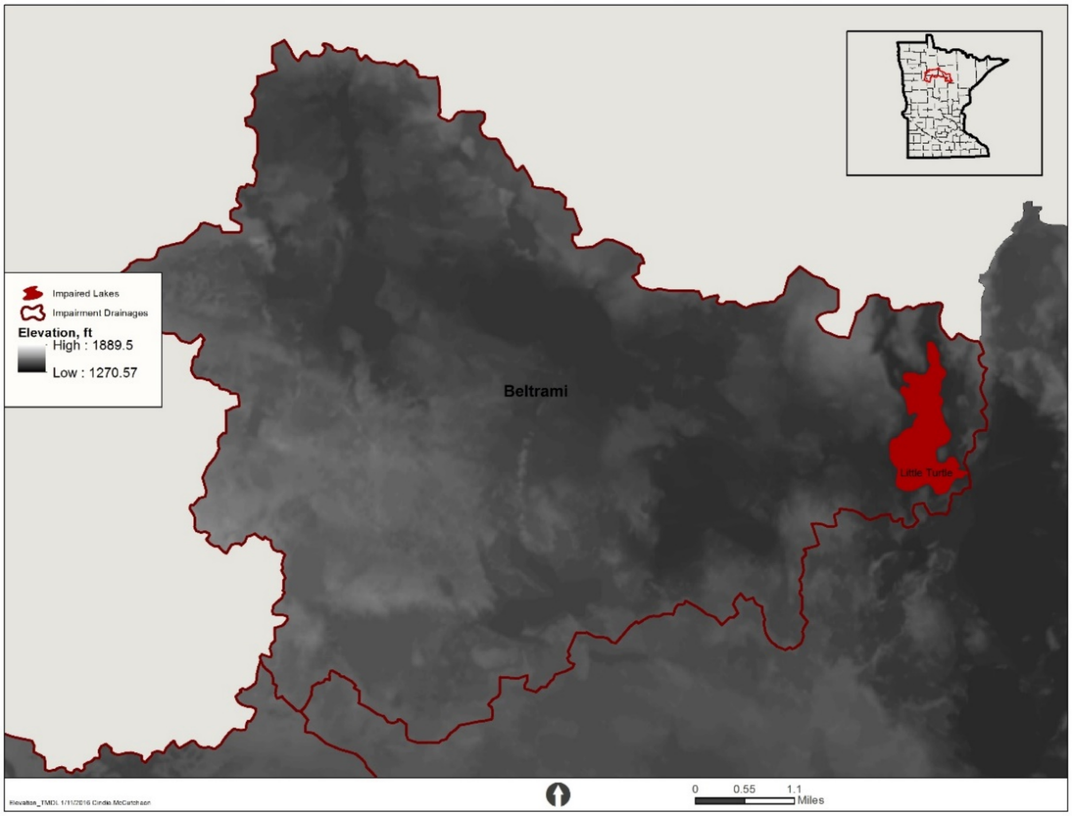


Figure 3-9. Little Turtle Lake Watershed Relief.

Table 3-4. Summary of 2011 National Land Cover Database Land Cover Classifications by Area

Land Use Classification (NLCD)	Little Turtle Watershed Area (%)	Lake Irving Watershed Area (%)
Cultivated Crops	2	2
Deciduous Forest	44	49
Developed–Low Intensity	4	4
Emergent Herbaceous Wetlands	4	5
Evergreen Forest	9	14
Grasslands	1	2
Open Water	10	4
Pasture/Hay	15	10
Shrub/Scrub	3	4
Woody Wetlands	7	6
Other	1	2

3.6.1 Soils

The watersheds for the two impaired lakes lie in the Northern Minnesota Till Moraine common resource area, which is rolling glacial moraines and associated outwash with short, choppy complex slopes. In this common resource area, soils are generally loamy with some clayey and sandy soils [Natural Resources Conservation Service 2016]. Watershed soils and their distributions are important factors to consider as soils can significantly affect runoff and its quality from particle sizes, nutrients, interflow, and infiltration/groundwater recharge. For this purpose, Hydrologic Soil Groups (HSGs) soils defined by the Natural Resource Center of the U.S. Department of Agriculture (USDA) were tabulated by four HSG soil groups (A, B, C, and D) and are summarized in Table 3-5. Soil cover can be summarized by HSG soils. Figure 3-11 shows a dominance of A and B soils throughout the middle and lower portion of the Little Turtle Lake Watershed, with C and D soils across the upper portion. Figure 3-12 shows a dominance of A and B soils in the northern and eastern portions of the Lake Irving Watershed, and C and D soils in the southeast. Areas dominated by HSG C and D soils have a higher runoff potential, especially from areas with higher slopes, while areas HSG A and B soils have greater infiltration and are more amenable to treatment of stormwater runoff using infiltration and filtration from developed and other modified areas. Dual HSG classification soils (notably A/D and B/D) behave as type D soils when undrained.

3.6.2 Demographics and Growth Projections

The Little Turtle drainage is wholly located within Beltrami County, which is expected to have a population increase of approximately 15% between 2015 and 2045 [Dayton 2014]. Lake Irving's Watershed is primarily located in Beltrami County with portions that extend into Hubbard and Clearwater Counties. Hubbard County is expected to increase by approximately 4% between 2015 and 2045, and Clearwater County is expected to increase by approximately 5% between 2015 and 2045. Both lakes have extensive lakeshore development.

3.7 Climate

Basic climate data were reviewed to: (1) define typical seasonal and annual cycles that affect runoff and water quality, (2) identify wet and dry patterns that affect pollutant loading dynamics, (3) assist implementation design considerations, and (4) help inform future performance monitoring efforts.

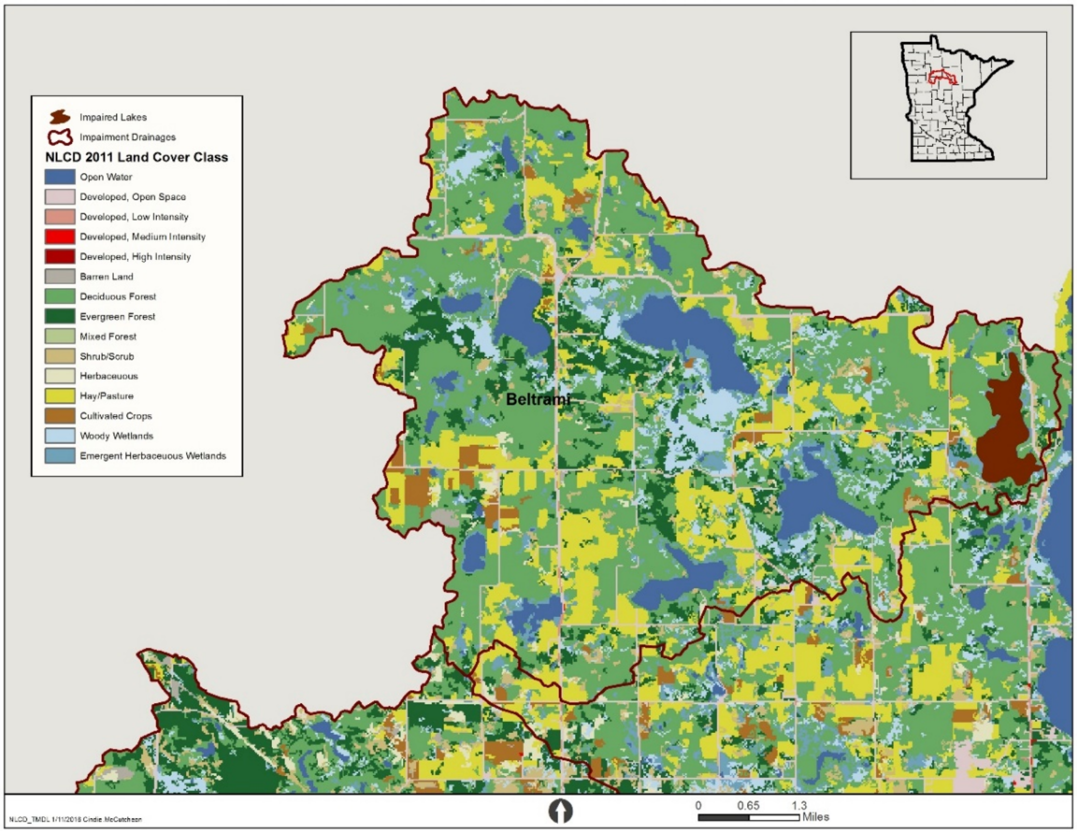


Figure 3-10. Little Turtle Lake Watershed Land Use Classifications [Homer et al. 2011].

Figure 3-11. Lake Irving Watershed Land Use Classifications [Homer et al. 2011].

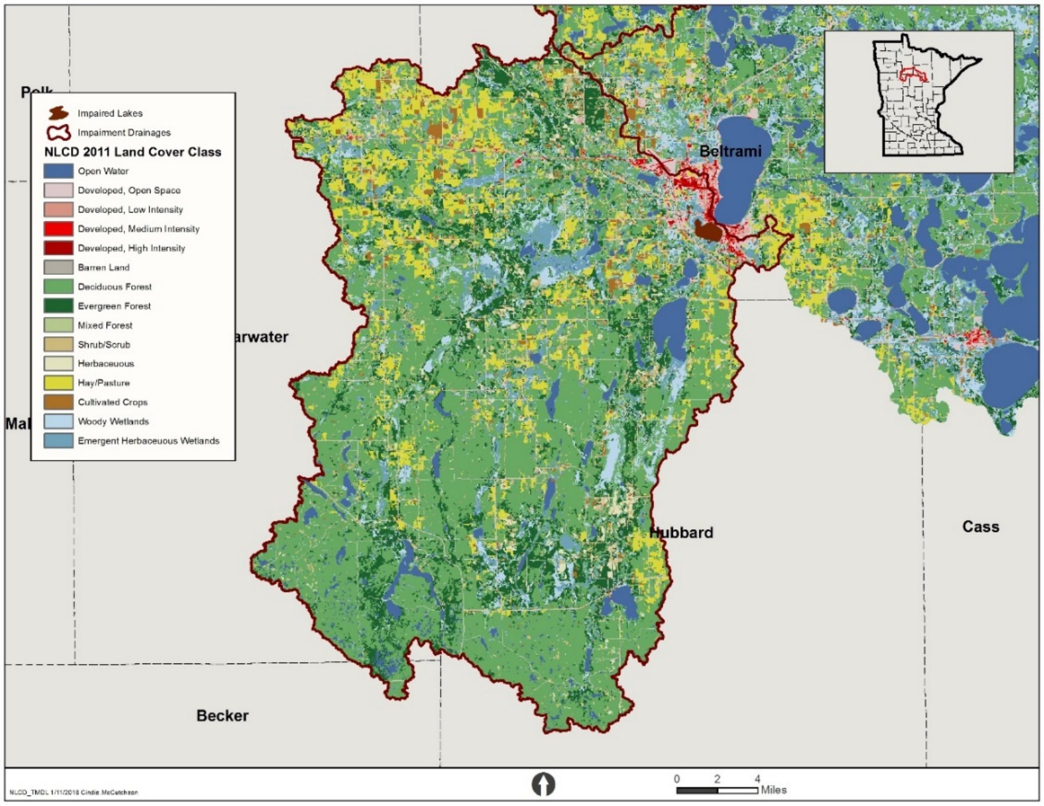


Table 3-5. General Description of Hydrologic Soil Groups [Natural Resources Conservation Service 2009]

Hydrologic Soil Group	Abbreviated Description
A Soils	Sand, sandy loams with high infiltration rates; well-drained soils with high transmission
B Soils	Silt loam or loam soils; moderate infiltration, moderately drained
C Soils	Sandy clay loams, low infiltration rates, impedes water transmission
D soils	Heavy soils, clay loams, silty, clay; low infiltration rates that impedes water transmission
Dual soils A/C and B/D	Dual HSG classification soils (notably A/D and B/D) that behave as type D soils when undrained

Figure 3-12. Little Turtle Lake Watershed Hydrologic Soil Groups.

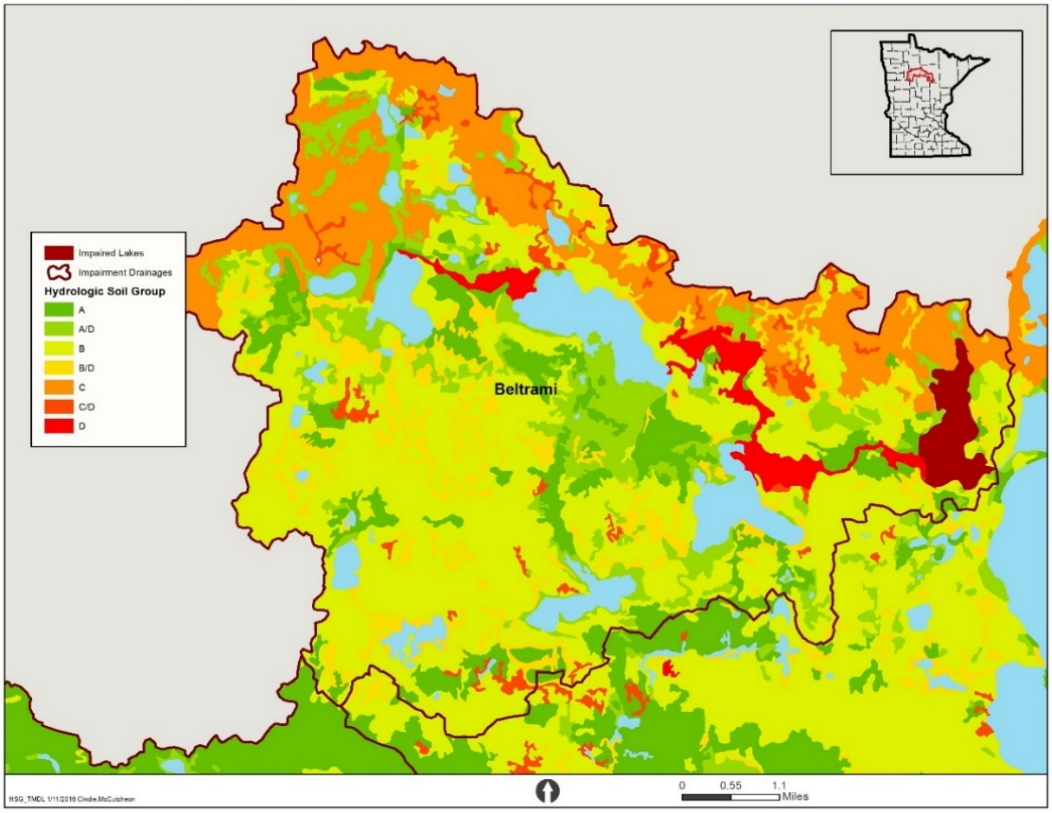
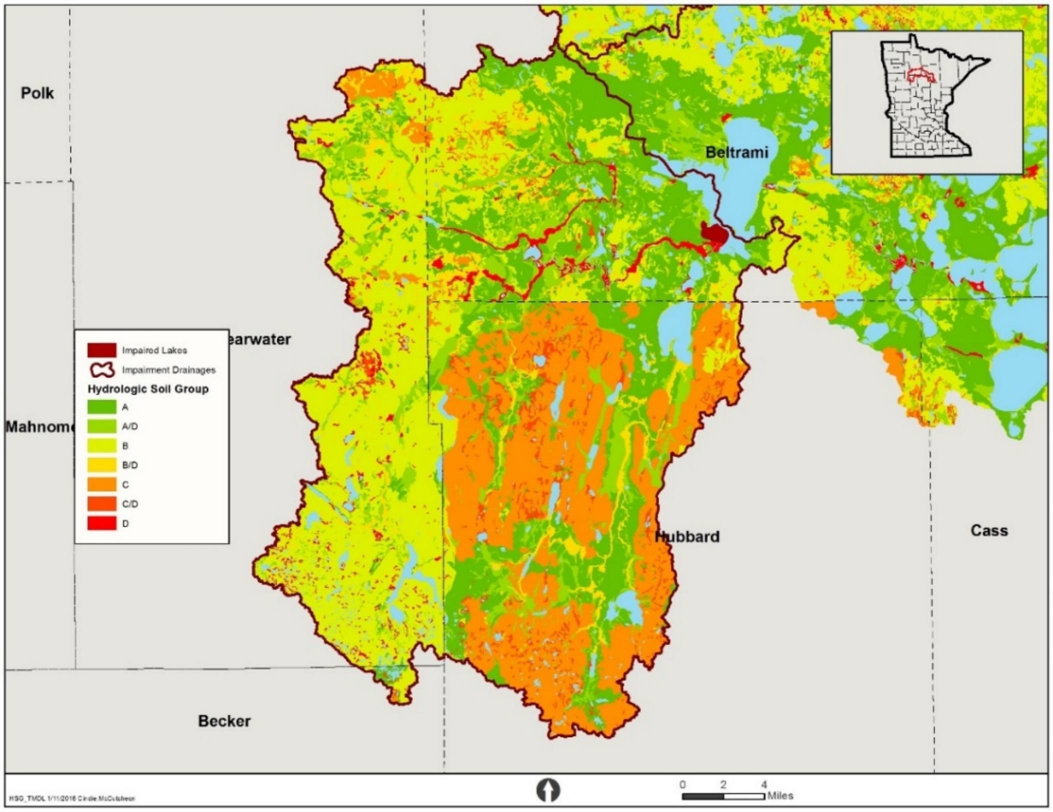


Figure 3-13. Lake Irving Watershed Hydrologic Soil Groups.



Climate variability for the Headwaters West Basin (e.g., the Mississippi River Watershed through Stump Lake) was assessed by using available long-term data for sites from the Midwest Regional Climate Center, the DNR gridded precipitation, and National Oceanic and Atmospheric Administration's (NOAA's) databases summarized for the north-central Minnesota (Climate Division 2). Monthly normal climate data from the Midwest Regional Climate Center for Bemidji (Site USC00210643) is presented in Figure 3-13 as monthly average precipitation with average maximum, mean, and minimum temperatures for 1981 through 2010. Peak precipitation ranging from about 3 to 4.5 inches per month are generally noted from May through September, which roughly coincide with the higher temperatures of the growing season.

Average growing season (June through September) temperatures for Climate Division 2 (north-central Minnesota) assessed by the NOAA, are plotted in Figure 3-14 with a distinct increasing pattern noted since about 1990. Because growing-season ambient temperatures affect surface waters and associated biological and sediment chemical reactions, this increasing pattern of temperatures is of special note.

Annual precipitation varied considerably and over the TMDL time period ranging from 17.5 inches/year to 27.14 inches/year. Over the broader time period (1970 through 2015) displayed in Figure 3-15, annual amounts ranged from approximately 15 inches/year (1976) to over approximately 36 inches/year in 1999 and again in 2010, which bracketed the TMDL time period with high precipitation periods. A three-year rolling average was also plotted to help discern broader wet and dry periods. As may be viewed in Figure 3-15, higher annual precipitation periods are typically followed by much lower annual precipitation periods, with the rolling averages central range occurring at approximately about 20 to 30 inches.

3.7.1 Precipitation Variability: Wet and Dry Periods

A closer examination of year-to-year and monthly precipitation variability was evaluated by using synthetic data from the *DNR's Monthly Precipitation Data From a Gridded Database* [DNR 2016]. Data were summarized by month and year and are presented in Table 3-6 for Bemidji, Minnesota. Over the TMDL time period of 2000 through 2009, annual precipitation amounts varied from 17.9 to 27.2 inches per year (in/yr) while warm season amounts varied from 10.3 to 18.1 inches per warm season (defined as May through September by the DNR). In this evaluation, the wet months (greater than 70th percentile months) were color-coded blue, and dry months (less than 30th percentile months) were color-coded red. The in-between values (normal) are color-coded green. Over the TMDL period, the majority of the warm seasons were normal (e.g., precipitation less than 70th percentile and greater than the 30th percentile), with two warm years identified as dry (precipitation less than 30th percentile). On an annual basis however, four annual totals were identified as wet, two as dry, and four as normal.

Early peak precipitation months are of particular note for the potential to generate stormwater runoff from fertilized fields, growing crops with undeveloped canopies, and urban conveyance systems just before the peak growing season. The data from 2000 to 2009 further show many substantial gyrations in monthly precipitation amounts, particularly during the period from June to September. Dry months tended to occur more commonly in the winter months and at the peak of the growing season (July and August). Higher precipitation amounts occur during July and August, when established vegetative canopies and higher evaporative losses may not generate peak runoff unless they are caused by extreme events and wet periods from back-to-back storm systems.

Lake Irving lake-monitoring data were primarily collected during the drier growing seasons of 2006 through 2008, with peak lake TP sample values noted in August. Very low monthly precipitation totals were noted for most of the 2006 growing season when peak internal loading may have occurred in the study's lakes.

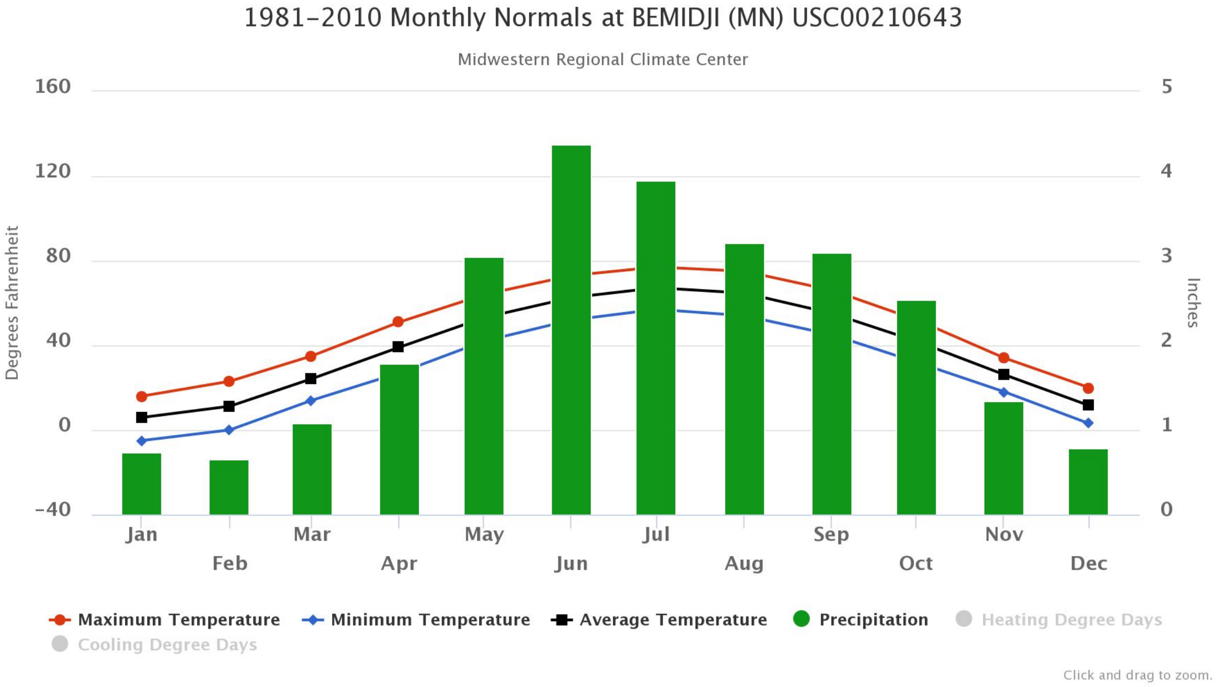


Figure 3-14. Observed Monthly Climate Normals for Bemidji, Minnesota (USC00210643), From 1981 to 2010 [Midwestern Regional Climate Center 2016].

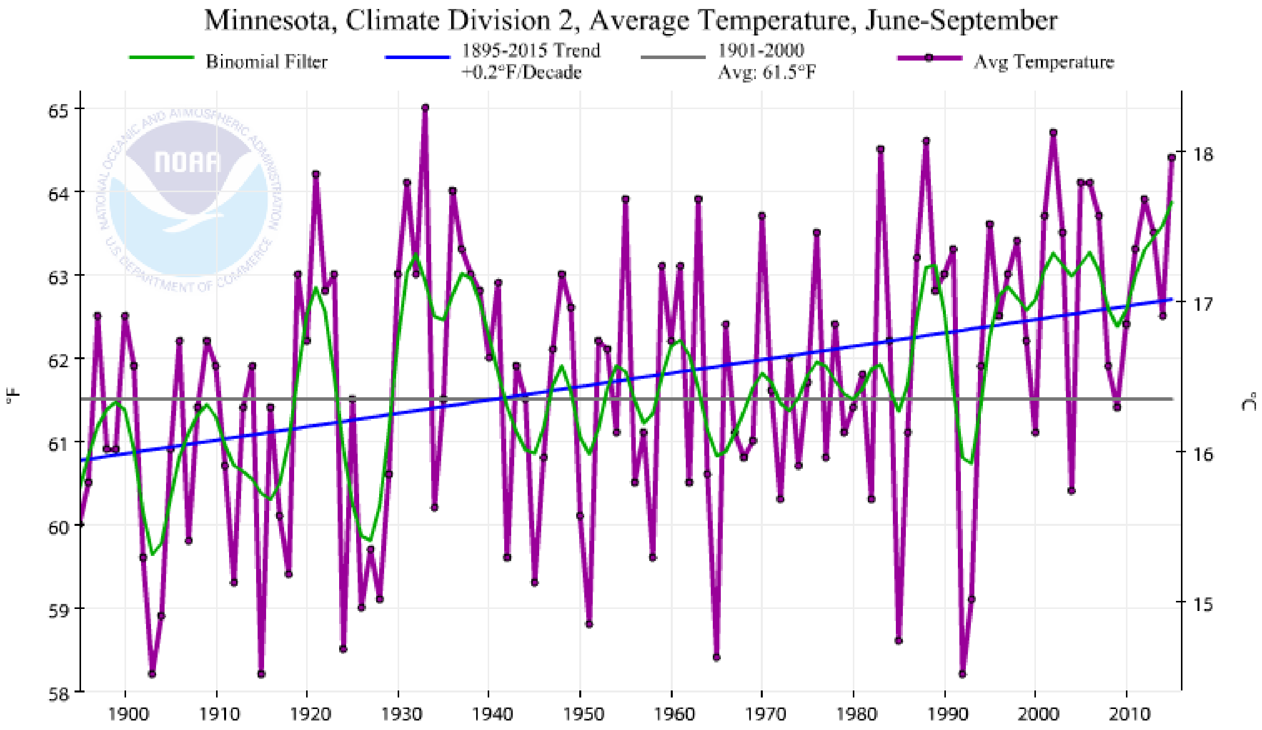


Figure 3-15. Growing-Season (June–September) Temperature for 1895–2014 from the National Oceanic and Atmospheric Administration [2016] for Minnesota Climate Division 2.

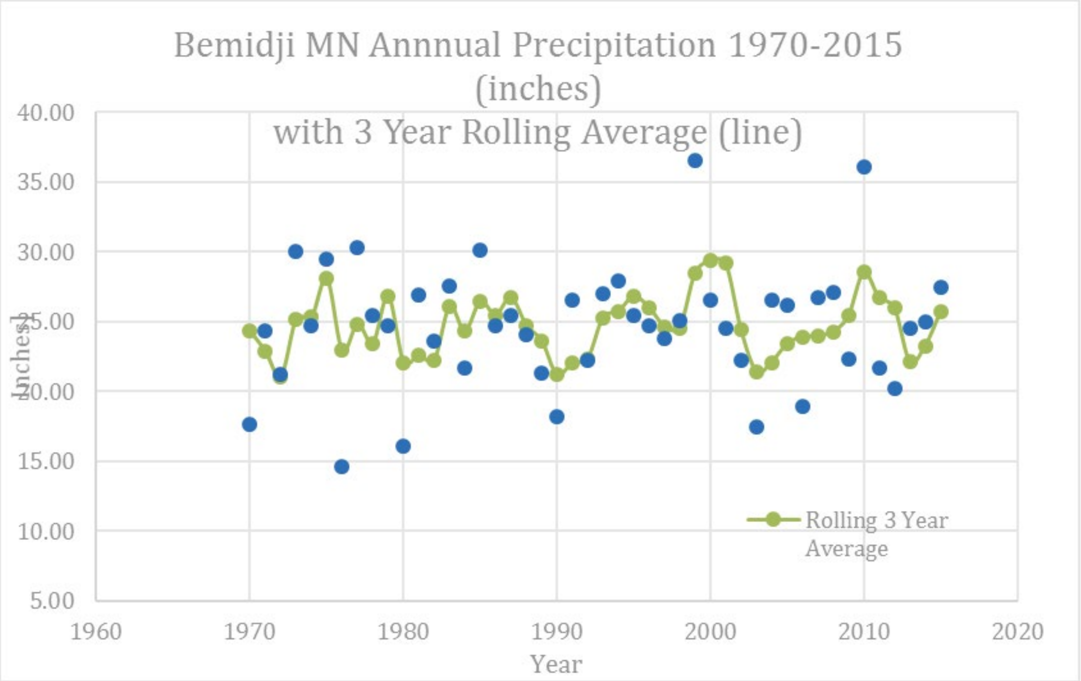


Figure 3-16. Comparison of Annual Precipitation and 3-Year Rolling Averages (Inches) for Bemidji, Minnesota [Minnesota Department of Natural Resources 2016a].

