Final Rum River Watershed Total Maximum Daily Load

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TMDL Summary Table

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Acronyms

AF	Anoxic factor
AFO(s)	Animal Feeding Operations
AUID	Assessment Unit Identification
BMP	Best management practices
BOD	Biochemical oxygen demand
CAFO(s)	Concentrated Animal Feeding Operation(s)
CBOD	Carbonaceous biochemical oxygen demand
cfu	colony-forming unit
Chl-*a*	Chlorophyll-*a*
CV	Coefficient of variation
CWA	Clean Water Act
CWLA	Clean Water Legacy Act
DNR	Minnesota Department of Natural Resources
EPA	Environmental Protection Agency
EQuIS	Environmental Quality Information System
GR	Geometry ratio
HSG	Hydrologic Soil Groups
in/yr	inches per year
km^2	square kilometer
LA	Load allocation
lb	pound
lb/day	pounds per day
lb/yr	pounds per year
LDC	Load duration curves
LID	Low-impact development
LiDAR	Light Detection and Ranging
m	meter
mg/L	milligrams per liter
MIDS	Minimal Impact Design Standards
MINLEAP	Minnesota Lake Eutrophication Analysis Procedure

mL	milliliter
MnDOT	Minnesota Department of Transportation
MOS	Margin of safety
MPCA	Minnesota Pollution Control Agency
MRCC	Midwestern Regional Climate Center
MS4	Municipal Separate Storm Sewer Systems
NBOD	Nitrogenous biochemical oxygen demand
NCHF	North Central Hardwood Forest
NHD	National Hydrology Dataset
NLF	Northern Lakes and Forest
NOAA	National Oceanic and Atmospheric Administration
NOD	Nitrogenous oxygen demand
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Services
P	phosphorus
RR	Release rates
RRW	Rum River Watershed
SDD	Secchi disc depth
SDS	State Disposal System
SOD	Sediment Oxygen Demand
SSTS	Subsurface sewage treatment systems
SWCD	Soil and water conservation districts
SWPPP	CHECK TEXT / EXISTING GLOSSARY FOR DEFINITION
TMDL	Total Maximum Daily Load
TP	Total phosphorus
TSI	Trophic State Index
µg/L	microgram per liter
WLA	Wasteload allocations
WRAPS	Watershed Restoration and Protection Strategy
WWTF	Wastewater Treatment Facility

Executive Summary

This Total Maximum Daily Load (TMDL) study was completed for impaired waterbodies of the Rum River Watershed (Hydrologic Unit Code [HUC] 07010207), which enters the Mississippi River at Anoka, Minnesota, and is part of the Lake Pepin Watershed. Portions of the Rum River were added to Minnesota's Wild and Scenic Rivers Program in 1978 with different Rum River mainstem segments being classified as wild, scenic, or recreational. The study addresses five river/stream-reach bacteria impairments, one river/stream-reach dissolved oxygen (DO) impairment, and eleven lake nutrient impairments. The goal of this TMDL is to quantify the pollutant reductions needed to meet the state water quality standards for DO, bacteria (*E. coli*), and nutrients (phosphorus [P]) for impaired streams and lakes located in the Rum River Watershed (RRW).

TMDLs described herein were primarily derived from output of the Hydrologic Simulation Program-Fortran (HSPF) model that was developed for the entire RRW. This model incorporated available flows (1996 through 2015), monitored water quality, and the latest land cover data of 2013 [Lupo, 2016a; 2016b; 2016c]. HSPF-estimated runoff and pollutant characterizations were employed to assess TMDLs for stream DO, stream bacteria (*E. coli*), and lake nutrient loads. HSPF-generated flows and outputs were used to establish load duration curves (LDCs) for five stream-reach bacteria impairments, with wasteload allocations (WLAs) and load allocations (LAs) established for five flow duration curve categories: Very high, high, mid, low, and very low-flow conditions.

Reductions required to achieve state bacteria standards range from 0% to 93% by TMDL duration curve category. For DO impairments, oxygen-demanding pollutants were systematically reduced throughout the impaired reach until the 5.0 milligram per liter (mg/L) DO standard was achieved. To meet the 5.0 mg/L DO standard 95% of the time, a 50% reduction of oxygen-demanding pollutants was required.

