Island Lake Total Maximum Daily Load Big Fork Watershed

Addressing excess phosphorus concentrations by quantifying phosphorus sources, identifying Best Management Practices, and developing a future monitoring plan.

MINNESOTA POLLUTION CONTROL AGENCY

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TMDL Summary Table

EPA/MPCA Required Elements	Summary	TMDL Page #
Location	Island Lake is located in northwestern Itasca County in north-central Minnesota, within the headwaters of the Big Fork River Watershed.	5
303(d) Listing Information	• Island Lake, AUID #31-0913-00 • Impaired for aquatic recreation • Impaired for nutrient/eutrophication biological indicators • Target completion date: 2016 • Originally listed in 2010	3
Applicable Water Quality Standards/ Numeric Targets	Criteria set forth in Minn. R. 7050.0150 (3) and (5). The water quality standards for the Northern Lakes and Forest ecoregion include: total phosphorus ≤ 30 µg/L; chlorophyll-a ≤ 9 µg/L; and Secchi depth ≥ 2 m. The numeric target for Island Lake discussed is a total phosphorus concentration of 30 µg/L or less.	5
Loading Capacity (expressed as daily load)	The loading capacity is the total maximum daily load for each of these conditions. The critical condition for this lake is the summer growing season. The loading capacity is set forth in Table 4.2. **Total maximum daily total phosphorus load = 7.19 lbs/day**	32
Wasteload Allocation	Portion of the loading capacity allocated to existing and future point sources [40 CFR §130.2(h)]. **Total WLA = 0.0028 lbs P/day**	35
Load Allocation	Identify the portion of the loading capacity allocated to existing and future nonpoint sources and to natural background if possible [40 CFR §130.2(g)]. **Total LA = 7.18 lbs P/day**	35
Margin of Safety	A 5% margin of safety was used in this TMDL.	35
Seasonal Variation	Warmer summer temperatures can result in periodic higher algal growth rates and higher chlorophyll-a concentrations. Warmer summer lake temperatures can also increase the potential for lake internal phosphorus release or loading that can also contribute to increased algal chlorophyll-a. This seasonal variation has been factored into the development of Minnesota's lake standards, based on swimmable and fishable beneficial uses, for the summer critical recreation period of June through September [Heiskary and Wilson 2005]. These TMDLs targeted allocations are based on Minnesota's lake standards and summer critical conditions.	36
Reasonable Assurance	Reasonable assurance is provided through the efforts of the Itasca SWCD. The Itasca SWCD's mission is to provide a local organization through which landowners and operators, local units of government and state and federal agencies can cooperate to improve, develop and conserve soil, water, wildlife and recreational resources. This existing mission, jurisdiction and framework coupled with their commitment to completing a TMDL study and implementing the load reductions provides reasonable assurance that goals will be reached. Further, adaptive management methodology proposed ensures periodic evaluations and course corrections when necessary to achieve the TMDL goal.	37
Monitoring	The Itasca SWCD currently monitors lake and stream water quality and flow throughout Itasca County based on an annual monitoring plan. A recommended monitoring plan for adaptive management of Island Lake is summarized in Section 7.	38
Implementation	This TMDL sets forth an implementation framework and load reduction strategies. A rudimentary implementation plan is presented herein, a final implementation plan will be prepared as part of this grant. The estimated cost of the implementation plan presented herein is approximately $300,000 to $2,300,000.	40
Public Participation	Three meetings were held in both counties and were conducted at times where year-round as well as seasonal residents could participate. These meetings resulted in an understanding of the issues in Island Lake, ideas for implementation projects, and provided several edits to the DRAFT document.	44

	• Public Comment period May 30, 2017 through June 29, 2017 • Document participation by regulated entities in TMDL development, particularly regulated cities and industries with stormwater and wastewater requirements. *Note: EPA regulations require public review [40 CFR §130.7(c)(1)(ii), 40 CFR §25] consistent with State or Tribe's own continuing planning process and public participation requirements.*	

Acronyms and Definitions

ac-ft/yr	acre-feet per year
AUID	Assessment Unit ID
BMP	Best Management Practice
BATHTUB	An EPA approved steady-state lake model
Chl-*a*	Chlorophyll-*a*
DNR	Minnesota Department of Natural Resources
DO	dissolved oxygen
EPA	Environmental Protection Agency
FWMC	Flow-weighted mean concentration
GW	Groundwater
HSPF	Hydrologic Simulation Program-Fortran
in/yr	inches per year
km^2	square kilometer
LA	Load Allocation
Lb	pound
lb/day	pounds per day
lb/yr	pounds per year
LGU	Local Government Unit
m	meter
mg/L	milligrams per liter
mg/m^2-day	milligram per square meter per day
mL	milliliter
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
NPDES	National Pollutant Discharge Elimination System
SSTS	Subsurface Sewage Treatment Systems
TDLC	Total Daily Loading Capacity
TMDL	Total Maximum Daily Load
TP	Total Phosphorus
UAL	Unit-area Load
µg/L	microgram per liter
WLA	Wasteload Allocation
WRAPS	Watershed Restoration and Protection Strategy

Executive Summary

This Total Maximum Daily Load (TMDL) study addresses the nutrient impairment of Island Lake (Assessment Unit ID [AUID] 31-0913) in the Big Fork River Watershed. Island Lake is on the western border of the Big Fork Watershed in the 61 square mile Island Lake-Popple River Subwatershed (12-HUC.) This lake does not meet Minnesota's water quality standards because of excessive nutrient concentrations and nuisance algal blooms. Phosphorus is the nutrient of focus for this TMDL. Excess phosphorus can cause algal blooms, shifts in lake biological responses (fisheries and aquatic plants) and strongly affects swimmable and fishable beneficial uses. The goal of this TMDL is to quantify the pollutant sources and reductions needed for Island Lake to meet state water quality standards. The findings from this TMDL study aided the selection of implementation activities as part of the Big Fork River Watershed Restoration and Protection Strategy (WRAPS) process. The purpose of the WRAPS report is to support local working groups and jointly develop scientifically supported restoration and protection strategies for subsequent implementation planning. The WRAPS report will be publically available on the Minnesota Pollution Control Agency (MPCA's) Big Fork River Watershed Webpage (*https://www.pca.state.mn.us/water/watersheds/big-fork-river*).

Island Lake is a headwater lake with a surface area of approximately 3,108 acres. Its bowl-shaped drainage area, including the lake's surface area, covers approximately 10,547 acres (16.5 mi^2). It has a low watershed to lake surface area ratio of approximately 2.4:1. Relatively poorly drained soils coincide with wetland areas throughout the watershed, while other areas range from poorly drained (western watershed) to moderately drained (eastern watershed). Relatively high slopes are present on the western side of Island Lake, while lower slopes and upland lakes (Williams and Welch Lakes) to the east serve to trap nutrients before entering Island Lake. As such, runoff from snow melt and storm events will be more rapid from the west and north-central watershed areas into ephemeral streams, while the eastern watershed will have more steady runoff that flows through Williams Lake. Island Lake's water levels typically fluctuate less than one foot per year with a recently noted 2.3-foot fluctuation during the wet year of 2014.

Violations of Minnesota's lake water quality standards were observed over the 2005 through 2014 time period for average summer surface water total phosphorus (TP) and chlorophyll-a (Chl-*a*) algae. The water quality of the last half of the TMDL time-period, 2010 through 2014, coincidental with generally drier summers, suggests a slight improving pattern with the recent years approaching water quality standards for this lake.

As there are no permitted phosphorus sources in Island Lake's Watershed, future management will need to focus on reducing existing nonpoint sources by 36% and internal loading by 30%, along with more closely tracking the effects of longer growing seasons and warmer summer peak temperatures on: (1) lake sediment phosphorus release and (2) upland wetlands' phosphorus release. As internal phosphorus loading is typically the result of excessive historical watershed loading, a recommended first step is to reduce watershed loading as much as possible. Wetland phosphorus release can be influenced by wetland types/substrates, historical drainage and ditching activities, and alternating dry and wet conditions. Hence, maintaining wetland water levels should be encouraged. Lake and stream monitoring needed to refine estimates of internal lake and wetland loadings, along with corresponding Best Management Practice (BMP) alternatives, are noted in the TMDL. Recent statewide legislation requires

buffer placement along all public waters, which will help Island Lake in some areas. New and redevelopment should employ low impact development designs, such as defined by Minnesota's Minimal Impact Design Standards (MIDS). Future agricultural and forest harvests should similarly employ industry-recommended BMPs.

The Big Fork River Watershed is located in North-Central Minnesota in the Northern Lakes and Forests (NLF) and Northern Minnesota Wetlands (NMW) ecoregions of Northern Minnesota. The Big Fork Watershed is the second largest U.S. tributary, in terms of size, in the greater Rainy River-Lake of the Woods Basin. Nearly 70% of the watershed is public land, managed by both the Itasca and Koochiching County Land Departments, state or Federal government. The watershed starts in Itasca County and flows north to Koochiching County where it enters the Rainy River approximately 12 miles Southwest of International Falls.

1. Project Overview

1.1 Purpose

Section 303(d) of the Federal Clean Water Act (CWA) requires the MPCA to identify waterbodies that do not meet water quality standards, and to develop pollutant TMDLs for those waterbodies. Island Lake (31-0913) was listed on the 2010 303(d) impaired waterbody list. 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 report, pollutant loads are allocated to permitted and non-permitted sources within the watershed that discharge to the waterbody. The goal of this TMDL report is to quantify the pollutant reductions needed to meet state water quality standards and the appropriate endpoint for nutrients in the lake. This TMDL report defines Island Lake's loading capacity and allocates phosphorus (P) loads to sources. This TMDL report's end points are based on Minnesota's ecoregion-based standards of 30 micrograms per liter (µg/L) TP, 9 µg/L 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

A summary of Island Lake classifications and 303(d) listing information is given in Table 1.1. Figure 1.1 shows the Island Lake Watershed.

Table 1.1. Water Quality Impairments Addressed by This Report

Lake Name	Lake ID	Lake Classification	Beneficial Use	Year Listed	Impairment
Island	31-0913-00	Deep	2B, 3C	2010	Nutrient/eutrophication biological indicators

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. MPCA has aligned our TMDL priorities with the watershed approach and our WRAPS cycle. The schedule for TMDL completion corresponds to the WRAPS report completion on the 10-year cycle. MPCA developed a state plan, Minnesota's TMDL Priority Framework Report, to meet the needs of the 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 that will be addressed by TMDLs by 2022. The Big Fork River Watershed's sole known impaired water, Island Lake, addressed by this TMDL, is part of that MPCA prioritization plan to meet EPA's national measure.

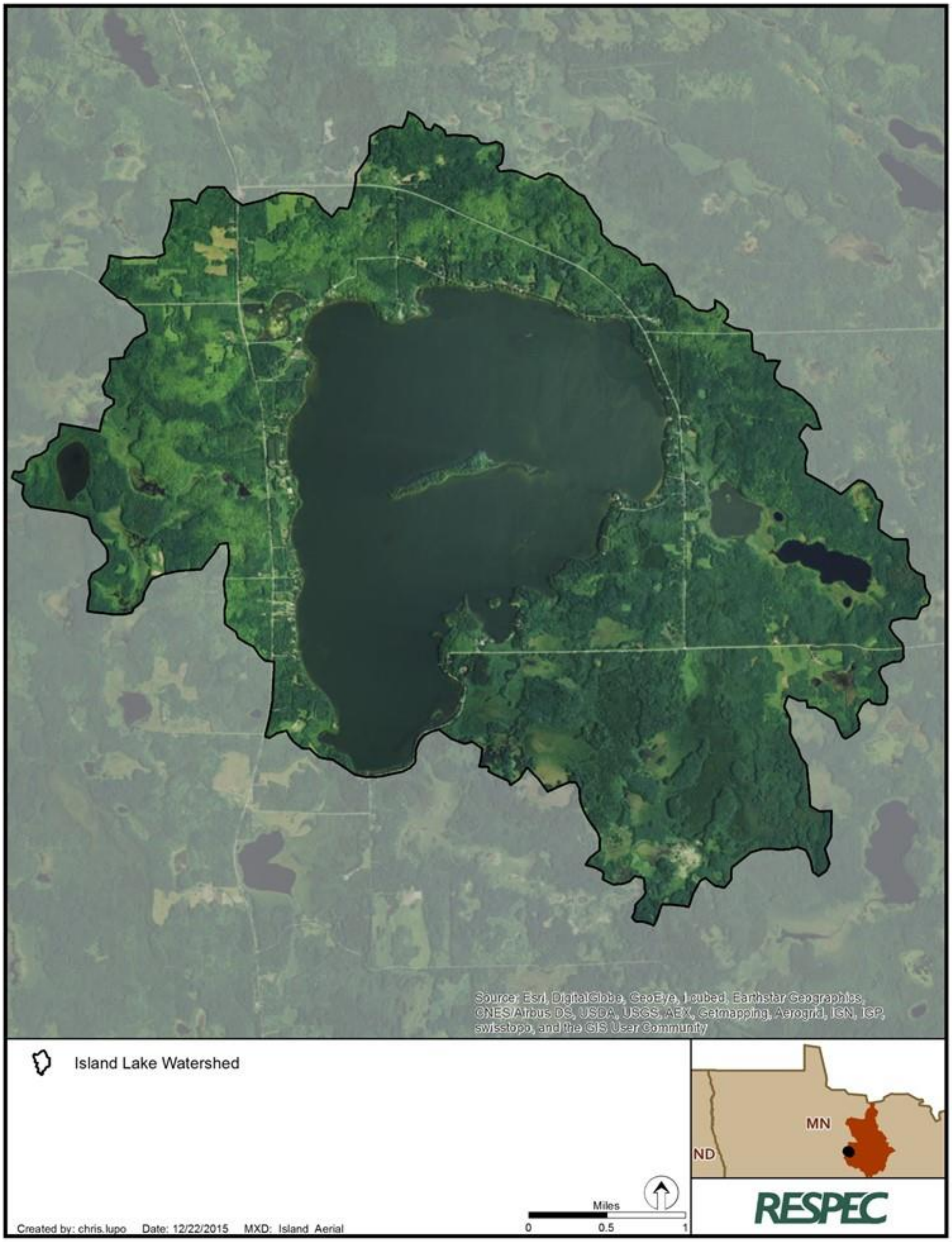


Figure 1.1. Aerial View of the Island Lake Watershed

2. Applicable Water Quality Standards and Numeric Water Quality Targets

Island Lake has been assigned a beneficial use classifications of 2B and 3C. Class 2 waters shall support "the propagation and maintenance of a healthy 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…" [Minn. R. 7050.0222, subp. 4]. Beneficial use Class 3 corresponds to industrial consumption [Minn. R. 7050.0223, subp. 1]. Island Lake lies in the NLF Ecoregion; NLF eutrophication standards for lakes, shallow lakes, and reservoirs are included in Table 2.1.

Table 2.1. Lake Nutrient/Eutrophication Standards for Lakes, Shallow Lakes, and Reservoirs in the Northern Lakes and Forest Ecoregion [Source: Minn. R. 7050.0222, subp. 4]

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

For a lake to be determined impaired, summer-average TP concentrations measured in the waterbody must show exceedances of the TP standard shown in Table 2.1 [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 it is expected that by meeting the TP target in each lake, the Chl-*a* and Secchi standards will likewise be met.

3. Watershed and Waterbody Characterization

3.1 Historical View

Island Lake lies in Ardenhurst Township of northwestern Itasca County, approximately three miles southeast of Northome. Ardenhurst was first called Island Lake Township, but was renamed by early settlers in reference to the Ardennes forest of northern France and Belgium, with "hurst" coming from the Anglo-Saxon word meaning "a grove or wooded hill." Settlement of the area increased after the Northern Pacific Railroad came to the Northhome area in 1903 [Upham 2001]. By 1919, maps of Itasca County's "automobile roads" had been published, including established roads around Island Lake (that later became Minnesota 46 and County 24), to support area development by sportsmen and families looking for lakeshore cabin areas [Lanegran 2008]. Hence, tourism and settlement of the area has occurred over the past 100+ years.

3.2 Lake Physical Characteristics

Island Lake is a headwater lake in the Big Fork River Watershed, with a surface area of approximately 3,108 acres. Its namesake, centrally located Elmwood Island, covers approximately 83 acres of the lake's surface area. The watershed, including the lake surface, is approximately 10,547 acres and yields a relatively small watershed-to-lake-area ratio of 2.4:1. 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 2.6:1 noted for identified minimally impacted NLF lakes. Summary morphometric data for Island Lake is tabulated in Table 3.1, and lake bathymetry is shown in Figure 3.1.

The lake lies just east of Minnesota State Highway 46, which is within ¼ mile of the lakeshore on much of the lake's west side. Approximately 158 homes and cabins line the lake's shore, including two resorts. The watershed is dominated by deciduous forest, woody wetlands, and open water land covers, typical of NLF areas.

Minn. R. 7050.0150 defines a "shallow lake" as an "enclosed basin filled or partially filled with standing fresh water with a maximum depth of 15 feet (ft) 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…" [Minnesota State Legislature 2008]. Hondzo and Stefan [1996] evaluated lake thermal stratification by evaluating the use of a lake geometry ratio (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]

$$\text{Lake Geometry Ratio} = \frac{A^{0.25}}{D_{max}} \qquad 3.1$$

where A is lake surface area (in square meters [m^2]) and D_{max} is maximum depth (in meters).

While Island Lake is not considered a shallow lake by Minnesota water quality rules, its lake GR of 5.6 suggests that it may have shallow lake characteristics. The Osgood Index [Osgood 1998] can also be used to characterize lakes by estimating the fraction of a lake's volume involved in mixing. The Osgood Index is defined as:

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

Table 3.1. Island Lake Morphometric and Select Watershed Characteristics

Characteristic	Island Lake	Source
Lake Surface Area (acres/hectares)	3,108/1,258	DNR LakeFinder
Number of Islands	1	Elmwood Island (83 acres)
Percent Lake Littoral Surface Area	38	DNR LakeFinder
Drainage Area, including Island Lake (acres/square miles/km^2)	10,547/16.5/4.27	Model Subwatersheds
Watershed Area to Lake Area Ratio	2.4	Calculated
Wetland Area (% of watershed)	23.2	NLCD, 2001
Number of Upland Lakes	4	USGS topographic maps

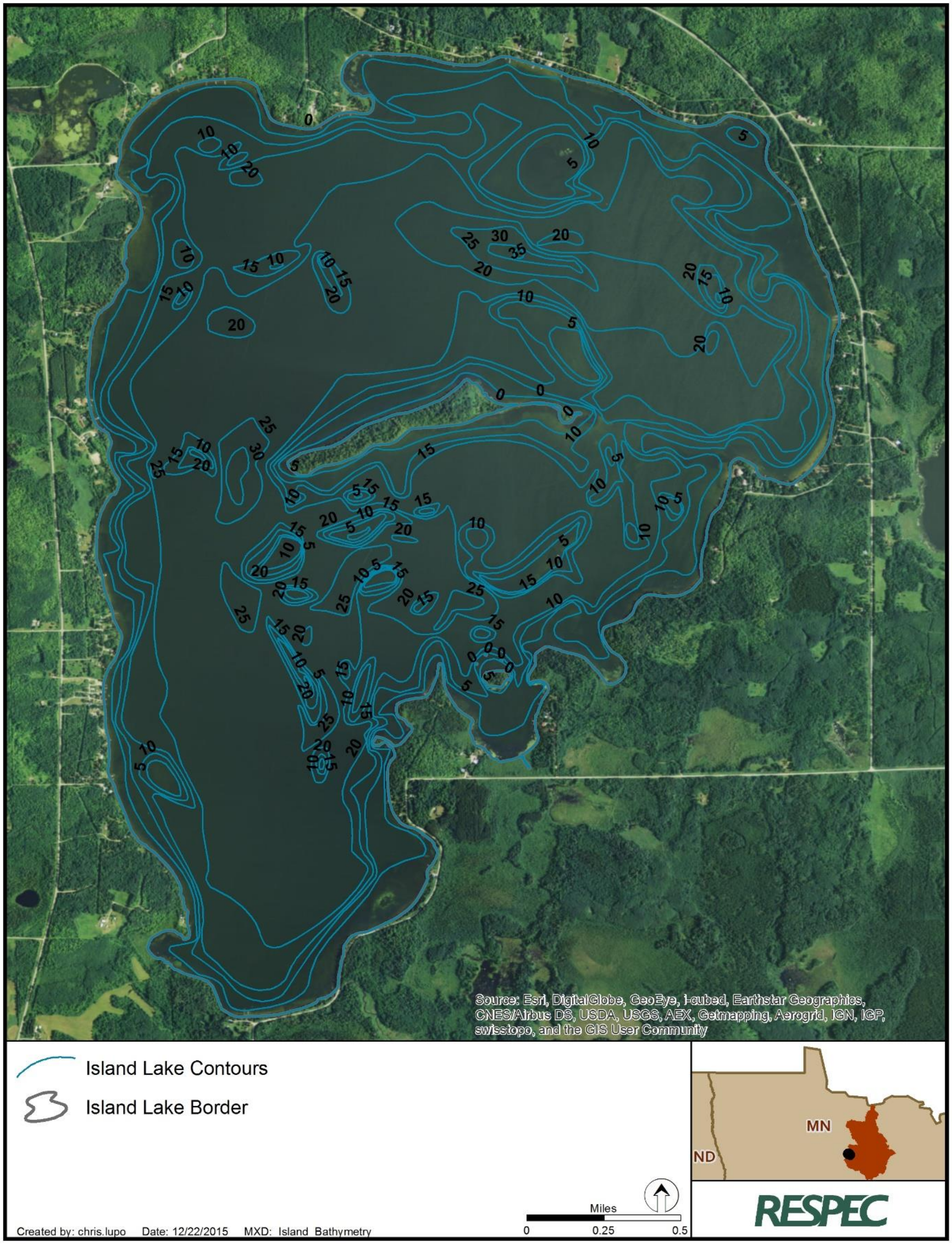
Number of perennial inlet streams	1 (Eastern)	USGS topographic maps
Number of ephemeral inlet streams	3	USGS topographic maps
Lake Volume (acre-feet/cubic hectometers)	46,277/ 57.1	DNR LakeFinder
Mean Depth (ft/m)	15/4.6	DNR LakeFinder
Annual Lake-Level Fluctuations (ft): typical, maximum	.75–3.5 ft	DNR Lake Levels
Maximum Depth (ft/m)	35/10.7	DNR LakeFinder
Maximum fetch length (mi/km)	3.0/4.9	Measured in GoogleEarth
Lake Geometry Ratio	5.6	Calculated
Osgood Index	1.3	Calculated
Estimated Water Residence Time (years)	16	Calculated
Public Access	1	DNR Owned
Shore land Properties	158	Counted from topographic maps

where D_{mean} is the mean lake depth (in meters) and $A_{surface}$ is the lake's surface area (in square kilometers [km^2]). Osgood Index values are used to categorize lakes as polymictic (less than 4); intermediate (4 to 9); or dimictic (greater than 9). The Osgood Index of 1.3 for Island Lake classifies it as a polymictic lake, which typically corresponds to well-mixed shallow lakes. With (1) a mean depth of 15 ft; (2) littoral area of 38%; (3) a GR of 5.6; and (4) an Osgood Index of 1.3, Island Lake shares both shallow and deep lake characteristics.