3.7.2 Characterization of Storm Events

NOAA, in cooperation with the MPCA, DNR State Climatology Office, and the Minnesota Department of Transportation, recently updated precipitation intensity and duration records for the entire state, which are referred to as Atlas 14. Storm-event totals, such as those reported in various media weather reports, typically for 24-hour periods, are yellow highlighted in Table 3-7 for recurrence periods noted for Bemidji, Minnesota, that range from annually (2.11 inches) to once every 1,000 years (9.34 inches). More common back-to-back storm periods often generate much larger total rainfall amounts associated with peak runoff events; therefore, frequencies of 2 to 10-day wet-period storms were summarized in Table 3-7 and highlight annual to 10-year recurrence intervals in light blue. The two-day storm totals ranged from 2.39 (annually) to 4.05 inches (10-year recurrence) with 10-day wet periods that range from 3.88 inches (annually) to 6.05 inches (10-year recurrence). From a flooding perspective, wet periods can have large cumulative storm totals that affect watershed runoff, agricultural producers, public safety, and pollutant loading.

The number of various storm events was further examined to aid urban and agricultural stormwater management. For this purpose, data from the Midwestern Regional Climate Center for 1987 through 2016 were parsed into the number of precipitation events by month greater than 0.01-inch, 0.1-inch, 0.5-inch, and 1.0-inch events are summarized in Table 3-8. Data for Cass Lake, Minnesota (USC USC00211374) were employed for this purpose because of data gaps noted for the Bemidji reporting sites. Focusing on the larger storm events that occur during the growing season (June through September), there are approximately 16, 8, and 2.8 rainfall events per growing season that exceed 0.25, 0.5, and 1 inch, respectively.

Table 3-6. Monthly Precipitation by Year (2000–2015) for Bemidji, Minnesota [Minnesota Department of Natural Resources 2016a]

	Period of Record Summary Statistics														
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	WARM	ANN	WAT
30%	0.36	0.32	0.67	1.26	1.96	2.87	2.40	2.03	1.81	1.08	0.53	0.44	13.60	21.46	21.22
70%	0.80	0.67	1.21	2.20	3.63	4.77	4.05	3.87	3.23	2.47	1.27	0.90	18.29	26.28	26.33
Mean	0.67	0.55	1.01	1.86	2.91	3.95	3.49	3.24	2.60	1.94	1.05	0.71	16.18	23.97	23.93
1981–2010 Normals															
Normal	0.64	0.50	1.03	1.72	3.00	4.22	3.77	3.04	3.07	2.52	1.20	0.70	17.10	25.42	25.35
Year-to-Year Data															
2015	0.44	0.49	0.68	1.01	6.59	4.18	4.21	2.60	1.88	2.87	2.56	1.08	19.46	28.59	24.03
2014	0.51	0.52	0.68	2.78	2.99	8.86	2.98	2.92	1.19	1.12	0.62	0.21	18.94	25.38	28.95
2013	1.41	1.49	1.60	2.15	3.02	3.45	2.36	2.03	2.05	2.98	0.94	1.60	12.91	25.08	22.84
2012	0.89	0.72	2.08	2.36	2.26	3.35	2.99	2.32	0.31	2.13	0.56	0.59	11.23	20.56	18.22
2011	0.90	0.12	0.29	3.58	4.11	4.12	2.22	3.78	1.43	0.42	0.34	0.18	15.66	21.49	25.12
2010	0.72	0.32	0.88	1.17	3.67	4.97	5.63	6.97	6.52	2.44	1.03	1.10	27.76	35.42	36.94
2009	0.55	0.82	3.47	1.28	1.81	2.74	1.71	1.98	2.05	4.40	0.78	0.91	10.29	22.50	23.50
2008	0.04	0.39	0.32	4.19	1.59	4.38	3.80	1.31	4.09	4.74	1.35	1.00	15.17	27.20	25.99
2007	0.12	1.12	1.86	2.53	2.75	4.27	2.83	0.84	4.34	4.22	0.40	1.26	15.03	26.54	23.31
2006	0.30	0.70	2.17	1.48	2.77	2.30	2.04	0.57	3.86	1.35	0.49	0.81	11.54	18.84	23.95
2005	1.59	0.32	0.23	0.98	4.77	4.61	0.97	2.33	2.62	3.29	3.25	1.22	15.30	26.18	24.19
2004	0.77	0.39	1.16	0.52	3.53	1.38	4.32	1.79	7.08	4.63	0.37	0.77	18.10	26.71	23.75
2003	0.17	0.12	0.40	1.25	2.44	5.35	2.63	1.65	1.05	1.20	1.01	0.60	13.12	17.87	17.05
2002	0.28	0.08	0.82	1.58	1.66	6.33	5.08	3.19	1.82	1.28	0.34	0.37	18.08	22.83	25.12
2001	0.28	0.73	0.15	4.12	4.22	2.47	2.72	3.29	2.31	2.83	0.98	0.47	15.01	24.57	27.77
2000	0.19	0.50	1.01	0.94	2.58	4.44	1.67	5.58	2.28	2.80	3.94	0.74	16.55	26.67	20.26

Note: Warm Season = May–September. Retrieved August 11, 2016.

Blue values = wet (or > 70th percentile)

Green values = mid-range (30th–70th percentile)

Red values = dry (or < 30th percentile)

Table 3-7. Atlas 14 Summaries of Precipitation Duration and Frequencies for Bemidji, Minnesota [National Oceanic and Atmospheric Administration 2016] (Page 1 of 2)

PDS-Based Precipitation Frequency Estimates With 90% Confidence Intervals (in inches)[1]										
Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	**0.319** (0.251–0.415)	**0.385** (0.302–0.500)	**0.493** (0.386–0.642)	**0.585** (0.455–0.763)	**0.714**(0.536–0.955)	**0.815** (0.598–1.10)	**0.917** (0.650–1.26)	**1.02** (0.696–1.43)	**1.17** (0.762–1.67)	**1.28** (0.813–1.84)
10-min	**0.468** (0.367–0.607)	**0.563** (0.442–0.732)	**0.722** (0.565–0.940)	**0.856** (0.666–1.12)	**1.04** (0.785–1.40)	**1.19** (0.875–1.61)	**1.34** (0.952–1.85)	**1.50** (1.02–2.10)	**1.71** (1.12–2.44)	**1.87** (1.19–2.70)
15-min	**0.570** (0.448–0.740)	**0.687** (0.539–0.892)	**0.881** (0.688–1.15)	**1.04**(0.812–1.36)	**1.27** (0.957–1.71)	**1.46** (1.07–1.96)	**1.64** (1.16–2.25)	**1.83** (1.24–2.56)	**2.08** (1.36–2.97)	**2.28** (1.45–3.29)
30-min	**0.794** (0.623–1.03)	**0.960** (0.753–1.25)	**1.24** (0.965–1.61)	**1.47** (1.14–1.91)	**1.79** (1.34–2.39)	**2.04** (1.50–2.76)	**2.30** (1.63–3.16)	**2.56** (1.74–3.59)	**2.92** (1.91–4.16)	**3.19** (2.03–4.60)
60-min	**1.01** (0.793–1.31)	**1.22** (0.957–1.58)	**1.57** (1.23–2.05)	**1.88** (1.46–2.46)	**2.32**(1.75–3.12)	**2.68** (1.97–3.63)	**3.04** (2.16–4.19)	**3.43** (2.33–4.81)	**3.95** (2.59–5.66)	**4.37** (2.78–6.30)
2-hr	**1.23** (0.975–1.57)	**1.48** (1.18–1.90)	**1.92** (1.52–2.46)	**2.30** (1.81–2.96)	**2.86** (2.18–3.81)	**3.31** (2.47–4.44)	**3.79** (2.72–5.17)	**4.29** (2.96–5.98)	**4.99** (3.31–7.09)	**5.55** (3.57–7.94)
3-hr	**1.35** (1.08–1.72)	**1.62** (1.30–2.06)	**2.10** (1.68–2.67)	**2.53** (2.00–3.23)	**3.17** (2.45–4.21)	**3.70** (2.78–4.94)	**4.26** (3.09–5.80)	**4.87** (3.38–6.76)	**5.72** (3.81–8.10)	**6.40** (4.14–9.12)
6-hr	**1.58** (1.28–1.98)	**1.88** (1.52–2.35)	**2.41** (1.94–3.02)	**2.90** (2.33–3.65)	**3.65** (2.86–4.81)	**4.29** (3.27–5.68)	**4.98** (3.66–6.72)	**5.73** (4.03–7.90)	**6.80** (4.59–9.58)	**7.68** (5.02–10.8)
12-hr	**1.84** (1.51–2.27)	**2.15** (1.76–2.65)	**2.71** (2.22–3.35)	**3.24** (2.63–4.02)	**4.06** (3.23–5.29)	**4.76** (3.68–6.25)	**5.53**(4.11–7.39)	**6.37** (4.54–8.71)	**7.58** (5.17–10.6)	**8.57** (5.66–12.0)
24-hr	**2.11** (1.75–2.56)	**2.43** (2.02–2.96)	**3.04** (2.52–3.70)	**3.60** (2.97–4.41)	**4.48** (3.61–5.76)	**5.24** (4.09–6.78)	**6.06** (4.56–8.02)	**6.97** (5.02–9.43)	**8.27** (5.71–11.5)	**9.34** (6.23–13.0)
2-day	**2.39** (2.02–2.86)	**2.76** (2.32–3.30)	**3.43** (2.88–4.12)	**4.05** (3.38–4.89)	**5.02** (4.09–6.36)	**5.84** (4.62–7.47)	**6.74** (5.13–8.80)	**7.72** (5.62–10.3)	**9.12**(6.36–12.5)	**10.3**(6.92–14.2)
3-day	**2.61** (2.22–3.10)	**3.00** (2.55–3.57)	**3.72** (3.15–4.44)	**4.39** (3.69–5.25)	**5.41** (4.43–6.78)	**6.27** (4.99–7.94)	**7.21** (5.52–9.34)	**8.23** (6.02–10.9)	**9.69** (6.79–13.2)	**10.9** (7.37–14.9)
4-day	**2.81** (2.41–3.32)	**3.23** (2.76–3.81)	**3.98** (3.39–4.71)	**4.67** (3.95–5.55)	**5.72** (4.71–7.12)	**6.60** (5.28–8.31)	**7.55** (5.82–9.74)	**8.59** (6.32–11.4)	**10.1** (7.09–13.7)	**11.3** (7.67–15.4)

Table 3-7. Atlas 14 Summaries of Precipitation Duration and Frequencies for Bemidji, Minnesota [National Oceanic and Atmospheric Administration 2016] (Page 2 of 2)

PDS-Based Precipitation Frequency Estimates With 90% Confidence Intervals (in inches)(a)										
Duration	**Average recurrence interval (years)**									
	1	**2**	**5**	**10**	**25**	**50**	**100**	**200**	**500**	**1000**
7-day	**3.37** (2.92–3.93)	**3.84** (3.32–4.48)	**4.66** (4.01–5.45)	**5.39** (4.61–6.33)	**6.47** (5.37–7.94)	**7.37** (5.95–9.15)	**8.33** (6.46–10.6)	**9.35** (6.93–12.2)	**10.8** (7.65–14.5)	**11.9** (8.20–16.2)
10-day	**3.88** (3.38–4.49)	**4.39** (3.82–5.08)	**5.28** (4.57–6.12)	**6.0** **5**(5.21–7.05)	**7.17** (5.97–8.69)	**8.08** (6.55–9.93)	**9.03** (7.04–11.4)	**10.0** (7.47–13.0)	**11.4** (8.14–15.2)	**12.5** (8.65–16.9)
20-day	**5.31** (4.69–6.05)	**5.98** (5.28–6.82)	**7.08** (6.23–8.10)	**8.01** (6.99–9.19)	**9.28** (7.80–11.0)	**10.3** (8.41–12.4)	**11.3** (8.88–14.0)	**12.3** (9.23–15.7)	**13.6** (9.81–18.0)	**14.7** (10.3–19.7)
30-day	**6.51** (5.80–7.34)	**7.32** (6.51–8.27)	**8.63** (7.65–9.77)	**9.69** (8.53–11.0)	**11.1** (9.40–13.0)	**12.2** (10.1–14.5)	**13.3** (10.5–16.2)	**14.3** (10.8–18.1)	**15.7** (11.3–20.4)	**16.6** (11.7–22.2)
45-day	**8.03** (7.21–8.97)	**9.04** (8.11–10.1)	**10.6** (9.49–11.9)	**11.9** (10.5–13.4)	**13.5** (11.5–15.6)	**14.7** (12.2–17.3)	**15.8** (12.6–19.2)	**16.9** (12.8–21.2)	**18.3** (13.3–23.6)	**19.2** (13.6–25.5)
60-day	**9.33** (8.44–10.4)	**10.5** (9.49–11.7)	**12.3** (11.1–13.8)	**13.8** (12.3–15.4)	**15.6** (13.3–17.9)	**16.9** (14.0–19.7)	**18.1** (14.5–21.8)	**19.2** (14.6–23.9)	**20.5** (14.9–26.4)	**21.4** (15.2–28.3)

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

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that PF 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 NOAA Atlas 14 document for more information.

Table 3-8. 2005–2009: Mean Number of Precipitation Events by Month for Cass Lake, Minnesota (USC00211374), From 1987–2016 [Midwestern Regional Climate Center 2016]

Month	Mean Precipitation Events Exceeding Specified Depth				
	>0.01 in	>0.1 in	>0.25 in	>0.5 in	>1.0 in
January	6.8	2	0.6	0.3	0
February	5.4	1.7	0.5	0.1	0
March	7	3	1.7	0.7	0.1
April	7.5	4.1	2.3	1.1	0.3
May	11.4	6.6	4	1.9	0.4
June	11.3	7	4.5	2.3	0.8
July	9.9	6.9	4.5	2.1	1
August	8.4	5.6	3.6	2	0.5
September	9	5.5	3.4	1.6	0.5
October	8.9	4.9	2.7	1.5	0.6
November	6.2	3.4	1.6	0.6	0.1
December	6.6	2.4	0.9	0.3	0
Annual	98.4	53.1	30.3	14.5	4.5
Growing Season (June–September)	38.6	25	16	8	2.8

3.7.3 Days between Freezing Dates: Season Length

Along with patterns of average summer ambient temperatures, variations of the frost-free season length were examined as they influence lake temperatures, algal growing-season length, and aquatic-sediment reactions (kinetics). The frost-free season, as defined by the number of days between the last 32°F day of spring and the first 32°F day of autumn, were tabulated for Cass Lake, Minnesota (USC00211374), and plotted as shown in Figure 3-16. While the Cass Lake dataset was limited by the number of missing years of data, the long-term pattern generally indicates a pattern of increasing frost-free periods from the 1960s of approximately 90+ days to approximately 120+ days noted by 2015.

3.7.4 Evaporation

Potential shallow-lake annual evaporation rates that were estimated from pan evaporation measurements for the Bemidji area, total approximately 30 in/year. [Farnsworth and Thompson 1982].

3.8 Water Quality

3.8.1 Long-Term Monitoring Data for Lake Irving

Available long-term monitoring data for Lake Irving have been plotted as average growing-season values (with standard errors bars) by year for TP, Chl-*a*, and Secchi in Figures 3-17 through 3-19, respectively. Corresponding Minnesota NLF lake water quality standards are indicated as dashed horizontal lines on these graphs. TP and Chl-*a* concentrations that were noted post-2005 frequently exceeded values that were noted in the 1990s. The more robust Secchi dataset also indicates a general declining pattern (e.g., less transparency); however, this decline is not statistically significant. The lowest Secchi values are associated with lower flow conditions (e.g., 1991 and 2006), with the highest recent Secchi value of

1993 occurred during high growing-season flows. Note that Mississippi River daily flows at the Stump Lake dam were not tabulated by the USGS before 1987. Lake Irving's growing-season TP and Chl-*a* and Secchi averages consistently exceed applicable water quality standards.

Figure 3-17. Days between Freezing Dates.

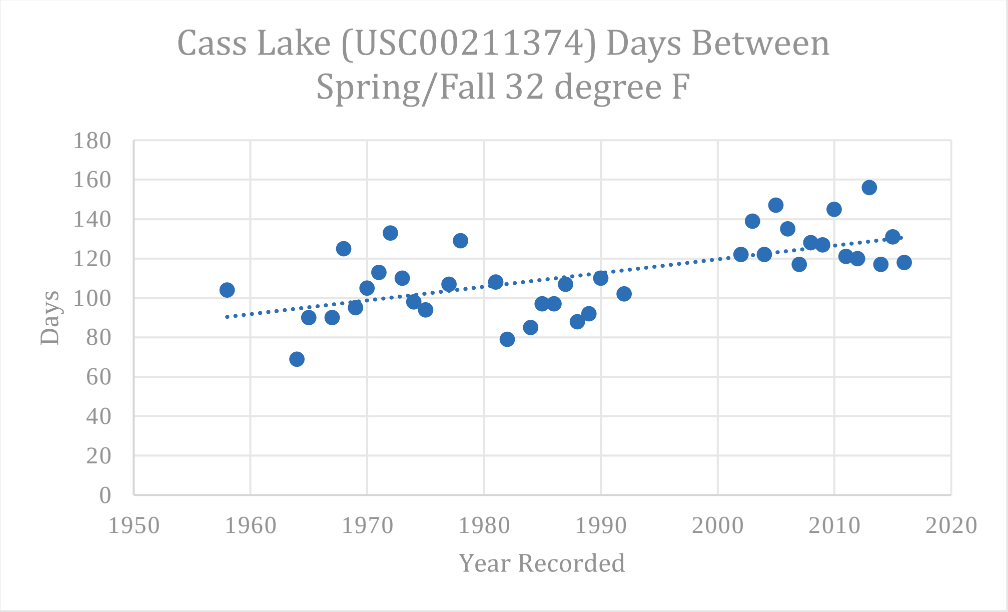


Figure 3-18. Lake Irving Mean Annual Growing-Season TP Concentration (All Monitoring Sites).

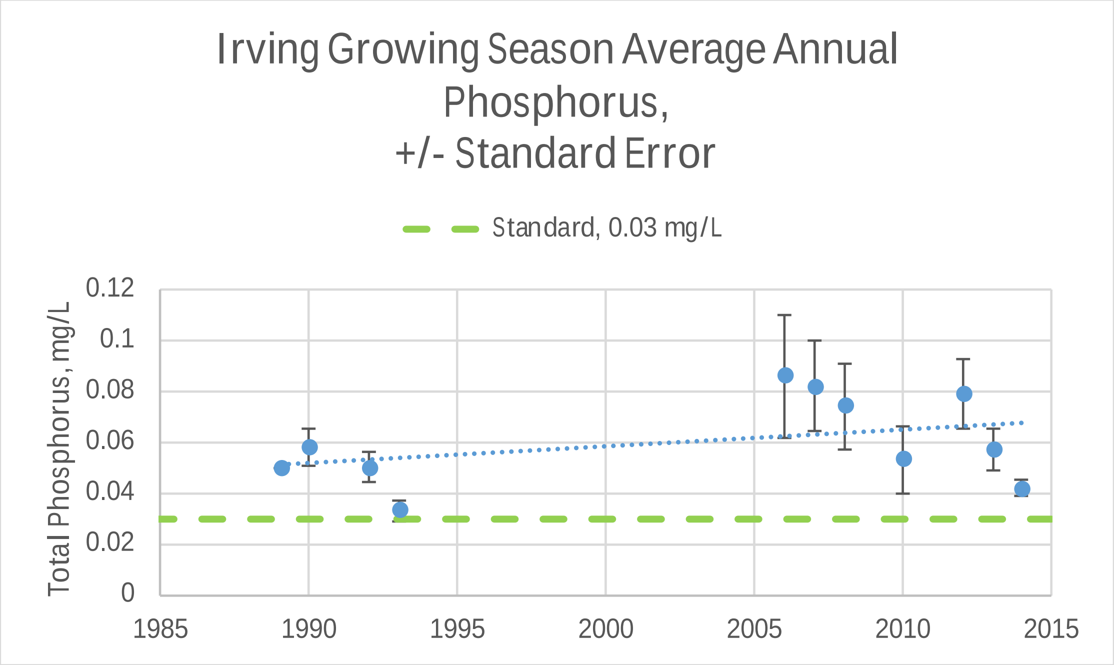


Figure 3-19. Lake Irving Mean Annual Chlorophyll-*a* Concentration (All Monitoring Sites).

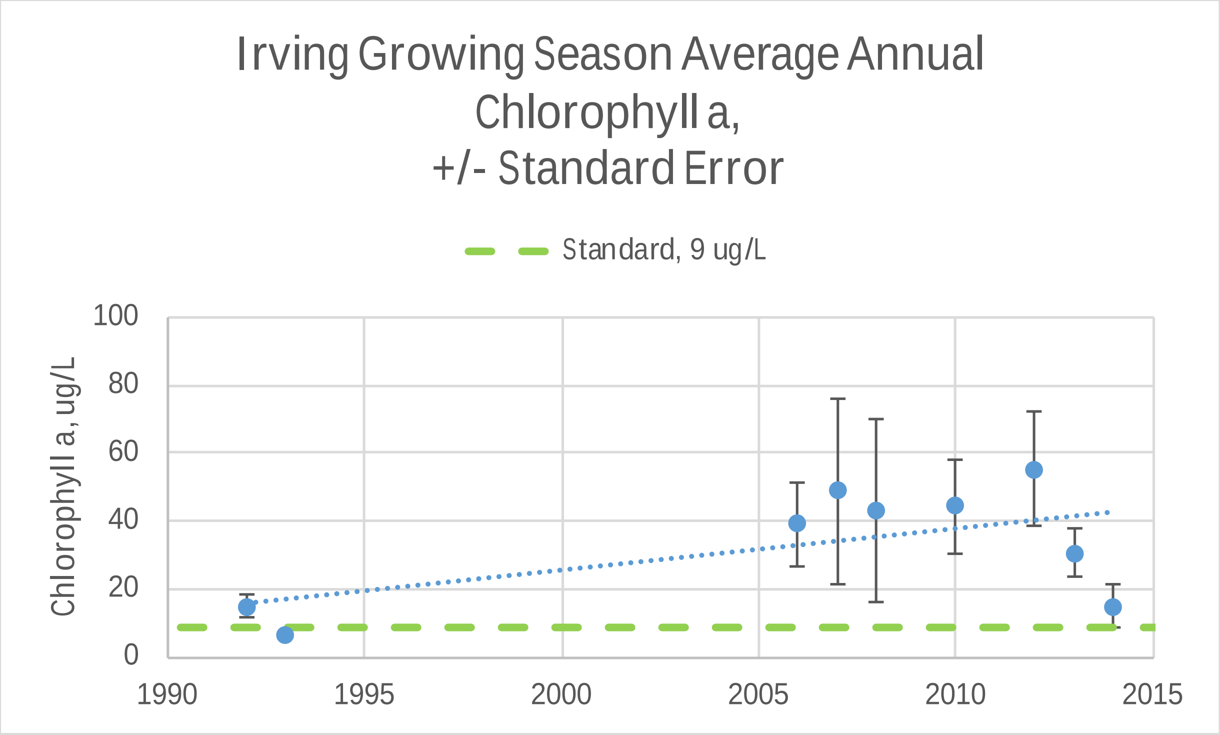
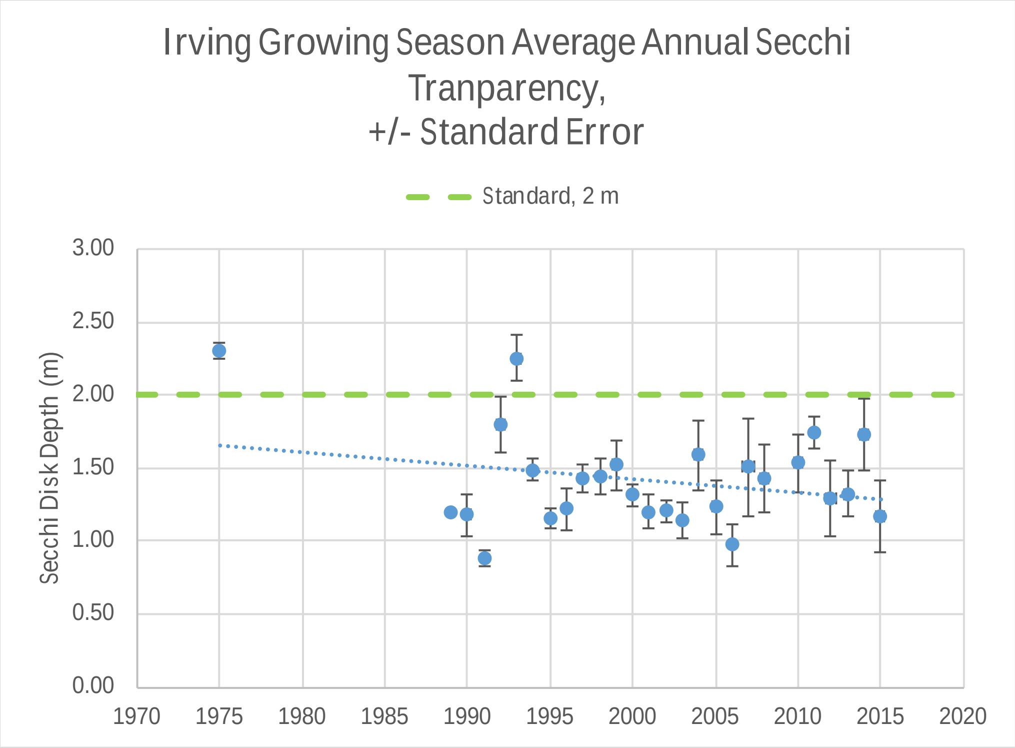


Figure 3-20. Lake Irving Mean Annual Growing-Season Secchi Disk Depth (All Monitoring Sites).



3.8.2 Long-Term Monitoring Data for Little Turtle Lake

Available long-term monitoring data for Little Turtle Lake (2000 through 2014) have been plotted as average growing-season values (with standard errors bars) by year for TP, Chl-*a*, and Secchi in Figures 3-20 through 3-22, respectively. Corresponding Minnesota NLF lake water quality standards are indicated as dashed horizontal lines on these graphs. Mean growing-season TP values exceed lake standards for all of the TMDL period (2000 through 2009), with 2014 slightly below the 30 µg/L standard. All of the corresponding growing-season mean Chl-*a* values exceeded the lake water quality standard of 9 µg/L. Growing-season mean Secchi values fluctuated above and below the standard of 2.0 m during the TMDL period, and were slightly less than the 2.0 m standard through 2014.

3.8.3 Lake Irving and Little Turtle Lake Mean Data by Growing-Season Month

The plotting of monitoring data by month for Lake Irving and Little Turtle Lake's TP, Chl-*a*, and Secchi, as seen in Figures 3-23 through 3-25, respectively, provide additional diagnostic perspectives of lake processes. In deeper lakes, TP concentrations may be generally expected to decline over the summer months because of sedimentation processes, while the opposite may occur in shallower well-mixed lakes and/or lakes with substantial lake sediment internal P loading.

Monthly average plots for Lake Irving show a substantial pattern of increasing TP from June through August as values increase from approximately 40 µg/L to over 100 µg/L, followed by a slight decline to approximately 70 µg/L in September. Corresponding monthly mean Chl-*a* also have a substantial increase from June to August as values increase from approximately 18 µg/L to 76 µg/L, followed by a large decline in September. Similarly, Secchi transparency generally decreases from June through August, with a slight increase in September. All of Lake Irving's growing-season monthly averages for TP, Chl-*a*, and Secchi violate state lake standards.

Monthly average plots for Little Turtle Lake's TP and Chl-*a* also show an increasing pattern over the entire growing season through September, but at much lower concentrations than noted in Lake Irving. Monthly mean Secchi values begin well above (better than) the 2.0 m standard, but quickly decline and remain below this level through September. All but June mean values exceed (violate) the state's lake water quality standards.

The TMDL period, multiyear, averaged growing-season values for TP, Chl-*a*, and Secchi were tabulated and summarized in Table 3-9 for Little Turtle Lake with corresponding Minnesota lake water quality standards for the NLF aquatic ecoregion. TMDL period data for Lake Irving were limited to 2006 through 2008, which included very low-flow years and exceptionally high values. To minimize a bias that could be introduced from a portion of the record with low-flow periods, data from the more extensive period of 2006 through 2015 were summarized in Table 3-10, and used for BATHTUB lake modeling purposes.

3.8.4 Lake Bemidji (Immediately Downstream of Lake Irving)

Available growing-season monitoring data were retrieved from the MPCA's Environmental Quality Information System (EQuIS) system for Lake Bemidji for Site 201 (north end of north basin), and assessed for 2009 through 2015 as summarized in Table 3-11 and depicted in Figure 3-26. Comparable data for the south basin of Lake Bemidji were not available for the 2009 through 2015. The data suggests that Lake Bemidji may be approaching LES values as assessed in the north basin, with an apparent increasing TP pattern noted in Figure 3-26. Historical data suggest that Lake Bemidji has average summer TP in the low to mid 20 µg/L range, with some higher excursions during wet years [EPA 1981]. While not definitive for the entire lake, the increasing pattern noted in Figure 3-26 indicates that Lake Bemidji is relatively sensitive to P loadings because of its large fetch and likely water column mixing. Dominant winds are from the northwest and southeast as depicted by the wind rose [Iowa State University of Science and Technology 2016] shown in Figure 3-27. Preliminary BATHTUB modeling of Lake Bemidji indicates that as Lake Irving's discharge exceeds about 60 µg/L (as an annual flow-weighted mean value), average lake P values may approach and exceed the LES level of 30 µg/L.