Lake average annual income-outgo P budgets were developed from HSPF-modeled flows and P loadings, and corresponding in-lake monitoring data were incorporated into the widely used lake-response model BATHTUB. Internal release of P was evaluated and explicitly incorporated as determined by a collective weight-of-evidence approach on a lake-by-lake basis. Lake assimilative capacity is strongly influenced by lake depth with seven of the lakes being evaluated as shallow and three lakes assessed as deep lakes. P reductions required to achieve shallow-lake standards ranged from a low of 10% to a high of 86%, and for deep lakes, P reductions ranged from 21% to 39%.

Lake rehabilitation actions should focus on reducing P sources by relying on the spectrum of agricultural and urban stormwater source controls, as well as rate and volume control (infiltration) practices. Based on HSPF modeling, elevated dissolved P loadings should receive high priority for phased implementation actions to directly reduce algal generation and internal loading potentials. As wetlands have generally lower P assimilative capacities than lakes, upgradient wetland complexes should be evaluated for the growing seasons internal P loading and release to downstream waterbodies. Offsetting effects of legacy loading and historical channelization to wetlands will require examining rehabilitation options. Subsequent to substantial reductions of lake watershed P sources, lakes with internal loading allocations (particularly Francis, Long, East Hunter, North Stanchfield and Baxter) should be reevaluated for lake-sediment treatments, such as aluminum sulfate (alum) or ferric chloride and oxygenation of bottom waters. Winter aeration to reduce winter fish kills should be considered, as guided by Minnesota Department of Natural Resources (DNR) Fisheries managers. Rum River and tributary backwatering of lakes during high-flow conditions need to be considered as impacts to water levels, nutrient loading, and fisheries.

Restoring water quality will continue to be aided by the interdependent and cooperative efforts of the RRW communities, counties, state, and federal partners via leveraged management actions phased over budgetary cycles in regard to the largest pollutant sources. Because this TMDL report's reductions are primarily focusing on impaired waters of the middle and lower Rum River areas, phased approaches beginning in headwaters of impaired stream reaches and lake areas (continuing downstream) may result in measurable changes being more quickly detected. Improving upgradient lakes will help improve the quality of downstream lakes. Of the best management practices (BMPs), widespread adoption of buffers and streambank stabilization should proceed as a high priority and will assist in reducing bacteria, organic matter linked to reduced DO, and nutrients (particularly P). Dominant bacterial sources have been identified by impaired stream and by flow pattern that will help prioritize and guide implementation by agricultural producers in municipal storm sewer system (MS4) areas. Reducing general system oxygen demand from excess sediments and organic matter will occur via cumulative implementation, beginning with adopting buffers. Legacy sources may have impacted low assimilative capacity wetlands and will require further characterization assessments. Looking ahead, anticipated shifts in land uses to more intense urban development and agriculture with corresponding increases in artificial drainage practices may present additional runoff volume and quality challenges within the basin.

Subtle north-south climate gradients were noted across the RRW, as defined by storm precipitation intensities and durations, annual precipitation, evaporation, and frost-free periods with higher levels of tracking in the southern part of the basin. Populations also increase along the north-to-south gradient. Storm rainfall amounts for the typical 24-hour storm and multiday wet periods can be substantial with potential wide-ranging negative impacts to communities and agricultural producers, as well as the receiving streams, lakes, wetlands, and associated aquatic habitats. Collectively, this report's dry- and wet-cycle characterizations may aid in considering BMP design factors for wet periods, and augmenting storage and retention practices for dry periods to increase stream-base flows and reuse (irrigation).

While the impaired waterbodies lie primarily in Mille Lacs, Isanti, Sherburne, and Anoka Counties, contributing portions of the impaired waterbody watersheds extend into upgradient areas of Morrison, Benton, Kanabec, and Chisago Counties. Hence, future implementation strategies to improve and protect local waters and those downstream will require continued close cooperative efforts of all of the RRW Counties, Mille Lacs Band of Ojibwe, and local units of government. The findings from this TMDL study will be used to assist in selecting the implementation and monitoring activities as part of the RR WRAPS process. The Rum River WRAPS team has conducted quarterly meetings to actively guide the WRAPS project since early 2014. The purpose of the WRAPS report is to support these local working groups and jointly develop scientifically supported restoration and protection strategies for subsequent implementation planning. Following completion, the WRAPS report will be publically available on the Minnesota Pollution Control Agency (MPCA) website.