Lake-level data indicate that typical annual water level fluctuations are 0.75 ft to 3.5 ft; the high end was noted in the wet year.

The estimated lake water residence time is approximately 16 years. Water residence time is the amount of time needed to fill an empty lake basin or replace its entire volume. For comparison, NLF lakes that were used to develop the Minnesota Lake Eutrophication Analysis Procedure (MINLEAP) software [Wilson and Walker 1989] were estimated to have water residence times of 0.5 to 15 years.

Figure 3.1. Island Lake Bathymetric Map [DNR 1982]



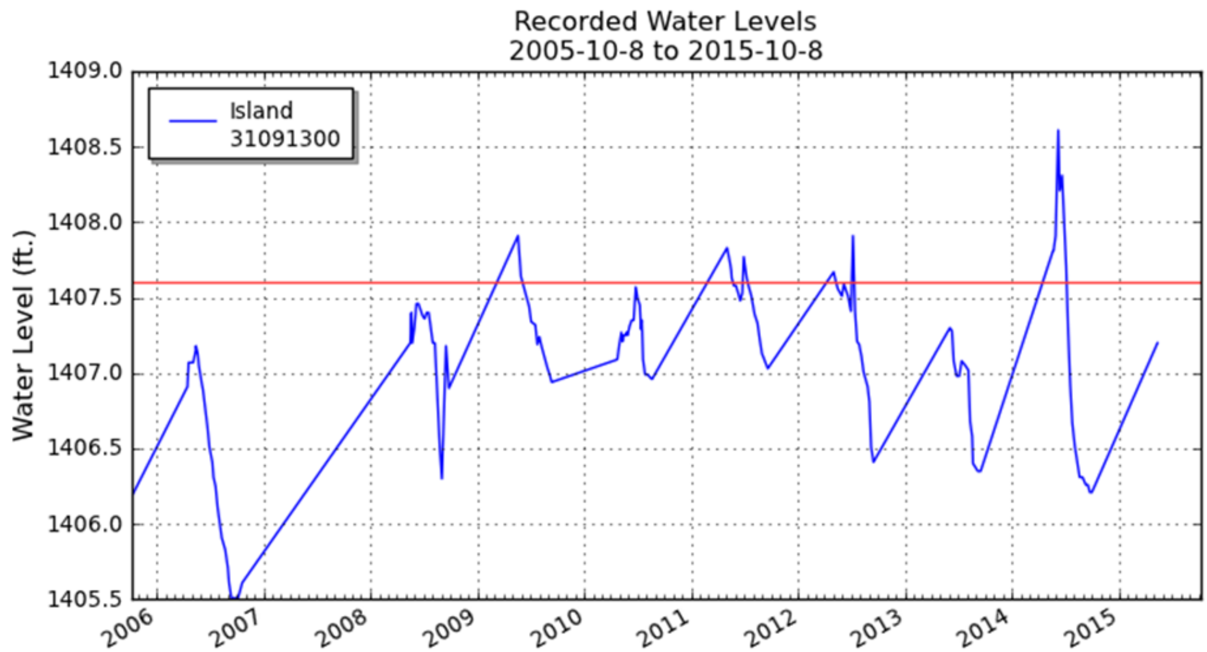


Figure 3.2. Lake-Level Recordings for Island Lake, with Ordinary High Water Level [DNR 2015]

3.3 Watershed Characteristics

Island Lake sits in the middle of a relatively small bowl-shaped watershed with four upland lakes, numerous wetlands, three ephemeral streams, and one perennial stream (from Williams Lake). Generally, the watershed slopes are less than 3% from the east, south and west, with greater slopes of up to 9% noted in the north-central area. Watershed relief is shown in Figure 3.3.

3.3.1 Stream Crossings

The Island Lake Watershed has numerous culverts and stream crossings. Culvert design, invert elevations (or flow lines at bottom of the culvert), and condition can greatly affect tributary hydrology and water levels in upstream lakes and wetlands. The United States Forest Service Chippewa National Forest identified 11 stream crossings and culverts upstream of Island Lake [Morley 2016]; the crossings and culverts and their condition with respect to stream erosion are shown in Figure 3.4. One of the crossings was categorized as stabilized, while three had minor erosion issues and one had moderate erosion issues; the remaining six crossings were not inspected.

Land use within the Island Lake Watershed [NLCD 2001] is summarized in Table 3.2 based on the National Land Cover Database [2001]. A TMDL study for Lake of the Woods is currently underway and as part of the Hydrologic Simulation Program-Fortran (HSPF) modeling effort for the entire Lake of the Woods Basin [Lupo 2015], consistent data was required. Because the most recent land use data available for the Canadian portion of the watershed is from 2000, 2001 NLCD data were used for the U.S. portion of the watershed. Further discussion of the HSPF modeling of the Big Fork River Watershed is included in Section 3.8.2.

Nearly one-third of the watershed is open water; the remainder is dominated by deciduous, evergreen, and mixed forests (36%) and woody and emergent herbaceous wetlands (23.2%). Developed land covers included open space and low intensity lands that amounted to slightly over 3.0% of the watershed, with smaller amounts of shrub/scrub, and hay and pasture.

Figure 3.3. Island Lake Watershed Relief

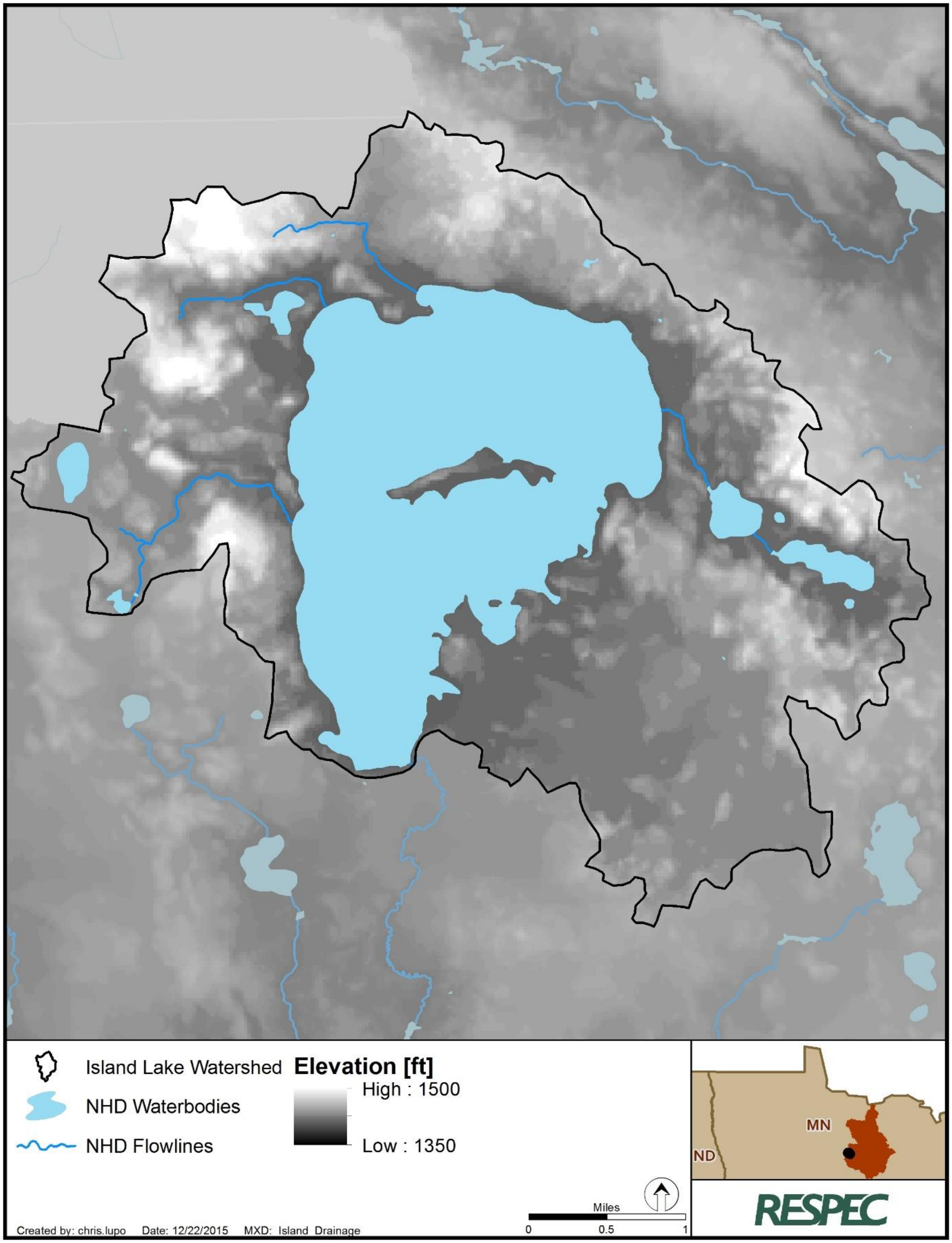


Figure 3.4. Crossing and Culvert Conditions in the Island Lake Watershed [Morley 2016]

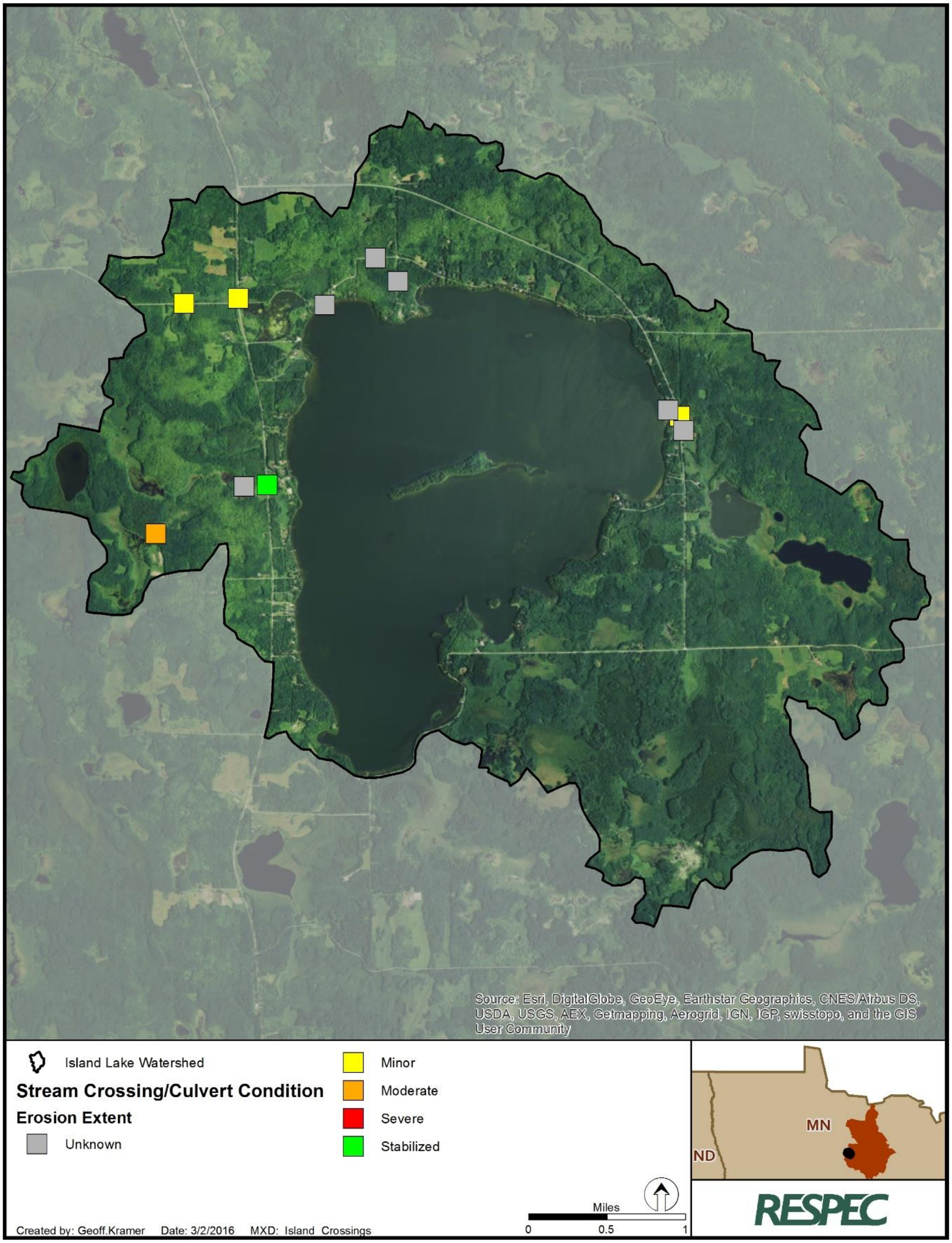
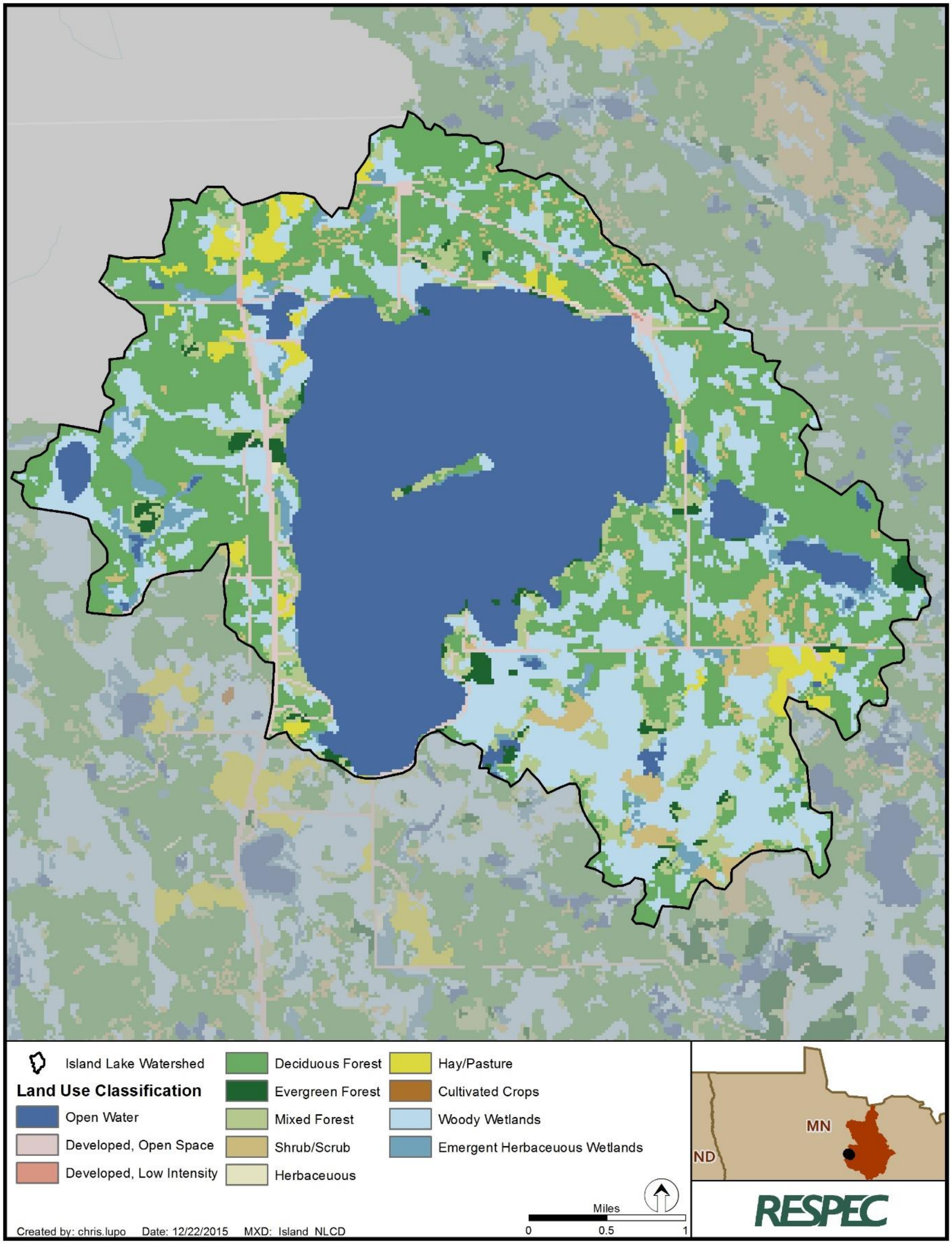


Table 3.2. Summary of National Land Cover Database Land Use Classifications by Area (2001 Data)

Land Use Classification (NLCD)	Watershed Area (%)
Open Water	32.5
Deciduous Forest	29.5
Woody Wetlands	20.9
Mixed Forest	5.2
Developed–Open Space	3.0
Shrub Scrub	2.9
Emergent Herbaceous Wetlands	2.3
Hay & Pasture	2.3
Evergreen Forest	1.3
Herbaceous	0.09
Developed–Low Intensity	0.02
Cultivated Crops	0.00

Figure 3.5. Island Lake Watershed Land Use Classifications [National Land Cover Database 2001]



The spatial distribution of land uses is shown in Figure 3.5. Forest and wetland areas are dominant in all areas of the watershed with hay and pasture lands also scattered throughout the watershed. These small hay and pasture lands are interspersed throughout the watershed and the animal units are very small in each operation. The southeastern portion of the watershed is dominated by woody wetlands with less forested land cover.

3.3.2 Soils

Island Lake's watershed lies in a region referred to as the Chippewa Sand Plains with soils ranging from sand to clay, depending upon the parent material. Data from the United States Department of Agriculture's Web Soil Survey for the Island Lake Watershed (including the water surface area) [NRCS 2015] indicate that the dominant soils are approximately 25% Warba fine sandy loams, 18% Suomi loams, 3% Seeleyville-Seeleyville ponded complex, and approximately 14% muck and peat soils (comprising mainly Moose Lake and Lupton Mucky Peats at 9.8%). While Warba fine sandy loams and Suomi loams are moderately well drained, the other dominant soil types tend to be poorly drained. Sandy soils of the area were derived from apatite-based parent minerals, and thus, may be expected to reflect those phosphorus levels [Rosen 2016].