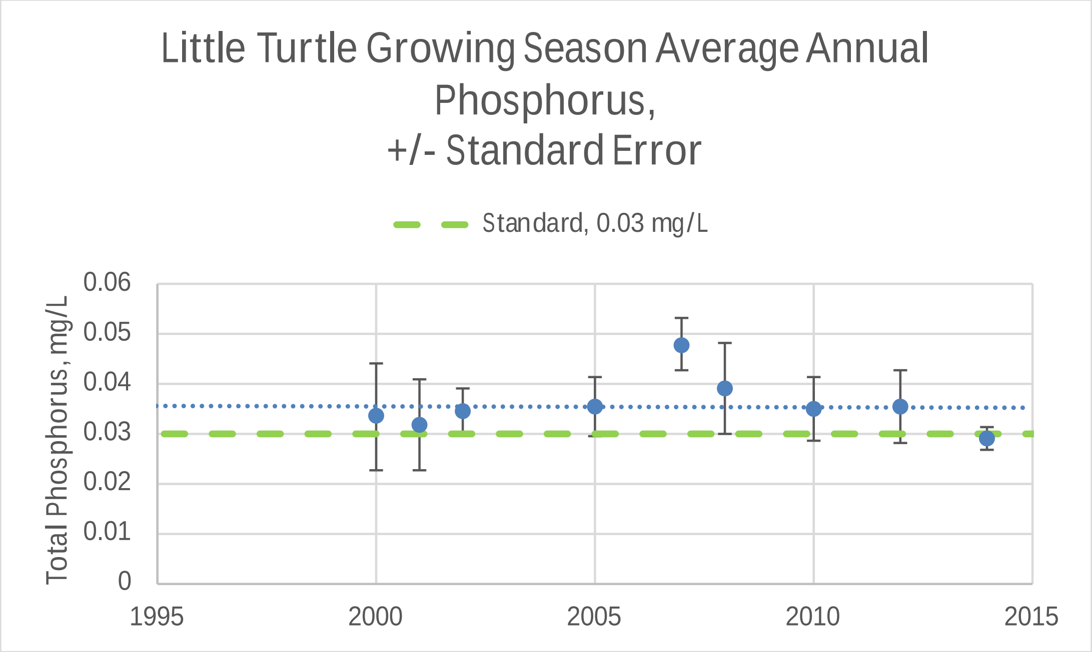


Figure 3-21. Little Turtle Lake Mean Annual Growing-Season TP Concentration (All Monitoring Sites).

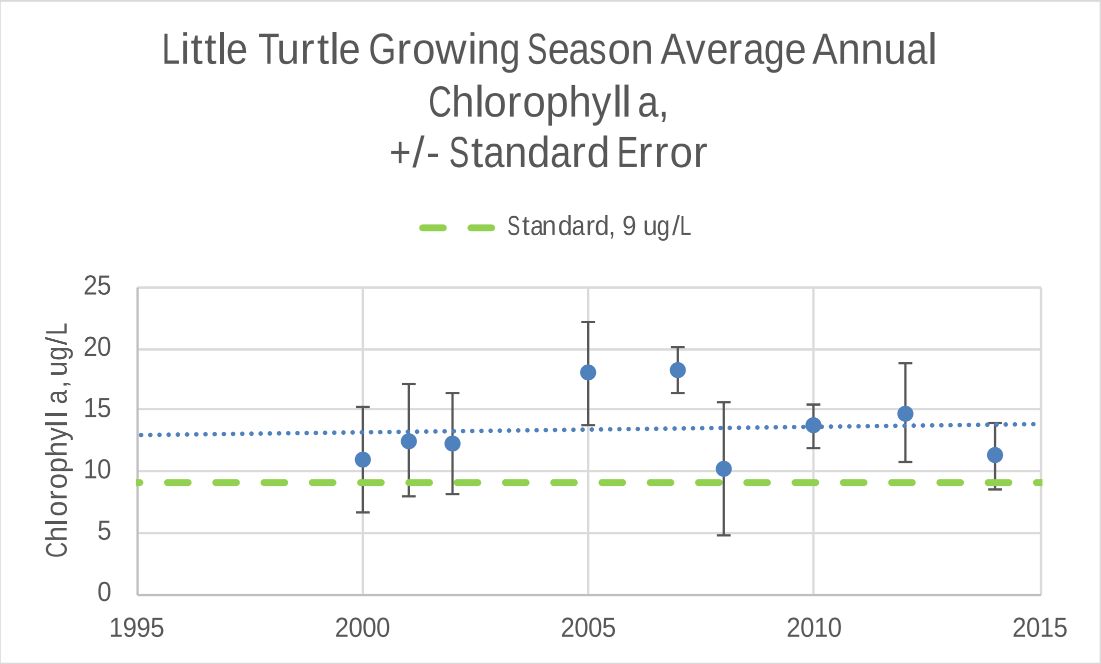


Figure 3-22. Little Turtle Lake Mean Annual Growing-Season Chlorophyll-*a* Concentration (All Monitoring Sites).

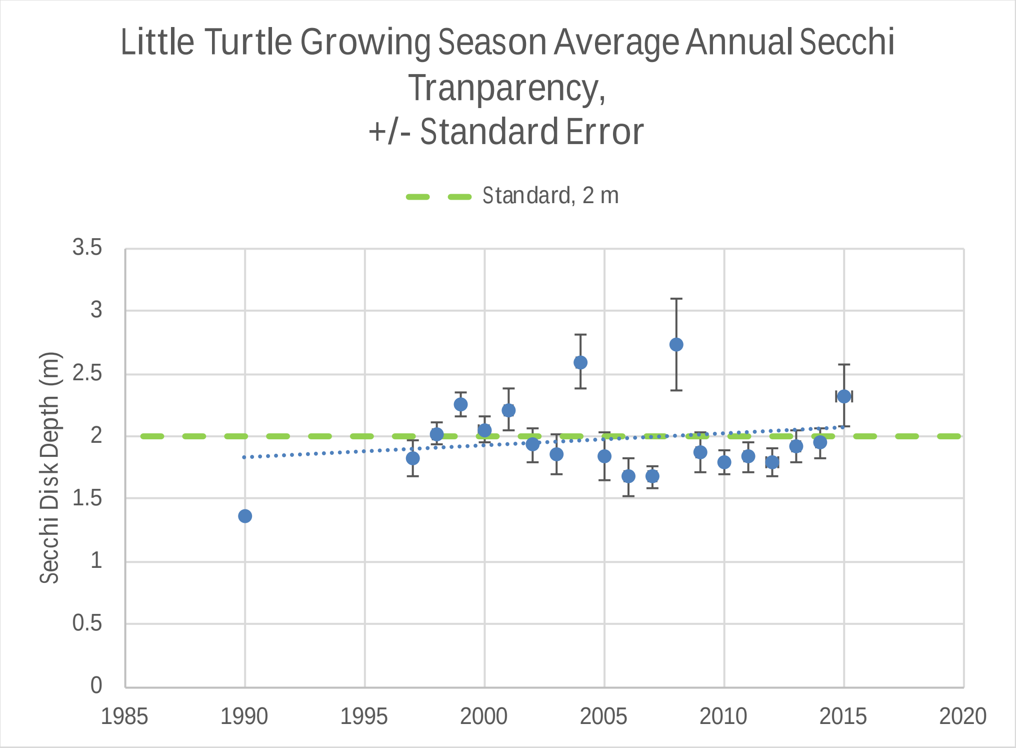


Figure 3-23. Little Turtle Lake Mean Annual Growing-Season Secchi Transparency Concentration (All Monitoring Sites).

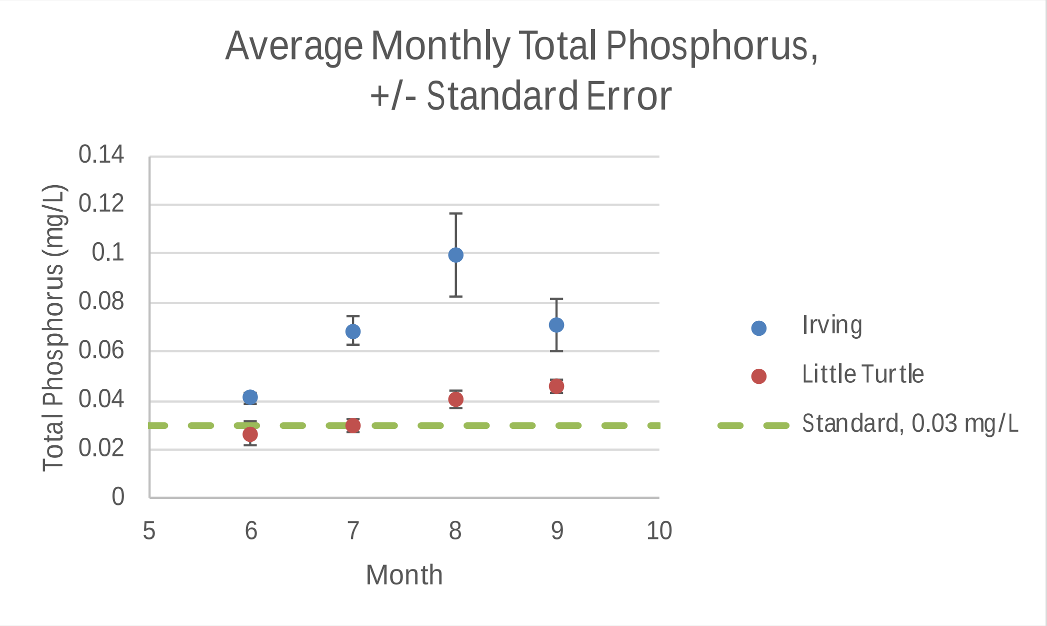


Figure 3-24. Mean Monthly TP Concentration, Lake Irving (Site 04-0140-00-204) and Little Turtle Lake (Site 04-0155-00-201) (All Available Data).

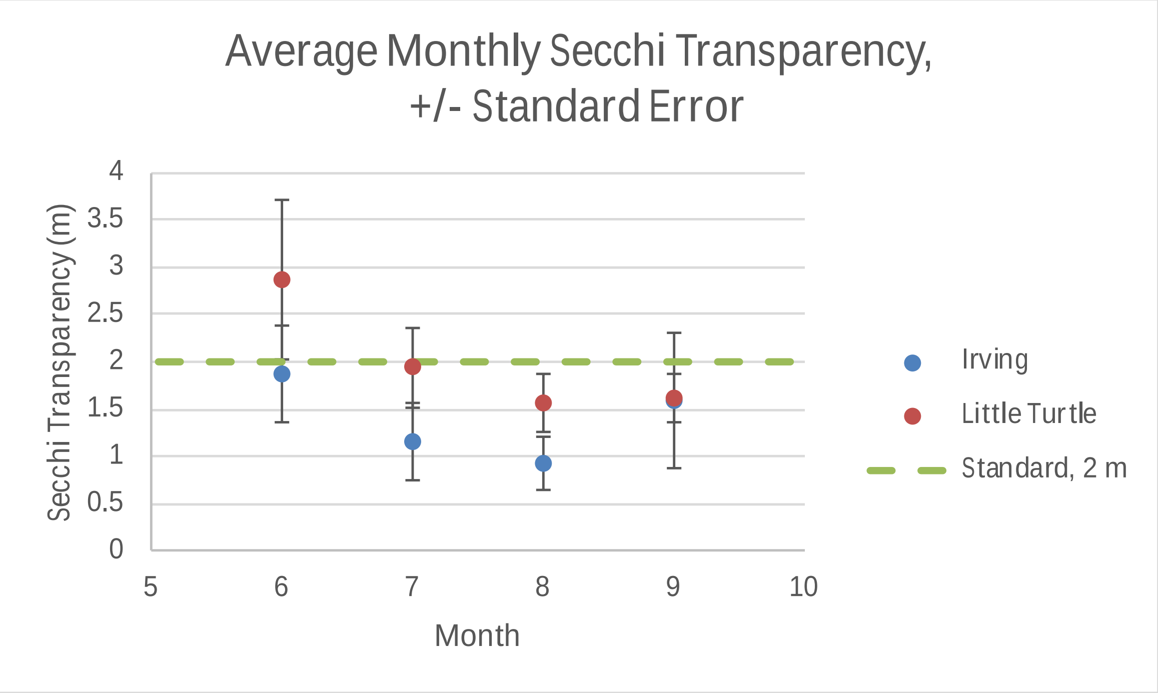


Figure 3-25. Mean Monthly Chlorophyll-*a* Concentration, Lake Irving (Site 04-0140-00-204) and Little Turtle Lake (Site 04-0155-00-201) (All Available Data).

Figure 3-26. Mean Monthly Secchi Disk Depth, Lake Irving (04-0140-00-204) and Little Turtle Lake (Site 04-0155-00-201) (All Available Data).

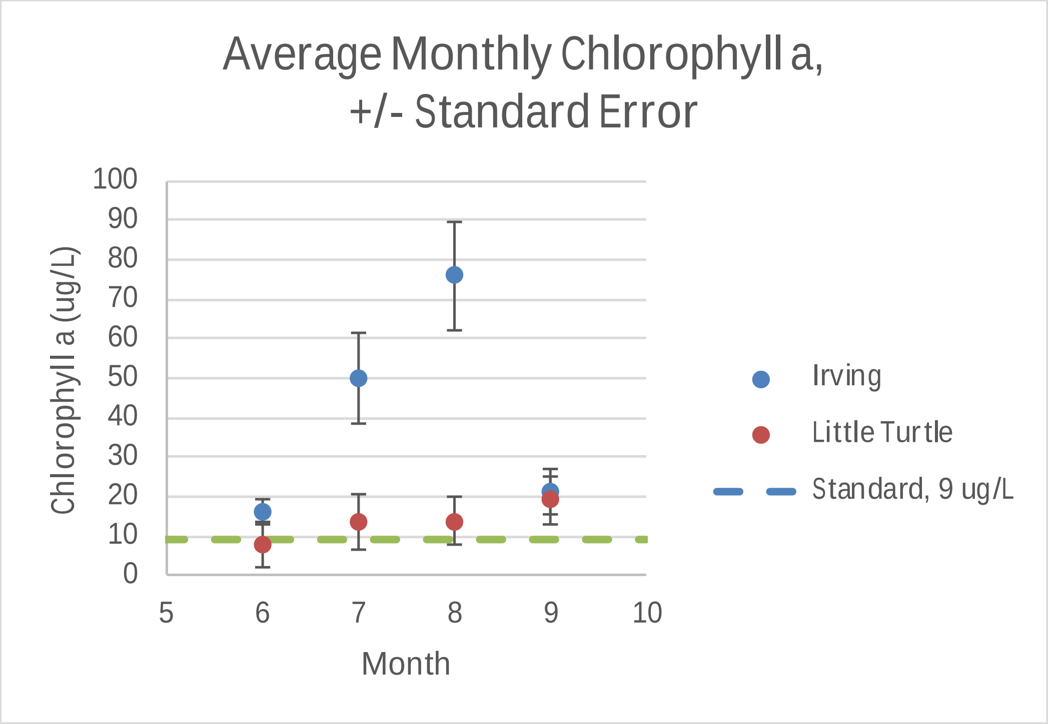


Table 3-9. Summary of 2000–2009 Lake Data for Little Turtle Lake

Little Turtle Lake (2000–2009)	Minimum	Mean	Maximum	Standard Deviation	Lake Standards
TP (µg/L)	17	37.1	64	13.9	≤ 30
Chlorophyll-*a* (µg/L)	1	13.8	26	8.0	≤ 9
Secchi Disk Depth (m)	1.1	2.0	6.1	0.8	≤ 2

Table 3-10. Summary of 2006–2015 Lake Data for Lake Irving

Irving Lake (2006–2015)	Minimum	Mean	Maximum	Standard Deviation	Lake Standards
TP (µg/L)	29	63.5	164	31.8	≤ 30
Chlorophyll-*a* (µg/L)	1	35.2	130	32.8	≤ 9
Secchi Disk Depth (m)	0.5	1.4	3.7	0.7	≤ 2

Table 3-11. Summary of 2009–2015 Lake Data for Lake Bemidji (North Basin Site 201)

Lake Bemidji (2009–2015)	Minimum	Mean	Maximum	Standard Deviation	Lake Standards
TP (µg/L)	12	30	63	14.2	≤ 30
Chlorophyll-*a* (µg/L)	3	12.4	31	7.9	≤ 9
Secchi Disk Depth (m)	.8	3.0	6.4	1.2	≤ 2

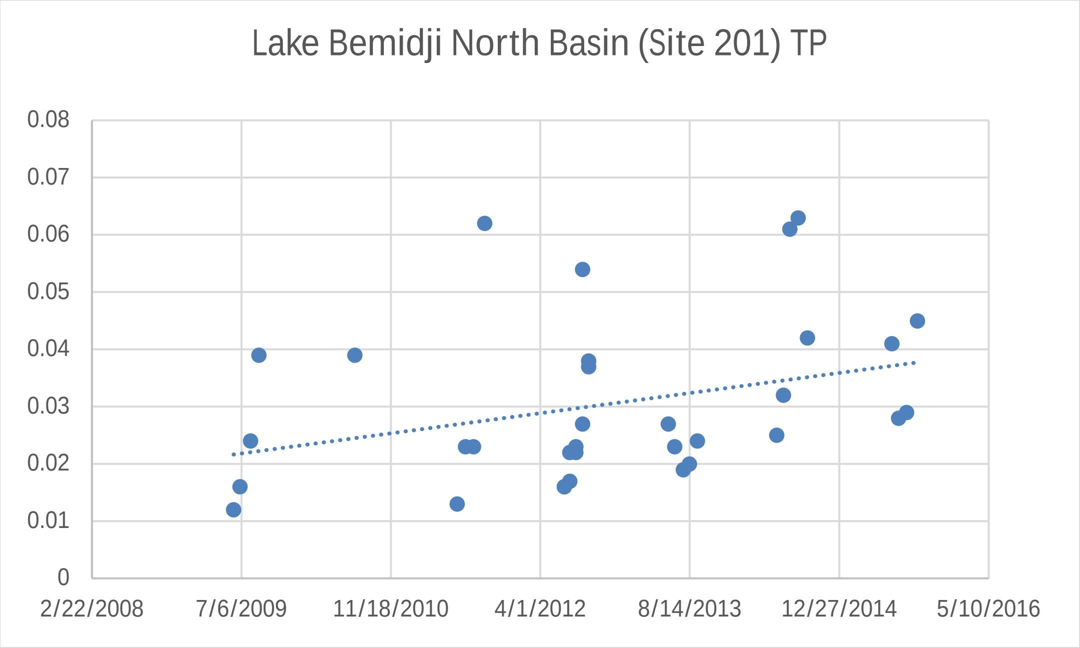


Figure 3-27. Lake Bemidji North Basin (Site 201) Monitored Surface TP Concentrations.

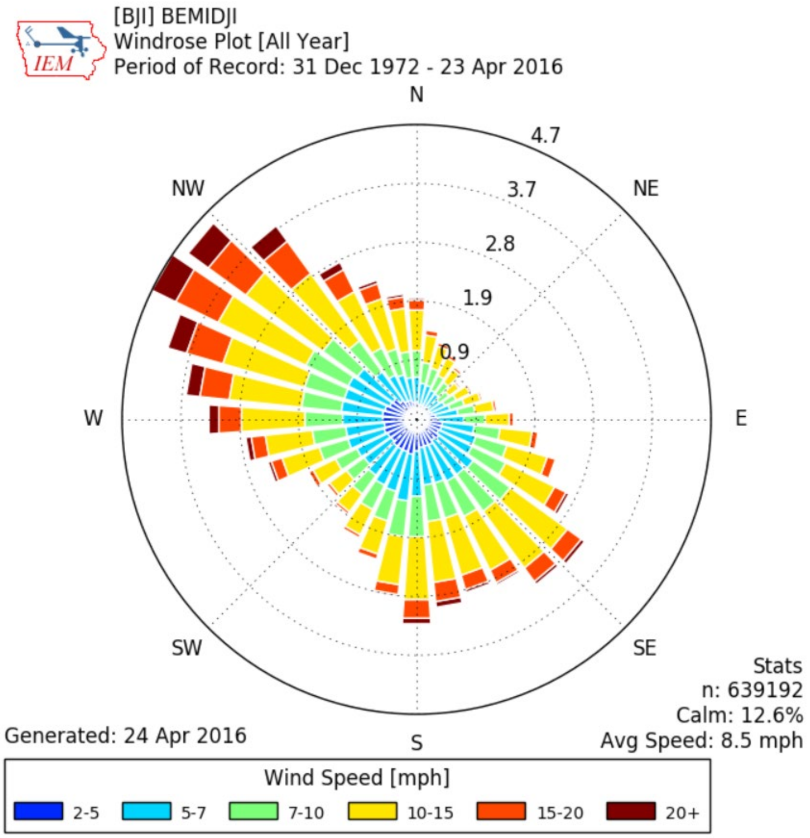


Figure 3-28. Annual Wind Rose for Bemidji, Minnesota [Iowa State University of Science and Technology 2016].

3.8.5 Dissolved Oxygen and Temperature Data Summary

DO and temperature data monitored by depth were examined in an effort to better define lake mixing patterns affecting biological responses and lake P dynamics. Available data for Lake Irving was limited to historical data from 1989 and 1990 that are plotted in Figure 3-28 and Figure 3-29. For Little Turtle Lake, available data from 2013 are shown in Figures 3-30 and 3-31. Temperature and DO data were noted to have been collected concurrently.

Lake Irving's available water temperature profile data indicate well-mixed conditions, with temperatures that are relatively similar going from the surface to depth. The August 27, 1990, temperature profile varied the most, with a net difference of 4.4°C noted between the surface and 4-meter depth. Peak monitored bottom water temperatures (July through September) ranged from approximately 15° to 21°C. Profile collected in June suggest a well-mixed condition, with similar DO concentrations over depths that range from 8 to 8.4 mg/L. In a similar fashion, DO profiles from September, October, and December show only slight differences from bottom to top with differences of approximately 1 to 2 mg/L between the maximum and minimum measured DO concentrations. However, growing-season DO profile data typically exhibited substantial concentration losses, with depth that indicate large oxygen depletion rates. Irving exhibited a clinograde-type oxygen pattern, with values that decreased with depth to values less than 4 mg/L observed on three dates. Sport fisheries generally require at least 5 mg/L. These data suggest periodic peak growing-season oxygen depletion rates.

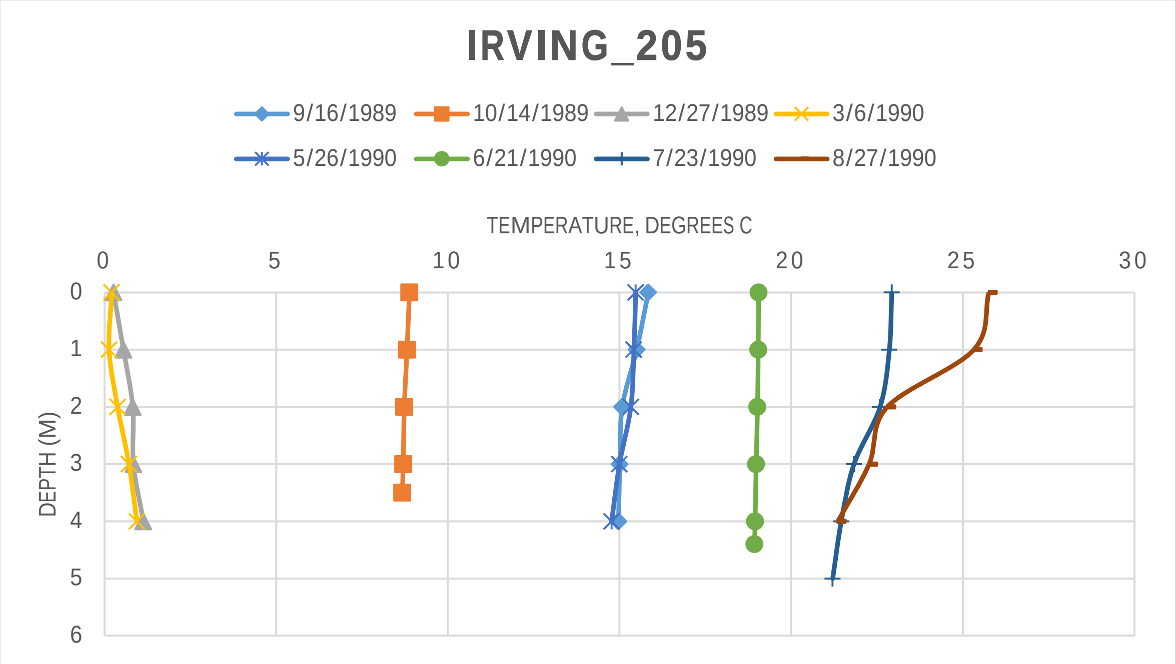


Figure 3-29. Lake Irving Water Temperature Profiles.

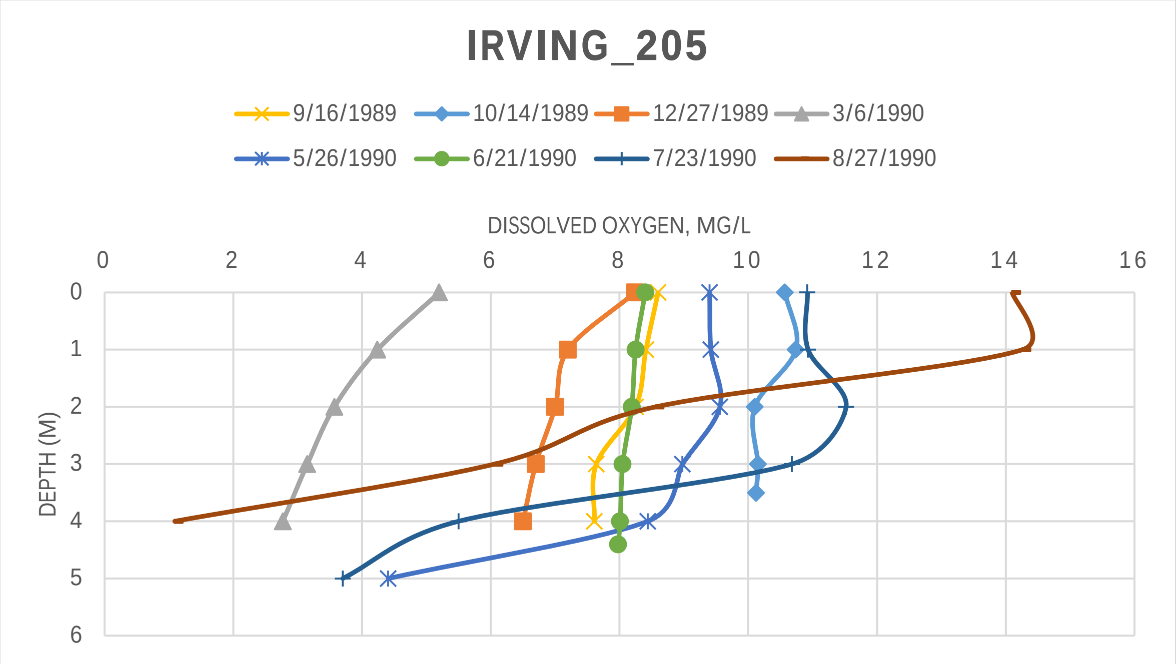


Figure 3-30. Lake Irving Dissolved Oxygen Profiles.

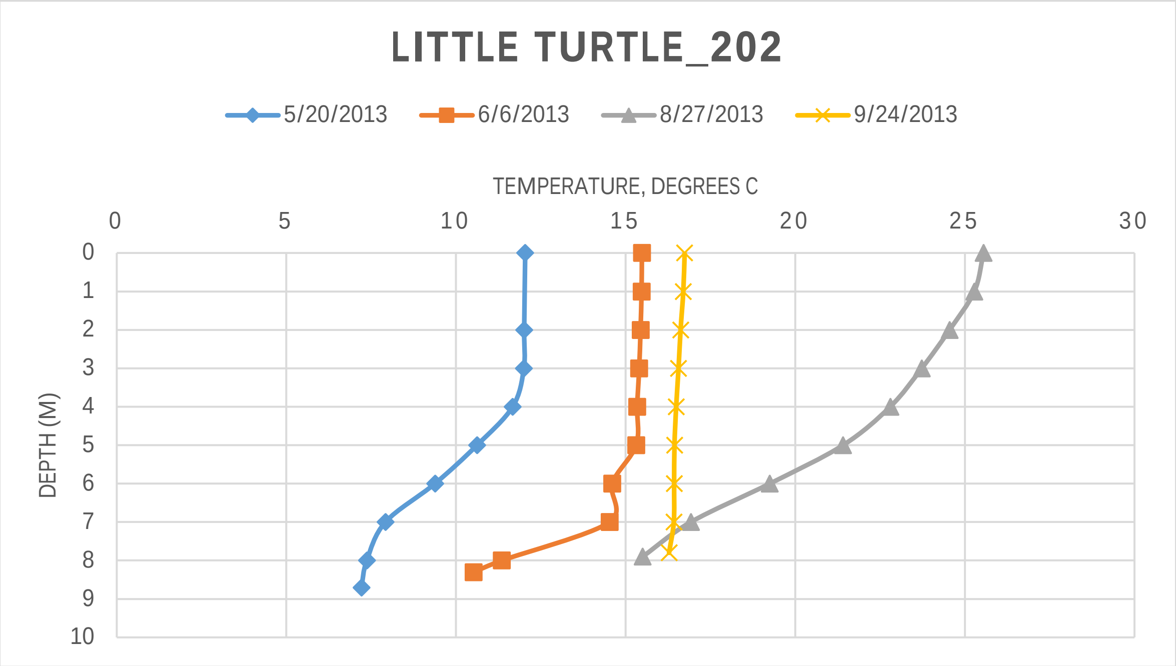


Figure 3-31. Little Turtle Lake Water Temperature Profiles.