1 Project Overview

1.1 Purpose

This TMDL study addresses five river/stream-reach Escherichia coli bacteria (*E. coli*) impairments, one river/stream-reach DO, and 10 lake nutrient (P) impairments of the RRW. While the impaired waterbodies lie primarily in Mille Lacs, Isanti, Sherburne, and Anoka Counties, contributing portions of their watersheds extend into corresponding areas of Morrison, Kanabec, and Chisago Counties. Hence, the Watershed Restoration and Protection Strategy (WRAPS) process needs to synchronize future restoration activities among the Rum River Basin Counties.

The goal of this TMDL report is to quantify the pollutant reductions needed to meet the state water quality standards for bacteria and DO for the stream reaches and P for the lakes listed in Table 1-1. This TMDL study is established in accordance with Section 303(d) of the Clean Water Act (CWA) and defines WLAs, LAs, and pollutant reductions needed to achieve state water quality standards.

Several impaired reaches and lakes are not addressed in this TMDL. Unaddressed impairments are listed in Table 1-2. The reasons for not addressing vary by impairment. Aquatic macroinvertebrate and fish bioassessment impairments were not addressed because of insufficient stressor data during TMDL development. The nutrient-impaired lakes were put on a hold status because of shallow depths and other unresolved determinations. The DO impairments were recently added and will be addressed in subsequent watershed assessment and restoration activities.

Table 1-1. Water Quality Impairments Addressed

Name	Lake/ Stream	ID	Proposed Use Subclass	Pollutant of Concern	Year Listed
Baxter	Lake	30011400	2B, 3C	Nutrients	2015
East Hunter	Lake	71002300	2B, 3C	Nutrients	2015
Fannie	Lake	30004300	2B, 3C	Nutrients	2013
Francis	Lake	30008000	2B, 3C	Nutrients	2013
Green	Lake	30013600	2B, 3C	Nutrients	2013
Long	Lake	30007200	2B, 3C	Nutrients	2015
North Stanchfield	Lake	30014300	2B, 3C	Nutrients	2015
Skogman	Lake	30002200	2B, 3C	Nutrients	2013
South Stanchfield	Lake	30013800	2B, 3C	Nutrients	2015
West Hunter	Lake	71002200	2B, 3C	Nutrients	2015
Bogus Brook	Stream	07010207-523	2Bg, 3C	*E. coli*	2015
Cedar Creek	Stream	07010207-521	2Bg, 3C	*E. coli*	2015
Estes Brook	Stream	07010207-679	2Bg, 3C	*E. coli*	2015
Seelye Brook	Stream	07010207-528	2Bg, 3C	*E. coli*	2015
West Branch Rum River	Stream	07010207-525	2Bg, 3C	*E. coli*	2015
Trott Brook	Stream	07010207-680	2Bg, 3C	Dissolved Oxygen	2015

Table 1-2. Water Quality Impairments Not Addressed

Name	Lake/ Stream	ID	Proposed Use Subclass	Pollutant of Concern	Year Listed
Tennyson	Stream	30011300	2B, 3C	Nutrients	2015
Twelve	Stream	49000600	2B, 3C	Nutrients	2015
Little Stanchfield	Stream	30004400	2B, 3C	Nutrients	2015
Francis	Lake	30008000	2B, 3C	Fish bioassessments	2015
Green	Lake	30013600	2B, 3C	Fish bioassessments	2015
Borden Creek	Stream	07010207-554	2Bg, 3C	Dissolved Oxygen	2013
Cedar Creek (Little River)	Stream	07010207-546	2Bg, 3C	Dissolved Oxygen	2013
Crooked Brook	Stream	07010207-575	2Bg, 3C	Dissolved Oxygen	2013
Malone Creek (Thains Creek)	Stream	07010207-547	2Bg, 3C	Dissolved Oxygen	2013
Estes Brook	Stream	07010207-679	2Bg, 3C	Aquatic macroinvertebrate bioassessments	2015
Isanti Brook	Stream	07010207-592	2Bg, 3C	Aquatic macroinvertebrate bioassessments	2015
Isanti Brook	Stream	07010207-592	2Bg, 3C	Fish bioassessments	2015
Mahoney Brook	Stream	07010207-682	2Bg, 3C	Fish bioassessments	2015
West Branch Rum River	Stream	07010207-525	2Bg, 3C	Aquatic macroinvertebrate bioassessments	2015
Stanchfield Creek	Stream	07010207-520	2Bg, 3C	Fish bioassessments	2015
Tibbets Brook	Stream	07010207-676	2Bm, 3C	Fish bioassessments	2015
Tibbets Brook	Stream	07010207-677	2Bg, 3C	Aquatic macroinvertebrate bioassessments	2015
Trott Brook	Stream	07010207-680	2Bg, 3C	Fish bioassessments	2015
Trott Brook	Stream	07010207-680	2Bg, 3C	Aquatic macroinvertebrate bioassessments	2015
Unnamed Creek	Stream	07010207-667	2Bg, 3C	Aquatic macroinvertebrate bioassessments	2015
Vondell Brook	Stream	07010207-567	2Bg, 3C	Fish bioassessments	2015
Vondell Brook	Stream	07010207-687	2Bg, 3C	Fish bioassessments	2015
Washburn Brook	Stream	07010207-641	2Bm, 3C	Fish bioassessments	2015