Soil cover can also be summarized by Hydrologic Soil Group (HSG) (Figure 3.6), which shows a dominance of B soils with moderate infiltration in the eastern two-thirds of the watershed and C/D soils with much lower infiltration potential in the western and northern watershed areas. Areas dominated by HSG C and D soils have a higher runoff potential, especially from areas with higher slopes. While areas of HSG B soils are more amenable to BMP treatments for stormwater runoff, using infiltration from developed and other modified areas. Dual HSG classification soils (notably A/D and B/D in the Island Lake Watershed) behave as type D soils when undrained. A/D and B/D soils coincide largely with wetlands in the Island Lake Watershed and are likely undrained and behaving hydrologically as D soils. Soil area-weighted mean TP concentrations in the Rainy River Basin were reported to be approximately 514 mg/kg, which was approximately equal to the statewide area-weighted TP concentration of 516 mg/kg [MPCA 2004].

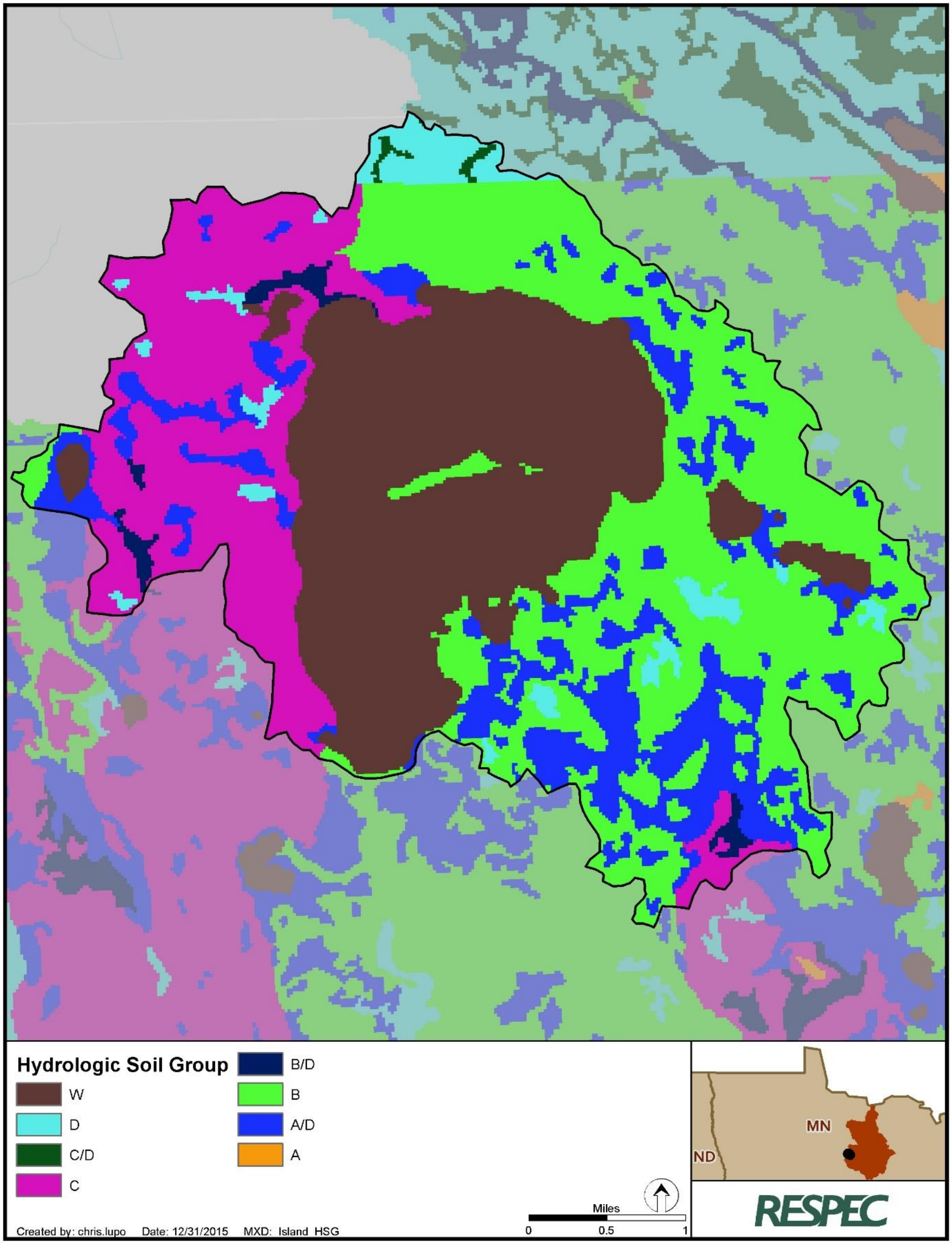


Figure 3.6. Island Lake Watershed Hydrologic Soil Groups Demographics and Growth Projections

Highways 46, 2, and 169 provide all season access to the Island Lake Watershed region, with recreational opportunities offered by lake shore development, hunting, extensive snowmobile trails, and management areas. While Itasca County has changed significantly over the past 45 years with a population increase of 22% noted for the time period 1970 through 1997 [MPCA 2000], future population increases are projected to be relatively muted. Future projected population changes published by the Minnesota State Demographic Center [Dayton 2014] for Itasca County estimate a population growth of approximately 3.2% for 2015 through 2030. Longer-term projections through 2045 indicate a lower increase in population relative to 2015 (47,721 versus 47,344, respectively). However, as recreational cabins and second homes will remain a highly cherished Minnesota tradition, additional development pressure may occur because of the finite number of lakes that offer premier settings with forests, hills and water that are within a few hours of major metropolitan areas.

3.4 Climate

Basic hydrologic and climatic information were reviewed to: (1) define conditions affecting lake water quality, and (2) inform future monitoring relating to internal loading and wetland loading and hysteresis.

Hysteresis occurs when a physical process's response depends on the past conditions of the system. An example is the moisture content of soil determined as a function of the soil's matric potential; depending on whether the soil moisture is increasing (wetting) or decreasing (drying), the soil moisture can vary greatly even at the same measured matric potential. This information included typical monthly temperature and precipitation information (normals), annual precipitation, growing season lengths, dry and wet periods, and peak summer temperatures. Climate variability for the Island Lake area was assessed by using available long-term data for sites from the Midwest Regional Climate Center, the Minnesota Department of Natural Resources' (DNR) gridded precipitation, and National Oceanic and Atmospheric Administration's (NOAA) databases summarized for north-central Minnesota (Climate Division 2).

Grand Rapids Forest Lab (USC 00213303) monthly climate average precipitation and maximum, mean, and minimum temperatures for the 1981 through 2010 period are plotted in Figure 3.7, with precipitation peaking during the growing season (e.g., approximately 4.25 inches noted for June and July). The total annual precipitation for the period of 1970 to 2014 is plotted in Figure 3.8. Annual precipitation ranged from 17.98 inches (1976) to 38 inches (1977), with an average of approximately 28.5 inches during this period. The past 10 years of Grand Rapids Forest Lab monitoring station data averaged slightly less (28.3 inches) and with a narrower range of values from 22.99 (2006) to 33.2 inches (2012). Another perspective of annual precipitation patterns is offered by the examination of rolling five-year averages, as seen in Figure 3.8. In this manner, the oscillations of annual peaks and valleys are dampened and show a more wave-like appearance, with a drier period leading into a wetter period noted in the 2005 through 2014 TMDL time period.

Long-term annual precipitation data from 1895 through 2014 is summarized for Climate Division 2 [NOAA 2015] to place perspective to patterns and inter-year variability, as illustrated in Figure 3.9.

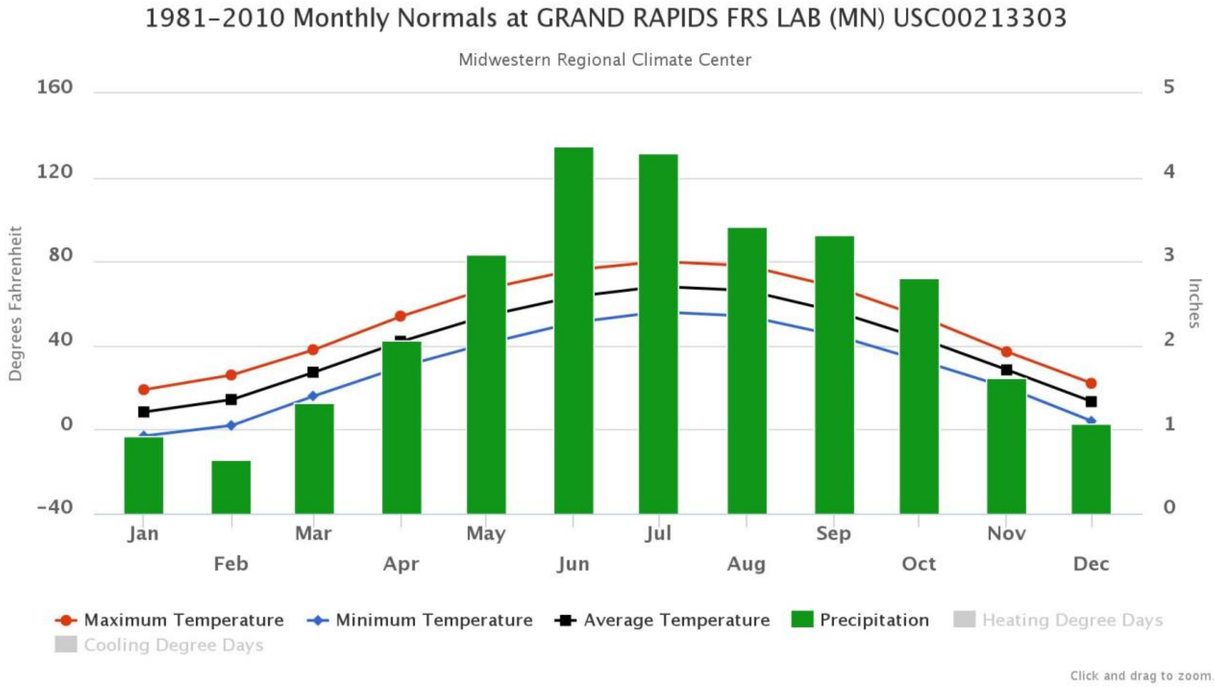


Figure 3.7. Observed Monthly Temperature and Precipitation for 1981–2010 [Midwestern Regional Climate Center 2015]

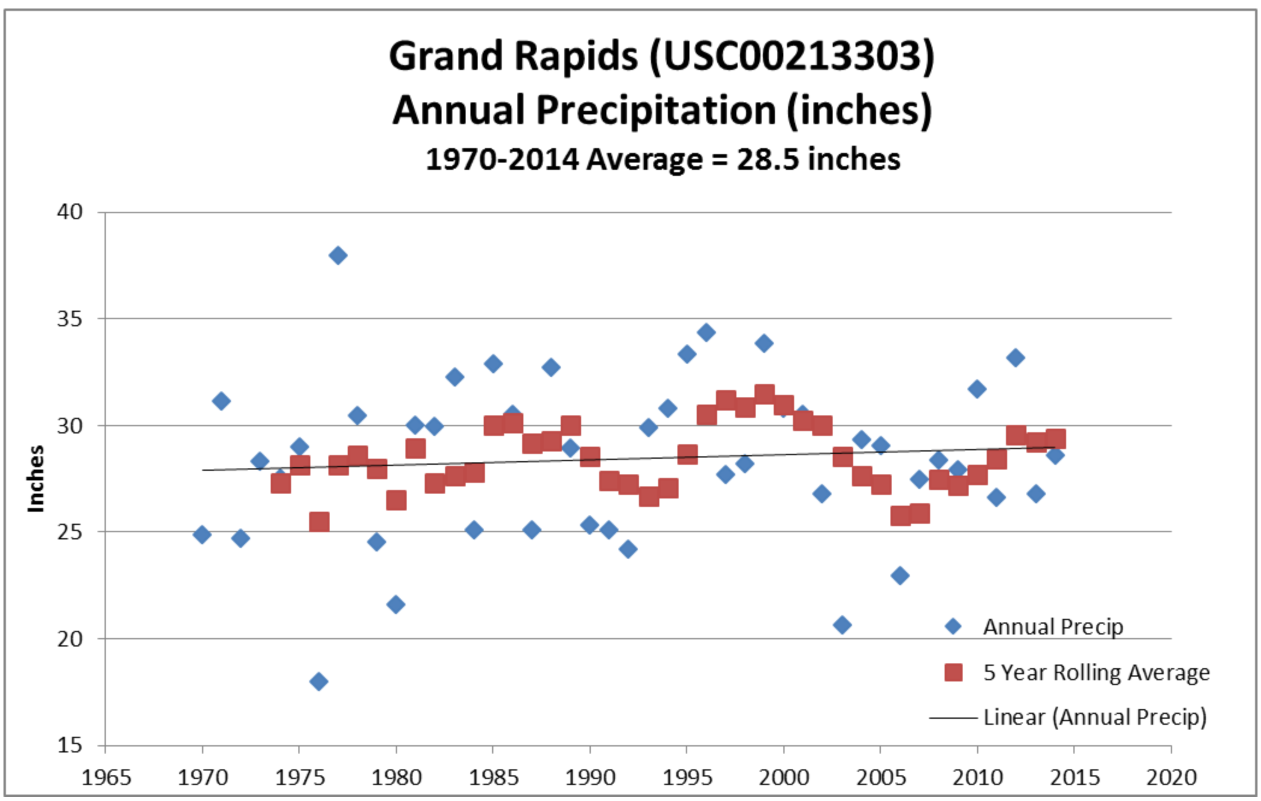


Figure 3.8 Annual Precipitation at Grand Rapids, Minnesota (USC 00213303), 1970–2014

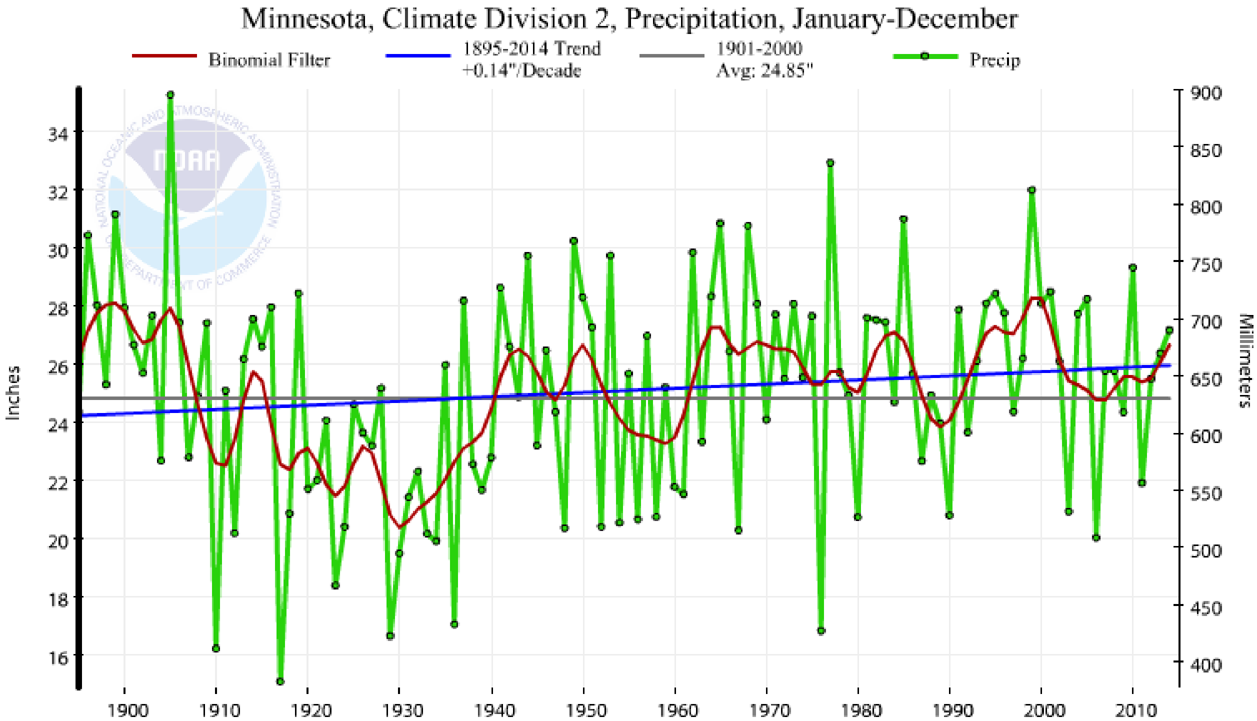


Figure 3.9. Annual Precipitation for 1895–2014 from the National Oceanic and Atmospheric Administration [2015] Climate Division 2

Growing season (June through September) precipitation quantities for the 1970 through 2015 period, which are depicted in Figure 3.10, indicate a long-term declining pattern with much lower summer precipitation amounts recorded in recent years. Using the smoothed time-series and rolling averaged data allow observing longer periods of wet and dry precipitation patterns that affect lakes with longer water residence times, such as Island Lake. Reduced summer precipitation patterns will tend to similarly reduce summer lake flushing.

Annual evaporation from shallow lakes, estimated from pan evaporation measurements, range from approximately 27 to 30 inches per year (in/yr) [Farnsworth and Thompson 1982] for this part of Minnesota. Hence, annual average evaporation can exceed annual average precipitation in the Island Lake Watershed.

NOAA data for 2005 through 2014 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 for data from the Grand Rapids Forest Lab site (USC USC00213303) and are summarized in Table 3.3.

Table 3.3Focusing on the larger storm events occurring during the growing season, approximately one to three rainfall events per month are greater than or equal to 0.5 inch, and slightly less than one event per month is greater than or equal to 1.0 inch. These events may be expected to generate runoff depending on storm intensities and durations as moderated by vegetation, evapotranspiration, and the amount of impervious surfaces.

3.4.1 Further Characterization of Storm Events

NOAA, in cooperation with the MPCA, DNR State Climatology Office, and Minnesota Department of Transportation, has recently updated precipitation intensity and duration data for the entire state, referred to as Atlas 14. Storm-event totals, such as reported in various media weather reports, are typically for 24-hour periods. An example of the updated data for Big Fork 5 ESE (21-0754) is tabulated in Appendix A. In this example, the 24-hour rainfall ranges from 2.15 inches (yearly) to 8.39 inches (the 1,000-year event). However, back-to-back storms over several days often generate much larger totals associated with peak runoff events. 2-day rainfall events for Big Fork have cumulative rainfall amounts varying from 2.44 (yearly) to 4.07 inches (every 10 years), while 10-day rainfall depths are 3.92 (yearly) and 5.59 inches (10-year), respectively. Accordingly, wet periods can have large cumulative storm totals affecting watershed runoff.