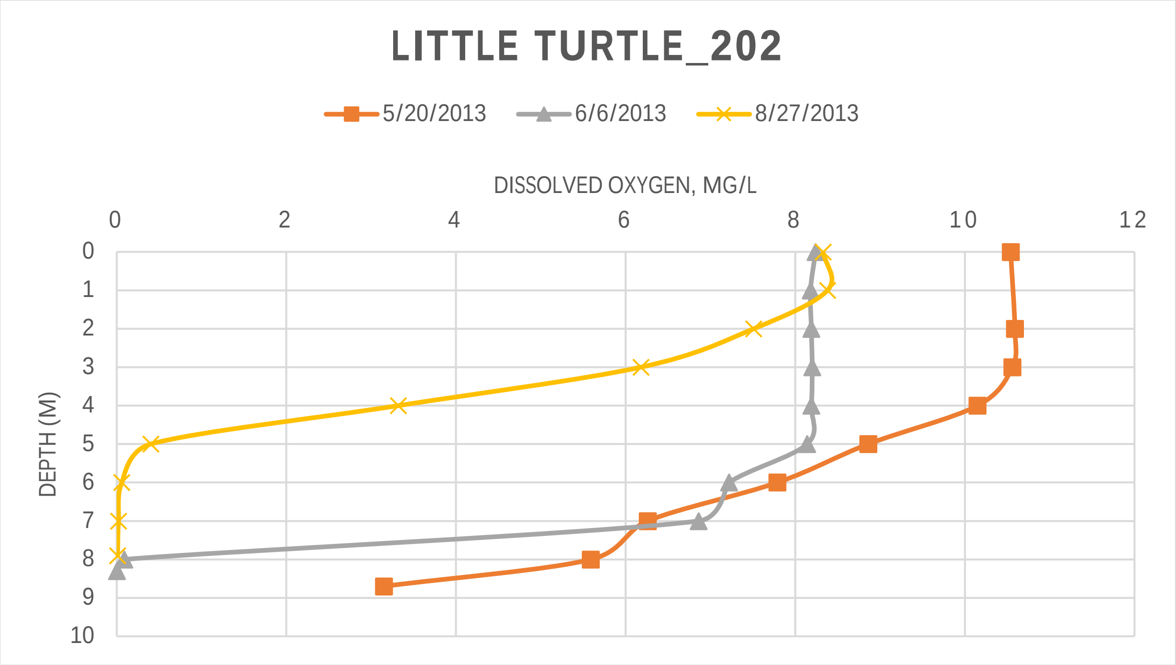


Figure 3-32. Little Turtle Lake Dissolved Oxygen Profiles.

Little Turtle Lake's available water temperature profile data indicate that this lake forms periodic or temporary thermal stratification. The August 24, 2013, profiled temperatures varied the most, with the surface temperatures declining by approximately 10°C by the 8-meter level. Peak monitored summer bottom water temperatures (July through September) ranged from approximately 15° to 16°C, indicating substantial mixing and warming of waters over the growing season. Little Turtle Lake's profile data displayed large decreases in DO concentrations with increasing depth to less than 2mg/l.

Lake water/sediment boundary temperature and DO concentrations greatly influence lake sediment chemistries related to internal P loading, and are thus important parameters for characterizing in-lake nutrient dynamics.

3.8.6 Minnesota Lake Eutrophication Analysis Procedure Modeling

The Minnesota Lake Eutrophication Analysis Procedure (MINLEAP) model [Wilson and Walker 1989] was used to estimate lake water quality based on aquatic ecoregion, watershed area, lake-surface area, and mean depth. MINLEAP-predicted data has been used to define lakes with water quality better or worse than regionally expected. These results are summarized in Tables 3-12 and 3-13. MINLEAP modeling indicated that Little Turtle Lake has lower water quality than generally expected given its mean depth, lake and watershed area, and NLF aquatic ecoregion. While Lake Irving's drainage basin is larger than employed in development of the MINLEAP model, results are tabulated to highlight the much higher observed TP and Chl-*a* levels than would be expected based on typical relationships developed from Minnesota lakes [Wilson and Walker 1989]. The higher Chl-*a* response may be attributed to Chl-*a* import from upgradient Mississippi River sources, elevated dissolved TP concentrations, and climatic factors.

Table 3-12. MINLEAP-Predicted Water Quality Parameters for Lake Irving

Average Lake Value		Lake Irving	NLF Lake Standards
TP concentration (µg/L)	Observed	63.5	≤ 30
	Predicted	47	
Chlorophyll-*a* (µg/L)	Observed	35.2	≤ 9
	Predicted	18.2	
Secchi Disk Depth (m)	Observed	1.41	≥ 2.0
	Predicted	1.4	

Table 3-13. MINLEAP-Predicted Water Quality Parameter for Little Turtle Lake

Average Lake Value		Little Turtle Lake	NLF Lake Standards
TP concentration (µg/L)	Observed	36.4	≤ 30
	Predicted	36	
Chlorophyll-*a* (µg/L)	Observed	13.0	≤ 9
	Predicted	12.2	
Secchi Disk Depth (m)	Observed	1.95	≥ 2.0
	Predicted	1.8	

3.9 Lake Biological Data

3.9.1 Lake Irving Fish Community

The DNR Fisheries Section performs fish population surveys of Lake Irving, with data from their 2012 field sampling used to support this summary. Considerable lakeshore development was noted as much of the lake is located in the city of Bemidji. The public access is located by the municipal wastewater plant; however, the channel between Lakes Irving and Bemidji is navigable for boat traffic from Lake Bemidji's other public accesses. Fish populations are benefited by seasonal movements of species via direct connections to Lake Bemidji and the Mississippi River. As a result, northern pike and walleye populations are sustained by natural reproduction and migration throughout the headwaters region. Healthy walleye and northern pike populations have been monitored across age groups. Black crappies and brown bullheads are present in low levels; yellow bullheads are much more abundant. The presence of brown and yellow bullheads instead of black bullheads is generally a good indication of better water quality [Schupp and Wilson 1993]. Other species present in the 2012 assessment included pumpkinseed, redhorse species, white sucker, rock bass, yellow perch, and largemouth bass. Fish consumption advisories because of mercury are posted for northern pike, walleye, white sucker and yellow perch. This lake is known as a good early season fishing lake for both the open and ice cover seasons.

3.9.2 Little Turtle Lake Fish Community

The DNR Fisheries Section performs fish population surveys of Little Turtle Lake, and data from their 2011 field sampling is used to support this summary. The fish community of Little Turtle Lake includes panfish, black crappie, walleye, northern pike, largemouth bass, yellow perch, sucker/redhorse and bullhead species (brown, yellow and lower levels of black bullheads). Also noted were cisco (tullibee), although this lake presents a marginal habitat for this species because of periodically occurring low DO concentrations. This lake is known for its panfish and has abundant bluegills and black crappies noted in the latest fish survey. The lake can be accessed via a carry-on walking access via the AMA, but can also be accessed via the channel from Turtle Lake, which has a single lane boat access and parking area.

3.9.3 Lake Irving Aquatic Plants

A Minnesota biological survey of aquatic plant species was conducted on the east shore of Lake Irving on August 8, 2011. In total, the aquatic plant community appears to be reasonably diverse and consisted of 19 species of submersed, free-floating, floating-leaf, and emergent plants, and three species of shoreline plants [DNR 2016]. Invasive species, such as curly-leaf pondweed (Potamogeton crispus) and Eurasian water milfoil, were not noted in this assessment. Lake Irving's aquatic plant community is substantially less diverse than that of the immediately downstream Lake Bemidji. Lake Bemidji's aquatic plant survey of August 15, 2011, noted 25 species of submersed, free-floating, floating-leaf, and emergent plants, as well as 25 species of shoreline plants [DNR 2016b].

3.9.4 Little Turtle Lake Aquatic Plants

Aquatic plant surveys were not available for Little Turtle Lake.

3.10 Water Quality Trends

A Seasonal Kendall Tau test was performed on growing season (June–September) Secchi transparency data for Little Turtle Lake (1997 through 2015), Lake Irving, and Lake Bemidji (1995 through 2015). A large number of measurements were available with well-defined variance components associated with this parameter. The Seasonal Kendall Tau test performs the Mann-Kendal trend test for individual seasons of the year, and then combines the individual results into one overall test to determine whether or not the dependent variable changes in a consistent direction over time. At least 10 years of data is recommended for detecting a serial correlation [Helsel et al. 2006]. No statistical trend in Secchi transparency was detected from the long-term records for Little Turtle Lake, Lake Irving, or Lake Bemidji.

3.11 HSPF Model Methodology

HSPF is a comprehensive watershed model of hydrology and water quality that includes modeling of surface and subsurface hydrologic and water quality processes, which are linked and closely integrated with corresponding stream and reservoir processes. The framework can be used to determine the critical environmental conditions (e.g., certain flows or seasons) for the impaired segments by providing continuous flows and pollutant loads at any point within the system. HSPF 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 in project HSPF modeling memoranda [Kenner 2013a and 2013b; Ackerman 2015].

The primary components of developing an HSPF model application include the following:

- Gathering and developing time-series data
- Characterizing and segmenting the watershed
- Calibrating and validating the HSPF model.

Each of these components is described in the following section.

3.11.1 Gathering and Developing Time-Series Data

Data requirements for developing and calibrating an HSPF model application are both spatially and temporally extensive. The modeling period was from 1995 through 2009. Time-series data that were used in developing the model application 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 needed for HSPF to simulate hydrology (including snow-related processes).

3.11.2 Characterizing and Segmenting the Watershed

The Headwaters Basin was delineated into 134 subwatersheds to capture hydrologic and water quality variability. The watershed was then segmented into individual land and channel pieces 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.

The land segmentation was defined by land cover. Land use and land cover affect the hydrologic and water quality response of a watershed to processes impacting infiltration, surface runoff, and water losses from evapotranspiration. Water that moves through the system is affected by land cover. Land use (as estimated by land cover) affects the rate of the accumulation of pollutants, because certain land uses often contain different pollutant sources.

Land cover categories (based on the NLCD) were aggregated into groups with similar characteristics, as shown in Figure 3-32. The 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 resulting overland flow will not run onto pervious areas but will directly enter the reach network.

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, the 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 is an expanded rating curve that 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. Tributaries that were not surveyed were assigned the geometry of hydraulically similar channels.

3.11.3 Calibrating and Validating the HSPF Model

Model calibration involved hydrologic and water quality calibration 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 by the sediment calibration, the temperature calibration, and finally the nutrient/oxygen/Chl-*a* calibration. The 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 15-year simulation period included a range of dry and wet years. This range of precipitation improves the model calibration and validation, and provides a model application that can simulate hydrology and water quality during a broad range of climatic conditions.

Hydrologic calibration is an iterative process intended to match simulated flow to observed flow by methodically adjusting model parameters. HSPF hydrologic calibration is divided into the following four sequential phases of adjusting parameters to improve model performance:

- Annual runoff

- Seasonal or monthly runoff
- Low- and high-flow distribution
- 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 are achieved. The procedures and parameter adjustments that have involved in these phases are more completely described in Donigian et al. [1984] and Lumb et al. [1994].

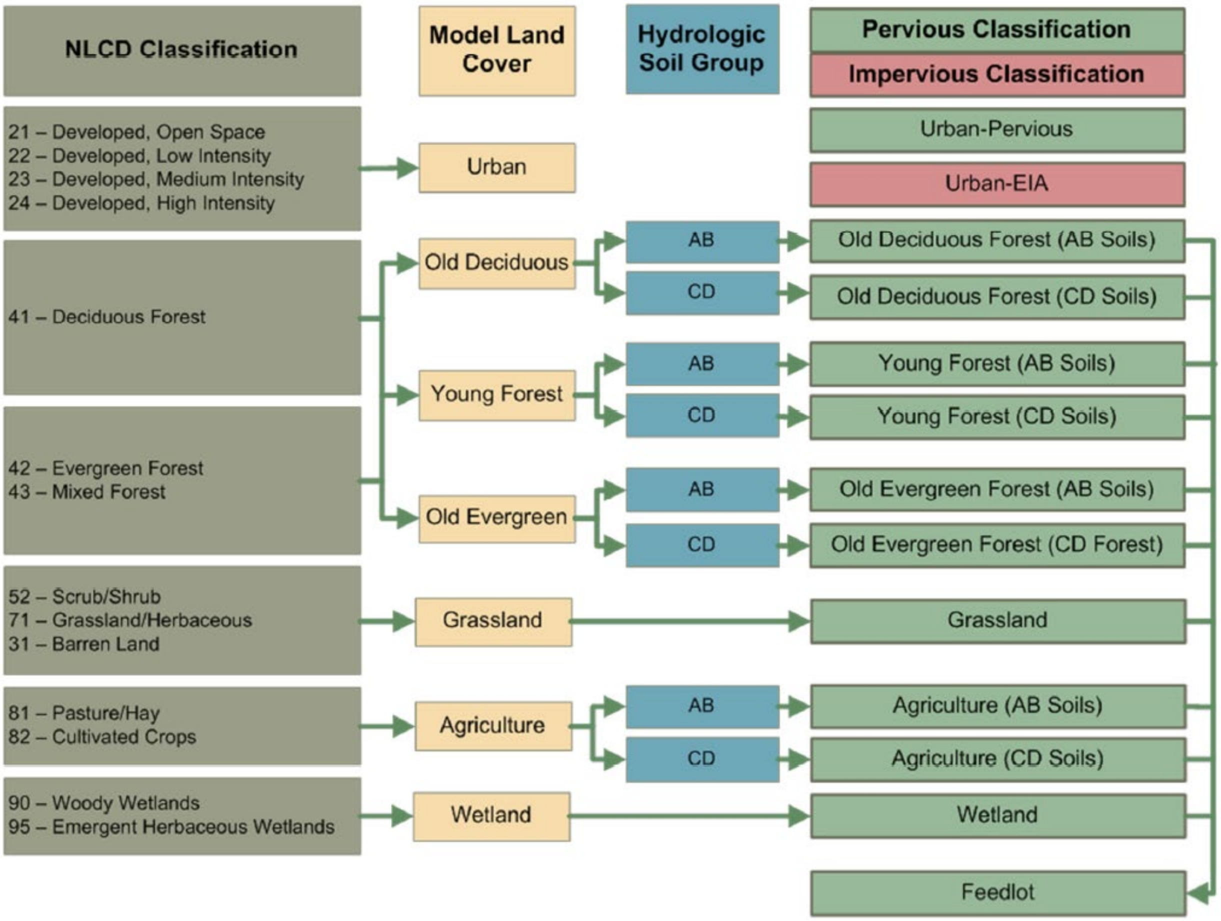
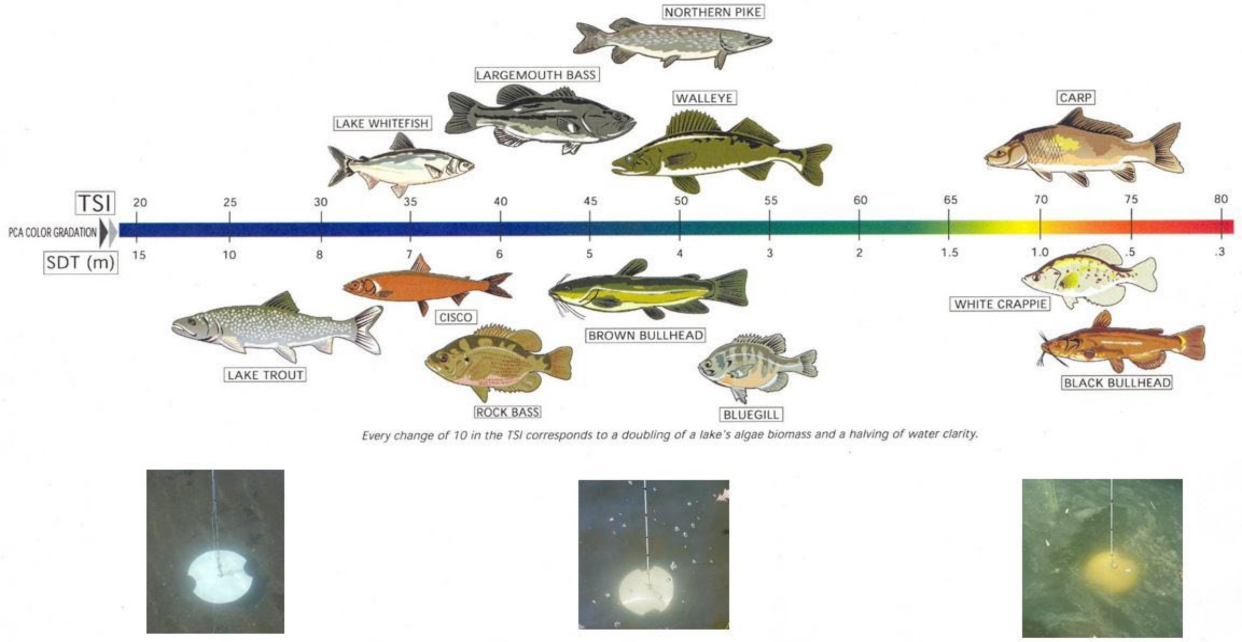


Figure 3-33. Land Cover Category Aggregation Schematic.

The hydrology calibration was evaluated 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 water quality calibration optimized alignment between the loads 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. More detailed information on the HSPF model application and model calibration results (hydrology and water quality) can be found in project modeling memoranda [Kenner 2013a and 2013b; and Ackerman 2015].

3.12 Phosphorus Source Summary

P is the primary nutrient of concern for this TMDL, because excess quantities typically drive a wide array of aquatic biological responses that can negatively affect established beneficial uses. High P concentrations are associated with elevated algal production, increased organic content and decay, and increased oxygen depletions that affect fish survival and propagation. Schupp and Wilson [1993] compared the relative abundance and presence of various fish across the spectrum of lake water quality by use of the Carlson Trophic State Index (TSI) [Carlson 1977], as depicted in Figure 3-33, which illustrates that the highest TP concentrations (and TSI values) are associated with carp and black bullheads. Recreational uses are also affected as TP concentrations increase, produce more algae, and reduce water clarity. Increased algal abundance and reduced water clarity are negatively related to user preferences for swimmable conditions [Heiskary and Wilson 2005]. Heiskary and Walker [1988] further refined lake quality summer Chl-*a* concentrations. Both Chl-*a* and Secchi transparency exhibit nonlinear responses to increased TP concentrations. The observed frequency of Chl-*a* concentrations that exceed 30 µg/L (or severe nuisance conditions in Heiskary and Wilson [2005]) is quite low at TP concentrations of approximately 30 µg/L, and increases steadily to approximately 70% of the summer with TP concentrations of approximately 100–120 µg/L. Algal blooms in severe form are frequently dominated by cyanobacteria that can be periodically toxic. Hence, these interrelationships were the building blocks used to define lake TP thresholds that became Minnesota's LES and the targets for the lake nutrient TMDL allocations described herein. One of the main components of a TMDL is identifying watershed P sources and the magnitude of their contributions to each lake.



Every change of 10 in the TSI corresponds to a doubling of a lake's algae biomass and a halving of water clarity.

Figure 3-34. Lake Fish Species Relative to Carlson Trophic State Index (Top of the Bar) With Average Summer Secchi Transparency (Across the Bottom of the Bar in Meters) (MPCA Graphic Adapted From Schupp and Wilson [1993]).

Natural background P sources to lakes include surface runoff from the natural landscape, background stream-channel erosion, groundwater discharge, and atmospheric deposition of windblown particulate matter from the natural landscape. Internal loading of P is an additional nonpoint source, which can be of anthropogenic or natural origin. This loading is primarily from release of P from lake sediments or aquatic plants. Typical human-made influences to lakes include state- and federal-permitted discharges from wastewater, industrial and commercial entities, shoreland development, impervious surfaces (roads, roofs, and driveways), stormwater via artificial drainages from urban and agricultural lands, row cropping, pastured lands, individual sanitary treatment systems, feedlots, and channelized streams/ditches. The following section provides a brief description of the potential permitted and non-permitted sources that can contribute to impaired lakes of the Mississippi River Headwaters Watershed.

3.12.1 Permitted Sources

Permitted sources are by definition point sources, or those that originate from a discrete, identifiable source within the watershed and are regulated by the National Pollutant Discharge Elimination System (NPDES) and State Disposal System (SDS) Permits. These include the following:

- Regulated municipal and industrial wastewater treatment systems
- Feedlots that require NPDES coverage
- Regulated stormwater.

Detailed information about specific permitted P sources is included in Chapter 4.0. Any industrial, municipal, or private-entity point source that discharges treated wastewater to surface waters of Minnesota must have an NPDES/SDS Permit that specifies discharge location(s), volumes, and treated effluent quality. However, no WWTPs are known to discharge to the two impaired lakes addressed in this TMDL. Backwatering of Lake Bemidji into Lake Irving during low-flow periods should be examined to assess whether Bemidji WWTP discharges periodically enter Lake Irving. The city of Bemidji has a stringent P limit (0.3 mg/L) for its wastewater discharge that has been maintained for over 25 years. Permit conditions (including environmental review and public notice) are specified by Minn. R. ch. 7001. Treated effluent P concentrations and loading rates are specified by permit, and require monitoring and reporting. Monitoring data, along with wastewater facility discharge rates, were used to develop P loading values used in this TMDL.

Municipal Stormwater Permits are required for specified Phase II cities that are defined as Municipal Separate Storm Sewer Systems (MS4s) by permit (General Permit Authorization to Discharge Stormwater Associated with Small MS4s under the NPDES/SDS permit (MNR040000). MS4s are defined by the MPCA as conveyance systems (roads with drainage systems, municipal streets, catch basin, curbs gutters, ditches, man-made channel, and storm drains) that are owned or operated by a public entity such as a state, city, town, county, district, or other public body that has jurisdiction. The city of Bemidji MS4 (MS400265) is located in the watershed of Lake Irving. Winter thaws and rainfall events generate runoff within city areas that reach storm sewer conveyances that are largely influenced by the amounts and distribution of impervious areas associated with 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.

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 Permit (MNR100001). Permits are required for construction activities that disturb: (1) one acre or more of soil, (2) less than one acre of soil if that activity is part of a "larger common plan of development or sale" that is larger than one acre, or (3) less than one acre of soil, but the MPCA determines that the activity poses a risk to water resources. Exposed soil surfaces can erode large quantities of suspended particles from construction sites, including P associated with soils, organic matter, and legacy sources. Industrial stormwater runoff is a regulated source as defined by the MPCA's reissued Multi-sector

Industrial Stormwater NPDES/SDS General Permit (MNR050000), and applies to facilities with Standard Industrial Classification Codes in 10 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 SWPPP that details stormwater BMPs that are implemented to manage stormwater at the facility. Permitted facilities are required to perform runoff sampling, which is compared to benchmark TP concentrations as specified by the EPA. P monitoring is required if a nutrient-impaired waterbody is located within one mile of the facility. A search of the MPCA's Industrial Stormwater Database indicated that 10 industrial permitted sites and another 15 sites that have no-exposure exclusions are located in Bemidji.

3.12.2 Non-permitted Sources

3.12.2.1 Direct Watershed Phosphorus Loading

A calibrated 1995 through 2009 HSPF model was used to develop loading estimates based on land cover in the Lake Irving and Little Turtle Lake Watersheds. HSPF is a continuous model that employs precipitation and other climatic variables to predict runoff and pollutant loading to waterbodies. Mean annual runoff (inches) and TP loads (pounds per acre) for each modeled land use in the watersheds were used to calculate mean annual loading to each lake.

3.12.2.2 Subsurface Sewage Treatment Systems

Homes and businesses in each impaired lake watershed are served by subsurface sewage treatment systems (SSTSs). All Little Turtle Lake homes and businesses are assumed to be served by SSTSs. A desktop analysis was performed to estimate the number of homes and cabins around each lake based on manual counting from the latest available Google Earth images for each lake's watershed. Assumptions and literature values were used to estimate total annual loading from septic systems.

3.12.2.3 Atmospheric Deposition

Atmospheric deposition of P on the lake surface can be an important part of the P budget. Atmospheric deposition occurs as wet (carried by precipitation) and dry (dry particles carried as dust) deposition. Unlike other nonpoint sources such as watershed runoff or septic loading, atmospheric P deposition originates outside at the watershed and cannot be controlled. An atmospheric P deposition of

26.8 milligrams per square meter per year (mg/m^2/year) [Twarowski et al. 2007] was used to quantify average annual total (wet + dry) deposition on the lake surface.

3.12.2.4 Lake Nutrient Cycling

Lake nutrient cycling, or internal loading, refers to several processes that can cause P to be released into the water column where it can be available to algal growth, often in dissolved P forms. For the purposes of this TMDL study, lake P cycling can occur from these types of processes:

1. P can be released from lake sediments in aerobic and anaerobic conditions, as typically moderated by amounts of available iron, organic loading, and other factors such as legacy sources.
2. Sediment resuspension from physical disturbance by bottom-feeding fish (e.g., rough fish such as carp and black bullheads), particularly in shallow-lake areas, can cause nutrient resuspension, including P. Small particles (clay and silt) are most vulnerable to resuspension; these particles also have the largest specific area (surface area per mass) and, therefore, are capable of holding much more P per unit mass than larger particles (sand). Carp and black bullhead populations were not noted by the DNR Fish Surveys for Lake Irving; however, low levels of black bullheads were noted in Little Turtle Lake. Bottom-feeding fish can influence resuspension of bottom sediments in either lake.
3. High concentrations of TP and dissolved P from tributary and lakeshed runoff pulses can contribute to elevated in-lake concentrations and increased algal growth. The resulting increased biological growth, decay, and deposition may increase the pool of soluble/dissolved P of surficial lake sediments and, hence, may be temporally mistaken for traditional internal loading sources. Therefore, particular attention was paid to HSPF-generated TP and dissolved P loading rates to each lake.

4 Total Maximum Daily Load Development

4.1 Loading Capacity

Loading capacity for both impaired lakes was determined with a calibrated BATHTUB model based on 2000 through 2009 HSPF loads, and 2000 through 2009 growing-season mean TP, Chl-*a*, and Secchi values from monitoring data. 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:

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

where LA is load allocation, WLA is wasteload allocation, MOS is margin of safety, and RC is reserve capacity. LA is the loading from nonpoint sources, while WLA is the load from point sources and permitted discharges. MOS is an explicit amount that is usually expressed as a percent of the TMDL, and used to increase the likelihood of compliance by accounting for potential unknown or unquantifiable nutrient sources. Reserve capacity is a load that is apportioned to account for anticipated future growth or land use change.

4.2 Watershed and Lake Modeling

4.2.1 Watershed Surface Runoff Loading

Watershed loading to lakes was provided from the calibrated Upper Mississippi Headwaters HSPF Model [Ackerman 2015]. Mean annual runoff and flow-weighted mean TP concentrations for watershed loading were provided as input to BATHTUB. Table 4-1 includes watershed areas and average areal rates of runoff from HSPF.

Table 4-1. Watershed Areas, Average Areal Rates of Runoff.

Impaired Lake	Source	Acres	Flow (in/ac/yr)
Little Turtle	Lakeshed	1,069.4	5.37
	Tributaries	24,762.3	4.15
Irving	Lakeshed	8,085.6	8.64
	Tributaries	346,559.5	4.62

4.2.2 Lake Model

BATHTUB is an empirical eutrophication model used to predict lake responses to nutrient loading. BATHTUB uses steady-state water and nutrient mass balances to model advective transport, diffusive transport, and nutrient sedimentation [Walker 2004]. Lake responses (e.g., Chl-*a* concentration or Secchi depth) are predicted by empirical relationships developed by Walker [1985]. BATHTUB allows users to specify single lake segments or multiple segments with complicated flow routing; lake response is calculated for each lake segment based on morphometry and lake fetch data entered by the user.

The cumulative annual P load, from all external watershed and internal lake sources has been empirically related to lake growing-season conditions [Walker 1996], expressed as average summer TP, Chl-*a,* and Secchi transparency. The empirical relationship is the basis of predictive models such as BATHTUB.