Section 303(d) of the CWA and the U.S. Environmental Protection Agency (EPA) Water Quality Planning and Management Regulations (40 CFR 130) require states to develop TMDLs for waterbodies that do not meet applicable water quality standards or guidelines to protect designated uses under technology-based controls. TMDLs specify the maximum pollutant load that a waterbody can receive and still meet water quality standards. Based on a calculation of the total allowable load, TMDLs allocate pollutant loads to sources and incorporate a margin of safety (MOS). TMDL pollutant load reduction goals for significant sources provide a scientific basis for restoring surface water quality by linking the development and implementation of control actions to attaining and maintaining water quality standards and designated uses.

Developing TMDLs for the RRW will provide a framework for the MPCA, other state and federal agencies, and county and tribal watershed managers upon which to base management decisions. TMDLs will also provide reasonable assurance that impairments will be addressed by continued BMP implementation, and that future impairments will be readily addressed with an in-place model and TMDL. Furthermore, outcomes from the TMDLs, such as increased implementation, will protect the designated uses of currently unimpaired waterbodies.

1.2 Identifying Waterbodies

The RRW is located in east-central Minnesota, as illustrated in Figure 1-1. At the time of this TMDL report preparation, the RRW contains 5 bacteria-impaired stream reaches, 5 DO-impaired reaches, 14 biologic-impaired reaches, and 15 nutrient-impaired lakes that are included in the draft 303(d) 2016 list of impaired waters submitted for EPA approval. Overall, 4 of the 5 DO impairments, the biologic impairments, and 4 of the 15 nutrient impairments are not addressed in this TMDL. This TMDL addresses aquatic recreational-use impairments from eutrophication (P) for 10 lakes and *E. coli* impairments of 5 stream reaches as well as aquatic life impairments from low DO noted for one stream reach. The 17 impairments addressed are described in Table 1-1. None of the drainage areas of impaired waterbodies addressed in this document contains Mille Lacs Band of Ojibwe tribal lands, as shown in Figure 1-1.

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

The quality of Class 2B surface waters shall be such as to permit the propagation and maintenance of a healthy community of cool- or warm-water sport or commercial fish and associated aquatic life, as well as their habitats. These waters shall be suitable for all kinds of aquatic recreation. This class of surface water is not protected as a source of drinking water.

The quality of Class 3C waters of the state shall be such as to permit their use for industrial cooling and transporting materials without a high degree of treatment being necessary to avoid severe fouling, corrosion, scaling, or other unsatisfactory conditions.

Applicable standards for Class 2B waters [Minnesota State Legislature 2008] are summarized in Section 2. Class 3C-related water quality standards (chlorides, hardness, and pH) are not impaired nor addressed in this TMDL.

1.3 Priority Ranking

The MPCA's projected schedule for TMDL completions, as defined in the draft 2016 303(d) Impaired Waters List submitted to the EPA, directly reflects Minnesota's priority ranking for this TMDL. Ranking criteria for scheduling TMDL projects include but are not limited to impairment impacts on public health and aquatic life; public value of the impaired water resource; likelihood of completing the TMDL in an expedient manner, including a strong base of existing data and restorability of the waterbody; technical capability and willingness locally to assist with the TMDL; and appropriate sequencing of TMDLs within a watershed or basin.