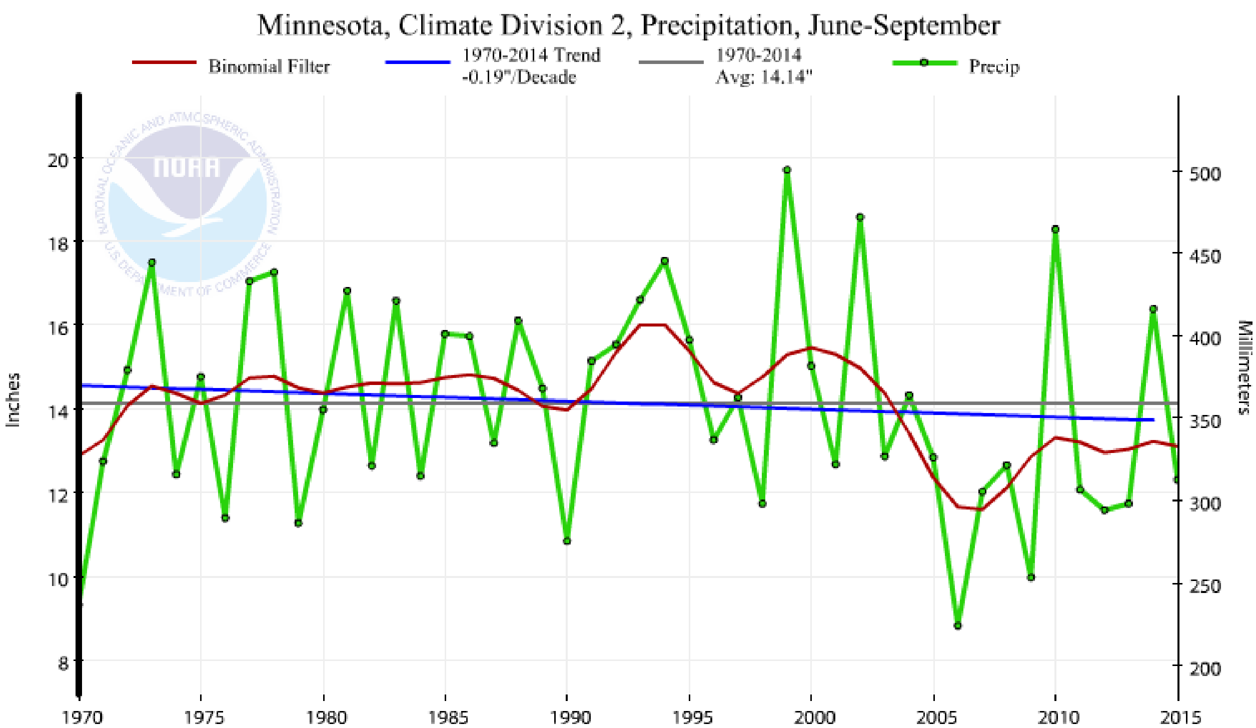


Figure 3.10. Growing Season Precipitation Trends and Patterns for 1970–2015 from the National Oceanic and Atmospheric Administration [2015] Climate Division 2

Table 3.3. 2005–2014: Number of Precipitation Events by Month for Grand Rapids Forest Laboratory (USC 0213303) [Midwestern Regional Climate Center 2015]

Month	> = 0.01 Inch	> = 0.1 Inch	> = 0.5 Inch	> = 1 Inch
January	7.4	2.1	0.1	0
February	6.6	2.2	0.1	0
March	7.8	3.9	0.4	0.2
April	9.2	5.7	1.5	0.4
May	12	6.9	2.4	0.4
June	13.2	7.9	3	0.8
July	11.2	6.6	2.5	0.6
August	8.6	5.5	1.9	0.7
September	8.3	5	1	0.6
October	10.5	6.2	1.4	0.4
November	7.7	2.6	0.3	0
December	8.4	2.6	0.7	0
Annual	110.9	57.2	15.3	4.1
Growing Season	41.3	25	8.4	2.7

3.4.2 Precipitation Variability: Wet and Dry Periods

A closer examination of year-to-year and within-year precipitation variability was evaluated by using data from the DNR's Precipitation Data Retrieval from a Gridded Database [DNR State Climatology 2015]. Data were summarized by month and by year and are presented in Table 3.4

Table 3.4for Big Fork Township. In this evaluation, the wet months of June through September (greater than 70 percentile) were color-coded blue and dry months (less than 30 percentile) were color-coded brown. From this analysis, numerous shifts were observed between growing season wet- and dry-month periods observed for most years, with dry periods tending to occur more commonly in the peak of the growing season during July through September. In the past 10 years, seven "warm" seasons have been dryer (e.g., precipitation less than 30 percentile). These observations underscore the number of wet and dry period gyrations that may affect lake and wetland hydrology, associated runoff chemistries and influence on lake internal loading of phosphorus.

Table 3.4. Monthly Precipitation by Year for Big Fork Township, Minnesota [DNR State Climatology 2015a] (Page 1 of 2)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	WARM	ANN	WAT
30%	0.49	0.36	0.68	1.26	1.92	3.04	2.63	2.38	1.91	1.26	0.76	0.61	15.02	23.59	23.69
70%	0.91	0.76	1.4	2.34	3.63	4.45	4.53	4.31	3.46	2.6	1.47	1.03	18.62	27.87	27.65
mean	0.81	0.64	1.12	1.87	2.88	3.95	3.74	3.54	2.91	2.08	1.25	0.85	17	25.64	25.65
1981–2010 Normals															
normal	0.81	0.61	1.13	1.86	3.15	4.29	4.15	3.29	3.24	2.67	1.51	0.98	18.12	27.7	27.64
Year-to-Year Data															
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**WARM**	**ANN**	**WAT**
2015	0.78	0.51	0.61	0.71	6.72	4.18	2.49	3.24	1.16						
2014	0.85	1.38	0.98	2.08	3.93	8.3	2.51	2.77	1.93	1.14	0.42	0.49	19.44	26.78	30.31
2013	2.17	1.03	2.04	2.74	2.51	2.65	3.1	1.06	1.53	3.07	0.92	1.59	10.85	24.41	23.46
2012	0.85	1.02	2.94	4.45	4.73	3.73	3.69	1.6	0.49	2.07	1.63	0.93	14.24	28.13	25.4
2011	1.24	0.16	0.17	3.56	2.36	4.46	2.11	3.29	1.53	1.22	0.43	0.25	13.75	20.78	24.01
2010	0.79	0.24	0.67	0.63	3.61	4.78	5.98	6.27	5.28	2.48	1.38	1.27	25.92	33.38	34.48
2009	0.6	0.86	3.17	1.32	2.76	2.51	2.93	2.57	1.15	3.73	1.18	1.32	11.92	24.1	24.49
2008	0.23	0.29	0.34	4.6	1.98	4.23	3.76	0.95	3.07	3.48	1.69	1.45	13.99	26.07	24.27
2007	0.2	0.72	1.58	2.33	3.65	2.72	2.41	1.94	6.33	3.23	0.51	1.08	17.05	26.7	26.33
2006	0.24	0.94	1.72	1.78	4.06	2.94	1.31	1.99	2.65	1.66	1.4	1.39	12.95	22.08	25.12
2005	2.26	0.28	0.63	0.93	5.18	4.89	2.68	2.84	1.68	3.18	3.45	0.86	17.27	28.86	26.63

Table 3.4. Monthly Precipitation by Year for Big Fork Township, Minnesota [DNR State Climatology 2015a] (Page 2 of 2)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	WARM	ANN	WAT
2004	1.09	0.44	1.2	1.08	3.46	2.62	4.93	1.71	8.43	3.43	0.31	1.52	21.15	30.22	28.69
2003	0.22	0.29	0.51	1.58	2.95	4.08	5.27	4.19	1.83	1.63	1.33	0.77	18.32	24.65	24.11
2002	0.27	0.17	0.94	1.04	2.06	6.22	4.24	3.31	1.59	2.25	0.46	0.48	17.42	23.03	26.47
2001	0.64	1.49	0.23	4.66	5.88	3.67	3.1	3.47	1.55	3.77	1.88	0.98	17.67	31.32	31.5
2000	0.45	0.58	1.27	1.64	2.68	4.54	2.66	5.07	2.11	3.11	2.95	0.75	17.06	27.81	22.65
1999	0.59	0.51	1.67	1.94	5.13	3.21	9.1	4.51	4.14	1.27	0.03	0.35	26.09	32.45	37.64

3.4.3 Growing Season Length and Maximum Temperatures

The growing season length and maximum average summer ambient temperatures were examined as they affect lake temperatures, algal growth and sediment reactions (kinetics). The growing season, as defined by the number of days between the last 32°F days of spring and the first 32°F day of autumn, were tabulated from Grand Rapids (USC00214652) data with an average of approximately 128 days from 2000 to 2014. This is in contrast to the shorter growing season of approximately 100 days noted in ~1940. Data plotted for the time period 1914 to 2014 further show a long-term, increasing pattern as illustrated in Figure 3.11. During this same period, the average summer mean temperatures in Minnesota's Climate Division 2 (north-central Minnesota) have increased as illustrated in Figure 3.12. Hence, the area has experienced longer growing seasons and warmer ambient growing-season average temperatures. Both of these key climatic factors can affect wetlands and lake sediment phosphorus internal loading.

3.5 Water Quality Data

A summary of minimum, mean, maximum, and standard deviations for TP, Chl-*a*, and Secchi disk depth data collected during the growing season is presented in Table 3.5. Mean values for TP and Chl-*a* are above the water quality standard, while the mean Secchi disk depth meets the water quality standard. Extreme high values of TP and Chl-*a* were 73 µg/L and 60.5 milligrams per liter (mg/L), respectively, while the lowest Secchi transparency reading was below 1 m.

Multiyear mean monthly water quality observations are summarized in Figures 3.13 and 3.15 for data available for the time period 2005 through 2014. Plots of this mean monthly data show a trend of generally increasing TP and Chl-*a* concentrations from June through August, with slight declines noted in September. The multiyear mean growing season monthly P concentrations increase from 20 µg/L to 50 µg/L from June through August and decline to 40 µg/L in September. Based on lake volume and stated concentrations, a mean increase of 1,142 kg of TP in Island Lake is observed between June and September. This is phosphorus from all external (watershed loading, septic systems) and internal sources. In a similar fashion, multiyear mean monthly Chl-*a* concentrations increase from June through August from approximately 5 µg/L to 33 µg/L with a decline to approximately 17 µg/L in September. Correspondingly, average monthly Secchi transparencies decline from approximately 3.8 m (12.5 ft) in June to 1.8 m (5.9 ft) in August, followed by an increase to approximately 2.3 m (7.5 ft) in September.

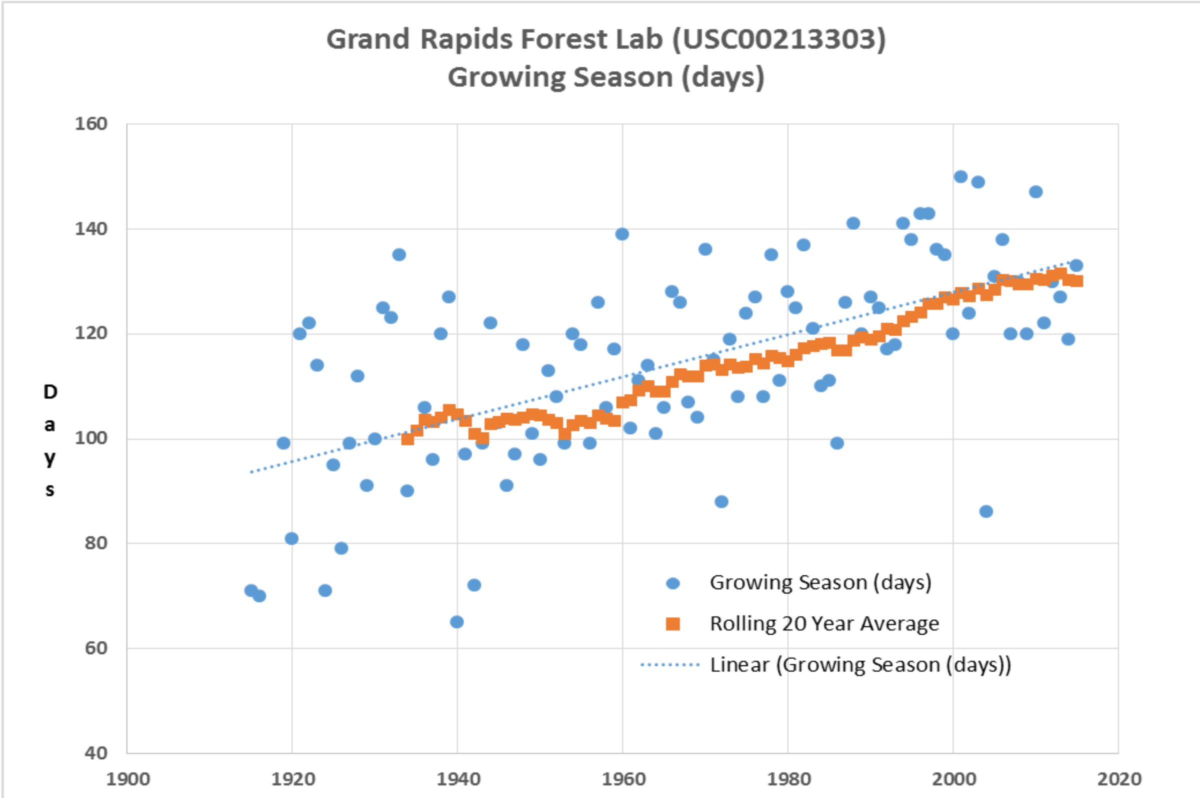


Figure 3.11. Growing Season Data for Grand Rapids (USC00213303) [Midwestern Regional Climate Center 2015]

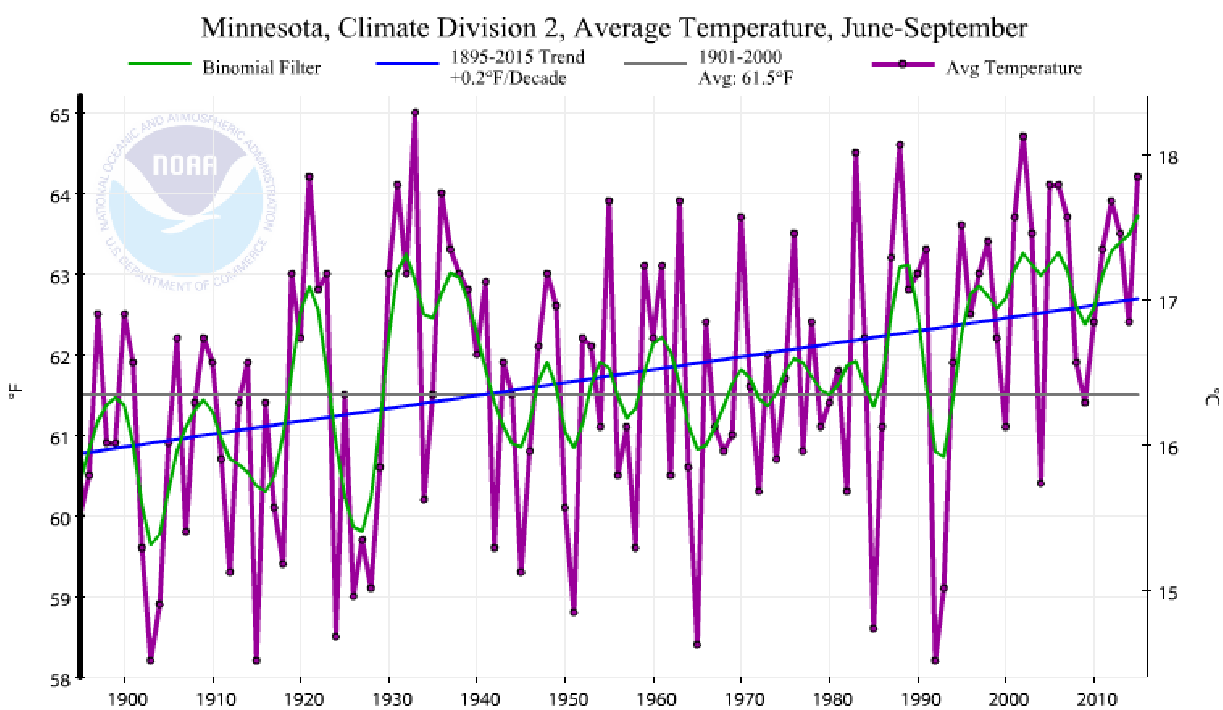


Figure 3.12. June to September Average Monthly Data for Pre-1900–2015 [National Oceanic and Atmospheric Administration 2015]

Table 3.5. Summary of Growing Season Water Quality Monitoring Data, 2005–2014

	Minimum	Mean	Maximum	Standard Deviation
TP (µg/L)	5	34.9	73	15.6
Chlorophyll-a (mg/L)	1	16.2	60.5	15.4
Secchi disk depth (m)	0.9	2.7	6.6	1.1

Yearly growing-season means for the TMDL period of 2005 through 2014 are plotted in Figures 3.16 through 3.18 for TP, Chl-*a*, and Secchi transparency.

- TP values were noted to range from approximately 47 µg/L (2006) to 28 µg/L (2014), with a slight declining pattern noted from 2010 to 2014. The 10-year average was 34 µg/L that violated the state water quality standard of 30 µg/L.
- Annual growing-season mean Chl-*a* values were noted to range from approximately 7 µg/L (2007) to 27 µg/L (2010), with a declining pattern noted from 2010 to 2014, when chlorophyll values were very near the state standard of 9 µg/L. The 10-year average was 16.2 µg/L that violated the water quality standard of 9 µg/L.
- Annual growing-season mean Secchi transparencies were noted to range from approximately 1.8 m or 5.9 ft in 2006 to 3.8 m or 12.5 ft in 2007, with an increasing pattern noted from 2010 to 2014. The 10-year average was 2.68 m or 8.8 ft and above (not violating) the state water quality standard of 2.0 m.

3.5.1 Dissolved Oxygen and Temperature Data Summary

Dissolved oxygen (DO) and temperature data monitored by depth were examined in an effort to better define lake mixing patterns affecting biological responses and lake phosphorus dynamics. Available data from 1991 through 2006 have been plotted in Figures 3.19 and 3.20. All available data (including those outside the TMDL period of 2005 through 2014) were included because of a lack of more recent temperature and DO data. Only three measurements were taken during the TMDL period; all three were measured in 2006. Additional data could greatly improve the understanding of the system. Temperature and DO data were noted to have been collected concurrently.

Water temperature profiles are shown in Figure 3.19, with data indicating relatively well-mixed conditions as temperatures are relatively similar going from the surface to depth. The August 14, 1991, profiled temperatures varied the most, with the surface and 8-meter values within 5°C. Peak monitored summer bottom water temperatures (July through September) ranged from approximately 15° to 24°C.

DO profile data typically exhibited substantial concentration losses, with depth measurements indicating large oxygen depletion rates are occurring (Figure 3.20). Island Lake exhibited clinograde oxygen patterns, with values decreasing with depth and sharply so below 5–6 m to values less than 4 mg/L observed on three dates. Sport fisheries generally require at least 5 mg/L. These data suggest a relatively high oxygen depletion rate, but additional data is required to refine water column oxygen depletion rates. The profile collected on September 20, 2006, suggests a well-mixed condition, with similar DO concentrations over depths ranging from 4.5 to 5.1 mg/L. All other DO profiles show a difference of approximately 5 mg/L or more between the maximum and minimum measured DO concentrations. Lake bottom water temperature and DO concentration greatly impact internal loading of phosphorus, and are thus important parameters for characterizing in-lake nutrient dynamics. A more complete discussion of this issue in general, and specific to Island Lake, is included below in Section 3.8.2.4.