Tributary inflows in the lake segment(s) are specified by the user as mean annual flow volume (hectometers [hm^3]); pollutant concentrations are entered as flow-weighted mean concentrations. BATHTUB includes several model choices for predicting TP, Chl-*a*, Secchi, and other lake responses based on model input. The model for in-lake TP prediction for Little Turtle Lake was the Canfield and Bachmann Lake model and First Order P Model for Lake Irving. Other inputs of note are mean annual precipitation, mean annual lake-surface evaporation, change in storage volume, atmospheric pollutant deposition, and internal loading release rates. Observed lake water quality data (TP, Chl-*a*, Secchi, conservative substances) are entered as growing-season (June through September) mean values for the period of interest. BATHTUB can be calibrated in many ways, including adjusting internal loading rates or calibrating coefficients (by lake segment) or model coefficients (globally for all segments).

4.2.3 Representation of Lake Systems in BATHTUB Models

Each of the lakes was represented by a single lake segment as defined by lake-surface area, mean depth, and length of fetch. While Lake Bemidji is not an impaired lake, it was modeled based on output from the Lake Irving's BATHTUB model outputs. HSPF-derived data for the TMDL period's (2000 through 2009) average annual water and P inputs to each lake were entered for all of the upgradient tributaries and each lake's immediate drainage areas (lakesheds). Additionally, lake-specific estimated SSTS (septic) contributions were added. For Lake Irving, estimated MS4 contributions were also added. Annual precipitation and evaporation values that were used in these models were 0.69 meter per year (m/year) and 0.70 m/year, respectively, for all of the lakes based on HSPF climate station average values. Observed lake water quality data (TP, Chl-*a*, SDD, and conservative substances) are entered as growing season (June through September) mean and CVMean values for the TMDL period. Tributary inflows to each lake segment included mean annual flow volume in cubic hectometers (hm^3); pollutant concentrations are entered as flow-weighted mean concentrations and CVMeans. Lakes that were assessed in a series included Lake Irving and Lake Bemidji, with TMDL allocations for upgradient Lake Irving determined separately and corresponding reductions incorporated into the downstream Lake Bemidji projections. BATHTUB includes several model choices for predicting TP, Chl-*a*, SDD, and other lake responses with selected models listed by lake in Appendix A. Additionally, a complete listing of inputs and modeling coefficients are included in Appendix A.

4.2.4 Modeling Sequence

Lake modeling was conducted to determine (1) present-day P loads that result in exceeding lake standards and (2) allowable P loads and reductions that are required to achieve water quality standards. Modeling of present-day conditions was completed for each lake and calibrated to the most recent and available water quality data (growing-season averages). Each of the lake's BATHTUB models was calibrated by adjusting coefficients and/or internal loading rates. The calibration coefficient adjustments were relatively minor for Little Turtle Lake, while Lake Irving's higher Chl-*a* response (that resulted from import from upgradient waters and internal loading) required larger calibration.

4.2.5 Load Allocation Methodology Overview

The LA represents the load allowed from nonpoint sources or nonregulated sources of TP. The LA was calculated as the loading capacity minus the MOS and the WLA.

Two of the central issues in this study focus on the extent of required P load reductions from watershed and lake internal sources. Climate characterizations (Section 3.7) noted patterns of increasing frost-free periods, increasing growing season temperatures and gyrating annual and growing season wet/dry monthly precipitation amounts. Climatic variability and its influences upon natural background conditions of the Upper Mississippi River and the Turtle River systems will complicate attainment of lake water quality standards, particularly during low flow periods. A previous MPCA study (Hodgson, Evenson and Magner, 2007 draft report) revealed that some Upper Mississippi River reaches during low flow periods also have large diel DO fluxes, attributed to discharges from adjoining wetland complexes and the lack of river riffle structure limiting reaeration. These natural background conditions of the Upper Mississippi River will exert influences upon downstream Lake Irving with similar factors affecting the Turtle River and Little Turtle Lake.

As noted in Section 3.6, elevated P concentrations were noted in Lake Irving during very low flow conditions. For instance Lake Irving's lowest monthly mean discharge (adjusted by watershed area from the downstream USGS gauging station on Stump Lake) of the TMDL period was estimated to be about 40 cfs in August 2006, with a corresponding monitored lake P value of 164 ug P/L. This peak P value suggests potential anthropomorphic influences.

Hence the influence of Mississippi River low flows that may facilitate potential back-watering from Lake Bemidji was examined. Low channel flow velocities coupled with wind induced water movement from Lake Bemidji and temperature/dissolved chemical related density differences could introduce complicated interflows between Lakes Bemidji and Irving. To examine the potential for backwatering, flows from the downstream USGS Stump Lake flow gauging station flows were adjusted by watershed area into Lake Irving discharges. These flows were used to approximate flow velocities through Irving's outlet channel.

Google Earth measurements of channel width (about 100 feet), along with an assumed average depth of 4 feet, were used to define an average channel cross-sectional area of about 400 square feet. An estimated August 2006 outlet flow of about 40 cfs would translate into an estimated average channel velocity of about 0.1 foot per second. Using this same methodology, an average Irving discharge of about 225 cfs would correspond to an average velocity of about 0.5 feet per second, while high flows noted for the system of 400 cfs would correspond to a velocity of 1 foot per second. Hence, it was recommended that potential back-watering from Lake Bemidji into Lake Irving during low flow/dry periods be further explored.

4.2.5.1 Natural Background Low Flow Considerations

In 1998, the Upper Mississippi River (upgradient of Lake Irving) was listed as impaired due to DO violations (Hodgson, Evenson and Magner, 2007 draft report). High diel DO flux was monitored by the MPCA during low flows in reaches adjoining large wetland areas and with limited riffle structure for reaeration (Hodgson, Evenson and Magner, 2007 draft report). The MPCA study concluded that natural background variability attributable to wetland dynamics as the dominant factor affecting DO levels, with some ground water influence. This study reported P concentrations ranging from approximately 37 to 85 µg P/L over the period of 1994 through 2003 (see Page 17) at 10 Upper Mississippi sites above Bemidji. These natural background influences likely extend down gradient to Lake Irving and present challenges for present day management.

4.2.6 Subsurface Sewage Treatment System Loading

Because sanitary sewer is available to all homes around Lake Irving, none were assumed to use SSTS. A desktop analysis was performed to estimate the number of homes and cabins around Little Turtle Lake; 54 homes and cabins were identified. An assumption was made that approximately half of the homes are occupied year-round, while the remaining 27 are seasonally occupied (100 days per year). Average house size was assumed to be 2.56 people per home, which is the 2009 through 2013 average for Beltrami County from the 2010 U.S. Census. A statewide noncompliance rate of 20% [MPCA 2013] was used to estimate the proportion of septic systems that are noncompliant. Assumptions were made that complying and non-complying septic systems retain 95 and 50% of their P loads, respectively. An estimate of annual TP loss per capita of 1 kilogram [Heiskary and Wilson, 2005] was used to estimate mean annual TP loading to septic systems.

HSPF septic-loading estimates are based on county data, and as such are not appropriately detailed for a TMDL in a small watershed. A refined estimate of septic system loading from the direct lakeshed was developed independently for this study. Because flow volumes and TP loads estimated by the calibrated HSPF model include runoff and TP loading from all sources, providing a separate estimate of loading from septic systems, and reducing the modeled loads from surface runoff accordingly, was necessary. Lakeshed flow volumes and loads were then reduced proportionally to ensure that the total flow volume and load from all sources was equal to that predicted by HSPF to account for the septic system adjustment. An adjusted flow-weighted mean concentration for the lakeshed was then determined based on adjusted flow volume and annual loads.

4.2.7 Atmospheric Loading

An atmospheric P deposition of 0.268 kilogram per hectare per year (kg/ha/yr) [Twarowski et al. 2007] was used to quantify average annual total (wet + dry) deposition on the lake surface. Values that were reported for dry and wet years were 0.249 and 0.290 kg/ha/yr, respectively.

4.2.8 Internal Loading

The wide range of Minnesota study estimates of internal loading rates reflect the range of lake sediment chemistries, low DO influenced sediment release rates, resuspension, and in the case of Lake Irving, potential back-flows from Lake Bemidji. This study's requisite lake diagnostic examinations included evaluation of lake mixing and P/temperature/DO concentration dynamics. Sediment chemical analyses that are required to employ Nürnberg-type P release equations [Nürnberg, 1995] and lake sediment cores used to measure aerobic and anaerobic release rates (James 2017) were not available. As a result, a collective weight of evidence approach was used to assess potential internal loading for each lake based on three methods: (1) literature values reported for similar northern Minnesota lakes,

(2) growing-season calculated changes in monthly mean surface TP concentrations used to estimate P mass balance changes; and (3) back-calculated internal loading (or unexplained residuals) calculated from annual HSPF stream flows and P loads incorporated into the BATHTUB model for quantification of annual P mass balances.

Growing season lake water quality is largely determined by annual nutrient loading rates as moderated by lake depth (morphometry), flushing and biological communities. However, historical high P loading can accumulate in lake sediments and re-emerge to influence present day lake conditions. This is called internal loading, or P that is recycled from enriched sediments back into lake waters, potentially increasing growing season lake P and algal concentrations.

- This can occur in lakes when low or no oxygen conditions occur along portions of the sediment-water interface, and is enhanced by other factors including: (1) reduced sediment P binding potential resulting from lower concentrations of iron, calcium and aluminum; and (2) invasive macrophyte species such as curly-leaf pondweed and rough fish. Lake surveys did not identify invasive macrophyte species. However, Little Turtle Lake was noted to have a low population of black bullhead fish.
- Internal loading may also occur with oxygenated sediments, but at substantially reduced rates that have been implicitly incorporated into typical lake P model development.
- Deep lakes that experience thermal stratification may have some degree of aerobic sediment P recycling, with deeper waters subject to more pronounced anaerobic sediment P generation. However, deep lakes with anoxic P generation may have limited effect on surface waters, due to limited circulation due to thermal stratification barriers over the growing season.

4.2.9 Background Internal Loading

This TMDL made use of the lake water quality model BATHTUB (BATHTUB for Windows Version 6.20) developed by Dr. William W. Walker (1999) for the U.S. Army Corps of Engineers. BATHTUB calculates a steady-state P mass balance for an ideal, well-mixed lake. The P mass balance includes inputs of watershed load, municipal and industrial wastewater discharges, septic systems, feedlots, atmospheric deposition, and internal loading; as well as two outputs, the outflow load (lake TP concentration multiplied by the outflow water volume) and its complement, the “retained load” (portion of the total load that settles and remains in the lake’s bottom sediments). The retained load prediction is the critical part of the P mass balance. BATHTUB has several optional sub-models for calculating the retained load; the option used for all lakes in this study is the Canfield-Bachmann “lake” option.

The Canfield-Bachmann formulation predicts the retained P load from a statistical relationship between retention and total load, based on data for 704 lakes and reservoirs (626 in the U.S). Whenever a Canfield-Bachmann model application has an explicit internal load specified, that load actually represents a deviation from a “normal” internal load reflected in the 704 lakes used in the original model development. And conversely, a “zero” internal load in a Canfield-Bachmann model application actually implies a “normal” internal load.

4.2.10 Lake mixing influences

Lake mixing was evaluated by calculating lake GR and Osgood Index values, with both of these shallow lakes assessed as polymictic (well-mixed) lakes. Shallow well-mixed lakes of the NLF aquatic ecoregion were found to have higher P concentrations than deep NLF lakes that thermally stratify, with 75th percentile concentrations ranging from 39 µg/L to 29, respectively. The higher P concentration attributed to shallow lakes is reasonably close to Little Turtle Lake's mean P value of 36 µg/L, but about one-half of Lake Irving's mean P value of 63.5 µg/L.

4.2.11 Growing season lake P dynamics and flow considerations

Net increases in growing season monthly mean surface water TP concentrations were tabulated for each lake. Progressive increases in monthly mean P concentrations reflect both internal and external (watershed) sources, which affect shallow lakes with limited dilution potential and that are subject to wind-induced resuspension.

From available data, Lake Irving's average monthly mean TP increased from a low of 40 µg/L in June to 66 µg/L in July, to 96 µg/L in August before declining to 71 µg/L in September. The lowest values noted in early summer suggest that lower lake P values may be attainable. The overall TMDL period average growing season value of 63.5 µg/L is more than double the lake standard of 30 µg/L.

Little Turtle Lake exhibited a much more muted response as average monthly mean TP increased from 28 µg/L in June to 30 µg /L in July, to 41 µg/L in August before climbing to 44 µg/L in September. June and July P values meet the lake standard (e.g. 30 µg/L) with an overall average growing season value of 37.1 µg/L that exceeds the lake P standard. Hence the calculated increased P mass from increasing summer concentrations were substantially less for Little Turtle Lake than Lake Irving.

Higher Mississippi River flows into Lake Irving were associated with lower lake P. As discussed in Section 3.5.1, lower flow conditions (less than 230 cfs) were noted during 50% of the TMDL period years, with flows less than 122 cfs representing the 10th percentile summer flows. Lake Irving's low flows correspond to elevated P concentrations during the TMDL period, while higher flows were noted to have lower P concentrations approaching the lake standard as depicted in Figure 3-5 of the draft TMDL report. Hence, peak growing season months with low flows (e.g. less than ~122 cfs) will present greater challenges, and may require adaptation of the TMDL by flows (greater than the 10th percentile flows).

Expressing the net P increase over the course of the growing season months as internal loading resulted in an estimated 0.20 mg/m2/day in Little Turtle Lake and 0.35 mg/m2/day in Lake Irving. These are static values and not adjusted for flow by this simple mass balance method. This is particularly relevant for Lake Irving which has substantial Mississippi River flows and hence, internal loading for the entire growing season will be considerably greater.

4.2.12 Dissolved Oxygen (DO) Influence Upon Internal Loading

Both of these lakes were noted to experience declining DO concentrations with depth during the growing season with some of the available data having bottom-most sample values of 2 mg/L or less noted in the months of July and August.

Lakes with oxygen concentrations above 2.0 mg/L along the sediments have been typically found to have lower sediment P release rates than sediments overlain by low or no (anaerobic) oxygen concentrations less than 2.0 mg/L. For example, James (2017) recently measured aerobic sediment P release rates measured from Lake of the Woods sediment cores that varied from 0.2 to 0.6 mg/m2/day, while anaerobic release rates ranged from 12 to 16 mg/m2/day or about 35 times more than the average aerobic rates. In this same study, James also studied the effects of water temperature and found increasing temperatures were strongly correlated with increasing P release rates. Five bays of Lake of the Woods were studied by RESPEC (draft Lake of the Woods TMDL), with growing season P losses estimated to range from 4.4 mg/m2/day (Four Mile), 0.15 (Muskeg) and 0.46 mg/m2/day (Big Traverse). RESPEC found large variations of Lake of the Woods' monthly P unexplained residuals among the bays, with peak sediment P loss occurring in July-August and net P gains to the sediments in the remaining cooler water calendar months. Estimated peak sediment P losses in Lake Irving were similarly noted in July and August. In another Minnesota lake study, Wang et al. (2004) investigated sediment release rates for the polymictic Jessie Lake (Itasca County) and reported an internal P release rate of 16.9 mg/m2/day.

4.2.13 Annual Mass Balance Method

BATHTUB modeling was conducted for each lake incorporating HSPF flow and nutrient inputs from watershed sources, and employing reported Minnesota atmospheric P deposition and estimated P loading from septic tanks. The unexplained residuals or P loads that are needed to balance the income and outgo budgets defined from HSPF inputs in the BATHTUB modeling were tabulated for each lake. Greater reliance was placed on this annual mass balance approach, which was based on the Mississippi River Basin calibrated HSPF model.

For Little Turtle Lake, the unexplained residual determined from lake P growing season increased concentrations mimic the value defined from HSPF mass balances, with a value of about 0.23 mg/m2/day. This value also represents the lower range of aerobic sediment P release rates of about 0.2 mg/m2/day noted by James (2017) in Lake of the Woods.

However, the HSPF/BATHTUB mass balance defined internal loading for Lake Irving was a factor of 10 higher than that calculated from the growing season monthly P increase method. Given the magnitude of Mississippi River inflows and the significance of the low flows in influencing Lake Irving's DO and P concentrations, preference was given to the time period modeled HSPF mass balance method. This higher sediment P generated internal loading rate (3.3 mg/m2/day) reflects peak growing season loss rates, similar to monitored shallow lake anaerobic P release rates from other recent Minnesota sediment studies (Lake of the Woods with 0.2 to 4.4 net P release in mg/m2/day).

TMDL allocations were based on internal P load (BATHTUB derived), translated to an annual P release rate of 3.3 mg/m2/day for Lake Irving and 0.23 mg/m2/day for Little Turtle Lake. Existing and TMDL-reduced mass balances are summarized in Table 4-2 for Little Turtle Lake and
Table 4-3 for a Lake Irving.

Table 4-2. Little Turtle Lake BATHTUB Model Summary.

Name	Little Turtle Lake Existing				Little Turtle Lake Reduced			
	lb/yr	%Total	Conc (µg/L)	Export (lb/acre/yr)	lb/yr	%Total *	Conc (µg/L) *	Export (lb/acre/yr)
Turtle River	967.6	62.8	41.4	0.04	860.4	82.5	41.4	0.04
Lakeshed	93.4	6.1	70.6	0.09	58.2	5.7	50.0	0.06
SSTS	27.5	1.8	10,000	11.12	0			
Precipitation	112.1	7.3	39.1	0.24	112.1	9.6	39.1	0.24
Internal Load	341.2	22.1			0			
Tributary Inflow	1,088.5	70.6	44.1	0.04	918.6	90.4	41.9	0.04
Total Input	1,541.8	100.0	55.9	0.06	1030.7	100.0	41.6	0.04
Total Outlet**	914.5	59.3			645.1	62.3		
Retention	627.2	40.7				37.7		

*Values modeled to meet standards

** Includes advective correction to balance water budget

Table 4-3. Lake Irving BATHTUB Model Summary

Name	Lake Irving Existing				Lake Irving Reduced			
	lb/yr	%Total	Conc (µg/L)	Export (lb/acre/yr)	lb/yr	%Total *	Conc (µg/L) *	Export (lb/acre/yr)
Miss. River	15,718.6	64.5	43.6	0.05	9,880.0	90.9	29.0	0.03
Bemidji MS4 to Mississippi	185.3	0.8	76.4	0.15	114.6	1.1	50.0	0.10
Lakeshed MS4	551.0	2.3	73.5	0.14	354.2	3.3	50.0	0.09
Lakeshed NonMS4	686.2	2.8	81.9	0.16	391.9	3.6	50.0	0.10
SSTS	63.9	0.3	10,000	25.87	0	0	10,000.0	0.09
Precipitation	159.3	0.7	39.1	0.24	159.3	1.5	39.1	0.24
Internal Load	7,004.4	28.7			0	0		
Tributary Inflow	17,205.1	70.6	45.4	0.05	10,740.7	98.8	30.1	0.03
Total Input	24,368.8	100.0	63.6	0.07	10,870.3	3.0	30.2	0.03
Total Outlet**	24,619.8	101.0	65	0.07	10,849.5	100	30	0.03
Retention	-251.0	–1.00			103.5	0.9		

*Values modeled to meet standards

** Includes advective correction to balance water budget

4.2.14 Wasteload Allocation Methodology

WLAs for TMDLs include permitted MS4s and industrial and construction stormwater.

4.2.14.1 Permitted Municipal Separate Storm Sewer Systems

Portions of the Bemidji MS4 (Permit number MS400265) extend into the watershed of Lake Irving as summarized in Table 4-4.

Table 4-4. Lake Irving Contributing MS4 Areas

Reach	MS4	Permit No.	Contributing Area
Tributary	Bemidji	MS400265	1047.5 acres
Lakeshed	Bemidji	MS400265	3317.7 acres

4.2.14.2 Construction and Industrial Stormwater

The Minnesota Construction Stormwater Permit is MNR100001, and the Minnesota Industrial Stormwater Permit is MNR050000. P loading from potential future permitted construction stormwater sites within each lake watershed were estimated based on the total area of permitted construction sites by County [Leegard 2015]. The Little Turtle Lake Watershed is within Beltrami County, while Lake Irving's watershed includes portions of Hubbard, Clearwater, Becker, and Beltrami Counties.

- The total permitted construction site area averaged 410 acres in the watershed of Lake Irving (for a prorated watershed value 0.0098%) and 179 acres per year within the watershed of Little Turtle Lake (for a prorated watershed value of 0.0092%).
- The total permitted industrial sites covered areas of 565 acres in Beltrami County, which results in a prorated watershed percent of 0.0289% for Little Turtle Lake. The total permitted industrial sites in Hubbard, Clearwater, Beltrami, and Becker counties were 103 acres, 6 acres, 565 acres, and 423 acres, respectively. These acreages represented a prorated watershed value of approximately 0.0152% of the Lake Irving Watershed.

For these estimates, an equal proportion of each watershed (not including open water) was expected to be covered by construction stormwater permits on a mean annual basis.

4.2.15 Margin of Safety

The watershed modeling period was from 1995 through 2009. Time-series data that were used in developing the model application 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 needed for HSPF to simulate hydrology. The HSPF-derived data was used for the TMDL period of 2000 through 2009 was used within BATHTUB, The simulation period included a range of dry and wet years. This range of precipitation improves the model calibration and validation, and provides a model application that can simulate hydrology and water quality during a broad range of climatic conditions. The HSPF model calibration and validation results further illustrate the calibration and fit of the data and modeling found in Ackerman, D., 2015.

In-lake TP concentrations vary over the course of the growing season (June through September), generally peaking in mid to late summer. The MPCA eutrophication water quality guideline for assessing TP is defined as the June through September mean concentration. The BATHTUB model was used to calculate the load capacities of each lake, incorporating mean growing season TP values. TP loadings were calculated to meet the water quality standards during the summer growing season, the most critical period of the year. Calibration to this critical period will also provide adequate protection during times of the year with reduced loading.

The use of an explicit 10% MOS accounted for environmental variability in pollutant loading, variability in water quality data (i.e., collected water quality monitoring data), calibration and validation processes of modeling efforts, uncertainty in modeling outputs, and conservative assumptions made during the modeling efforts. In addition a small implicit MOS was also incorporated into the Little Turtle Lake calculations by using an endpoint of 29 µg/L for TMDL modeling purposes.

4.2.16 Load Allocation Methodology

After accounting for both the WLA and the MOS, the remaining loading capacity was apportioned among the following: watershed loading, septic loading, atmospheric deposition, and internal loading. The flow-weighted mean TP concentration associated with watershed loading was reduced to 50 µg/L, which is equal to the water quality standard for rivers of the North River Nutrient Region [Minn. R. 7050.0150, subp. 2]. Loading from SSTS were reduced to zero with the assumption that all of the septic systems will be in compliance with local SSTS regulations. Internal loading was reduced to zero for both lakes.

Lake Irving's summer P concentrations, particularly during low-flow periods in July and August, appear to be substantially influenced by lake internal P processing, as noted in Section 3.8. Hence, reducing Mississippi River contributions and controlling internal P will be central aspects of remediation. Lake Irving's TP is also influenced by Mississippi River inflows, with typical flow-weighted mean TPs estimated to be approximately 40 µg/L, which exceeds the 30 µg/L LES for TP. Higher Mississippi River flows also reduce residence times, and thereby limit internal loading and algal growth and accumulation, with higher flow periods having lower average summer TP and Chl-*a* in Lake Irving. To achieve the 30 µg/L lake eutrophication TP standard requires require reducing the Mississippi River inflow concentration to 29 µg P/L, for a reduction of approximately 37%. Water quality of downstream Lake Bemidji is largely dependent upon that of Lake Irving. BATHTUB modeling of Lake Bemidji reinforces that increases in P loading from Lake Irving may be expected to increase TP concentrations in Lake Bemidji.

Based on the MPCA's waterbody assessment process and the TMDL source assessment exercises, there is no evidence at this time to suggest natural background sources are a major contributor to the impairments in Lake Irving or Little Turtle Lake. For each impairment, natural background levels are implicitly incorporated in the water quality standards used by the MPCA to determine/assess impairment, and therefore natural background is accounted for and addressed through the MPCA's waterbody assessment process. For the impairments addressed in this study, natural background sources are implicitly included in the LA portion of the TMDL allocation tables, and TMDL reductions should focus on the internal loading and anthropogenic sources identified in the source assessment.

4.3 Seasonal Variation and Critical Conditions

Greater lake water quality variability is observed seasonally (intra-year) than year-to-year (inter-year) due to 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.

In deeper lakes, P concentrations may tend to decline, or not change substantially, in the absence of major runoff events during the growing 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 (June through September) [Heiskary and Wilson 2005]. This TMDL's targeted allocations are based on Minnesota's lake standards and summer critical conditions.

4.4 Reserve Capacity

Little Turtle Lake is located in Beltrami County. No municipalities are located within the relatively small watershed. Substantial development is not anticipated, but many of the areas in which growth may be expected are lakeshore properties, which have the greatest potential to impact water quality. To protect and improve the water quality in Little Turtle Lake, a net decrease in P loading should be accomplished by implementing shoreline buffers and retrofitting of existing lake shore properties as possible, as well as adopting low impact development practices for new development such as outlined by the Minimal Impact Design Standards (MIDS) recently developed in Minnesota [MPCA 2016]. This may require adopting regulatory frameworks and intergovernmental cooperation to achieve these goals as outlined in the implementation plan. Achieving MIDS performance goals will result in development runoff that mimics natural present-day prairies and forests.

Portions of the city of Bemidji extend into the watershed of Lake Irving and, as such, influence urban runoff that reaches the lake. To protect and improve water quality in Lake Irving, a net decrease in P loading should be accomplished by implementing shoreline buffers and retrofitting of existing lake shore properties and stormwater conveyances as possible. The presence of HSG A and B soils in the city of Bemidji will continue to facilitate implementation of low impact design (LID) BMPs, including infiltration and filtration as outlined by the MIDS recently developed in Minnesota [MPCA 2016]. Implementing MIDs may require modification of the city's regulatory framework. Achieving MIDS performance goals will result in development runoff that mimics natural present-day prairies and forests.

Potential changes in population and land use over time could result in changing sources of pollutants and runoff characteristics to both lakes. Possible changes and how they may or may not impact TMDL allocations are discussed below, particularly in relation to urban (Irving) and shore land development (both lakes). Future growth is expected to be low, and may be offset by adopting additional stormwater management practices. Given these considerations, reserve capacity was not included as part of this TMDL.

The TMDL tables for Little Turtle Lake and Lake Irving are shown in Tables 4-5 and 4-6, respectively. Required reduction in Little Turtle Lake is 33%, and required reduction in Lake Irving is 57%.

Table 4-5. Lake Total Maximum Daily Load Summary for Little Turtle Lake

Little Turtle Lake Load Allocation		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lb/year	lb/day	lb/year	lb/day	lb/year	%
Loading Capacity				**1,145.89**	**3.14**		
Margin of Safety 10%				**114.59**	**0.31**		
Total Load (excluding MOS)		**1,541.83**	**4.22**	**1,031.30**	**2.82**	**510.53**	**33.11**
Wasteload	**Total WLA**	0.59	**< 0.01**	0.59	**< 0.01**	**< 0.01**	**–**
	Construction Stormwater	0.14	< 0.01	0.14	< 0.01	< 0.01	–
	Industrial Stormwater	0.45	< 0.01	0.45	< 0.01	< 0.01	–
Load	**Total LA**	**1,541.24**	**4.22**	**1,030.71**	**2.82**	**510.53**	**33.12**
	Turtle River Inlet	967.05	2.65	860.40	2.36	106.65	11.03
	Lakeshed	93.40	0.26	58.21	0.16	35.19	37.68
	Internal Load	341.22	0.93	0	0	341.22	100
	SSTS	27.47	0.08	0	0	27.47	100
	Atmospheric deposition	112.10	0.31	112.10	0.31	0.00	–
Total Load (excluding MOS)		**1,541.83**	**4.22**	**1,031.30**	**2.82**	**510.53**	**33.11**

Table 4-6. Lake Total Maximum Daily Load Summary for Lake Irving

Irving Lake Load Allocation		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lb/year	lb/day	lb/year	lb/day	lb/year	%
Loading Capacity				**11,442.38**	**31.33**		
Margin of Safety 10%				**1040.22**	**2.85**		
Total Load (excluding MOS)		**24,368.77**	**66.72**	**10,402.16**	**28.48**	**13,966.61**	**57**
Wasteload	**Total WLA**	**742.44**	**2.03**	**474.94**	**1.30**	**267.50**	**36**
	Bemidji MS4	736.34	2.02	468.84	1.28	267.50	36
	Construction Stormwater	2.39	0.01	2.39	0.01	0	-
	Industrial Stormwater	3.71	0.01	3.71	0.01	0	-
Load	**Total LA**	**23,626.33**	**64.69**	**9,927.22**	**27.18**	**13,699.11**	**58**
	Mississippi Inlet	15,712.46	43.02	9382.1	25.69	6,330.36	40
	Lakeshed	686.24	1.88	385.8	1.06	300.44	44
	Internal Load	7,004.36	19.18	0	0	7,004.36	100
	SSTS	63.95	0.18	0	0	63.95	100
	Atmospheric deposition	159.32	0.44	159.32	0.44	0	-
Total Load (excluding MOS)		**24,368.77**	**66.72**	**10,402.16**	**28.48**	**13,966.61**	**57**

5 Future Growth Considerations

5.1 New or Expanding Permitted MS4 WLA Transfer Process

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

1. New development occurs within a regulated MS4. Newly developed areas that are not already included in the WLA must be transferred from the LA to the WLA to account for the growth.
2. One regulated MS4 acquires land from another regulated MS4. Examples include annexation or highway expansions. In these cases, the transfer is WLA to WLA.
3. One or more nonregulated MS4s become regulated. If the new MS4s have not been accounted for in the WLA, then a transfer must occur from the LA to the WLA.
4. U.S. Census Bureau Urban Area expansion encompasses new regulated areas for existing permittees. An example of this scenario 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. A WLA-to-WLA transfer or an LA-to-WLA transfer is required.
5. A new MS4 or other stormwater-related point source is identified and is covered under an NPDES Permit. In this situation, a transfer must occur from the LA.