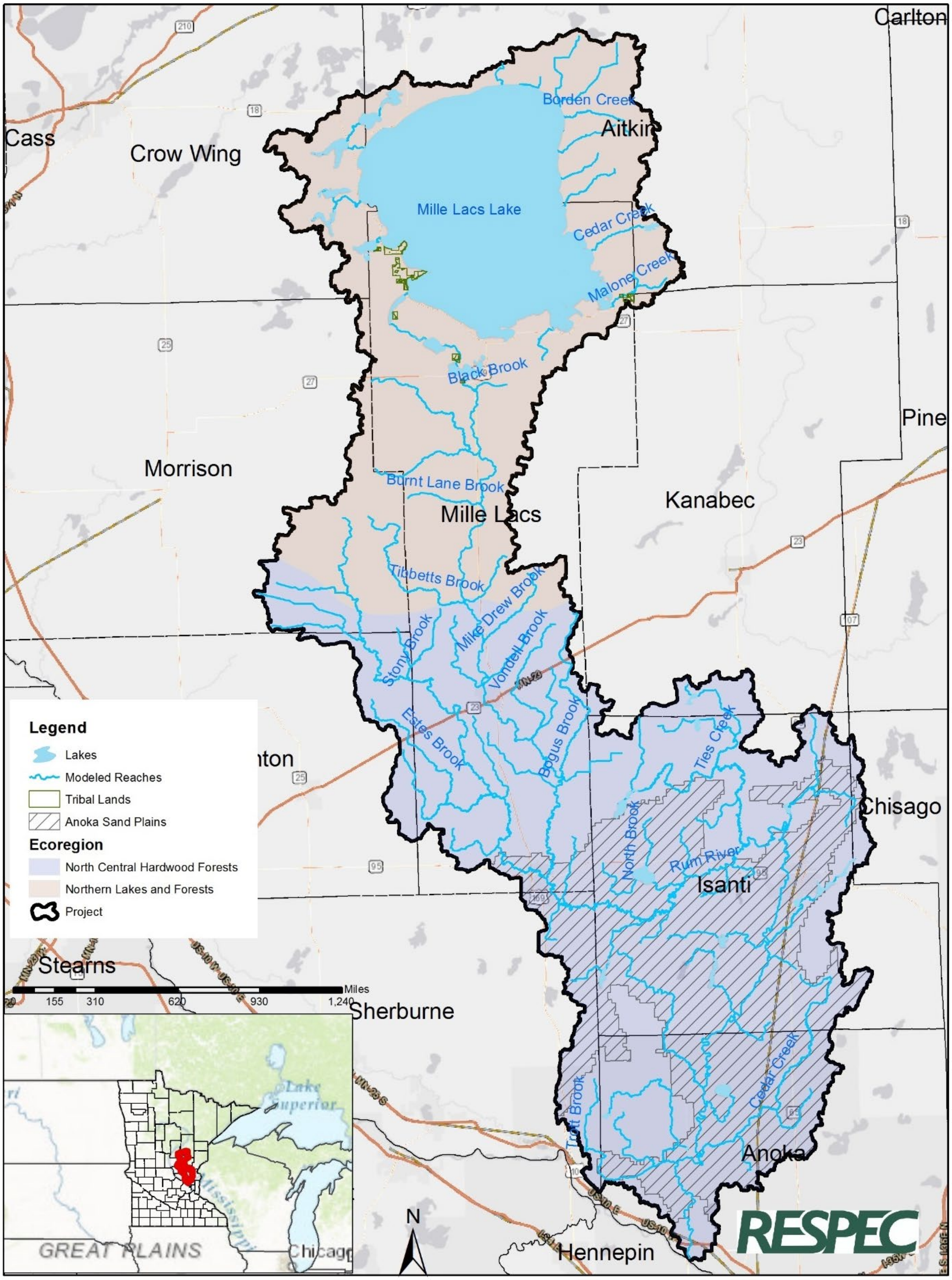


Figure 1-1. Rum River Watershed.

2 Applicable Water Quality Standards and Numeric Water Quality Targets

The Rum River Basin begins in the Northern Lakes and Forest (NLF) aquatic ecoregion from Lake Mille Lacs, with the majority of the basin located in the North Central Hardwood Forest (NCHF) ecoregion of central Minnesota. All of the impaired streams and lakes addressed in this TMDL are located in the NCHF ecoregion. Within the RRW, the recently adopted Minnesota River Nutrient Region boundaries align with the boundary between the NLF aquatic ecoregion and the NCHF ecoregion, with the North River Nutrient Region on the north side of the Watershed and the Central River Nutrient Region on the south side of the Watershed.

2.1 *E. coli* Bacteria

The Minnesota water quality rules [Minnesota State Legislature 2008] state that "*E. coli* bacteria shall not exceed 126 organisms per 100 milliliters (mL) as a geometric mean of not less than five samples representative of conditions within any calendar month, nor shall more than 10% of all samples taken during any calendar month individually exceed 1,260 organisms per 100 mLs. The standard applies only between April 1 and October 31."