Figure 3.13. Mean Monthly Total Phosphorus Concentration, 2005–2014

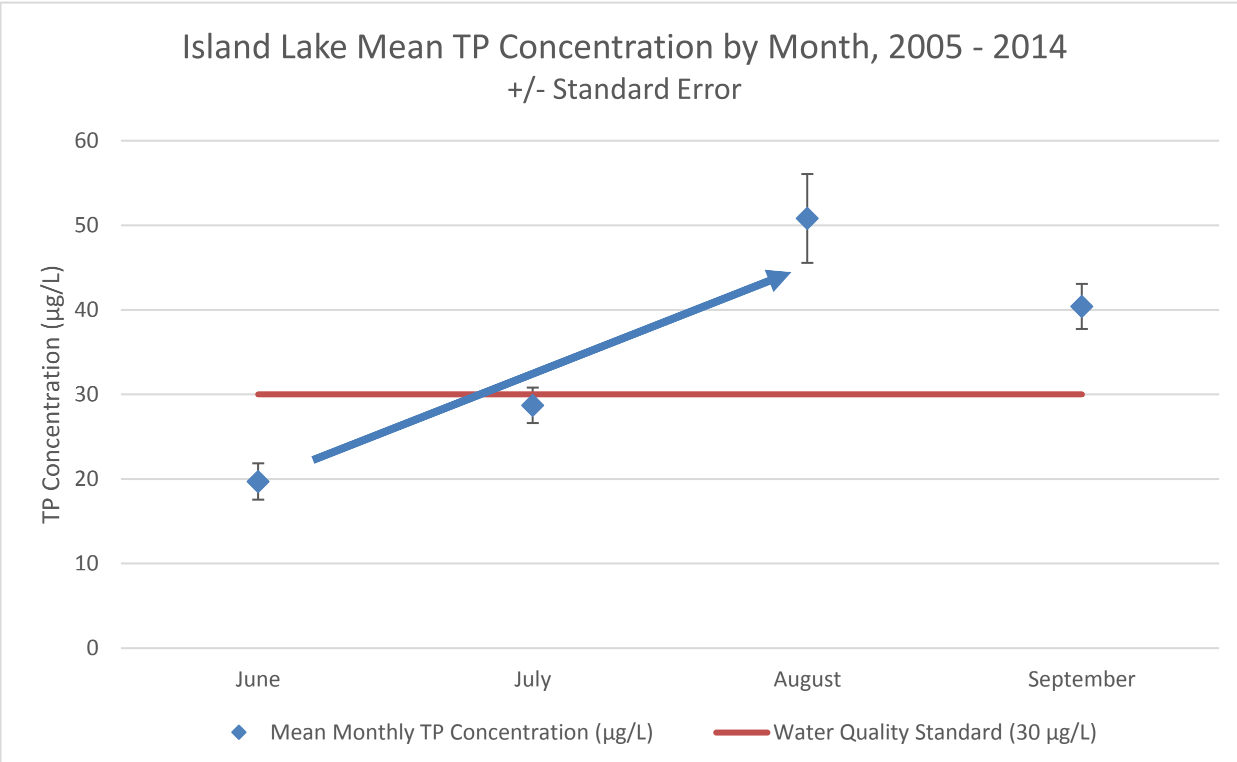


Figure 3.14. Mean Monthly Chlorophyll-a Concentration, 2005–2014

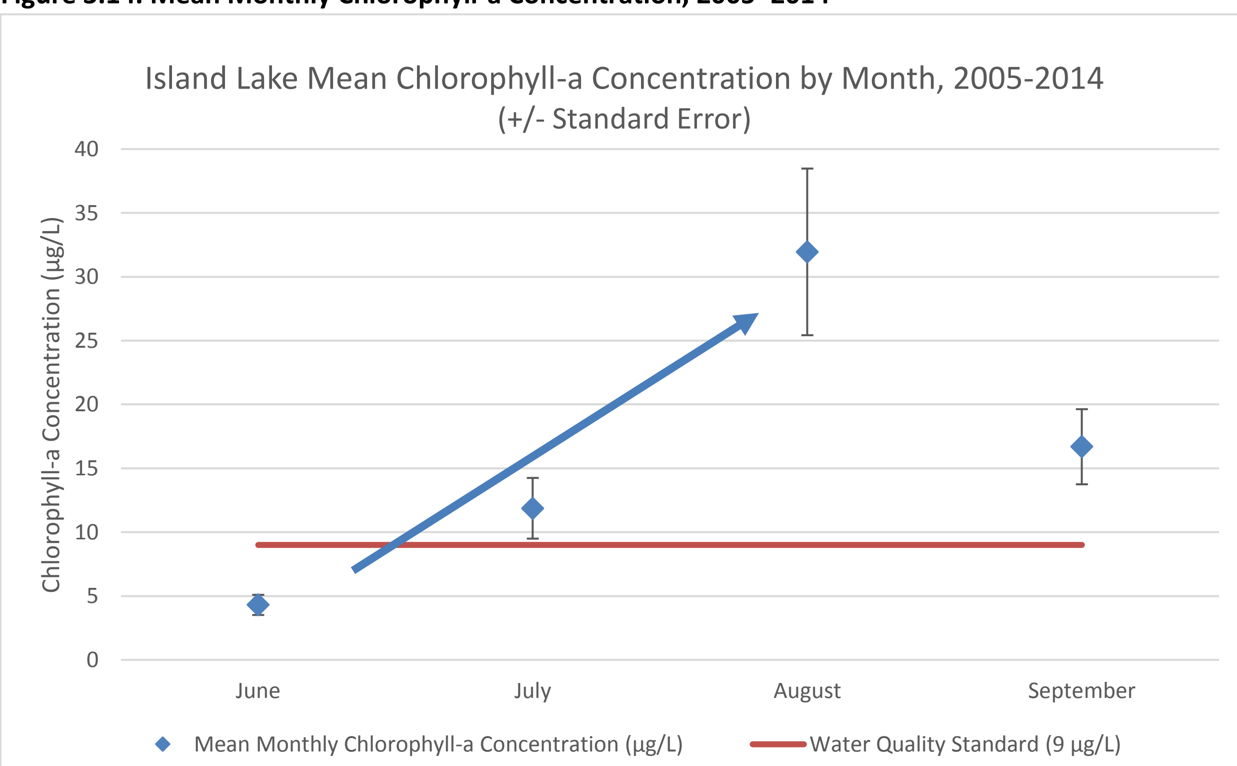


Figure 3.15. Mean Monthly Secchi Disk Depth, 2005–2014

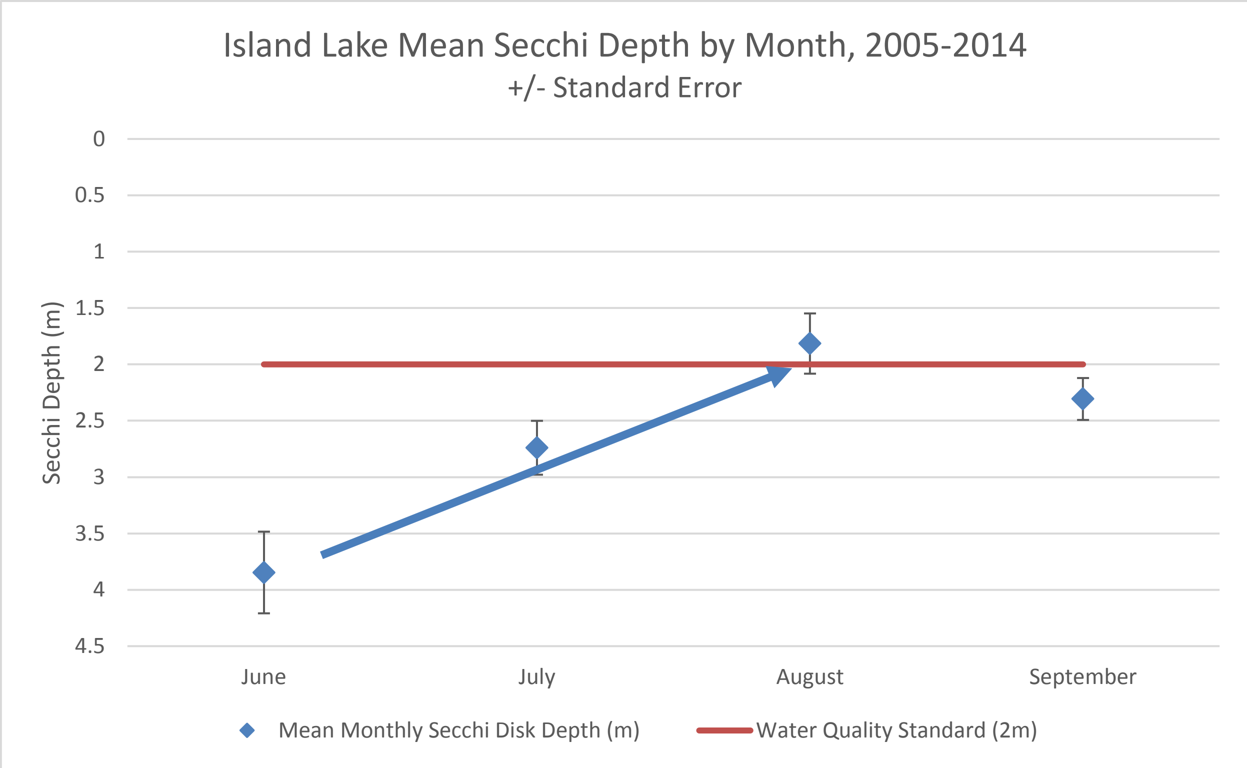


Figure 3.16. Mean Annual Growing Season Total Phosphorus Concentration, 2005–2014

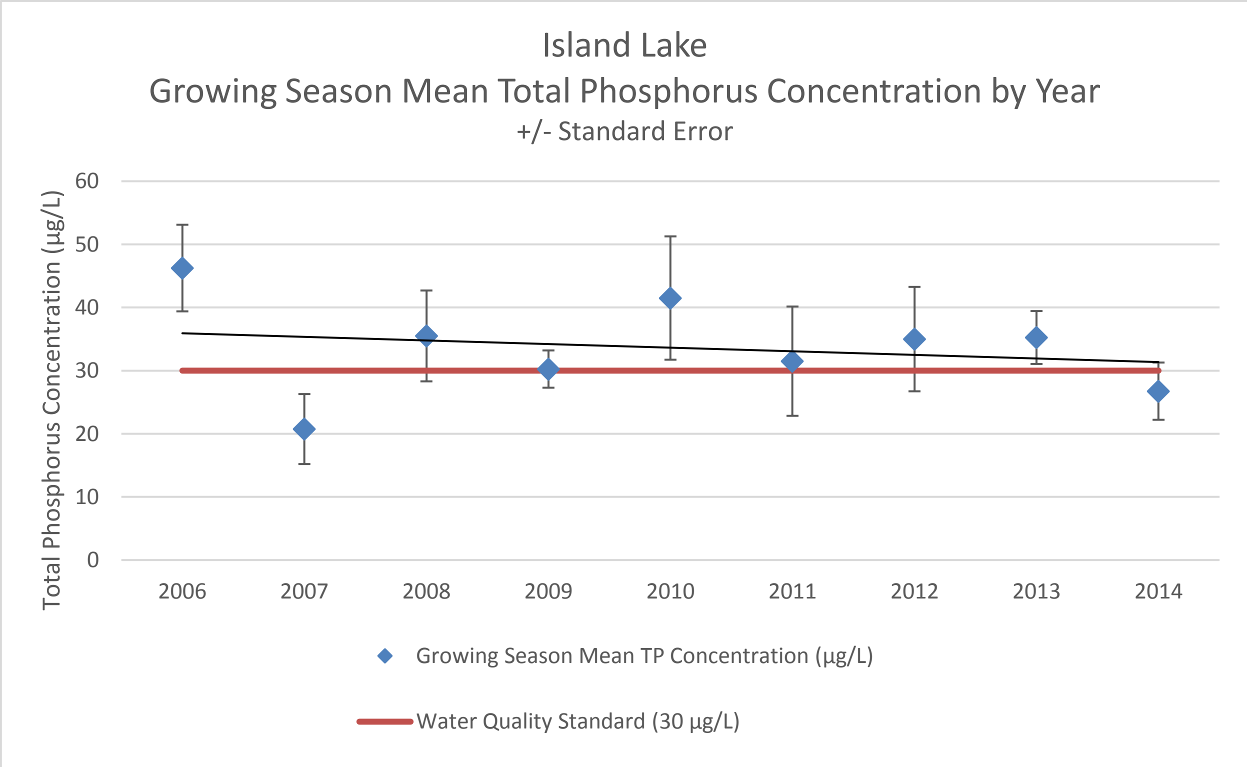


Figure 3.17. Mean Annual Growing Season Chlorophyll-a Concentration, 2005–2014

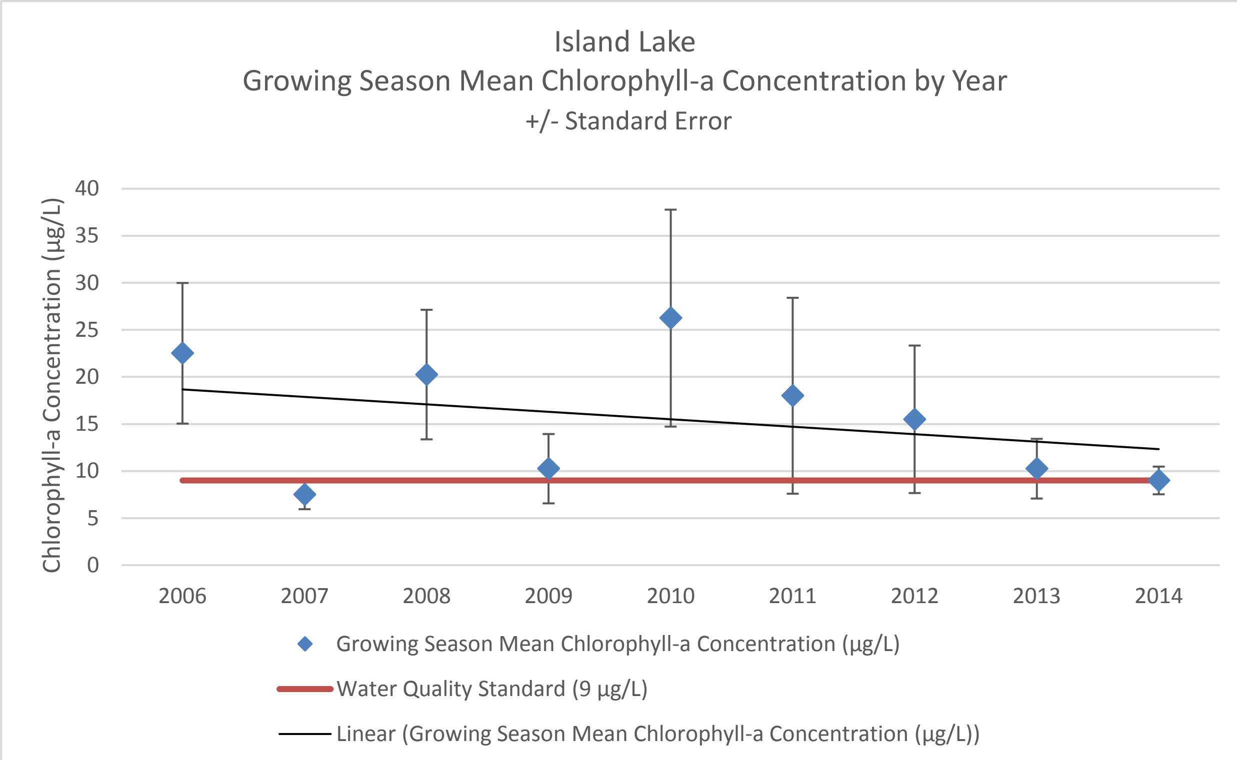


Figure 3.18. Mean Annual Growing Season Secchi Disk Depth, 2005–2014

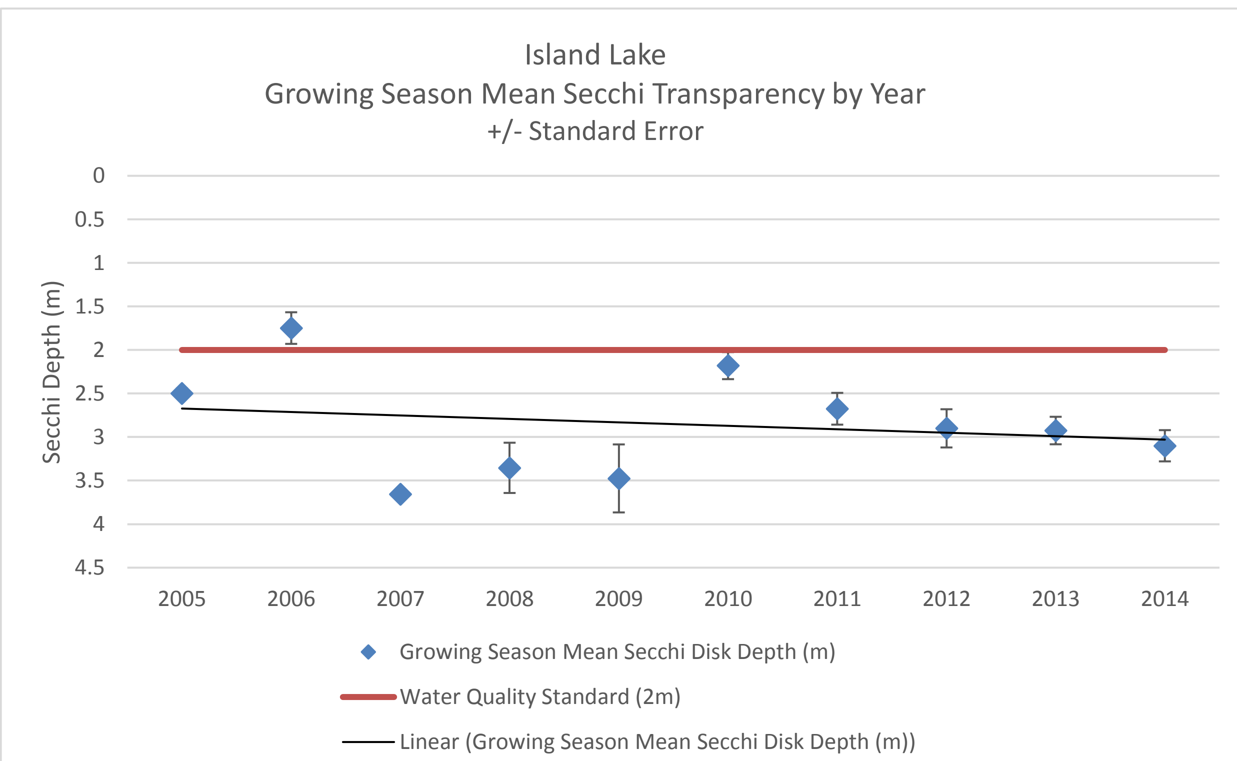


Figure 3.19. Water Temperature Profiles, 1991–2006

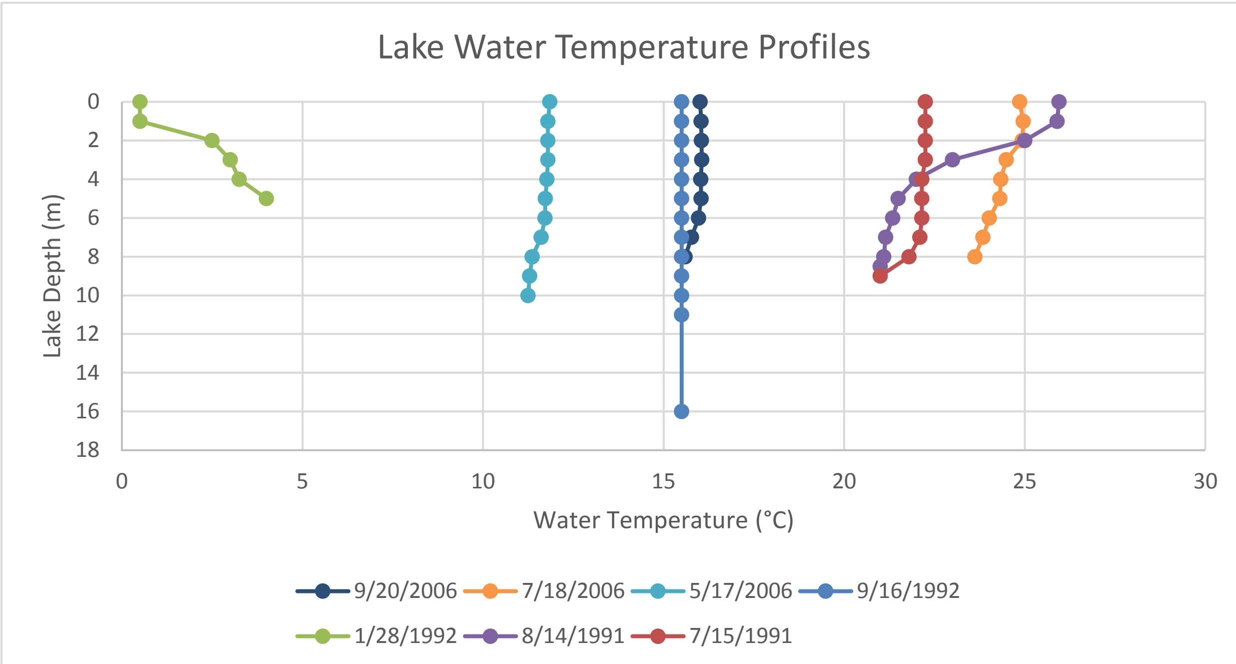
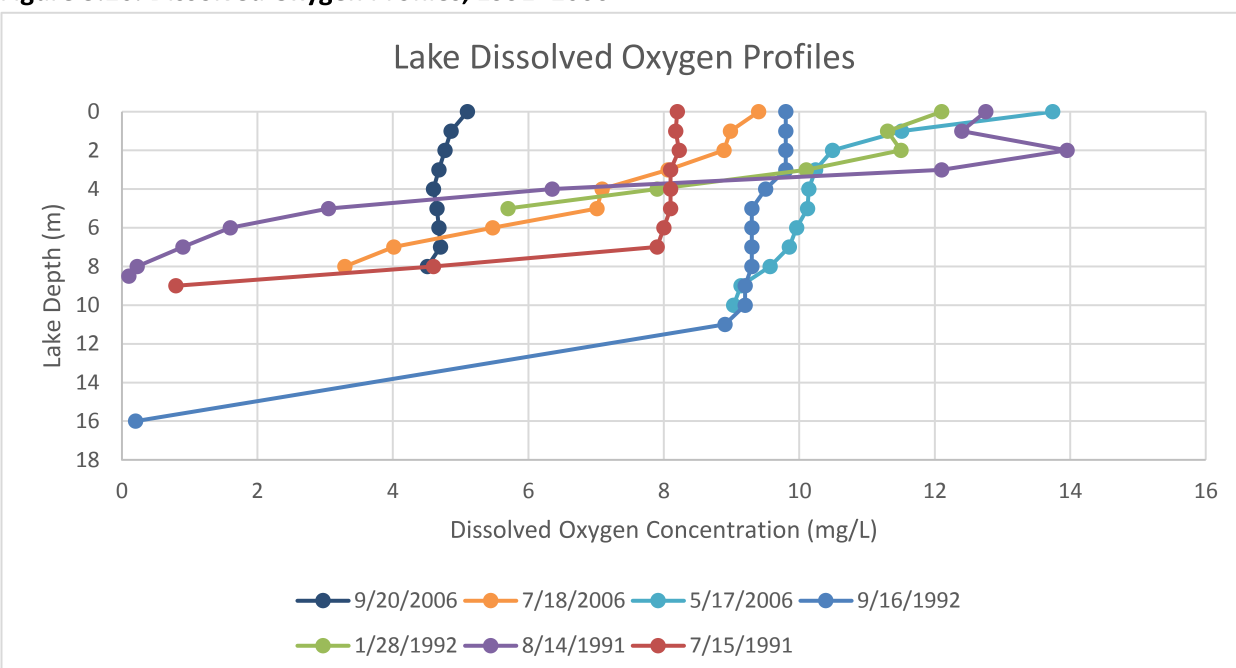


Figure 3.20. Dissolved Oxygen Profiles, 1991–2006



3.5.2 Minnesota Lake Eutrophication Analysis Procedure Modeling

The 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 as having water quality better or worse than regionally expected. These results are summarized in Table 3.6. MINLEAP modeling indicated Island Lake has lower water quality than generally expected given its mean depth, lake and watershed area, and location in the NLF aquatic ecoregion.