Load transfers will be based on methods that are consistent with those used in setting the allocations in this TMDL (a land-area basis). In cases where the 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 reasonable assurance that the TMDL allocations (1) were properly developed, documented, and calibrated and (2) will be implemented by local, state, and federal entities. The TMDL allocations described herein have been based on the best available information, which was incorporated into a Mississippi Headwaters HSPF model and subject to rigorous state oversight. Lake modeling was accomplished by using widely accepted standard assessment and quality control methods. TMDL goals defined by this study are consistent with objectives defined in local county water plans that were further refined by the concurrent WRAPS development process. The local counties have been active participants in the TMDL planning and development process, and they have decades of water quality management experience. Stakeholder meetings have been conducted to provide comment/feedback and support, including local governmental units receiving TMDL allocations. Future water quality restoration efforts will be led by the Mississippi Headwaters Watershed local and county entities. Funding resources may be obtained from the following state and/or federal programs:

- Minnesota Clean Water, Land, and Legacy Funds
- EPA funding, such as Section 319 grants
- MPCA Clean Water Partnership Loan Program
- Natural Resources Conservation Services (NRCS) cost-share funds
- U.S. Forest Service (USFS) programs
- Local governmental funds and utility fees.

6.1 Nonregulatory

Local, state, and federal partners have worked closely over the past 30 years to characterize water quality in the Mississippi Headwaters Watershed and to devise restoration and protection strategies, particularly relating to forest management. This has included baseline and long-term lake monitoring, coupled with Citizen Lake Monitoring Program volunteer tracking of Secchi transparency patterns. Effective long-term partnerships will remain an important base for leveraging future restoration and protection projects for impaired lakes.

Potential state funding of restoration and protection projects include Clean Water Fund grants and Clean Water Partnership loans. At the federal level, funding can be provided through Section 319 grants, NRCS and U.S. Forest Service (USFS) programs. Various other funding and cost-share sources exist, which are listed in the Mississippi River Headwaters WRAPS Report. The implementation strategies described in this plan have been demonstrated to be effective in reducing nutrient loading to lakes and streams. Programs are in place within the watershed 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

Phase II MS4 NPDES-permitted stormwater communities are required by permit (the General Permit Authorization to Discharge Stormwater Associated with Small MS4s under the NPDES/SDS Permit [MNR040000]) to develop and implement a Stormwater Pollution Prevention Plan (SWPPP). This permit requires MS4s to develop regulatory mechanisms, including enforcing construction sites under the MPCA's General Permit, Discharges of Stormwater Associated with Construction Activity (MNR100001), and post construction stormwater management. MS4s are also required to inventory and map the storm sewer system and implement a minimum of six control measures (public education and outreach, public participation and involvement, illicit discharge detection and elimination, construction site runoff controls, post construction stormwater runoff controls and pollution prevention, and good housekeeping measures). Measurable goals must be specified for each of the six minimum control measures, including public participation and involvement in reviewing the SWPPPs. Routinely inspecting and maintaining the MS4 conveyance system is required. Additionally, the MS4 Permit requires regulated communities to provide reasonable assurance that progress is being made toward achieving all of the TMDL WLAs that were approved by the EPA before the effective date of the General MS4 Permit issued at five-year intervals. MS4s must determine that the WLA(s) are being met; if not, a compliance schedule is required. The compliance schedule includes interim milestones (expressed as BMPs) that will be implemented over the current five-year permit term. As MS4 management activities occur across 10-year capital budgetary cycles, a long-term implementation strategy and target date for full compliance to the WLAs must be included.

The city of Bemidji is an MS4 community and has done a commendable job in cooperatively working to address stormwater issues with the city. The city has been very proactive in implementing stormwater treatments over the years in the efforts to protect the surface water quality of Lake Bemidji and Lake Irving. The city has been an active participant throughout this TMDL project and is committed to working together in the future "to do their part" in the protection of the surface water within the city and beyond.

7 Monitoring Plan

Future monitoring will be required to track: (1) water quality trends in impaired lakes, (2) performance of future remedial and protection projects to improve water quality, and (3) compliance to surface and groundwater quality standards. The scope and nature of future remedial actions will rely on comparisons of monitored conditions to management goals as adjusted for changing land uses, weather, and runoff patterns. The ability to detect changes and the reliability of comparisons will depend on the design of the monitoring program, including potential adjustment for hydrologic and climatologic variations. Future monitoring plans should be further developed contingent on availability and prioritization of resources, including monitoring site locations, sampling schedules, and responsible persons. As a high priority, low-flow growing-season conditions should include investigating whether or not backwatering occurs from Lake Bemidji into Lake Irving. Secondly, additional monitoring of the Mississippi River inflows to Lake Irving will define upgradient improvements or declines from the western portion of the Basin.

7.1 Trend Detection

Data from recent years have indicated a steady to slight increasing pattern in TP and Chl-a concentrations or Secchi transparency. The simplest approach and most statistically powerful tool to identify water quality trends is to maintain a long-term Citizen Volunteer Lake Monitoring effort with 10 to 12 transparency measurements per summer (June through September) for the next five years, at a minimum. This level of monitoring will be important to statistically identify whether improving trends are in fact occurring.

- Volunteer Secchi monitoring can be used to record algal blooms by reporting recreational suitability and physical appearance at the time of their Secchi measures.
- Additional lake monitoring data needs:
    - Lake TP and Chl-*a* monitoring paired with Secchi transparency measurements should be obtained six times over the growing season (June through September) with two samples per month in August and September. Bottom waters should be sampled for TP and total iron.
    - Temperature and DO profiling data (by depth) are quite limited. Future detailed measurements to the lake bottoms are recommended to be obtained approximately six times over the growing season (June through September) with two samples per month in August and September. This data will be helpful in further defining mixing characteristics that affect lake water quality.

7.2 Tracking the Effects of Weather Patterns

Tracking recent and monthly weather reporting events from volunteer monitoring and weather station data will be helpful in interpreting data to reflect weather variability. Tracking mid-to-late summer hot/dry periods that are followed by Canadian storm systems that may increase internal loading potential is particularly important.

Several free weather-reporting services are available to help better track weather patterns. Data summaries are available from the Minnesota Climatology Office (*http://climate.umn.edu/*) and the Midwestern Regional Climate Center (http://mrcc.isws.illinois.edu/) for Bemidji, Minnesota.

8 Implementation Strategy Summary

Implementing the TMDLs that are addressed in this document will be a collaborative effort between individuals, and state and local government. The overall effort will be led by the Beltrami Soil and Water Conservation District (SWCD) who can provide technical support, funding coordination, and local leadership. The SWCD can leverage existing relationships and regulatory frameworks to generate support for the TMDL implementation. These existing governmental programs and services will provide efficiency and related cost savings to the maximum extent possible. As noted in the regulatory section of this report (Section 6.2), the city has been an active and cooperative participant throughout this TMDL and Mississippi River Headwaters WRAPS project and is committed to working together in the future "to do their part" in the protection of the surface water within the city and beyond.

8.1 Permitted Sources

8.1.1 Phase II Municipal Separate Storm Sewer Systems

Phase II MS4 NPDES-permitted stormwater communities are required by permit (the General Permit Authorization to Discharge Stormwater Associated with Small MS4s Under the NPDES/SDS Permit [MNR040000]) to develop and implement a SWPPP. This permit requires MS4s to develop regulatory mechanisms, including regulating construction sites under the MPCA's General Permit to Discharge Stormwater Associated with Construction Activity (MN R100001) and post construction stormwater management. MS4s are also required to inventory and map the storm sewer system and implement a minimum of six control measures (public education and outreach, public participation and involvement, illicit discharge detection and elimination, construction site runoff controls, post construction stormwater runoff controls and pollution prevention, and good housekeeping measures). Measurable goals must be specified for each of the six minimum control measures, including public participation and involvement in reviewing the SWPPPs. Routine inspection and maintenance of the MS4 conveyance system is required. Additionally, the MS4 permit requires regulated communities to provide reasonable assurance that progress is being made toward achieving all of the TMDL WLAs that were approved by the EPA before the effective date of the General MS4 permit that were issued in five-year intervals. MS4s must determine that the WLA(s) are being and, if not, a compliance schedule is required. The compliance schedule includes interim milestones (expressed as BMPs) that are not one of the six minimum control measures and that will be implemented over the current five-year permit term. As MS4 management activities occur across 10-year capital budgetary cycles, a long-term implementation strategy and target date for full compliance to the WLAs must be included.

The city of Bemidji is a MS4 community and has done a commendable job in meeting MS4 requirements prior to this TMDL and is committed to working with the MPCA and other partners in addressing the additional water quality measures required by the TMDL.

8.1.2 Baseline Year

The city of Bemidji has MS4 loads allocated in this TMDL, and the baseline year will be the middle of the TMDL time period (2004). A baseline year is used because the effects of BMPs are not always immediate. BMPs that have been implemented since 2004 will qualify toward MS4 load reductions for these TMDLs. The Mississippi River Headwaters WRAPS report developed concurrently with this TMDL report defines appropriate implementation strategies and MS4 BMPs.

8.1.3 Construction Stormwater

The WLA for stormwater discharges from sites with construction activity reflects the number of construction sites greater than one acre that are expected to be active in the watershed at any one time 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 that are required under the permit (including those related to impaired waters discharges and any applicable additional requirements found in Appendix A of the Construction General Permit) the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local construction stormwater requirements must also be met.

8.1.4 Industrial Stormwater

The WLA for stormwater discharges from sites with industrial activity reflects the number of sites in the watershed that require NPDES 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 and Gravel, Rock Quarrying and Hot Mix Asphalt Production Facilities (MNG490000). If a facility owner/operator obtains stormwater coverage under the appropriate NPDES/SDS Permit and properly selects, installs, and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All of the local stormwater management requirements must also be met. 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. P monitoring is required if a nutrient-impaired waterbody is located within one mile of the facility.

8.2 Non-permitted Sources

8.2.1 Subsurface Sewage Treatment Systems

Because homes and businesses around Lake Irving are served by the Bemidji WWTP, no SSTSs were assumed to contribute to this lake. However, opportunities exist to expand sanitary connections as the area develops in the future and the city of Bemidji expands to the west of the lake. An example of this is the new Gene Dillon Elementary School, which is scheduled to open in the fall of 2018. This city of Bemidji expansion (annexation) will include providing sanitary services to the school with the potential for existing homes and businesses along this this corridor to connect to the sanitary system. Around Little Turtle Lake, homes and businesses are served by SSTS. Future SSTS surveys will aid in obtaining 100% compliance and reducing nutrient loading from noncompliant systems. In addition, the Clean Water Partnership (CWP) program now offers zero-interest loans to local units of government for implementing nonpoint-source BMPs and other activities that target the restoration and protection of a water resource such as a lake, stream, or groundwater aquifer. A common use of these CWP loan program is for upgrading SSTS.

8.2.2 Shoreland and Lake Management

A 50-foot average 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). Local conservation districts will be the point of contact for requirements and technical assistance for implementation of buffers along public waters and shore lands. In Fiscal Year 2016, the Clean Water Legacy Fund included $5 million to the Board of Soil and Water Resources (BWSR) for local government implementation.

For all interested lakeshore property owners on the lakes addressed by this TMDL, one option involves acquiring professional design-build landscaping services to provide landscape designs. Lakeshore 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. Lake association education and partnered demonstration plots may be beneficial. Options used elsewhere could include vegetation buffer agreements with follow-up yearly inspections of sites to help address maintenance concerns and to document performance. The unit cost is estimated to be approximately $10,000 per property.

BMPs that are expected to reduce nutrient loads to impaired reaches and lakes are summarized below with greater detail provided by *The Agricultural BMP Handbook for Minnesota* [Miller et al. 2012] and the *Minnesota Stormwater Manual* [MPCA 2016], which includes MIDS information. Cost, targets, and other BMP information are further discussed in the Mississippi River Headwaters WRAPS Report.

- Encouraging and tracking the adoption of lakeshore buffers and SSTS compliance rates are efforts that lake associations can provide local leadership for information campaigns, acquiring local/state funding to aid homeowners, and tracking lakeshore buffers and septic compliance rates with support provided by the headwaters counties. For example, the Courte Oreilles Lakes Association near Hayward, Wisconsin, acquired grants and the services of a design-build landscaping contractor to cost-effectively work with several landowners at a time to develop attractive and individualized lakeshore vegetated buffers [Courte Oreilles Lakes Association 2015]. A corresponding lake TMDL was completed that showed lakeshore areas would reduce P loads by approximately 200 lb/year by enhancing or establishing shoreline buffers where none exist. A shoreline assessment is available for use that was employed on a parcel-by-parcel basis for evaluation purposes.
- Riparian vegetation helps to filter pollutants and stabilize banks.

- Encouraging and tracking implementation of urban BMPs, as detailed by the *Minnesota Stormwater Manual* and MIDS, will cover the spectrum of source, rate, and volume controls that will substantially reduce developed land's pollutant loadings of biochemical oxygen demand (BOD) and related sediment losses, nutrients, and bacteria. Proper site designs, construction, and maintenance are key components for effective performance of urban BMPs. Encouraging and tracking implementation of agricultural BMPs, as detailed by *The Agricultural BMP Manual for Minnesota*, will substantially reduce agricultural lands' pollutant loadings of BOD and related sediment losses, nutrients, and bacteria. Proper site designs, construction, and maintenance are key components for effective performance of agricultural best practices.
- Internal loading can comprise an important portion of the P budget of impaired lakes and legacy source-impacted wetlands. Internal P loading is typically the result of excessive historical watershed loading and a recommended first step is to reduce watershed P loading as much as possible. This effort includes reducing runoff from shore lands, developed land, noncompliant SSTSs, and other upland sources (potentially including wetlands). Wetland discharge pulsing is possible from the succession of dry and wet periods, and resulting shifting water levels that can induce P release from legacy sources. During dry periods, water levels recede and provide greater oxygen concentrations for aerobic digestion of organic substrates, including mobilization of various dissolved and particulate P forms [Dunne et al. 2010]. Upon refilling during wet periods, growing-season oxygen concentrations can quickly be depleted, which results in releasing digested TP concentrations that depend on other factors, such as sediment iron, aluminum, and calcium. The extent of this occurrence from watershed wetland complexes is generally not known but can be initially characterized by relatively simple P monitoring, such as sequential diagnostic grab sampling of upgradient and downgradient waters after summer storm events.
    - Whole lake treatment by alum can be very effective in reducing lake internal loading of P for 10 to 30 years. Following alum treatment, a white alum band is deposited along the top of the lake's sediments and serves to trap released P. However, effectiveness in shallow lakes may be reduced because of wind mixing and disruption of the sediment's alum layer [Cooke et al. 1986]. After reducing watershed P-loading sources, the appropriateness of a whole lake alum treatment can be assessed by a detailed feasibility study. Mobilization and treatment costs could amount to approximately $1,000 per acre depending on dosage requirements and alum costs.
- Hypolimnetic treatments include ferric chloride, aeration, and oxygenation. A recommended total iron to TP concentration ratio of 3:1 for lake bottom water has been used to control lake sediment-released P. If the total iron to TP ratio is less than 3:1, then iron may not effectively reduce sediment-liberated P concentrations. In the latter case, iron augmentation of lake sediments may be required by using ferric chloride or similar iron compounds. The details, including oxygen supply rates, would have to be determined by an engineering design study. Chemical treatment of lakes will require a permit from the MPCA.

  - High oxygen depletion rates can be expected to accompany elevated lake productivity (e.g., algal concentrations). Replenishing oxygen supplies by oxygenating bottom waters may be a viable option in some cases, and would require installing a series of pipes and diffusers on the lake bottom along with a required pump house and oxygenation system on land. The details, including oxygen supply rates, would have to be determined by an engineering design study. Lake aeration (without oxygenation) will require careful examination if intended for something other than reduced winter fish kill potential. Whole lake aeration during the growing season can result in increased TP concentrations that feed increased algal growth and potentially degrade lake quality.

- Public education about the benefits of the above practices should continue with partnering counties providing core materials for reinforcing messages aimed at targeted audiences.

8.3 Cost

The Clean Water Legacy Act (CWLA) requires that a TMDL include an overall approximation of the cost to implement a TMDL [Minn. Stat. 2007 § 114D.25]. The cost estimate for this TMDL includes buffer implementation along NHD flowlines in impaired drainage areas (50 foot buffers on both sides of approximately 544 stream miles at approximately $200 per acre after cost share [Shaw 2016]), alum treatment on Irving Lake acres (approximately 660 acres at $1,000 per acre [Kretsch 2016]), septic updates around Little Turtle Lake (20% replacement of approximately 54 septic systems at $10,000 a system), and MIDS on high- and medium-intensity developed lands that drain to impairments (approximately 1,572 acres at $5,000 per acre) [Minnesota BWSR 2016]. The initial estimate for implementing the Mississippi River Headwaters WRAPS is approximately $2,088,000 for nonpoint source implementation such as stream buffers, alum in lakes, and SSTS updates and approximately $7,862,000 for implementing MIDS in medium- and high-intensity developed areas. Urban BMP costs that were estimated in this overview are primarily based on construction and maintenance costs. Land areas that are required for constructed BMPs generally require 2% to 5% of the watershed drainage area and land costs are not generally included because they can vary. This estimate is, by nature, a very general approximation with considerable uncertainties associated with complexity of designs, local regulatory requirements, unknown site constraints and choice of BMPs with widely variable costs per water quality volume treated. This estimate is a large-scale estimate and many other implementation strategies will likely be used in addition to or to replace general practices used in this estimate.

8.4 Adaptive Management

This list of implementation elements and the more detailed concurrently developed WRAPS focus on adaptive management as shown in Figure 8-1. Continued monitoring and “course corrections” that respond to monitoring results are the most appropriate strategy for attaining the water quality goals established in this TMDL. Management activities will be changed or refined to efficiently meet the TMDL and lay the groundwork for delisting the impaired waterbodies.

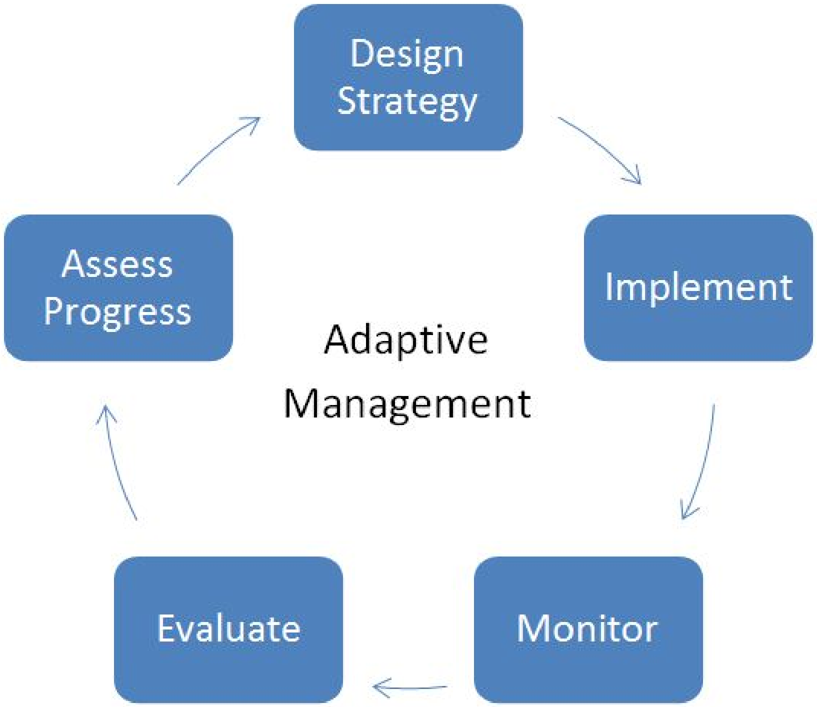


Figure 8-1. Adaptive Management.

9 Public Participation

Development of this TMDL report included meetings with WRAPS project members about the watershed assessment and TMDL process findings, and a 30-day public notice period for public review and comment of the draft TMDL document occurred from June 4, 2018 to July 5, 2018. All input, comments, responses, and suggestions from public meetings and the public notice period were addressed or were taken into consideration in developing and modifying the TMDL. The draft TMDL report was made available at https://www.pca.state.mn.us/sites/default/files/wq-iw8-57b.pdf . Regular updates regarding the TMDL process with the WRAPS team included meetings to discuss TMDL processes and results.

- WRAPS team meetings were held throughout the WRAPS/TMDL project to keep stakeholders informed on the development of the draft WRAPS/TMDL. See Table 18 of the Mississippi River Headwaters WRAPS for a specific listing of meetings held for the WRAPS/TMDL project.
- A Bemidji MS4 meeting was held on June 12th, 2017, to present the draft TMDL to the city of Bemidji. The meeting was held to formally review the draft TMDL allocations, their development, and to receive comments and suggestions. The city of Bemidji has been an active participant and supporter of the WRAPS effort.
- Public and stakeholder meetings were held at key points throughout the WRAPS/TMDL project. The final Public meetings for the project were held on January 12th, 2017 (Bemidji), January 26th, 2017 (Cohasset), and June 20th 2017 (Bemidji), to present the draft TMDL report and allocations before public notice and receive public comments and concerns. Subsequent WRAPS/TMDL presentations were given on July 20th, 2017, at the Beltrami SWCD's monthly Board meeting and at the Minnesota Association of Planning and Zoning Administrators annual conference on October 13th, 2017 (Bemidji).

The Beltrami SWCD is the lead local governmental unit (LGU) and has jurisdiction over both the Lake Irving and Little Turtle Lake watersheds, and will coordinate implementation of the TMDL with stakeholders. The Beltrami SWCD maintains qualified staff who have worked over the past 30 years with state and federal agencies to advance watershed management, including monitoring programs in the Lake Bemidji Watershed.

The stakeholder process for the TMDLs has been part of the Mississippi River Headwaters WRAPS process. Its technical advisory committee was formed from representatives of the following stakeholder groups:

- Beltrami SWCD (Bill Best, Brent Rudd)
- Bemidji State University (Steve Balmes, Pat Welle [BSU Emeritus])
- Cass County SWCD (John Ringle)
- City of Bemidji (Craig Gray, Nate Mathews, Shon Snopl)
- Clearwater SWCD (Nathan Nordlund, Nick Phillips)

- Greater Bemidji Area Joint Planning Board (Josh Stearns)
- Headwaters Science Center
- Hubbard SWCD (Jamin Carlson and Julie Kingsley)
- Itasca S SWCD (Kim Yankowiak)
- Leech Lake Band of Objibwe (Sam Malloy)
- Minnesota BWSR (Jeff Hrubes, Chad Severts)
- Minnesota Department of Health (Chris Parthun)
- Minnesota DNR (Andy Thompson, Dan Thul, Dick Rossman, Jaime Thibodeaux, Jennifer Corcoran, Michael Harris, Rian Reed, Rita Albrecht, Tony Standera)
- Mississippi Headwaters Board (Tim Terrill)
- USFS–Chippewa National Forest (David Morely)
- Turtle River Watershed Association (Carl Isaacson).

10 Tracking Total Maximum Daily Load Effectiveness

Tracking progress toward achieving the TMDL load reductions will primarily rely on monitoring each impaired watershed for (1) BMP implementation and (2) tracking attainment of lake water quality standards. Each of the Mississippi River – Headwaters SWCDs (Headwaters) will track and report implementation projects annually within their jurisdictions. Existing tools, such as pollutant reduction calculators and input into BWSR's web-based eLINK tracking system [BWSR 2016] and other methods of tracking will be used to report progress. BMP effectiveness may be estimated by BWSR and MPCA calculators based on BMP designs, construction, and operation and maintenance considerations.

River and lake monitoring will be conducted by a combination of volunteer monitors and county/SWCD technicians as resources and priorities allow. The monitoring level of effort will vary among the Headwaters entities because staffing and budgets vary. Annual reporting by the Headwaters partners will provide benchmarks for measuring progress of the implemented TMDLs and for adaptive management. Details of the lake and stream monitoring will be specified by the Headwaters WRAPS process.

Headwater TMDL lakes' water quality should continue to be monitored; monitoring should be coordinated by the various WRAPS partners who work throughout the watershed. The monitoring goals may include the following:

- Growing-season monitoring should be continued for Lake Irving and Little Turtle Lake for TP, Chl-*a* and Secchi transparency at one lake site. Secchi volunteer monitoring should target 10 to 12 growing-season transparency measurements per year. Monitoring of upgradient river inlets for both lakes is encouraged.
- Lake Irving monitoring, particularly during peak growing-season low-flow periods (e.g., less than 225 cfs at Stump Lake Dam) should include TP, total dissolved P, and three to four paired bottom water samples for TP and total iron.
- Initiate growing season paired monitoring of the north and south basin of Lake Bemidji for TP, Chl-*a* and Secchi. Secchi volunteer monitoring should target 10 to 12 growing-season transparency measurements per year. Lake monitoring sites should include three to four paired bottom water samples for TP and total iron.
- Growing-season interflows between Lakes Irving and Bemidji should be investigated during low-flow periods to determine the degree and magnitude of potential backwatering of flows from Lake Bemidji into Lake Irving. These low-flow evaluations should also consider the potential for Bemidji WWTP flows to be carried into Lake Irving, and include influence factors such as density and temperature. If low-flow backwatering is observed, then potential remediation measures to limit Bemidji WWTP effluent discharges is encouraged.
- The degree of upgradient wetland complex TP and total dissolved P contributions that result from dry and wet cycles should be further evaluated.

11 Literature Cited

Ackerman, D., 2015. *Hydrologic and Water Quality Calibration for the Pine River, Leech Lake River, Mississippi River Headwaters, Mississippi River-Grand Rapids, Mississippi River-Brainerd, Mississippi River-Sartell Watersheds, Mississippi River-St. Cloud and Rum River HSPF Models*, RSI(RCO)-2111/5-15/34, prepared by RESPEC, Rapid City, SD for C. Regan, Minnesota Pollution Control Agency, St. Paul, MN, June 1.

Cooke, G. D., E. B. Welch, S. A. Peterson, and P. R. Newroth, 1986. "Lake and Reservoir Restoration," *Phosphorus Precipitation and Inactivation*, Chapter 6, Butterworth Publishers, Stoneham, MA.

Courte Oreilles Lakes Association, 2015. "The Lac Courte Oreilles Lakes Shoreline Assessment and Restoration Project,"*adceval.com*, retrieved July 15, 2016, from *http://cola.adceval.com/media/cushycms/Maps_22_1668652244.pdf*

Dayton, M., 2014. "Minnesota County Population Projections by Age and Gender, 2015-2045," Minnesota State Demographic Center, retrieved January 7, 2016, from *http://mn.gov/admin/demography/data-by-topic/population-data/our-projections/*

Donigian, A. S., Jr.; J. C. Imhoff; B. R. Bicknell; and J. L. Kittle, Jr., 1984. *Application Guide for the Hydrological Simulation Program-FORTRAN,* EPA 600/3-84-066, Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, GA.

Dunne, E. J., M. W. Clark, J. Mitchell, J. W. Jawitx, and K. R. Reddy, 2010. "Soil Phosphorus Flux From Emergent Marsh Wetlands and Surrounding Grazed pasture Uplands," *Ecological Engineering*, Vol. 36, No. 10, pp. 1392–1400.

Fang, X., S. R. Alam, L. Jiang, P. Jacobson, D. Pereira, and H. G. Stefan, 2010. *Simulations of Cisco Fish Habitat in Minnesota Lakes Under Future Climate Scenarios*, Project Report 547, prepared by the University of Minnesota, St. Anthony Falls Laboratory, St. Paul, MN.

Farnsworth, R. and E. S. Thompson, 1982. *Evaporation Atlas for the Contiguous 48 United States*, National Oceanic and Atmospheric Administration Technical Report #33, prepared by the Office of Hydrology, National Weather Service, Washington, DC, for the National Oceanic and Atmospheric Administration, Washington, D.C.

Heiskary, S. A. and C. B. Wilson, 2005. *Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria*, Third Edition, prepared for the Minnesota Pollution Control Agency, St. Paul, MN.

Heiskary, S. A. and C. B. Wilson, 2008. "Minnesota's Approach to Lake Nutrient Criteria Development," *Lake and Reservoir Management*, Vol. 24, No. 3, pp. 282–297.

Helsel, D. R., D. K. Mueller, and J. R. Slack, 2006. *Computer Program for the Kendall Family of Trend Tests*, U.S. Geological Survey Scientific Investigations Report 2005-5275, U.S. Geological Survey, Reston, VA.