Table 3.6. MINLEAP-Predicted Water Quality Parameters for Island Lake

Average Lake Value		Island Lake	NLF Lake Standards
TP concentration (µg/L)	Observed	35	≤ 30
	Predicted	17	
Chlorophyll-a (µg/L)	Observed	16.2	≤ 9
	Predicted	4.2	
Secchi disk depth (m)	Observed	2.7	≥ 2.0
	Predicted	3.3	

3.6 Lake Biological Data

3.6.1 Fish Community

Island Lake is actively managed by the DNR Grand Rapids Area Fisheries as a Class 27 lake, with primary species including walleye and northern pike and yellow perch as a secondary species. DNR Class 27 lakes tend to have more regular configurations and higher fish biomass, especially of white sucker and yellow perch. The DNR has stocked walleye fry annually from 2005 to 2010 (last available reporting period). Of particular note is the presence of tullibee (cisco), which are an important food source of the primary species. Tullibee are also a key cool water fish that require good water quality with cooler temperatures and DO in deeper lake water layers to thrive. Hence, cisco are more vulnerable to climate variations and lake eutrophication that can squeeze the higher DO layers closer to the warmer surface waters, increasing mortality because of chronic or acute thermal requirements. While walleye is the primary species sought by anglers, other species present in Island Lake include black crappie, pumpkinseed sunfish, rock bass, smallmouth bass and white sucker. The DNR Fish Survey did not report the presence of carp and black bullheads for Island Lake.

As cisco fisheries are relatively rare, Island Lake was evaluated for temperature at 3 mg/L of DO (TDO3) following the methodology of Jacobson et al. [2010] and Fang et al. [2010]. Based on available lake profile data, Island Lake was estimated to be a marginal TDO3 Tier 3 lake.

3.6.2 Aquatic Plants

A qualitative survey of aquatic plants along the northwest shore of Island Lake was performed on July 21, 2001 [DNR 2001]. Of note were the absence, at that time, of typical invasive species such as curly-leaf pondweed (*Potamogeton Crispus*) and Eurasian watermilfoil (*Myriophyllum spicatum*). In general, the observed aquatic plant survey showed a balanced aquatic plant community.

3.7 Water Quality Trends

A Seasonal Kendall Tau test was performed on growing season (June through September) Secchi transparency data (2005 through 2014) because of the larger number of available measurements and 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 Island Lake's long-term record. However, visual inspection of Chl-*a* and Secchi disk data shows improving trends from 2010 through 2014. Mean annual growing season TP concentration, Chl-*a* concentration, and Secchi disk depth are reported in Figures 3.16 to 3.18. Continued volunteer Secchi monitoring with 10 to 12 measurements during the growing season will improve the ability to detect trends statistically.

3.8 Phosphorus Source Summary

To develop a complete understanding of Island Lake's nutrient dynamics, it was necessary to create an inventory of potential phosphorus sources and develop estimates of associated annual loads. Each of these sources are described below.

3.8.1 Permitted Sources

While there are no regulated National Pollutant Discharge Elimination System (NPDES) wastewater point sources within the Island Lake drainage area, three recent Construction Stormwater Permits were noted (C00019324, C00026732 and C00038768). P loading from potential future permitted construction stormwater sites within the Island Lake Watershed was estimated based on the total area of permitted construction sites in Itasca County from 2005 to 2014 [Leegard 2015]. The total permitted area in Itasca County from 2005 through 2014 was 6,822 ac. One large (4,067 ac) permitted site associated with a large mine in eastern Itasca County was excluded because it is not representative of typical construction projects that would occur in the Island Lake Watershed. The total adjusted permitted construction site area for the 10-year period was 2,755 ac; an assumption of 1 year of construction was used to estimate the mean annual area under construction (275.5 ac). This area constitutes 0.016% of the total area of Itasca County; it was assumed that an equal proportion of the Island Lake Watershed (not including open water) would be covered by construction stormwater permits, on a mean annual basis. The estimated mean annual permitted area in the Island Lake Watershed is 1.15 ac, which corresponds to a mean annual P load of 1.03 lbs (based on an assumption of 1 kg/ha/yr P loss).

3.8.2 Nonpermitted Sources

3.8.2.1 Direct Watershed Phosphorus Loading

Because Island Lake is a headwater lake, there are no major tributaries that enter the lake. As such, all nonpoint source loading from the watershed is considered to be direct watershed loading. The calibrated 1995 through 2014 Big Fork Watershed HSPF model [Lupo 2015] was used to develop loading estimates based on land use within the Island Lake Watershed. HSPF is a continuous model that employs precipitation and other climatic variables to predict runoff and pollutant loading to waterbodies. Mean annual runoff (in) and TP loads (lbs/ac) for each modeled land use in the Island Lake Watershed were used to calculate mean annual loading to the lake.

3.8.2.2 Subsurface Sewage Treatment Systems or Septic Systems

No municipal wastewater treatment systems are present in the Island Lake Watershed. Thus, all homes and businesses are served by County permitted subsurface sewage treatment systems (SSTS). A desktop analysis was carried out to estimate the number of homes and cabins around the lake. Assumptions and literature values were used to estimate total annual loading from septic systems. Further information and details on these calculations are included in Section 4.2.3.

3.8.2.3 Atmospheric Deposition

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

3.8.2.4 Lake Nutrient Cycling

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

1. Phosphorus released from lake sediments in aerobic and anaerobic conditions, as typically moderated by amounts of available iron and other factors such as legacy loading.

2. Resuspension of lake sediments by rough fish, wind, and wave mixing that generate currents along the water-sediment interface that lift particles into the water column. 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 phosphorus per unit mass than larger particles (sand). Recent studies of Jessie Lake in Itasca County defined storm induced wind mixing to the lake's bottom at ~40 ft [Wang et al. 1993] with velocities along the sediment-water boundary as much as 5+ cm/sec. Resuspension of bottom particles was implicitly addressed by the use of an appropriate phosphorus lake model. Resuspension of sediments from physical disturbance by bottom-feeding fish (e.g., rough fish such as carp and black bullheads), particularly in shallow lake areas, causing resuspension of nutrients including phosphorus. Carp and black bullheads were not recorded in the most recent DNR Fish Survey of Island Lake (DNR 2010) and thus is not a likely contributing internal loading source.

3. Phosphorus can be released from senescence and decay of macrophytes, particularly of dense stands of invasive species such as curly-leaf pondweed (*Potamogeton crispus*) and Eurasian watermilfoil (*Myriophyllum spicatum*) that can dominate littoral areas. Curly-leaf pondweed typically dies back in early to mid-summer and is subject to rapid decay in warm-water thereby potentially contributing to summer phosphorus concentrations. In other instances, macrophytes can be effective at stabilizing sediment and limiting resuspension. However, peak macrophyte growth and senescence can increase pH and contribute to low DO concentrations at the sediment-water interface, causing phosphorus release from sediments. Wave mixing of deeper waters can result in

transport of sediment phosphorus into the surface waters. Curly-leaf pondweed and Eurasian watermilfoil have not been reported for Island Lake and thus this is not a likely contributing phosphorus source in this assessment.

4. TMDL Development

4.1 Loading Capacity

Loading capacity for Island Lake was determined with a calibrated BATHTUB model based on 2005 through 2014 HSPF loads and 2005 through 2014 growing-season mean TP, Chl-*a*, and Secchi disk 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:

$$TMDL = \Sigma(WLA) + \Sigma(LA) + MOS + RC \qquad 4.1$$

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, usually expressed as a percent of the TMDL, used to increase the likelihood of compliance by accounting for potential unknown or unquantifiable nutrient sources. Reserve capacity is a load apportioned to account for anticipated future growth or land use change.

4.2 Watershed and Lake Modeling

4.2.1 Lakeshed Surface Runoff Loading

Watershed loading was provided from the calibrated Big Fork River HSPF Model [Lupo 2015]. Mean annual runoff and flow-weighted mean concentrations (FWMCs) for TP for watershed loading were provided as input to BATHTUB. Because of a lack of streamflow gages immediately downstream of Island Lake, the only two discharge (runoff) calibration sites downstream of Island Lake are 1) Bigfork River at Minnesota State Highway 6 (approximately seven miles northwest of Craigville) (gage H77107001) and 2) Bigfork River at Big Falls (gage 05132000). A summary of the observed and simulated discharge for 1996 through 2014 is summarized (as runoff depth) in Table 4.1. Simulated mean annual runoff agrees well with observed runoff at both sites, with differences of less than 6% at both sites. The HSPF model underestimates runoff, on average, by approximately 4% at the further upstream site.

Table 4.1. Comparison of HSPF Hydrology Calibration for the Bigfork River

Observed Flow Gage	HSPF Reach	Mean Annual Runoff Depth (in), 1996–2014		
		Observed	Simulated	% Δ
H77107001	350	4.42	4.25	–3.96
05132000	470	6.96	7.36	5.80

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 disk 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 phosphorus 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; this is the basis of predictive models such as BATHTUB.

Tributary inflows to lake segment(s) are specified by the user as mean annual flow volume (hm^3); pollutant concentrations are entered as FWMCs. BATHTUB includes nine model choices for predicting TP, Chl-*a*, Secchi disk, and other lake responses based on model input. The model for in-lake TP prediction for Island Lake was the Canfield & Bachmann Natural Lake model. 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 disk depth, conservative substances) are entered as growing-season (June through September) mean values for the period of interest. There are many ways to calibrate BATHTUB, including adjustments of internal loading rates, calibration coefficients (by lake segment), or model coefficients (globally for all segments).

4.2.3 SSTS Loading

A desktop analysis was done to estimate the number of homes and cabins around Island Lake; 158 homes and cabins were identified. An assumption was made that 25 of the homes are occupied year-round, while the remaining 133 are seasonally occupied (100 days per year). Average house size assumed was 2.34 people per home, the 2009 through 2013 average for Itasca County [U.S. Census Bureau 2015]. 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 phosphorus loads, respectively. An estimate of annual TP loss per capita of 1 kg [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 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, it was necessary to provide a separate estimate of loading from septic systems and reduce the loads from surface runoff accordingly. Tributary and lakeshed flow volumes and annual load were then reduced proportionally to ensure that the total flow volume and load from all sources were equal to that predicted by HSPF to account for the septic system adjustment. An adjusted Flow-weighted mean concentration (FWMC) for the lakeshed was then determined based on adjusted flow volume and annual loads.

4.2.4 Atmospheric Loading

An atmospheric phosphorus deposition of 19.3 mg m^{-2}/yr [Twarowski et al. 2007] was used to quantify average annual total (wet + dry) deposition on the lake surface. Values reported for dry and wet years were 18.0 and 20.7 mg m^{-2}/yr, respectively, a difference of approximately ± 7% from average years.

4.2.5 Internal Loading

Evidence of potential internal loading was observed from examination of lake TP dynamics, lake mixing, and DO concentrations. Sediment chemical analyses required to employ Nurnberg-type release estimates [Nurnberg 1995] and phosphorus release rates determined from sediment cores were not available. As a result, three methods were employed to define internal loading ranges for Island Lake: (1) literature values reported for similar northern Minnesota lakes, (2) values calculated from growing season changes in monthly mean surface TP concentrations, and (3) values calculated as unexplained residual loads determined from BATHTUB modeling of phosphorus income-outgo balances.

1. Minnesota lake sediment P release studies: James [2012] quantified aerobic and anaerobic phosphorus release rates for Lake of the Woods from sediment cores obtained from three of the lake's major bays. Aerobic release rates varied from 0.2 to 0.6 mg/m^2-day with anaerobic release rates noted to be approximately 20 times greater with a range from 8.3 to 12.5 mg/m^2-day. Wang et al. [2004] observed a phosphorus release rate of 16.9 mg/m^2-day from Jessie Lake, Itasca County sediment cores under anaerobic conditions with no aerobic release rates observed. (Temperatures for sediment core analyses reported by Wang et al. was not reported but assumed to be room temperature or 20°C.) James [2015] further examined the effects of temperature on phosphorus release rates for Lake of the Woods sediment cores and reported that sediment phosphorus release rates increased in an exponential pattern as a function of temperature. He found that (1) aerobic rates varied from 0.05 mg/m^2-day at 5°C to 0.36 mg/m^2-day at 25°C and (2) anaerobic rates varied from 0.8 mg/m^2-day at 5°and 16.8 mg/m^2-day at 25°C. Using James' temperature moderated phosphorus release rates, estimating annual loads instead of extrapolating summer release rates to an annual rate is possible. There are relatively few available DO measurements for Island Lake, but the measurements from the earlier 1990s suggest that Island Lake may commonly experience growing season anoxic conditions along the deeper sediments with the corresponding increased potential for internal loading.

2. Growing season monthly mean phosphorus concentration method: Mean TP concentrations, calculated by growing season month for available data from the 2005 through 2014 time period, increased by 20 µg/L as values increased from June (19.7 µg/L) to September (40 µg/L). Increase of in-lake TP can be described by:

   $$\Delta\, Mass = Lake\, Volume * \, \Delta\, Concentration \qquad 4.1$$

   where ΔMass is the mass increase of TP, Lake Volume is the normal volume of the lake, and ΔConcentration is the increase in concentration over a specific time period. With a ΔConcentration of 20µg/L (June through September) and a lake volume of 57.1 hm^3, an increase of TP mass of 1,142 kg P is calculated for the over the growing season. This increase is a result of both external (watershed runoff and septic loading) and internal loading. Growing season runoff (as a percentage of rainfall) is lower because of vegetation canopies and evapotranspiration. Additionally, as 7 of the past 10 years have experienced drier growing seasons, most of the increased lake phosphorus is likely because of internal loading sources. The increased growing season lake phosphorus mass can be converted to an aerial rate over the lake surface by:

   $$\frac{\Delta Mass}{Lake\ Area*Time} = \frac{\Delta Mass}{Lake\ Area*\Delta Time} \qquad 4.2$$

where Lake Area is the normal lake surface area and ΔTime is the time period corresponding to the change in mass signified by ΔMass. For ΔMass of 1142 kg, a lake surface area of 1.258 x 10^7 m^2, and ΔTime of 121 days, a summer internal loading rate of 0.77 mg/m^2-day is calculated for Island Lake, which is similar to the upper range of aerobic release rates reported for Lake of the Woods. To calculate the annual internal loading release rate, a ΔTime of 365 days is used, and an assumption is made that ΔMass for the growing season is equal to the ΔMass for the entire year. This results in an annual phosphorus release rate of 0.25 mg/m^2-day.

3. Mass balance estimating: BATHTUB modeling was conducted for Island Lake based on HSPF inputs from watershed sources, along with reported Minnesota atmospheric phosphorus deposition and estimated phosphorus loading from septic tanks. The unexplained residual or phosphorus loads needed to balance the income and outgo budgets was assigned as internal load. This is described as:

$$Unexplained\ Residual = \sum External\ and\ Internal\ Loads - \sum External\ Loads \qquad 4.3$$

where external loads include watershed loading, atmospheric deposition, septic tank loading, and construction stormwater loading. Internal loads are associated with phosphorus release from bottom sediments and resuspension of particulate phosphorus. The quantity Σ (External and Internal Loads) is the equivalent to the annual inflow as determined by the calibrated BATHTUB model, and was estimated at 3,565.0 pounds per year (lbs/year) (1,616.8 kg/year). The quantity Σ (External loads) is the sum of all estimated external inputs, and was estimated at 1,416.8 lbs/year (642.5 kg/year). The unexplained residual is equal to the difference of these two summations, or 2147.2 lbs/year (973.8 kg/year), which corresponds to an annual mean annual phosphorus release rate of 0.212 mg/m^2-day.

The mean annual phosphorus release rates as calculated in methods 2 (0.25mg/m^2-day) and 3 (0.212 mg/m^2-day) above show reasonably close agreement and convergence toward a lower net P release rate more indicative of aerobic than anaerobic release rates. The relatively low maximum summer lake TP concentrations (e.g., generally less than 60 µg/L) suggest that higher sediment release rates are not occurring as these would generate much higher P peak surface concentrations.

4.3 BATHTUB Calibration and Results

The Island Lake BATHTUB model was calibrated for TP iteratively by adjusting the internal loading release rate and the allowable load (Load Capacity) was determined to be 2765.0 lbs/yr (7.58 lbs/d).

4.4 Wasteload Allocation Methodology

The only component of the WLA is discharge from permitted construction stormwater sites. No reduction in TP loading from permitted construction sites is proposed.

4.5 Margin of Safety

An explicit 5% MOS was included to further ensure achievement of water quality goals. A low MOS was used to provide reasonable and achievable reductions that will still achieve water quality goals.

A 5% MOS was utilized for this TMDL due to the confidence level the MPCA has in the extensive field work that the staff conducted on Island Lake. In addition, our detailed modeling work had good convergence in the projections of internal loading for this lake. Therefore we feel a 5% MOS is warranted.

4.6 Load Allocation Methodology

After accounting for both the wasteload allocation and the margin of safety, the remaining loading capacity was apportioned amongst the following: watershed loading, septic loading, atmospheric deposition, and internal loading. The annual TP FWMC associated with watershed loading was reduced to 50 µg/L, equal to the growing season water quality standard for rivers in the North River Nutrient Region [MR 7050.0222]. This corresponds to a load of 537.8 lbs/yr, a 34 percent reduction in loading from the watershed. The TMDL assumes complete (100%) future compliance with SSTS regulations with an assumed annual load of zero pounds per year. The remaining load reduction comes from internal loading; the required release rate to satisfy the loading capacity is 0.152 mg/m^{2-}day. This corresponds to an internal loading reduction of 598.2 lbs/yr, or 28 percent reduction.

4.7 Seasonal Variation and Critical Conditions

Greater lake water quality variability is observed seasonally (intra-year) than year-to-year (inter-year) because of temperature and precipitation cycles. In this annual cycle, the majority of annual watershed phosphorus 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 phosphorus loading during higher flow periods.

In deeper lakes, phosphorus 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 phosphorus release or loading that can also contribute to increased algal Chl-*a*. This seasonal variation has been factored into the development of Minnesota’s lake standards, based on swimmable and fishable beneficial uses, for the summer critical recreation period of June through September [Heiskary and Wilson 2005]. This TMDLs targeted allocations are based on Minnesota’s lake standards and summer critical conditions.

4.8 Reserve Capacity

Island Lake is located in rural Itasca County, and as such, there are no municipalities within the relatively small watershed. Substantial development is not anticipated, but many of the areas in which growth may be expected are lake shore properties, which have the greatest potential to impact water quality. To protect and improve Island Lake’s water quality, a net decrease in phosphorus loading should be a fundamental goal that will require buffers and retrofitting of existing lakeshore properties. Adoption of low impact development practices for new lake shore development, such as defined by the MIDS, recently developed in Minnesota [MPCA 2012] can also be of help in future development. This approach will require the adoption of a regulatory framework as well as intergovernmental cooperation to achieve these goals.

Potential changes in population and land use over time in the Island Lake Watershed could result in changing sources of pollutants and runoff characteristics. Possible changes and how they may or may not impact TMDL allocations are discussed below in Section 5 particularly relating to shore land development. Future growth is not anticipated to include future Municipal Separate Storm Sewer Systems (MS4s) community development. Given these considerations, reserve capacity was not included as part of this TMDL.

4.9 TMDL Summary

The TMDL Summary table is shown in Table 4.2. The BATHTUB-estimated loading capacity for Island Lake is 2765.1 lbs TP/yr. The MOS and WLA reduce the loading capacity such that 2623.0 lbs TP/yr can be assigned to the LA. All necessary TP load reductions must come from the LA; the total required reduction necessary to achieve the water quality standard is approximately 942.0 lbs TP/yr. The calibrated BATHTUB model predicts a growing-season mean TP concentration of 29.2 µg/L after load reductions are achieved.