Hodgson, J., M. Evenson, and J. Magner, 2007. *The Upper Mississippi River Low Dissolved Oxygen Water Quality Impairment Total Maximum Daily Load Report.* Prepared for EPA Region 5 by Minnesota Pollution Control Agency.

Homer, C. G., J. A. Dewitz, L. Yang, S. Jin, P. Danielson, G. Xian, J. Coulston, N. D. Herold, J. D. Wickham, and K. Megown, 2015. "Completion of the 2011 National Land Cover Database for the Conterminous United States-Representing a Decade of Land Cover Change Information," *Photogrammetric Engineering and Remote Sensing*, Vol. 81, No. 5, pp. 345–354.

Hondzo, M. and H. Stefan. 1996. "Dependence of Water Quality and Fish Habitat on Lake Morphometry and Meteorology," *Journal of Water Resources Plan and Management*, Vol. 122, No. 5, pp. 364–373.

Iowa State University of Science and Technology, 2016. "Wind Roses," *iastate.edu*, retrieved November 14, 2016, from *http://mesonet.agron.iastate.edu/sites/windrose.phtml?station=FGN&network=MN_ASOS*

Jacobson, P., H. G. Stefan, and D. L. Pereira, 2010. "Coldwater Fish Oxythermal Habitat in Minnesota Lakes: Influence of Total Phosphorus, July Air Temperature, and Relative Depth," *Canadian Journal of Fisheries and Aquatic Sciences*, Vol. 67, No. 12, 2002–2013.

James, W. F., 2012. *Estimation of Internal Phosphorus Loading Contributions to the Lake of the Woods, Minnesota,* prepared by ERDC Eau Galle Aquatic Ecology Laboratory. Spring Valley, WI for the Minnesota Pollution Control Agency, St. Paul, MN.

James, W. F., 2015. *Diffusive Phosphorus Flux and Sediment Characteristics in Big Traverse, Lake of the Woods*, prepared by the University of Wisconsin-Stout, Menomonie, WI, for the Minnesota Pollution Control Agency, St. Paul, MN.

Kenner, S., 2013a. *Model Development for Mississippi River Headwaters (07010101), Leech Lake River (07010102), and Pine River Watersheds (07010105)*, RSI(RCO)-2046/6-13/40, prepared by RESPEC, Rapid City, SD for C. Regan, Minnesota Pollution Control Agency, St. Paul, MN, June 20.

Kenner, S., 2013b. *Hydrology Calibration of Mississippi River Headwaters (07010101), Leech Lake River (07010102), and Pine River (07010105)*, RSI(RCO)-2046/6-13/37, prepared by RESPEC, Rapid City, SD for C. Regan, Minnesota Pollution Control Agency, St. Paul, MN, June 20.

Kretsch K., 2016. Personal communication between K. Kretsch, Lake Restoration, Inc., Rogers, MN, and B. Wilson, RESPEC, Roseville, MN. May 25.

Lanegran, D. A., 2008. *Minnesota On The Map, A Historical Atlas*, prepared for the Minnesota Historical Society Press, St. Paul, MN.

Leegard, P., 2015. *Itasca County Construction Stormwater Projects 1-1-2005 to 7-27-2015*, electronic communication from P. Leegard, Minnesota Pollution Control Agency, Saint Paul, MN, to G. Kramer, RESPEC, Roseville, MN, July 27.

Lumb, A. M., R. B. McCammon, and J. L. Kittle, Jr., 1994. *Users Manual for an Expert System (HSPEXP) for Calibration of the Hydrological Simulation Program-FORTRAN,* U.S. Geological Survey Water Resources Investigations Report 94-4168, U.S. Geological Survey, Reston, VA.

Midwestern Regional Climate Center, 2016. "cli-MATE, the MRCC's Application Tools Environment Database," *illinois.edu*, retrieved November 7, 2016, from *http://mrcc.illinois.edu/CLIMATE*

Minnesota Board of Soils and Water Resources, 2016. "eLink Web-Based Conservation Tracking System Development," accessed August 5, 2016, from *http://www.bwsr.state.mn.us/outreach/eLINK/*

Minnesota Department of Natural Resources, 1982. "Little Turtle Lake Bathymetry," *state.mn.us*, retrieved December 31, 2015, from *http://files.dnr.state.mn.us/lakefind/data/lakemaps/b3011012.pdf*

Minnesota Department of Natural Resources, 2016a. "Monthly Precipitation Data from Gridded Database," *state.mn.us*, retrieved November 7, 2016, from *http://www.dnr.state.mn.us/climate/historical/monthly.html*

Minnesota Department of Natural Resources, 2016b. "Lake Level Minnesota," *state.mn.us*, retrieved November 7, 2016, from *http://www.dnr.state.mn.us/climate/waterlevels/lakes/index.html*

Minnesota Department of Natural Resources, 2016c. "Fisheries Lake Survey for Little Turtle Lake," *state.mn.us,* retrieved January 7, 2016, from *http://www.dnr.state.mn.us/lakefind/showreport.html?downum=31091300*

Minnesota Pollution Control Agency, 2000. *Upper Mississippi River: Basin Information Document 2000*, prepared by the Minnesota Pollution Control Agency, St. Paul, MN.

Minnesota Pollution Control Agency, 2005. *Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria, 3rd Edition*, prepared by the Minnesota Pollution Control Agency, St. Paul, MN.

Minnesota Pollution Control Agency, 2013. "2013 SSTS Annual Report," *pca.state.mn.us*, retrieved December 23, 2015, from *https://www.pca.state.mn.us/sites/default/files/wq-wwists1-52.pdf*

Minnesota Pollution Control Agency, 2016. "Minnesota Stormwater Manual," retrieved August 5, 2016, from *http://stormwater.pca.state.mn.us/index.php/Main_Page*

Minnesota State Legislature, 2008. "Chapter 7050, Waters of the State," *mn.gov*, retrieved August 10, 2015, from *https://www.revisor.mn.gov/rules/?id=7050*

Minnesota State Legislature, 2014. "Chapter 7041, Sewage Sludge Management," *mn.gov*, retrieved August 3, 2016, from *https://www.revisor.mn.gov/rules/?id=7041*

Minnesota State Legislature, 2015a. "Chapter 7001, Permits and Certifications," *mn.gov*, retrieved August 5, 2016, *https://www.revisor.mn.gov/rules/?id=7001&version=2015-09-23T11:08:59-05:00&format=pdf*

Minnesota State Legislature, 2015b. "Chapter 103F.48, Riparian Protection and Water Quality Practices," *mn.gov*, retrieved August 5, 2016, from *https://www.revisor.leg.state.mn.us/statutes/?id=103F.48*

Minnesota State Legislature, 2015c. "Chapter 115.03, Powers and Duties," *mn.gov*, retrieved August 5, 2016, from *https://www.revisor.mn.gov/statutes/?id=115.03&format=pdf*

National Oceanic and Atmospheric Administration, 1982. "Hydrometeorological Design Studies Center, Precipitation Frequency Data Server," *noaa.gov*, retrieved November 3, 2015, from *http://hdsc.nws.noaa.gov/hdsc/pfds/*

National Oceanic and Atmospheric Administration, 2016. "Hydrometeorological Design Studies Center, Precipitation Frequency Data Server," *noaa.gov*, retrieved November 7, 2016, from *http://hdsc.nws.noaa.gov/hdsc/pfds/*

Natural Resource Conservation Service, 2009. "Chapter 7 Hydrologic Soil Groups," *Part 30 Hydrology National Engineering Handbook*, prepared by the U.S. Department of Agriculture Natural Resources Conservation Service, Washington, DC.

Natural Resources Conservation Service, 2015. "Web Soil Survey for Little Turtle Lake Watershed," *usda.gov*, retrieved December 27, 2015, from *http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm*

Natural Resources Conservation Service, 2016. "Rapid Watershed Assessment Mississippi Headwaters (MN) HUC: 7010101," *usda.gov*, retrieved <date>, from *https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_022926.pdf*

Nürnberg, G. K., 1995. "Quantifying Anoxia in Lakes," *Limnology and Oceanography*, Vol. 40, No. 6.

Osgood, R. A., 1998. "Lake Mixes and Internal Phosphorus Dynamics," *ARCH HYDROBIOL*, Vol. 113, pp. 629–638.

Richardson, C. J., 1985. "Mechanisms Controlling Phosphorus Retention Capacity in Wetlands," *Science*, Vol. 228, pp. 1424–1427.

Schupp, D. and B. Wilson, 1993. Developing Lake Goals for Water Quality and Fisheries," *LakeLine*, December, pp 18–21.

Shaw, D., 2016. Personal communication between D. Shaw, Minnesota Board of Water and Soil Resources, St. Paul, MN and B. Wilson, RESPEC, Roseville, MN, October 13.

Twarowski, C., N. Czoschke, and T. Anderson, 2007. *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds – Atmospheric Deposition: 2007 Update*, prepared by Barr Engineering Company, Bloomington, MN for the Minnesota Pollution Control Agency, St. Paul, MN.

Upham, W., 2001. *Minnesota Place Names, A Geographical Encyclopedia*, third edition, Minnesota Historical Society Press, St. Paul, MN.

U.S. Environmental Protection Agency, 1981. *Final Environmental Impact Statement. Final Volumes 1 and 2, Bemidji Wastewater Treatment System, Beltrami County, Minnesota,* EPA-5-MN-Beltrami-Bemidji-WWTP, prepared by the U.S. Environmental Protection Agency, Region V, Chicago, IL, and the Minnesota Pollution Control Agency, Roseville, MN, and Wapora, Incorporated, Chicago, IL.

Walker, W. W., 1985. *Empirical Methods for Predicting Eutrophication in Impoundments - Report 3, Phase II: Model Refinements*, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Walker, W. W., et al 1989. *Design and Evaluation of Eutrophication Control Measures for the St. Paul Water Supply.* Lake and Reservoir Management 5(1); 71-83

Walker, W., 1996. *Simplified Procedures for Eutrophication Assessment and Prediction: User Manual*, Instruction Rep. W-96-2, prepared for the US. Army Corps of Engineers, Washington, D.C.

Walker, W. W., 2000. *Evaluation of Water Quality Controls in the St. Paul Water Utility Watersheds,* Analysis of 1984-1999 Monitoring Data, May 2000. http://www.wwwalker.net/spwu/index.htm

Walker, W., 2004. *BATHTUB Version 6.1, Simplified Techniques for Eutrophication Assessment and Prediction*, software developed for U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Wang, H., M. Hondzo, B. Stauffer, and B. Wilson, 2004. "Phosphorus Dynamics in Jessie Lake: Mass Flux Across the Sediment-Water Interface," *Lake and Reservoir Management*, Vol. 20, No.4, pp.333–346.

Wilson, B. and W. W. Walker, 1989. "Development of Lake Assessment Methods Based upon the Aquatic Ecoregion Concept," *Lake and Reservoir Management*, Vol. 5, No.2, pp.11–22.

Wilson, B. and G. Kramer, 2015. *Big Fork Lakes: Water Quality Review of Select Lakes for Natural Background Exceedances of Water Quality Standards*, RSI(MPO)2596/12-15/5, prepared by RESPEC, Roseville, MN, for Minnesota Pollution Control Agency, St. Paul, MN.

Appendix A BATHTUB Case Data and Overall Balances

Table A-1. Lake Irving Existing Inputs (Page 1 of 2)

File: E:\BATHTUB\Headwaters lakes\Lake Irving Cal Exisiting.btb

Description:

Global Variables	Mean	CV	Model Options	Code	Description
Averaging Period (yrs)	1	0.0	Conservative Substance	0	NOT COMPUTED
Precipitation (m)	0.689999998	0.1	Phosphorus Balance	6	FIRST ORDER
Evaporation (m)	0.699999988	0.2	Nitrogen Balance	0	NOT COMPUTED
Storage Increase (m)	0	0.0	Chlorophyll-a	2	P, LIGHT, T
			Secchi Depth	1	VS. CHLA & TURBIDITY
Atmos. Loads (kg/km	**Mean**	**CV**	Dispersion	1	FISCHER-NUMERIC
Conserv. Substance	0	0.00	Phosphorus Calibration	2	CONCENTRATIONS
Total P	27	0.20	Nitrogen Calibration	2	CONCENTRATIONS
Total N	1000	0.50	Error Analysis	1	MODEL & DATA
Ortho P	15	0.50	Availability Factors	0	IGNORE
Inorganic N	500	0.50	Mass-Balance Tables	1	USE ESTIMATED CONCS
			Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Main Basin	0	1	2.676	2.3	2.4	2.3	0	0	0	0.75	0	0	0	3.25	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seq	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	65	0.04	0	0	37	0.07	1.42	0.01	0	0	0	0	0	0	0	0

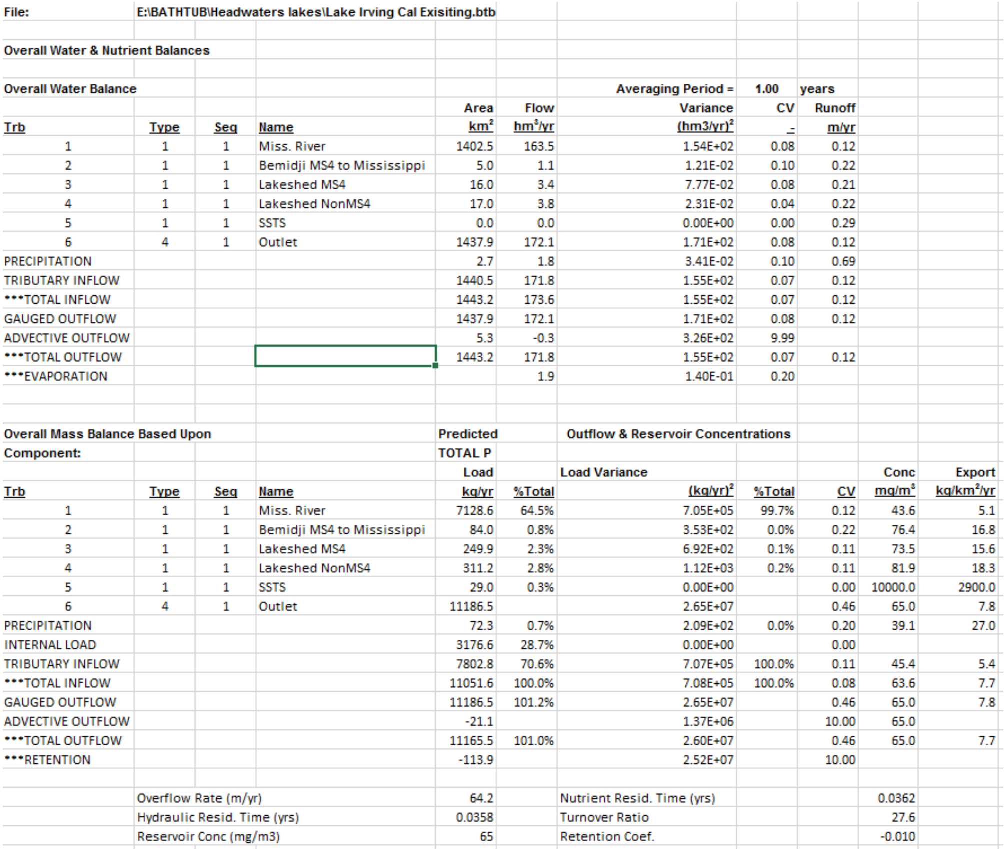
Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seq	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1.018019	0	1	0	1.034796	0	2.3	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Miss. River	1	1	1402.48	163.5	0.076	0	0	43.6	0.09	0	0	11.3	0.27	0	0
2	Bemidji MS4 to Mississippi	1	1	5	1.1	0.1	0	0	76.4	0.2	0	0	47	0.2	0	0
3	Lakeshed MS4	1	1	16	3.4	0.082	0	0	73.5	0.066	0	0	44.3	0.109	0	0
4	Lakeshed NonMS4	1	1	17	3.8	0.04	0	0	81.9	0.1	0	0	38.5	0.1	0	0
5	SSTS	1	1	0.01	0.0029	0	0	0	10000	0	0	0	10000	0	0	0
6	Outlet	1	4	1437.88	172.1	0.076	0	0	41.1	0.092	0	0	0	0	0	0

Table A-1. Lake Irving Existing Inputs (Page 2 of 2)



File: E:\BATHTUB\Headwaters lakes\Lake Irving Cal Exisiting.btb

Overall Water & Nutrient Balances

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

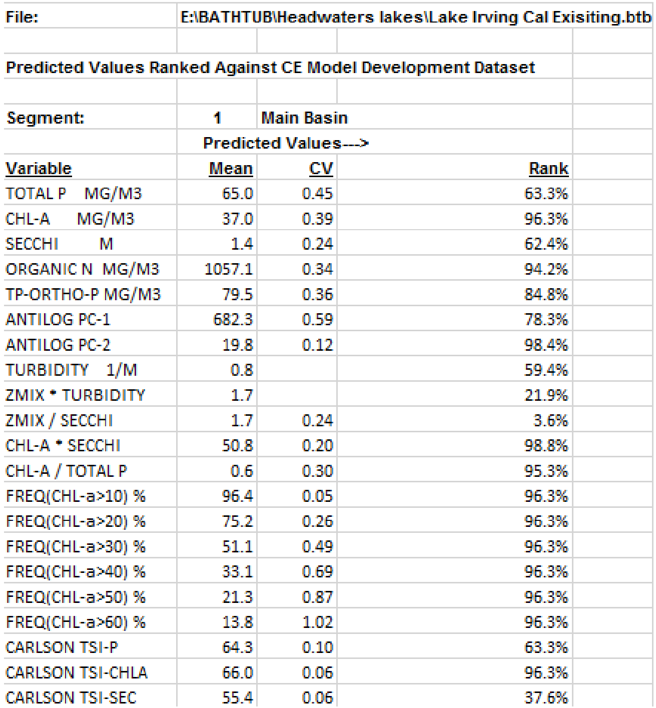
Trb	Type	Seq	Name	Area km²	Flow hm³/yr	Variance (hm3/yr)²	CV -	Runoff m/yr
1	1	1	Miss. River	1402.5	163.5	1.54E+02	0.08	0.12
2	1	1	Bemidji MS4 to Mississippi	5.0	1.1	1.21E-02	0.10	0.22
3	1	1	Lakeshed MS4	16.0	3.4	7.77E-02	0.08	0.21
4	1	1	Lakeshed NonMS4	17.0	3.8	2.31E-02	0.04	0.22
5	1	1	SSTS	0.0	0.0	0.00E+00	0.00	0.29
6	4	1	Outlet	1437.9	172.1	1.71E+02	0.08	0.12
PRECIPITATION				2.7	1.8	3.41E-02	0.10	0.69
TRIBUTARY INFLOW				1440.5	171.8	1.55E+02	0.07	0.12
***TOTAL INFLOW				1443.2	173.6	1.55E+02	0.07	0.12
GAUGED OUTFLOW				1437.9	172.1	1.71E+02	0.08	0.12
ADVECTIVE OUTFLOW				5.3	-0.3	3.26E+02	9.99	
***TOTAL OUTFLOW				1443.2	171.8	1.55E+02	0.07	0.12
***EVAPORATION					1.9	1.40E-01	0.20	

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

Component: **TOTAL P**

Trb	Type	Seq	Name	Load kg/yr	%Total	Load Variance (kg/yr)²	%Total	CV	Conc mg/m³	Export kg/km²/yr
1	1	1	Miss. River	7128.6	64.5%	7.05E+05	99.7%	0.12	43.6	5.1
2	1	1	Bemidji MS4 to Mississippi	84.0	0.8%	3.53E+02	0.0%	0.22	76.4	16.8
3	1	1	Lakeshed MS4	249.9	2.3%	6.92E+02	0.1%	0.11	73.5	15.6
4	1	1	Lakeshed NonMS4	311.2	2.8%	1.12E+03	0.2%	0.11	81.9	18.3
5	1	1	SSTS	29.0	0.3%	0.00E+00		0.00	10000.0	2900.0
6	4	1	Outlet	11186.5		2.65E+07		0.46	65.0	7.8
PRECIPITATION				72.3	0.7%	2.09E+02	0.0%	0.20	39.1	27.0
INTERNAL LOAD				3176.6	28.7%	0.00E+00		0.00		
TRIBUTARY INFLOW				7802.8	70.6%	7.07E+05	100.0%	0.11	45.4	5.4
***TOTAL INFLOW				11051.6	100.0%	7.08E+05	100.0%	0.08	63.6	7.7
GAUGED OUTFLOW				11186.5	101.2%	2.65E+07		0.46	65.0	7.8
ADVECTIVE OUTFLOW				-21.1		1.37E+06		10.00	65.0	
***TOTAL OUTFLOW				11165.5	101.0%	2.60E+07		0.46	65.0	7.7
***RETENTION				-113.9		2.52E+07		10.00		

Overflow Rate (m/yr)	64.2	Nutrient Resid. Time (yrs)	0.0362
Hydraulic Resid. Time (yrs)	0.0358	Turnover Ratio	27.6
Reservoir Conc (mg/m3)	65	Retention Coef.	-0.010



File: E:\BATHTUB\Headwaters lakes\Lake Irving Cal Exisiting.btb

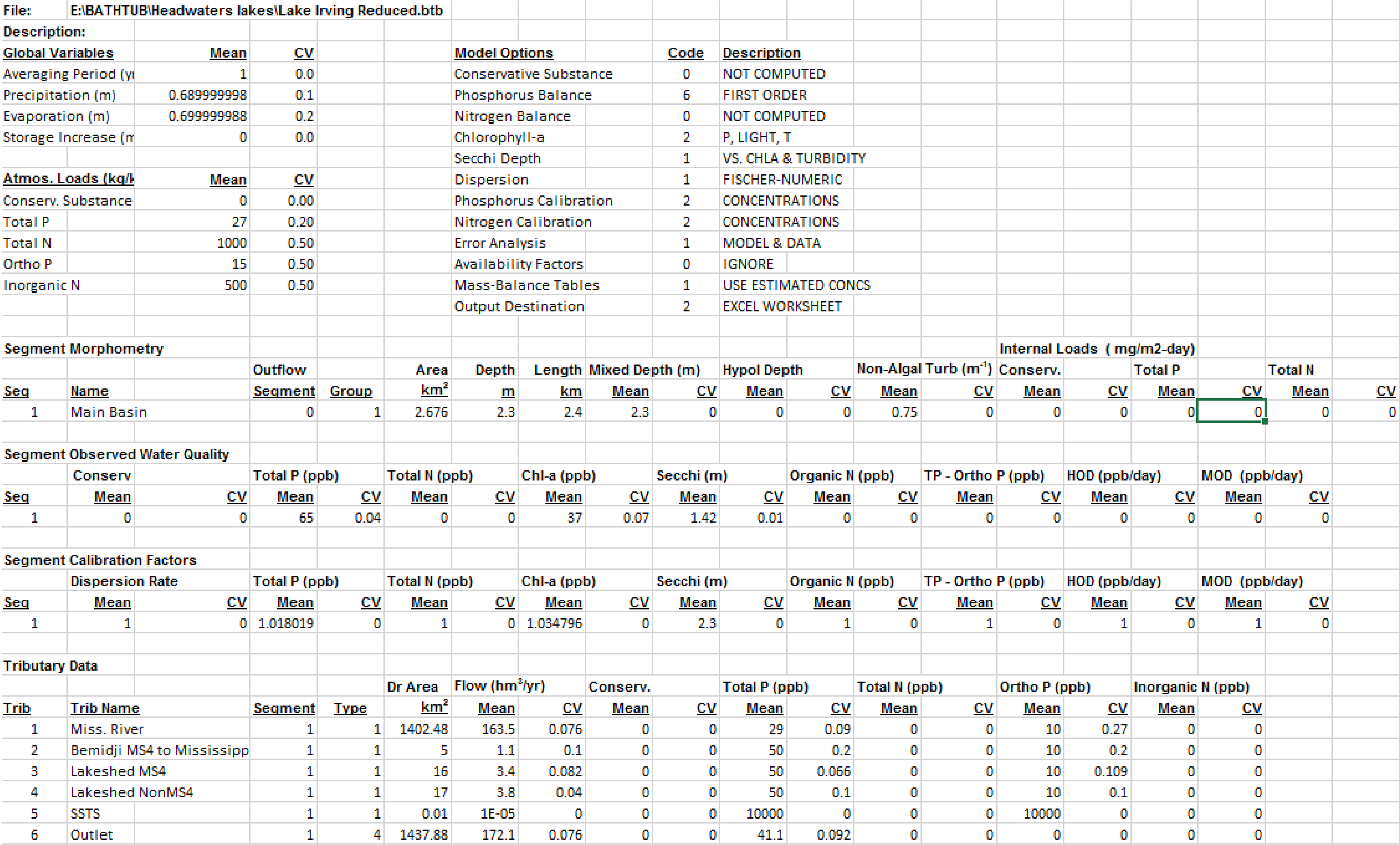
Predicted Values Ranked Against CE Model Development Dataset

Segment: **1** **Main Basin**

Predicted Values--->

Variable	Mean	CV	Rank
TOTAL P MG/M3	65.0	0.45	63.3%
CHL-A MG/M3	37.0	0.39	96.3%
SECCHI M	1.4	0.24	62.4%
ORGANIC N MG/M3	1057.1	0.34	94.2%
TP-ORTHO-P MG/M3	79.5	0.36	84.8%
ANTILOG PC-1	682.3	0.59	78.3%
ANTILOG PC-2	19.8	0.12	98.4%
TURBIDITY 1/M	0.8		59.4%
ZMIX * TURBIDITY	1.7		21.9%
ZMIX / SECCHI	1.7	0.24	3.6%
CHL-A * SECCHI	50.8	0.20	98.8%
CHL-A / TOTAL P	0.6	0.30	95.3%
FREQ(CHL-a>10) %	96.4	0.05	96.3%
FREQ(CHL-a>20) %	75.2	0.26	96.3%
FREQ(CHL-a>30) %	51.1	0.49	96.3%
FREQ(CHL-a>40) %	33.1	0.69	96.3%
FREQ(CHL-a>50) %	21.3	0.87	96.3%
FREQ(CHL-a>60) %	13.8	1.02	96.3%
CARLSON TSI-P	64.3	0.10	63.3%
CARLSON TSI-CHLA	66.0	0.06	96.3%
CARLSON TSI-SEC	55.4	0.06	37.6%

Table A-2. Lake Irving Reduced Inputs (Page 1 of 2)



File: E:\BATHTUB\Headwaters lakes\Lake Irving Reduced.btb

Description:

Global Variables	Mean	CV
Averaging Period (y	1	0.0
Precipitation (m)	0.689999998	0.1
Evaporation (m)	0.699999988	0.2
Storage Increase (	0	0.0

Atmos. Loads (kg/k	Mean	CV
Conserv. Substance	0	0.00
Total P	27	0.20
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	6	FIRST ORDER
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	2	CONCENTRATIONS
Nitrogen Calibration	2	CONCENTRATIONS
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seq	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Main Basin	0	1	2.676	2.3	2.4	2.3	0	0	0	0.75	0	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seq	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	65	0.04	0	0	37	0.07	1.42	0.01	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seq	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1.018019	0	1	0	1.034796	0	2.3	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Miss. River	1	1	1402.48	163.5	0.076	0	0	29	0.09	0	0	10	0.27	0	0
2	Bemidji MS4 to Mississipp	1	1	5	1.1	0.1	0	0	50	0.2	0	0	10	0.2	0	0
3	Lakeshed MS4	1	1	16	3.4	0.082	0	0	50	0.066	0	0	10	0.109	0	0
4	Lakeshed NonMS4	1	1	17	3.8	0.04	0	0	50	0.1	0	0	10	0.1	0	0
5	SSTS	1	1	0.01	1E-05	0	0	0	10000	0	0	0	10000	0	0	0
6	Outlet	1	4	1437.88	172.1	0.076	0	0	41.1	0.092	0	0	0	0	0	0

Table A-2. Lake Irving Reduced Inputs (Page 2 of 2)

File: **E:\BATHTUB\Headwaters lakes\Lake Irving Reduced.btb**

Overall Water & Nutrient Balances

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

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Miss. River	1402.5	163.5	1.54E+02	0.08	0.12
2	1	1	Bemidji MS4 to Mississippi	5.0	1.1	1.21E-02	0.10	0.22
3	1	1	Lakeshed MS4	16.0	3.4	7.77E-02	0.08	0.21
4	1	1	Lakeshed NonMS4	17.0	3.8	2.31E-02	0.04	0.22
5	1	1	SSTS	0.0	0.0	0.00E+00	0.00	0.00
6	4	1	Outlet	1437.9	172.1	1.71E+02	0.08	0.12
PRECIPITATION				2.7	1.8	3.41E-02	0.10	0.69
TRIBUTARY INFLOW				1440.5	171.8	1.55E+02	0.07	0.12
***TOTAL INFLOW				1443.2	173.6	1.55E+02	0.07	0.12
GAUGED OUTFLOW				1437.9	172.1	1.71E+02	0.08	0.12
ADVECTIVE OUTFLOW				5.3	-0.3	3.26E+02	9.99	
***TOTAL OUTFLOW				1443.2	171.8	1.55E+02	0.07	0.12
***EVAPORATION					1.9	1.40E-01	0.20	