Table 4.2. Island Lake Total Maximum Daily Load Summary

Island Lake Load Allocation		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Loading Capacity				2,765.1	7.58		
Margin of Safety				142.0	0.39		
Total Load		**3,565.0**	**9.77**	**2,623.0**	**7.19**	**942.0**	**26**
Wasteload	**Total WLA**	**1.0**	**0.0028**	**1.0**	**0.0028**	**0**	**0**
	Construction Stormwater	*1.0*	*0.0028*	*1.0*	*0.0028*	*0*	–
Load	**Total LA**	**3,564.0**	**9.76**	**2,622.0**	**7.18**	**942.0**	**26**
	Local Watershed	*814.9*	*2.23*	*537.8*	*1.47*	*277.1*	*34*
	SSTS	*66.7*	*0.18*	*0*	*0*	*66.7*	*100*
	Atmospheric deposition	*535.2*	*1.47*	*535.2*	*1.47*	*0*	–
	Internal load	*2147.2*	*5.88*	*1549.0*	*4.24*	*598.2*	*28*
Total Load		**3,565.0**	**9.77**	**2,623.0**	**7.19**	**942.0**	**26**

5. Future Growth Considerations

Due to the low population of this area, it is unlikely that any new municipal separate storm sewer system (MS4) permitted areas will develop. Therefore, the MPCA's "New or Expanding Permitted MS4 WLA Transfer Process" is not applicable for this TMDL. For more information on MS4 please see: https://www.pca.state.mn.us/water/municipal-stormwater-ms4

6. Reasonable Assurance

The findings from this TMDL study were used to aid the selection of implementation strategies as part of the Big Fork River WRAPS process. The purpose of the WRAPS report is to support local working groups and jointly develop scientifically-supported restoration and protection strategies to be used for subsequent implementation planning. The WRAPS report will be publically available on the MPCA's Big Fork River Webpage (*https://www.pca.state.mn.us/water/watersheds/big-fork-river*).

6.1 Nonregulatory

Local, state, and federal partners have worked closely over the past 30 years to characterize Itasca County's water quality and to devise restoration and protection strategies, particularly relating to forest management. Characterization has included baseline and long-term lake monitoring coupled with Citizen Lake Monitoring Program volunteer tracking of Secchi transparency patterns. Researchers from the MPCA, the University of Minnesota St. Anthony Falls Laboratory, the University of Minnesota Duluth, and the University of Wisconsin-Stout have conducted internal loading investigations of several Itasca County lakes. The DNR, along with Itasca Soil and Water Conservation District, developed lake sensitivity indices, including the work of Paul Radomski [2014] and Dr. William Walker and Rian Reed (Itasca MINLEAP – Walker [2008]). Long-term patterns of Itasca County lake quality have included detailed studies of the potential effects of taconite mining activities on lakes such as Swan Lake. In short, effective long-term partnerships will remain an important base for leveraging future restoration and protection projects for Island Lake.

State funding of restoration and protection projects include the 2006 Minnesota Clean Water Legacy Act and the 2008 Clean Water, Land, and Legacy Amendment to the state constitution. The act launched Minnesota on an accelerated path toward addressing impaired waters, including but not limited to TMDL development, implementation activities and other related work. The amendment, through the clean water fund, provides over $100 million a year for Clean Water Legacy Act activities, with the majority of the funds used for implementation activities, including implementation of TMDLS, WRAPS, and One Watershed-One Plan. This will ensure progress towards restoring and protecting Minnesota's waters. Also, the MPCA Clean Water Partnership loan program is available for activities like upgrading septic systems.

At the federal level, funding can be provided through CWA Section 319 grants and U.S. Forest Service programs. Various other funding and cost-share sources exist, which will be listed in the Big Fork WRAPS Plan. The implementation strategies described in this plan have been demonstrated to be effective in reducing nutrient loading to lakes and streams. There are programs in place within the watershed to continue implementing the recommended rehabilitative activities. Detailed monitoring will continue along with adaptive management assessments to periodically (every five years) evaluate the progress made toward achieving and maintaining water quality goals.

6.2 Regulatory

There are no regulated NPDES point sources within the Island Lake drainage area. However, any future regulated entities would fall under federal, state, and County (SWCD) jurisdiction. The MPCA is responsible for applying federal and state regulations to protect and enhance water quality within the Island Lake Watershed.

7. Monitoring Plan

Future monitoring will be required to track: (1) Island Lake's water quality trends; (2) performance of future remedial and protection projects to improve water quality; and (3) compliance with water quality standards. The scope and nature of future remedial actions will rely upon 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. An abbreviated monitoring plan is defined that should be further developed including monitoring site locations, sampling schedules, and responsible entities.

7.1 Island Lake Trend Detection

Data from recent years have indicated a declining pattern in TP and Chl-*a* concentrations, along with increasing Secchi transparency. The simplest approach and most economical 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 5 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 and to report recreational suitability and physical appearance at the time of their Secchi measures.

- Additional lake-monitoring data could include:

  -Lake TP, 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 measurements. Temperature and DO profiling data (by depth) are quite limited. Future detailed measurements to the lake bottom at 35 feet 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 affecting lake water quality.

  -Future monitoring should consider quantification of lake sediment internal phosphorus loading including (1) diffusive P fluxes from deposited sediment, and (2) equilibrium P fluxes from resuspended sediment. Sediment textural characteristics and biologically labile (i.e., subject to recycling) and refractory (i.e., low recycling potential and subject to burial) P fractions should be determined for sediment samples. Methods for determining rates of diffusive P flux from intact sediment cores should be consistent with those specified by James et al. [1995] for oxic and anoxic P release determinations.

  -Developing an understanding of historical water quality through core-sampling could be considered to understand TP/P pre-development through modern time.

- 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. It is particularly important to track mid-to-late summer hot/dry periods followed by Canadian storm systems that may increase internal loading potential.

  - 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/CLIMATE/) for the Grand Rapids Forest Research Station.

- Work closely with the DNR's Grand Rapids Fishery staff to report any fish kills, particularly of cisco, an important DO /temperature sensitive species and prey for walleye and northern pike.

7.2 Streams

Discharges from inlet streams on the east (Welch/Williams Lakes, Bender AMA) and western watershed wetland discharges should be sampled for nutrients and sediments in the spring and during/following large summer storm events (greater than 1.0 inch). Approximately 5 to 10 sampling rounds for each of the streams should be accomplished in the near future. The arithmetic average values for TP and total suspended sediment should be less than 50 µg/L and 15 mg/L, respectively. Exceedances would indicate that further investigation of upland wetland areas may be in order.

Updating of the inventory of culverts and stream crossings may be beneficial, with particular interest in crossings that are perched, or subject to excessive erosion or poor transport of water and sediment. The inventory should contain the following information: latitude/longitude, culvert material, dimensions (length, diameter), invert elevations (to datum), condition, and overtopping elevation if used for flood control. The presence of control structures should also be noted.

8. Implementation Strategy Summary

Implementing the Island Lake TMDL will be a collaborative effort between individuals and state and local government. The overall effort will be led by the Itasca and Koochiching SWCDs who can provide technical support, funding coordination and local leadership. The SWCDs can leverage existing relationships and regulatory frameworks to generate support for the TMDL implementation. Use of these existing governmental programs and services will provide efficiency and related cost savings to the maximum extent possible.

8.1 Permitted Sources

8.1.1 Construction Stormwater

Three construction stormwater permits were noted (C00019324, C00026732and C00038768) in the Island Lake Watershed between 2006 and 2014. The WLA for stormwater discharges from sites where there is construction activity reflects the number of construction sites greater than one acre expected to be active in the watershed at any one time, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in the State's NPDES/SDS General Stormwater Permit for Construction Activity (MN R100001). If a construction site owner/operator obtains coverage under the NPDES/SDS General Stormwater Permit and properly selects, installs and maintains all BMPs required under the permit, including those related to impaired waters discharges and any applicable additional requirements found in Appendix A of the Construction General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local construction stormwater requirements must also be met.

8.1.2 Industrial Stormwater

There are no industrial stormwater permitted sites in the Island Lake Watershed. If industrial permitted sites become located in the watershed, future modification of the TMDL may be required, that will list BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at the industrial sites are defined in the State's NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000) or NPDES/SDS General Permit for Construction Sand & Gravel, Rock Quarrying and Hot Mix Asphalt Production facilities (MNG490000). If a facility owner/operator obtains stormwater coverage under the appropriate NPDES/SDS Permit and properly selects, installs and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with WLAs in future modifications of the TMDL. All local stormwater management requirements must also be met.

8.1.3 MS4

There are no regulated MS4s in the Island Lake Watershed, nor are new MS4s expected based on demographic growth projections for Itasca County.

8.1.4 Wastewater

There are no regulated wastewater systems in the Island Lake Watershed, nor are new permitted wastewater systems projected based on demographic growth projections for Itasca County.

8.2 Nonpermitted Sources

8.2.1 Subsurface Sewage Treatment Systems (Septic Systems)

As there are no municipal wastewater treatment systems in the Island Lake Watershed, homes and businesses are served by SSTS. Both Itasca and Koochiching Counties have subsurface treatment system ordinances with detailed requirements and enforcement procedures. Future SSTS surveys will aid in obtaining 100% compliance and reducing nutrient loading from noncompliant systems.

8.2.2 Shore Lands

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]. Koochiching and Itasca Soil and Water Conservation Districts will be the point of contact for requirements and technical assistance for implementation of buffers along public waters and shore lands. Details of the buffer implementation are being developed. The 2008 Clean Water Legacy Fund included $5 million to the Board of Soil and Water Resources for local government implementation. The SWCDs will be identifying the priority for placement of perennial vegetation buffers along small streams and headwater areas.

An option is to acquire professional design-build landscaping services to provide landscape designs for all interested Island Lake shore property owners. Lake shore residents can develop individualized plans with the landscape services contractor who can begin installations as feasible with a phased implementation to increase efficiencies and reduce unit costs. The contractor could conduct site reviews, prepare designs with property owners, design specifications, complete installation per specifications, and provide long-term maintenance checklists. 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.

8.2.3 Internal Loading

Assessment of Island Lake's phosphorus dynamics and mass balances indicate that internal loading comprises an important portion of the phosphorus budget. As internal phosphorus loading is typically the result of cumulative historical watershed loading, a recommended first step is to reduce watershed loading as much as possible. For Island Lake, this includes reducing runoff from shore lands, development, noncompliant SSTSs and other upland sources including wetlands by 33%. Wetland hysteresis or pulsing is possible from the succession of dry and wet periods and resulting shifting water levels that can induce phosphorus release. During dry periods, water levels recede and subsequently provide greater oxygen concentrations (in unsaturated soils) for aerobic digestion of organic substrates, including mobilization of various dissolved and particulate phosphorus forms [Richardson 1985]. Upon refilling during wet periods, growing season oxygen concentrations can quickly be depleted resulting in the release of digested phosphorus concentrations dependent upon many factors such as available iron. The extent of this occurrence in the watershed wetland complexes is not known but can be characterized with relatively simple wetland outlet growing season monitoring.

8.2.4 Permitted Internal Loading Management Options

As Island Lake is a polymictic or well-mixed lake, hypolimnetic treatment is not possible without an established hypolimnion. Substantial oxygen depletion occurring in waters deeper than approximately 5 m (approximately 16 feet) was noted from available temperature and DO profile data. Further monitoring data is required to identify potential remedial actions. For example, monitoring recommended in this study includes additional temperature and DO profile data acquisition and sampling of bottom waters during the growing season for TP and total iron.

- A recommended total iron to TP concentration ratio of at least 3:1 is needed for control of lake sediment released phosphorus. If the total iron to TP ratio is less than 3:1, then iron is likely not effectively reducing sediment liberated phosphorus concentrations. In this case, iron augmentation of lake sediments may be required using ferric chloride or similar iron compounds. The details, including oxygen supply rates, would have to be determined by an engineering design study.
- High oxygen depletion rates are expected to accompany elevated Chl-*a* concentrations. Off-setting the high oxygen depletion rates by the addition of oxygen (oxygenation) into the bottom waters is a potential option. This would require the installation of 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.
- Whole lake treatment by alum (aluminum sulfate) can be very effective in reducing lake internal loading of phosphorus for 10 to 30 years. However, effectiveness in shallower lakes such as Island Lake may reduce effectiveness because of wind mixing of the alum sediment layers (Cooke et al. 1975). After reduction of watershed phosphorus loading sources, the appropriateness of a whole lake alum treatment can be assessed by a detailed feasibility study, including sediment

core sampling for estimation of P release rates. Mobilization and treatment costs could amount to approximately $1,000 per acre depending on dosage requirements and fluctuating alum costs (cost/gallon, transportation and buffering requirements).

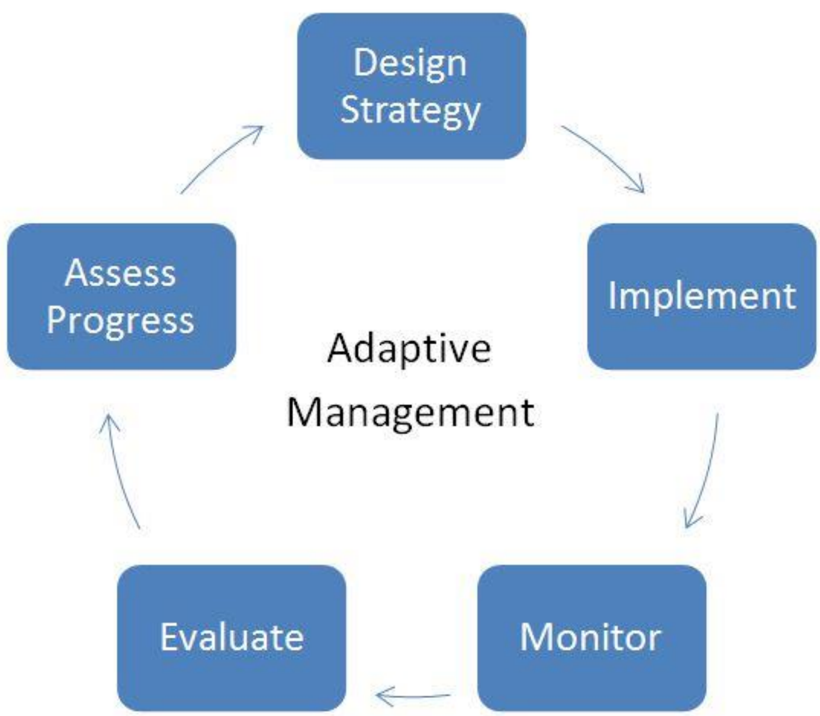
8.3 Cost

The estimated costs for implementation is projected to be less than $300,000 for the implementation of non-permitted remedial actions consisting of (1) installation of buffers along all public waters ($165,000) as well as monitoring and implementation of development practices. However, if internal loading of phosphorus continues or worsens, the worst-case estimated cost for iron or alum chemical treatments could be as high as $2 million.

8.4 Adaptive Management

This list of implementation elements and the more detailed WRAPS report accompanying this TMDL assessment focus on adaptive management (Figure 8.1). Continued monitoring and “course corrections” responding to monitoring results are the most appropriate strategy for attaining the water quality goals established in this TMDL. Management activities will be changed or refined to efficiently meet the TMDL and lay the groundwork for de-listing the impaired waterbody.

Figure 8.1. Adaptive Management



9. Public Participation

The Itasca SWCD and Koochiching SWCD are the lead local governmental units (LGUs) with jurisdiction over Island Lake's Watershed, and will coordinate communication and implementation of the TMDL with stakeholders. The Itasca SWCD and Koochiching SWCD have maintained qualified staff who have worked over the past 20 years with state and federal agencies to advance watershed management, including monitoring programs.

The stakeholder process for the Island Lake TMDL has been part of the Big Fork WRAPS process, including its technical advisory committee (TAC) that was formed from representatives of stakeholder groups including:

- Island Lake Association
- Itasca Soil and Water Conservation District (Itasca SWCD)
- Koochiching Soil and Water Conservation District (Koochiching SWCD)
- DNR fisheries and hydrology departments (DNR)
- US Forest Service (USFS)
- Big Fork River Board
- MPCA

Itasca SWCD and Koochiching SWCD conducted three meetings, between 2010 and 2014, in the Big Fork River Watershed to specifically discuss the Island Lake TMDL. These three meetings were a part of a series of meetings that discussed all aspects of the WRAPS process; however, these meetings were specifically dedicated to the Island Lake TMDL. These meetings were held in both counties and were conducted at times where year-round as well as seasonal residents could participate. These meetings resulted in an understanding of the issues in Island Lake, ideas for implementation projects, and provided several edits to the DRAFT document.

Modeling, as a part of the TMDL development, was presented at two of the meetings for the public to understand and engage in how the TMDL is calculated. This was perhaps too technical for this general public audience (as demonstrated by "b." in the table below), however the time the counties and state took to do this was appreciated.

An opportunity for public comment on the draft TMDL report was provided via a public notice in the State Register from May 30, 2017 through June 29, 2017.

The results of the Island Lake TMDL meetings are as follows:

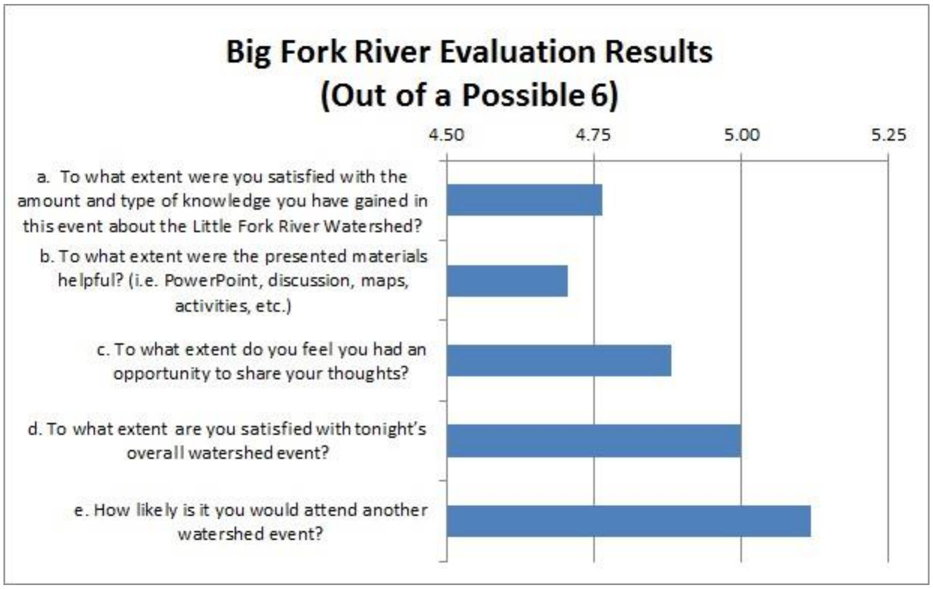


Figure 9.1 Big Fork Evaluation Results

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Appendix A Atlas 14 Precipitation Intensity and Duration Summary (NOAA)