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

Component: **TOTAL P**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Miss. River	4741.5	90.7%	3.12E+05	99.6%	0.12	29.0	3.4
2	1	1	Bemidji MS4 to Mississippi	55.0	1.1%	1.51E+02	0.0%	0.22	50.0	11.0
3	1	1	Lakeshed MS4	170.0	3.3%	3.20E+02	0.1%	0.11	50.0	10.6
4	1	1	Lakeshed NonMS4	190.0	3.6%	4.19E+02	0.1%	0.11	50.0	11.2
5	1	1	SSTS	0.1	0.0%	0.00E+00		0.00	10000.0	10.0
6	4	1	Outlet	5189.3		5.79E+06		0.46	30.2	3.6
PRECIPITATION				72.3	1.4%	2.09E+02	0.1%	0.20	39.1	27.0
TRIBUTARY INFLOW				5156.6	98.6%	3.13E+05	99.9%	0.11	30.0	3.6
***TOTAL INFLOW				5228.9	100.0%	3.13E+05	100.0%	0.11	30.1	3.6
GAUGED OUTFLOW				5189.3	99.2%	5.79E+06		0.46	30.2	3.6
ADVECTIVE OUTFLOW				-9.9		2.96E+05		10.00	30.2	
***TOTAL OUTFLOW				5179.4	99.1%	5.75E+06		0.46	30.2	3.6
***RETENTION				49.4	0.9%	5.43E+06		10.00		

Overflow Rate (m/yr)	64.2		Nutrient Resid. Time (yrs)	0.0355
Hydraulic Resid. Time (yrs)	0.0358		Turnover Ratio	28.2
Reservoir Conc (mg/m3)	30		Retention Coef.	0.009

File: **E:\BATHTUB\Headwaters lakes\Lake Irving Reduced.btb**

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: **1** **Main Basin**

	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	30.0	0.46	30.4%	65.0	0.04	63.3%
CHL-A MG/M3	19.6	0.52	83.1%	37.0	0.07	96.3%
SECCHI M	1.9	0.23	76.2%	1.4	0.01	64.1%
ORGANIC N MG/M3	660.6	0.37	74.2%			
TP-ORTHO-P MG/M3	48.6	0.40	69.4%			
ANTILOG PC-1	282.3	0.70	54.3%	661.2	0.07	77.6%
ANTILOG PC-2	16.3	0.20	96.2%	20.3	0.05	98.6%
TURBIDITY 1/M	0.8		59.4%	0.8		59.4%
ZMIX * TURBIDITY	1.7		21.9%	1.7		21.9%
ZMIX / SECCHI	1.2	0.23	1.0%	1.6	0.01	3.2%
CHL-A * SECCHI	36.4	0.33	96.4%	52.5	0.07	99.0%
CHL-A / TOTAL P	0.7	0.26	97.0%	0.6	0.08	95.3%
FREQ(CHL-a>10) %	78.1	0.31	83.1%	96.4	0.01	96.3%
FREQ(CHL-a>20) %	36.6	0.86	83.1%	75.2	0.05	96.3%
FREQ(CHL-a>30) %	16.0	1.29	83.1%	51.1	0.09	96.3%
FREQ(CHL-a>40) %	7.2	1.63	83.1%	33.1	0.12	96.3%
FREQ(CHL-a>50) %	3.4	1.91	83.1%	21.3	0.15	96.3%
FREQ(CHL-a>60) %	1.7	2.15	83.1%	13.8	0.18	96.3%
CARLSON TSI-P	53.3	0.12	30.4%	64.3	0.01	63.3%
CARLSON TSI-CHLA	59.8	0.08	83.1%	66.0	0.01	96.3%
CARLSON TSI-SEC	51.1	0.06	23.8%	54.9	0.00	35.9%

Table A-3. Little Turtle Lake Existing Inputs (Page 1 of 2)

File: E:\BATHTUB\Headwaters lakes\Little Turtle Calibrated.btb

Description:

Global Variables	Mean	CV	Model Options	Code	Description
Averaging Period (yrs)	1	0.0	Conservative Substance	0	NOT COMPUTED
Precipitation (m)	0.69	0.1	Phosphorus Balance	8	CANF & BACH, LAKES
Evaporation (m)	0.72	0.2	Nitrogen Balance	0	NOT COMPUTED
Storage Increase (m)	0	0.0	Chlorophyll-a	2	P, LIGHT, T
			Secchi Depth	1	VS. CHLA & TURBIDITY
Atmos. Loads (kg/km^2-y	**Mean**	**CV**	Dispersion	1	FISCHER-NUMERIC
Conserv. Substance	0	0.00	Phosphorus Calibration	1	DECAY RATES
Total P	27	0.30	Nitrogen Calibration	1	DECAY RATES
Total N	1000	0.50	Error Analysis	1	MODEL & DATA
Ortho P	14	0.30	Availability Factors	0	IGNORE
Inorganic N	500	0.50	Mass-Balance Tables	1	USE ESTIMATED CONCS
			Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

													Internal Loads (mg/m2-day)					
		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Main Basin	0	1	1.883	3.4	2.775	3.4	0.12	0	0	0.15	0	0	0	0.225	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	37.1	0.016	0	0	13.8	0.025	2.04	0.01	0	0	0	0	0	0	0	0

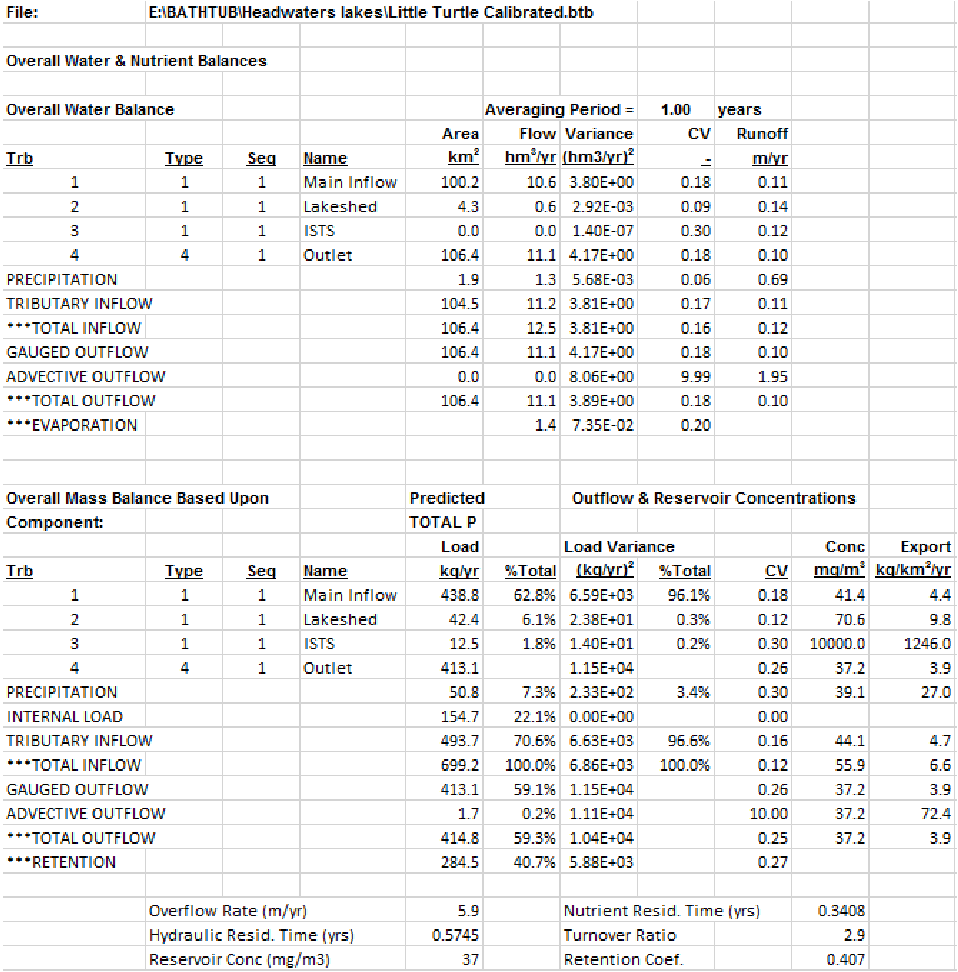
Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Main Inflow	1	1	100.21	10.6	0.184	0	0	41.4	0.019	0	0	8.6	0.047	0	0
2	Lakeshed	1	1	4.32	0.6	0.09	0	0	70.6	0.072	0	0	24.6	0.19	0	0
3	ISTS	1	1	0.01	0.001246	0.3	0	0	10000	0	0	0	0	0	0	0
4	Outlet	1	4	106.4	11.1	0.184	0	0	36.1	0.021	0	0	0	0	0	0

Table A-3. Little Turtle Lake Irving Existing Inputs (Page 2 of 2)



File: E:\BATHTUB\Headwaters lakes\Little Turtle Calibrated.btb

Overall Water & Nutrient Balances

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

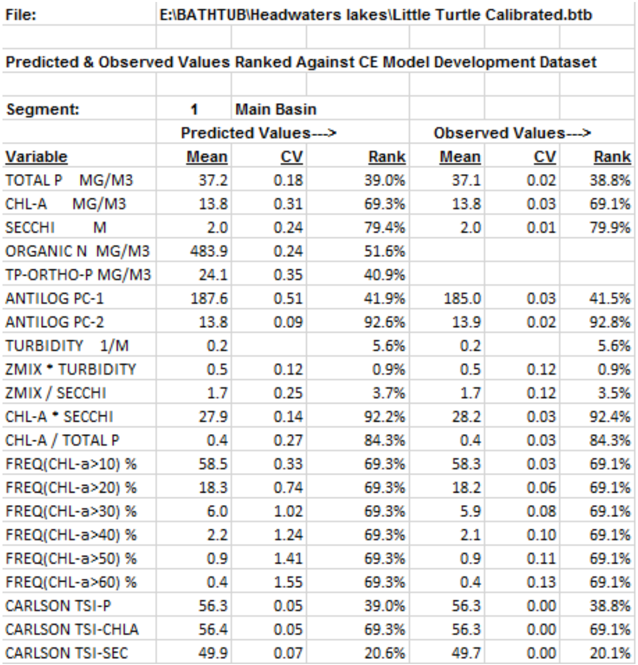
Trb	Type	Seq	Name	Area km²	Flow hm³/yr	Variance (hm3/yr)²	CV -	Runoff m/yr
1	1	1	Main Inflow	100.2	10.6	3.80E+00	0.18	0.11
2	1	1	Lakeshed	4.3	0.6	2.92E-03	0.09	0.14
3	1	1	ISTS	0.0	0.0	1.40E-07	0.30	0.12
4	4	1	Outlet	106.4	11.1	4.17E+00	0.18	0.10
PRECIPITATION				1.9	1.3	5.68E-03	0.06	0.69
TRIBUTARY INFLOW				104.5	11.2	3.81E+00	0.17	0.11
***TOTAL INFLOW				106.4	12.5	3.81E+00	0.16	0.12
GAUGED OUTFLOW				106.4	11.1	4.17E+00	0.18	0.10
ADVECTIVE OUTFLOW				0.0	0.0	8.06E+00	9.99	1.95
***TOTAL OUTFLOW				106.4	11.1	3.89E+00	0.18	0.10
***EVAPORATION					1.4	7.35E-02	0.20	

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

Component: **TOTAL P**

Trb	Type	Seq	Name	Load kg/yr	%Total	Load Variance (kg/yr)²	%Total	CV	Conc mg/m³	Export kg/km²/yr
1	1	1	Main Inflow	438.8	62.8%	6.59E+03	96.1%	0.18	41.4	4.4
2	1	1	Lakeshed	42.4	6.1%	2.38E+01	0.3%	0.12	70.6	9.8
3	1	1	ISTS	12.5	1.8%	1.40E+01	0.2%	0.30	10000.0	1246.0
4	4	1	Outlet	413.1		1.15E+04		0.26	37.2	3.9
PRECIPITATION				50.8	7.3%	2.33E+02	3.4%	0.30	39.1	27.0
INTERNAL LOAD				154.7	22.1%	0.00E+00		0.00		
TRIBUTARY INFLOW				493.7	70.6%	6.63E+03	96.6%	0.16	44.1	4.7
***TOTAL INFLOW				699.2	100.0%	6.86E+03	100.0%	0.12	55.9	6.6
GAUGED OUTFLOW				413.1	59.1%	1.15E+04		0.26	37.2	3.9
ADVECTIVE OUTFLOW				1.7	0.2%	1.11E+04		10.00	37.2	72.4
***TOTAL OUTFLOW				414.8	59.3%	1.04E+04		0.25	37.2	3.9
***RETENTION				284.5	40.7%	5.88E+03		0.27		

Overflow Rate (m/yr)	5.9	Nutrient Resid. Time (yrs)	0.3408
Hydraulic Resid. Time (yrs)	0.5745	Turnover Ratio	2.9
Reservoir Conc (mg/m3)	37	Retention Coef.	0.407



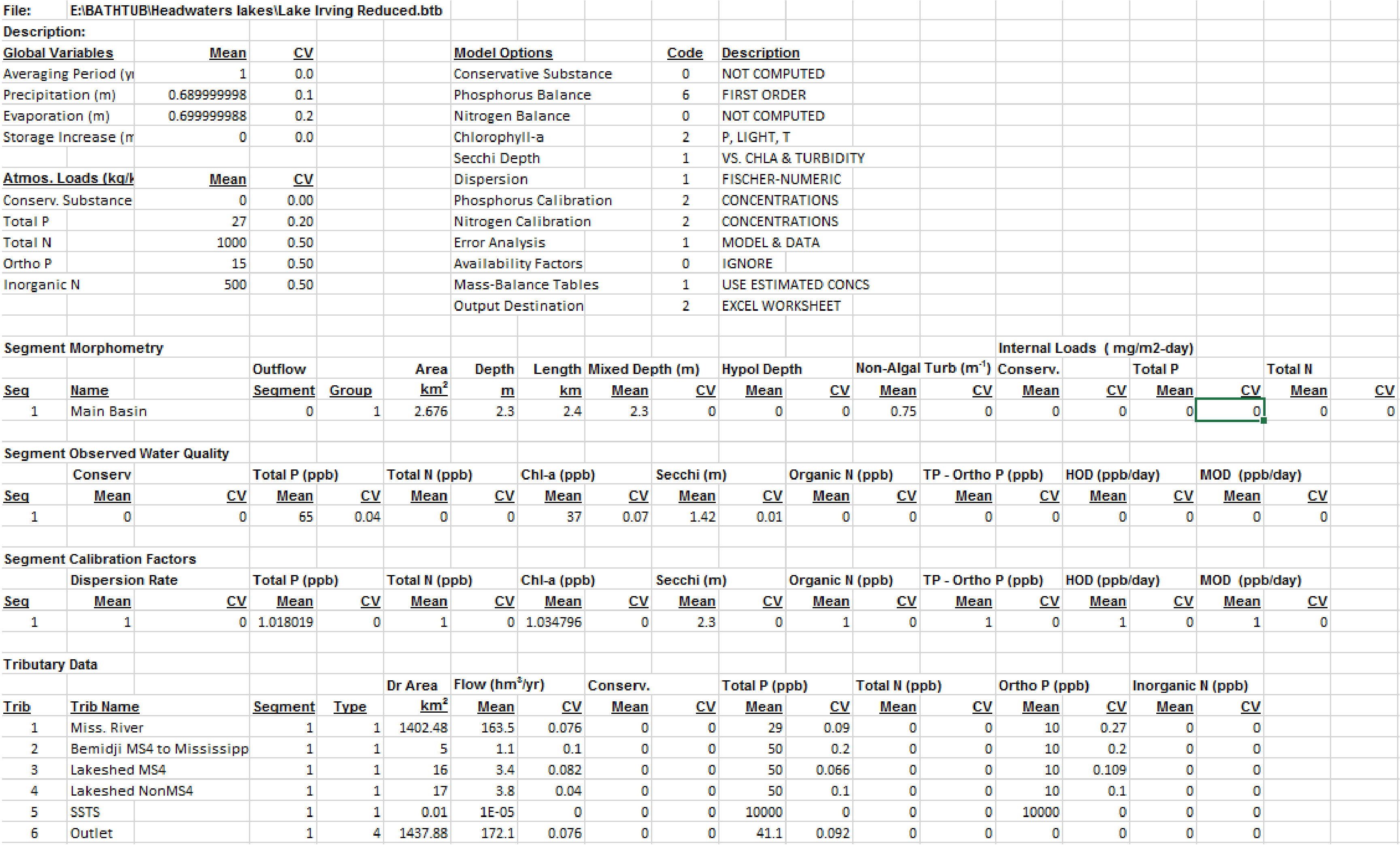
File: E:\BATHTUB\Headwaters lakes\Little Turtle Calibrated.btb

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 Main Basin

	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	37.2	0.18	39.0%	37.1	0.02	38.8%
CHL-A MG/M3	13.8	0.31	69.3%	13.8	0.03	69.1%
SECCHI M	2.0	0.24	79.4%	2.0	0.01	79.9%
ORGANIC N MG/M3	483.9	0.24	51.6%			
TP-ORTHO-P MG/M3	24.1	0.35	40.9%			
ANTILOG PC-1	187.6	0.51	41.9%	185.0	0.03	41.5%
ANTILOG PC-2	13.8	0.09	92.6%	13.9	0.02	92.8%
TURBIDITY 1/M	0.2		5.6%	0.2		5.6%
ZMIX * TURBIDITY	0.5	0.12	0.9%	0.5	0.12	0.9%
ZMIX / SECCHI	1.7	0.25	3.7%	1.7	0.12	3.5%
CHL-A * SECCHI	27.9	0.14	92.2%	28.2	0.03	92.4%
CHL-A / TOTAL P	0.4	0.27	84.3%	0.4	0.03	84.3%
FREQ(CHL-a>10) %	58.5	0.33	69.3%	58.3	0.03	69.1%
FREQ(CHL-a>20) %	18.3	0.74	69.3%	18.2	0.06	69.1%
FREQ(CHL-a>30) %	6.0	1.02	69.3%	5.9	0.08	69.1%
FREQ(CHL-a>40) %	2.2	1.24	69.3%	2.1	0.10	69.1%
FREQ(CHL-a>50) %	0.9	1.41	69.3%	0.9	0.11	69.1%
FREQ(CHL-a>60) %	0.4	1.55	69.3%	0.4	0.13	69.1%
CARLSON TSI-P	56.3	0.05	39.0%	56.3	0.00	38.8%
CARLSON TSI-CHLA	56.4	0.05	69.3%	56.3	0.00	69.1%
CARLSON TSI-SEC	49.9	0.07	20.6%	49.7	0.00	20.1%

Table A-4. Little Turtle Lake Reduced Inputs (Page 1 of 2)



File: E:\BATHTUB\Headwaters lakes\Lake Irving Reduced.btb

Description:

Global Variables	Mean	CV
Averaging Period (yı	1	0.0
Precipitation (m)	0.689999998	0.1
Evaporation (m)	0.699999988	0.2
Storage Increase (m	0	0.0

Atmos. Loads (kg/k	Mean	CV
Conserv. Substance	0	0.00
Total P	27	0.20
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	6	FIRST ORDER
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	2	CONCENTRATIONS
Nitrogen Calibration	2	CONCENTRATIONS
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

													Internal Loads (mg/m2-day)					
		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Conserv.		Total P		Total N	
Seq	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Main Basin	0	1	2.676	2.3	2.4	2.3	0	0	0	0.75	0	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seq	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	65	0.04	0	0	37	0.07	1.42	0.01	0	0	0	0	0	0	0	0

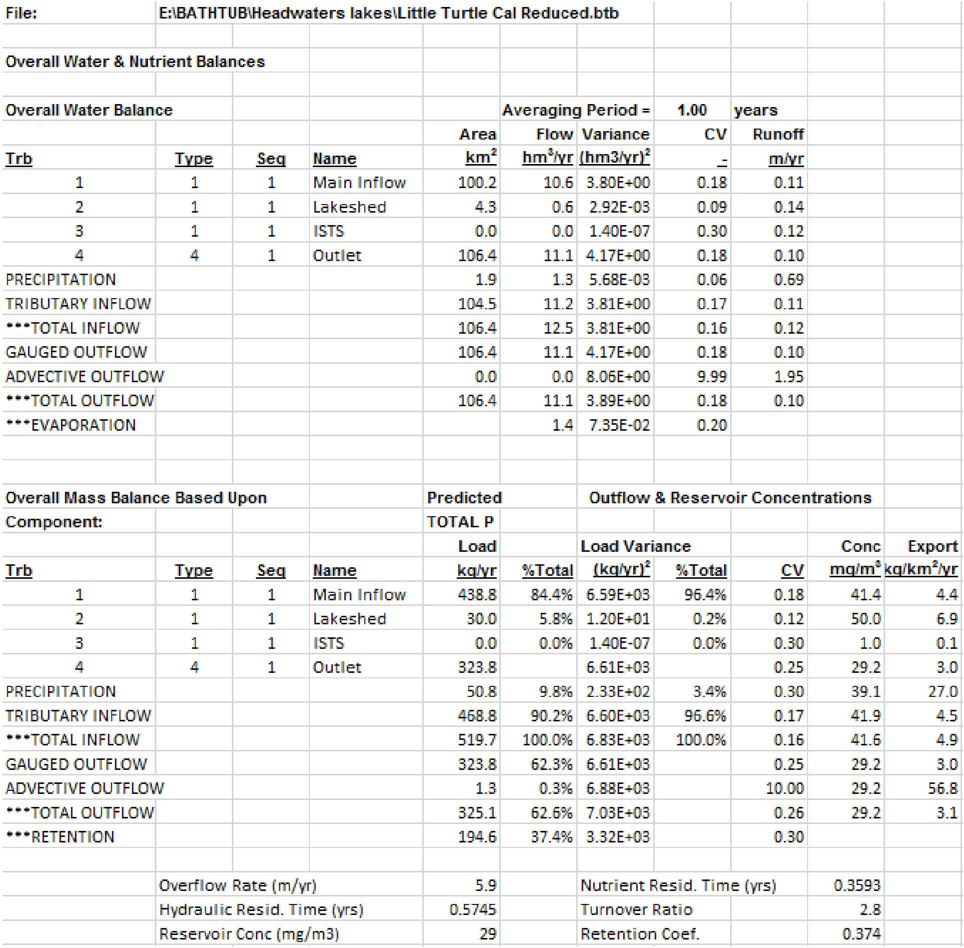
Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seq	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1.018019	0	1	0	1.034796	0	2.3	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Miss. River	1	1	1402.48	163.5	0.076	0	0	29	0.09	0	0	10	0.27	0	0
2	Bemidji MS4 to Mississipp	1	1	5	1.1	0.1	0	0	50	0.2	0	0	10	0.2	0	0
3	Lakeshed MS4	1	1	16	3.4	0.082	0	0	50	0.066	0	0	10	0.109	0	0
4	Lakeshed NonMS4	1	1	17	3.8	0.04	0	0	50	0.1	0	0	10	0.1	0	0
5	SSTS	1	1	0.01	1E-05	0	0	0	10000	0	0	0	10000	0	0	0
6	Outlet	1	4	1437.88	172.1	0.076	0	0	41.1	0.092	0	0	0	0	0	0

Table A-4. Little Turtle Lake Reduced Inputs (Page 2 of 2)



File: E:\BATHTUB\Headwaters lakes\Little Turtle Cal Reduced.btb

Overall Water & Nutrient Balances

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

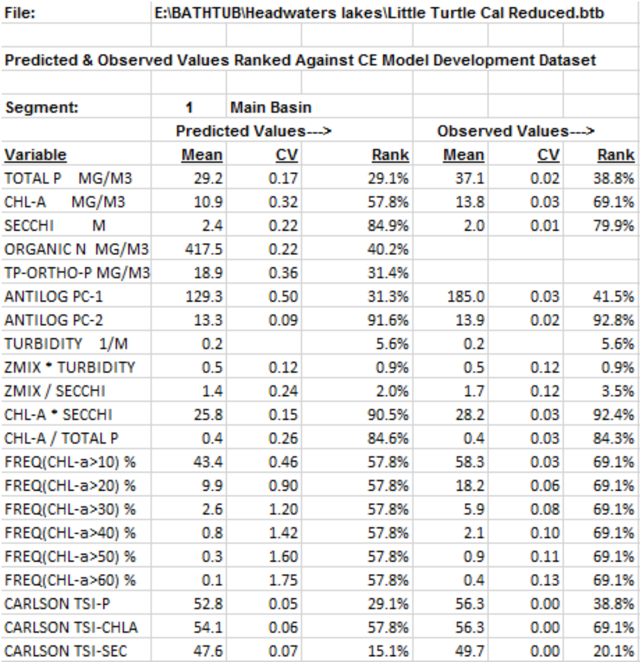
Trb	Type	Seq	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Main Inflow	100.2	10.6	3.80E+00	0.18	0.11
2	1	1	Lakeshed	4.3	0.6	2.92E-03	0.09	0.14
3	1	1	ISTS	0.0	0.0	1.40E-07	0.30	0.12
4	4	1	Outlet	106.4	11.1	4.17E+00	0.18	0.10
PRECIPITATION				1.9	1.3	5.68E-03	0.06	0.69
TRIBUTARY INFLOW				104.5	11.2	3.81E+00	0.17	0.11
***TOTAL INFLOW				106.4	12.5	3.81E+00	0.16	0.12
GAUGED OUTFLOW				106.4	11.1	4.17E+00	0.18	0.10
ADVECTIVE OUTFLOW				0.0	0.0	8.06E+00	9.99	1.95
***TOTAL OUTFLOW				106.4	11.1	3.89E+00	0.18	0.10
***EVAPORATION					1.4	7.35E-02	0.20	

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

Component: — **TOTAL P**

Trb	Type	Seq	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Main Inflow	438.8	84.4%	6.59E+03	96.4%	0.18	41.4	4.4
2	1	1	Lakeshed	30.0	5.8%	1.20E+01	0.2%	0.12	50.0	6.9
3	1	1	ISTS	0.0	0.0%	1.40E-07	0.0%	0.30	1.0	0.1
4	4	1	Outlet	323.8		6.61E+03		0.25	29.2	3.0
PRECIPITATION				50.8	9.8%	2.33E+02	3.4%	0.30	39.1	27.0
TRIBUTARY INFLOW				468.8	90.2%	6.60E+03	96.6%	0.17	41.9	4.5
***TOTAL INFLOW				519.7	100.0%	6.83E+03	100.0%	0.16	41.6	4.9
GAUGED OUTFLOW				323.8	62.3%	6.61E+03		0.25	29.2	3.0
ADVECTIVE OUTFLOW				1.3	0.3%	6.88E+03		10.00	29.2	56.8
***TOTAL OUTFLOW				325.1	62.6%	7.03E+03		0.26	29.2	3.1
***RETENTION				194.6	37.4%	3.32E+03		0.30		

Overflow Rate (m/yr)	5.9	Nutrient Resid. Time (yrs)	0.3593
Hydraulic Resid. Time (yrs)	0.5745	Turnover Ratio	2.8
Reservoir Conc (mg/m3)	29	Retention Coef.	0.374



File: E:\BATHTUB\Headwaters lakes\Little Turtle Cal Reduced.btb

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: **1** **Main Basin**

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	29.2	0.17	29.1%	37.1	0.02	38.8%
CHL-A MG/M3	10.9	0.32	57.8%	13.8	0.03	69.1%
SECCHI M	2.4	0.22	84.9%	2.0	0.01	79.9%
ORGANIC N MG/M3	417.5	0.22	40.2%			
TP-ORTHO-P MG/M3	18.9	0.36	31.4%			
ANTILOG PC-1	129.3	0.50	31.3%	185.0	0.03	41.5%
ANTILOG PC-2	13.3	0.09	91.6%	13.9	0.02	92.8%
TURBIDITY 1/M	0.2		5.6%	0.2		5.6%
ZMIX * TURBIDITY	0.5	0.12	0.9%	0.5	0.12	0.9%
ZMIX / SECCHI	1.4	0.24	2.0%	1.7	0.12	3.5%
CHL-A * SECCHI	25.8	0.15	90.5%	28.2	0.03	92.4%
CHL-A / TOTAL P	0.4	0.26	84.6%	0.4	0.03	84.3%
FREQ(CHL-a>10) %	43.4	0.46	57.8%	58.3	0.03	69.1%
FREQ(CHL-a>20) %	9.9	0.90	57.8%	18.2	0.06	69.1%
FREQ(CHL-a>30) %	2.6	1.20	57.8%	5.9	0.08	69.1%
FREQ(CHL-a>40) %	0.8	1.42	57.8%	2.1	0.10	69.1%
FREQ(CHL-a>50) %	0.3	1.60	57.8%	0.9	0.11	69.1%
FREQ(CHL-a>60) %	0.1	1.75	57.8%	0.4	0.13	69.1%
CARLSON TSI-P	52.8	0.05	29.1%	56.3	0.00	38.8%
CARLSON TSI-CHLA	54.1	0.06	57.8%	56.3	0.00	69.1%
CARLSON TSI-SEC	47.6	0.07	15.1%	49.7	0.00	20.1%