Table A-1. Atlas 14 Precipitation Intensity and Duration Summary for Big Fork ESE (21-0754) (NOAA) (Page 1 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	1,000
5-min	**0.314**	**0.376**	**0.48**	**0.568**	**0.693**	**0.792**	**0.892**	**0.997**	**1.14**	**1.25**
	(0.253–0.398)	(0.302–0.477)	(0.384–0.610)	(0.453–0.724)	(0.535–0.908)	(0.598–1.05)	(0.653–1.20)	(0.701–1.37)	(0.771-1.60)	(0.824-1.77)
10-min	**0.46**	**0.551**	**0.703**	**0.832**	**1.02**	**1.16**	**1.31**	**1.46**	**1.67**	**1.83**
	(0.370–0.583)	(0.443–0.698)	(0.563–0.893)	(0.663–1.06)	(0.784–1.33)	(0.875–1.53)	(0.956–1.76)	(1.03–2.01)	(1.13-2.34)	(1.21-2.59)
15-min	**0.561**	**0.672**	**0.857**	**1.02**	**1.24**	**1.41**	**1.59**	**1.78**	**2.03**	**2.23**
	(0.451–0.711)	(0.540–0.852)	(0.687–1.09)	(0.808–1.29)	(0.956–1.62)	(1.07–1.87)	(1.17–2.15)	(1.25–2.45)	(1.38–2.86)	(1.47–3.16)
30-min	**0.803**	**0.96**	**1.22**	**1.44**	**1.76**	**2**	**2.25**	**2.51**	**2.87**	**3.14**
	(0.646–1.02)	(0.771–1.22)	(0.978–1.55)	(1.15–1.84)	(1.36–2.30)	(1.51–2.65)	(1.65–3.04)	(1.77–3.46)	(1.94–4.02)	(2.07–4.45)
60-min	**1.06**	**1.26**	**1.6**	**1.88**	**2.27**	**2.58**	**2.89**	**3.21**	**3.64**	**3.96**
	(0.850–1.34)	(1.01–1.60)	(1.28–2.03)	(1.50–2.40)	(1.75–2.97)	(1.95–3.41)	(2.11–3.89)	(2.25–4.41)	(2.46–5.10)	(2.62–5.62)
2-hr	**1.31**	**1.56**	**1.97**	**2.32**	**2.79**	**3.16**	**3.53**	**3.9**	**4.41**	**4.79**
	(1.06–1.65)	(1.26–1.97)	(1.59–2.49)	(1.85–2.93)	(2.16–3.62)	(2.39–4.14)	(2.59–4.71)	(2.76–5.32)	(3.00–6.14)	(3.18–6.75)
3-hr	**1.46**	**1.74**	**2.19**	**2.57**	**3.09**	**3.49**	**3.89**	**4.3**	**4.84**	**5.24**
	(1.19–1.84)	(1.41–2.18)	(1.77–2.76)	(2.06–3.24)	(2.40–3.99)	(2.65–4.55)	(2.86–5.17)	(3.04–5.83)	(3.30–6.71)	(3.50–7.37)
6-hr	**1.71**	**2.02**	**2.55**	**2.98**	**3.59**	**4.06**	**4.53**	**5.02**	**5.67**	**6.16**
	(1.39–2.13)	(1.65–2.52)	(2.06–3.18)	(2.40–3.74)	(2.80–4.61)	(3.10–5.26)	(3.36–5.99)	(3.58–6.77)	(3.90–7.81)	(4.14–8.60)
12-hr	**1.93**	**2.27**	**2.86**	**3.36**	**4.07**	**4.63**	**5.21**	**5.82**	**6.64**	**7.29**
	(1.58–2.38)	(1.86–2.82)	(2.33–3.55)	(2.72–4.18)	(3.20–5.21)	(3.57–5.99)	(3.89–6.87)	(4.18–7.82)	(4.61–9.12)	(4.93–10.1)
24-hr	**2.15**	**2.52**	**3.15**	**3.7**	**4.51**	**5.16**	**5.85**	**6.58**	**7.59**	**8.39**
	(1.77–2.65)	(2.07–3.10)	(2.58–3.88)	(3.02–4.58)	(3.58–5.76)	(4.01–6.65)	(4.40–7.68)	(4.77–8.81)	(5.31–10.4)	(5.71–11.6)
2-day	**2.44**	**2.82**	**3.48**	**4.07**	**4.93**	**5.65**	**6.41**	**7.21**	**8.35**	**9.25**
	(2.01–2.98)	(2.32–3.44)	(2.86–4.26)	(3.33–4.99)	(3.95–6.27)	(4.42–7.24)	(4.85–8.36)	(5.27–9.60)	(5.88–11.3)	(6.34–12.7)
3-day	**2.66**	**3.05**	**3.74**	**4.35**	**5.25**	**5.99**	**6.78**	**7.61**	**8.77**	**9.7**
	(2.20–3.23)	(2.53–3.71)	(3.09–4.56)	(3.57–5.33)	(4.22–6.65)	(4.70–7.65)	(5.15–8.80)	(5.57–10.1)	(6.20–11.9)	(6.68–13.2)

Table A-1. Atlas 14 Precipitation Intensity and Duration Summary for Big Fork ESE (21-0754) (NOAA) (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	1,000
4-day	**2.85**	**3.27**	**3.98**	**4.61**	**5.54**	**6.29**	**7.08**	**7.92**	**9.1**	**10**
	(2.37–3.46)	(2.71–3.97)	(3.29–4.84)	(3.80–5.63)	(4.45–6.98)	(4.94–7.99)	(5.40–9.17)	(5.82–10.5)	(6.45–12.3)	(6.92–13.6)
7-day	**3.4**	**3.86**	**4.64**	**5.31**	**6.28**	**7.05**	**7.85**	**8.7**	**9.85**	**10.8**
	(2.83–4.10)	(3.21–4.66)	(3.85–5.61)	(4.39–6.45)	(5.05–7.84)	(5.56–8.89)	(6.01–10.1)	(6.41–11.4)	(7.01–13.2)	(7.47–14.5)
10-day	**3.92**	**4.42**	**5.24**	**5.95**	**6.95**	**7.74**	**8.55**	**9.4**	**10.5**	**11.4**
	(3.28–4.71)	(3.69–5.31)	(4.36–6.32)	(4.93–7.20)	(5.60–8.62)	(6.11–9.70)	(6.55–10.9)	(6.94–12.2)	(7.52–14.0)	(7.96–15.4)
20-day	**5.47**	**6.07**	**7.05**	**7.86**	**8.98**	**9.83**	**10.7**	**11.6**	**12.7**	**13.6**
	(4.59–6.53)	(5.09–7.25)	(5.90–8.44)	(6.54–9.44)	(7.26–11.0)	(7.80–12.2)	(8.23–13.5)	(8.58–14.9)	(9.12–16.8)	(9.52–18.1)
30-day	**6.75**	**7.47**	**8.61**	**9.54**	**10.8**	**11.7**	**12.6**	**13.6**	**14.7**	**15.6**
	(5.68–8.03)	(6.28–8.88)	(7.23–10.3)	(7.97–11.4)	(8.74–13.1)	(9.32–14.5)	(9.76–15.9)	(10.1–17.4)	(10.6–19.3)	(11.0–20.7)
45-day	**8.35**	**9.24**	**10.7**	**11.8**	**13.2**	**14.3**	**15.3**	**16.3**	**17.5**	**18.3**
	(7.05–9.89)	(7.80–11.0)	(8.96–12.7)	(9.86–14.0)	(10.7–16.0)	(11.4–17.5)	(11.8–19.1)	(12.1–20.7)	(12.6–22.7)	(13.0–24.3)
60-day	**9.69**	**10.8**	**12.4**	**13.7**	**15.4**	**16.6**	**17.7**	**18.7**	**19.9**	**20.8**
	(8.20–11.4)	(9.10–12.7)	(10.5–14.7)	(11.5–16.3)	(12.5–18.5)	(13.2–20.2)	(13.7–22.0)	(14.0–23.7)	(14.4–25.9)	(14.7–27.5)

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

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

Please refer to NOAA Atlas 14 document for more information.

Appendix B Calibrated Island Lake BATHTUB Model

File: X:\Clients\Koochiching County SWCD\Big Fork WRAPS\6.5_TMDLs\Modeling\Bathtub\Island_existing_updated_SSTS.btb

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3,"EVAPORATION (METERS)",.7366,.3
4,"INCREASE IN STORAGE (METERS)",0,0
12,"Model Options"
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3,"NITROGEN BALANCE",0
4,"CHLOROPHYLL-A",2
5,"SECCHI DEPTH",1
6,"DISPERSION",1
7,"PHOSPHORUS CALIBRATION",1
8,"NITROGEN CALIBRATION",1
9,"ERROR ANALYSIS",1
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
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2,"P DECAY RATE",1,.45
3,"N DECAY RATE",1,.55
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5,"SECCHI MODEL",1.3,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",.33,0
15,"Avail Factor - Ortho P",1.93,0
16,"Avail Factor - TN",.59,0
17,"Avail Factor - Inorganic N",.79,0
5,"Atmospheric Loads"
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1,"MOD-V MG/M3-DAY",0,0,1,0
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7,"TOTAL N",0,0
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"Notes"
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Appendix C BATHTUB Output

Table C-1. Existing Conditions Overall Mass Balance

File: X:\Clients\Koochiching County SWCD\Big Fork WRAPS\6.5_TMDLs\Modeling\Bathtub\Island_existing_updated_SSTS.btb

Overall Water & Nutrient Balances										
Overall Water Balance						**Averaging Period = 1.00 years**				
Trb	**Type**	**Seg**	**Name**	**Area (km²) (mi²)**	**Flow (hm³/yr) (ac-ft/yr)**	**Variance (hm3/yr)² (ac-ft/yr)²**	**CV -**	**Runoff (m/yr) (in/yr)**		
1	1	1	Lakeshed	29.9 (11.5)	4.9 (3,989)	0.45 (298,722)	0.14	0.16 (6.4)		
2	1	1	Septics		0.003 (2)	0 (0)	0.00			
PRECIPITATION				12.6 (4.9)	7.9 (6,470)	0.18 (117,588)	0.05	0.63 (24.8)		
TRIBUTARY INFLOW				29.9 (11.5)	4.9 (3,992)	0.45 (298,722)	0.14	0.16 (6.4)		
***TOTAL INFLOW				42.5 (16.4)	12.8 (10,462)	0.62 (416,310)	0.06	0.3 (11.9)		
ADVECTIVE OUTFLOW				42.5 (16.4)	3.5 (2,886)	8.35 (5,581,377)	0.82	0.08 (3.3)		
***TOTAL OUTFLOW				42.5 (16.4)	3.5 (2,886)	8.35 (5,581,377)	0.82	0.08 (3.3)		
***EVAPORATION					9.3 (7,576)	7.73 (5,165,058)	0.30			
Overall Mass Balance Based Upon Component:						**Outflow and Reservoir Concentrations**				
Trb	**Type**	**Seg**	**Name**	**Predicted Total P Load (kg/yr) (lb/yr)**	**Total (%)**	**Load Variance (kg/yr)²(lb/yr)²**	**Total (%)**	**CV**	**Conc (mg/m³)**	**Export (kg/km²/yr) (lb/ac/yr)**
1	1	1	Lakeshed	369.6 (814.9)	22.9%	2,806 (13,636)	1.1%	0.14	75.8	12.4 (0.11)
2	1	1	Septics	30.2 (66.7)	1.9%	0 (0)		0.00	10000.0	
PRECIPITATION				242.8 (535.2)	15.0%	14,733 (71,606)	5.8%	0.50	30.7	19.3 (0.172)
INTERNAL LOAD				974 (2,147.2)	60.2%	237,146 (1,152,618)	93.1%	0.50		
TRIBUTARY INFLOW				399.9 (881.6)	24.7%	2,806 (13,636)	1.1%	0.13	81.9	13.4 (0.119)
***TOTAL INFLOW				1,616.6 (3,564)	100.0%	254,683 (1,237,854)	100.0%	0.31	126.3	38.1 (0.34)
ADVECTIVE OUTFLOW				123.3 (271.8)	7.6%	11,854 (57,617)		0.88	34.934.9	2.9
***TOTAL OUTFLOW				123.3 (271.8)	7.6%	11,854 (57,617)		0.88	34.9	2.9 (0.026)
***RETENTION				1,493.3 (3,292.2)	92.4%	242,030 (1,176,354)		0.33		
	Overflow Rate (m/yr) (in/yr)			0.3 (11)		Nutrient Resid. Time (yrs)			1.2330	
	Hydraulic Resid. Time (yrs)			16.1705		Turnover Ratio			0.8	
	Reservoir Conc (mg/m³)			35		Retention Coef.			0.924	

Table C-2. Existing Conditions: Predicted Versus Observed

File: X:\Clients\Koochiching County SWCD\Big Fork WRAPS\6.5_TMDLs\Modeling\Bathtub\Island_ existing_updated_SSTS.btb

Predicted and Observed Values Ranked Against CE Model Development Dataset						
Segment: 1 Island Lake						
	Predicted Values			Observed Values		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	34.9	0.45	36.3%	34.9	0.07	36.2%
CHL-A MG/M3	16.2	0.47	76.1%	16.2	0.15	76.1%
SECCHI M	2.7	0.42	88.4%	2.7	0.04	88.4%
ORGANIC N MG/M3	532.8	0.35	59.1%			
TP-ORTHO-P MG/M3	26.7	0.53	45.1%			
ANTILOG PC-1	167.4	0.82	38.6%	167.1	0.15	38.5%
ANTILOG PC-2	19.1	0.13	98.1%	19.1	0.11	98.1%
TURBIDITY 1/M	0.1	0.78	1.1%	0.1	0.78	1.1%
ZMIX * TURBIDITY	0.4	0.79	0.3%	0.4	0.79	0.3%
ZMIX / SECCHI	1.7	0.42	3.8%	1.7	0.13	3.8%
CHL-A * SECCHI	43.4	0.19	98.0%	43.4	0.16	98.0%
CHL-A / TOTAL P	0.5	0.28	91.3%	0.5	0.16	91.2%
FREQ(CHL-a>10) %	68.1	0.40	76.1%	68.0	0.12	76.1%
FREQ(CHL-a>20) %	25.8	0.96	76.1%	25.8	0.30	76.1%
FREQ(CHL-a>30) %	9.6	1.35	76.1%	9.6	0.44	76.1%
FREQ(CHL-a>40) %	3.9	1.65	76.1%	3.9	0.54	76.1%
FREQ(CHL-a>50) %	1.7	1.89	76.1%	1.7	0.62	76.1%
FREQ(CHL-a>60) %	0.8	2.10	76.1%	0.8	0.69	76.1%
CARLSON TSI-P	55.4	0.12	36.3%	55.4	0.02	36.2%
CARLSON TSI-CHLA	57.9	0.08	76.1%	57.9	0.03	76.1%
CARLSON TSI-SEC	45.8	0.13	11.6%	45.8	0.01	11.6%

Table C-3. Proposed Conditions: Overall Mass Balances

File: X:\Clients\Koochiching County SWCD\Big Fork WRAPS\6.5_TMDLs\Modeling\Bathtub\Island_proposed_updated_SSTS_FINAL.btb

Overall Water & Nutrient Balances										
Overall Water Balance						**Averaging Period = 1.00 years**				
Trb	**Type**	**Seg**	**Name**	**Area (km²) (mi²)**	**Flow (hm³/yr) (ac-ft/yr)**	**Variance (hm3/yr)² (ac-ft/yr)²**	**CV**	**Runoff (m/yr) (in/yr)**		
1	1	1	Lakeshed	29.9 (11.5)	4.9 (3,989)	0.45 (298,722)	0.14	0.16 (6.4)		
2	1	1	Septics		0.003 (2)	0 (0)	0.00			
PRECIPITATION				12.6 (4.9)	7.9 (6,470)	0.18 (117,588)	0.05	0.63 (24.8)		
TRIBUTARY INFLOW				29.9 (11.5)	4.9 (3,992)	0.45 (298,722)	0.14	0.16 (6.4)		
***TOTAL INFLOW				42.5 (16.4)	12.8 (10,462)	0.62 (416,310)	0.06	0.3 (11.9)		
ADVECTIVE OUTFLOW				42.5 (16.4)	3.5 (2,886)	8.35 (5,581,377)	0.82	0.08 (3.3)		
***TOTAL OUTFLOW				42.5 (16.4)	3.5 (2,886)	8.35 (5,581,377)	0.82	0.08 (3.3)		
***EVAPORATION					9.3 (7,576)	7.73 (5,165,058)	0.30			
Overall Mass Balance Based Upon Component:						**Outflow and Reservoir Concentrations**				
Trb	**Type**	**Seg**	**Name**	**Predicted Total P Load (kg/yr) (lb/yr)**	**Total (%)**	**Load Variance (kg/yr)²(lb/yr)²**	**Total (%)**	**CV**	**Conc (mg/m³)**	**Export (kg/km²/yr) (lb/ac/yr)**
1	1	1	Lakeshed	244 (537.8)	20.5%	1,222 (5,939)	0.9%	0.14	50.0	8.2 (0.073)
2	1	1	Septics	22.7 (50)	1.9%	0 (0)		0.00	7,500.0	
PRECIPITATION				242.8 (535.2)	20.4%	14,733 (71,606)	11.2%	0.50	30.7	19.3 (0.172)
INTERNAL LOAD				679.9 (1,499)	57.2%	115,576 (561,740)	87.9%	0.50		
TRIBUTARY INFLOW				266.6 (587.8)	22.4%	1,222 (5,939)	0.9%	0.13	54.6	8.9 (0.08)
***TOTAL INFLOW				1,189.3 (2,622)	100.0%	131,531 (639,287)	100.0%	0.30	93.0	28 (0.25)
ADVECTIVE OUTFLOW				103.2 (227.5)	8.7%	8,121 (39,470)		0.87	29.2	2.4 (0.022)
***TOTAL OUTFLOW				103.2 (227.5)	8.7%	8,121 (39,470)		0.87	29.2	2.4 (0.022)
***RETENTION				1,086.1 (2,394.5)	91.3%	125,227 (608,651)		0.33		
	Overflow Rate (m/yr)			0.3 (0.11)		Nutrient Resid. Time (yrs)			1.4030	
	Hydraulic Resid. Time (yrs)			16.2		Turnover Ratio			0.7	
	Reservoir Conc (mg/m³)			29		Retention Coef.			0.913	

Appendix D Minnesota Lake Eutrophication Analysis Procedure Summary

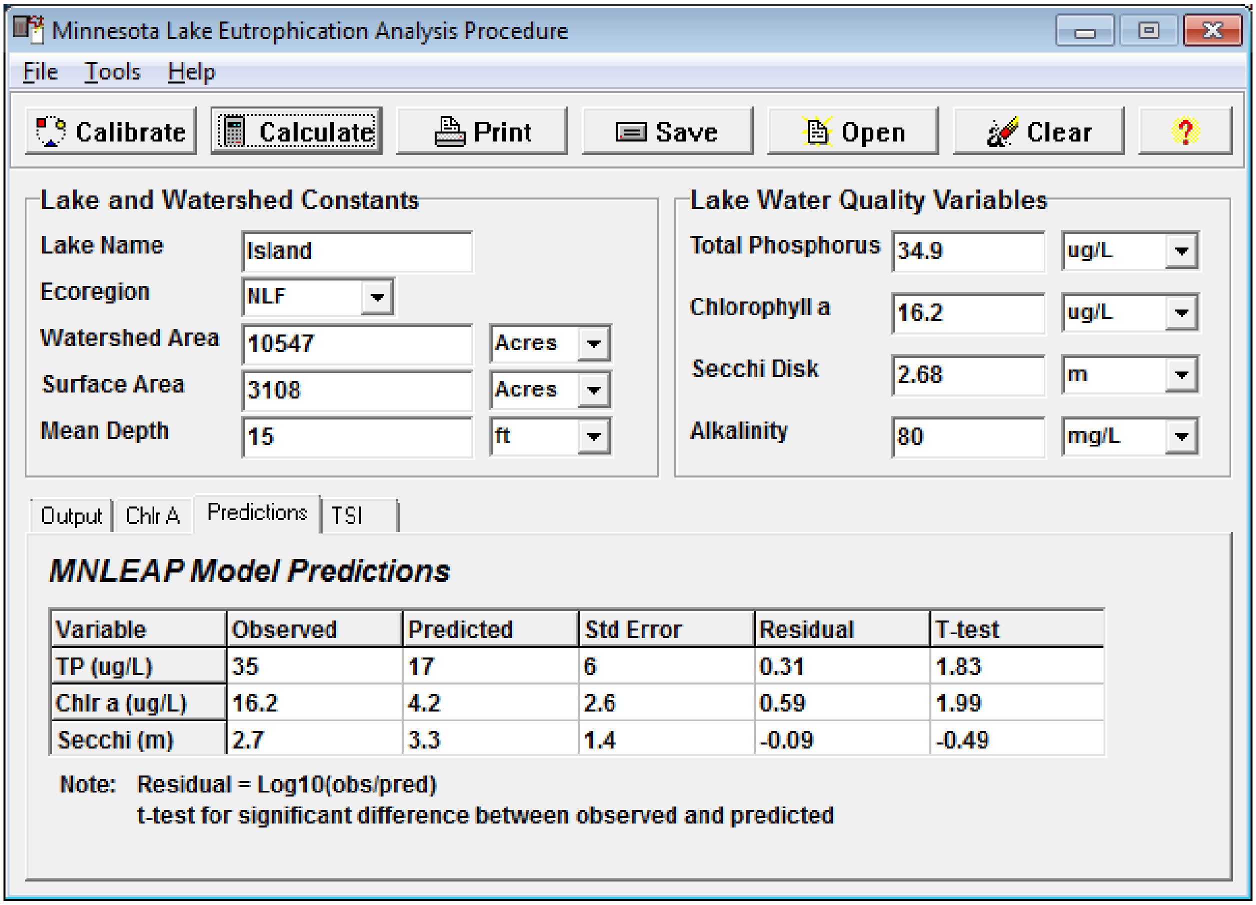

Figure D- 1. MINLEAP Summary for Island Lake.