2.2 Dissolved Oxygen

The Minnesota water quality rules [Minnesota State Legislature 2008] state that for 2B waters, the DO standard is "5 mg/L as a daily minimum. This DO standard may be modified on a site-specific basis according to Minn. R. 7050.0220, subp. 7, except that no site-specific standard shall be less than 5 mg/L as a daily average and 4 mg/L as a daily minimum. Compliance with this standard is required 50% of days at which the flow of the receiving water is equal to the $7Q_{10}$." Regional stream-nutrient standards were recently adopted in Minnesota and are listed in Table 2-1. DO flux was incorporated into these river nutrient standards.

Table 2-1. Northern River Nutrient Region Standards and Total Suspended Solids Standards

River Nutrient Region	TP (ppb)	Chl-*a* (ppb)	Diel Dissolved Oxygen (ppm)	Biochemical Oxygen Demand (ppm)
Northern	≤ 50	≤ 7	≤ 3.0	≤ 1.5
Central	≤ 100	≤ 18	≤ 3.5	≤ 2.0

ppb = parts per billion
ppm = parts per million

2.3 Nutrients (Phosphorus)

The Rum River Basin TMDL lakes described herein have been assigned 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…." Beneficial use Class 3 corresponds to industrial consumption [Minnesota State Legislature 2008]. Applicable NCHF lake eutrophication standards are listed in Table 2-2.

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

North Central Hardwood Forest	Total Phosphorus (ppb)	Chlorophyll-*a* (ppb)	Secchi Depth (m)
Deep Lakes	≤ 40	≤ 14	≥ 1.4 m
Shallow Lakes	≤ 60	≤ 20	≥ 1.0 m

ppb = parts per billion
m = meters

For a lake to be determined impaired, summer-average total phosphorus (TP) concentrations measured in the waterbody must show exceedances of the TP standard shown in Table 2-1 [Minnesota State Legislature 2008] along with one or both of the eutrophication response standards for Chlorophyll-*a* (Chl-*a*) and Secchi disk transparency (Secchi). Minnesota State Legislature [2008] 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 [Minnesota State Legislature 2008], the MPCA evaluated data from a large cross section of lakes within each of the state’s ecoregions [Minnesota Pollution Control Agency 2005]. Clear relationships were established between the causal factor TP and the response variables Chl-*a*, Secchi, or Secchi disc depth (SDD). Based on these relationships, the Chl-*a* and Secchi standards are expected to be met by meeting the TP target in each lake.

3 Watershed and Waterbody Characterization

3.1 Historical/Legacy Perspectives

The Rum River Basin's development has occurred over the past 175 years with most growth occurring over the last approximately 75 years. Following surveys of Rum River Basin in the late 1700s and early 1800s by early explorers (such as Joseph Nicollet, Jonathan Carver, and James Allen), later explorers came to this area in the 1840s in search of white pine [Lanegran 2008]. Timber crews followed the development of logging industry sawmills with the export of lumber occurring via river and roads. When Minnesota became a state in 1858, most of this area was sparsely settled and served by a few roads, which were built to serve military forts [Lanegran 2008]. One of these first government roads was built in about 1856 from the mouth of the Rum River to Mille Lacs Lake and passed through Princeton, Minnesota. Anoka County was formed in 1857 and named after the town of Anoka, which was first settled in 1851. The word "Anoka" is the Dakota word for "both sides" (i.e., settlement occurred on both sides of the Rum River). Isanti County, named after ancient Isanyati (a division of the Dakota or Sioux Nation) was established in 1857. Mille Lacs County was organized in 1857 and named for its prominent lake, Mille Lacs. Additional roads and railroads were developed in the Rum River Basin by the 1880s and connected sawmills and logging operations to markets. Widespread agricultural settlement followed the logging boom into the early 1900s with county townships being established. Dairying became a prominent agricultural mainstay, particularly around Princeton, Minnesota, from the early 1900s until the late 1970s [Upham 2001]. Since that time, industries and commerce have become well diversified throughout the Rum River Basin as evidenced by the diverse land covers monitored today. Looking ahead, anticipated shifts in land uses to more intense urban development and agriculture (with corresponding increases in artificial drainage practices) may present additional runoff volume and water quality challenges within the basin.

3.2 Demographic Growth Projections

Recent demographic projections (2015 through 2045) by the Minnesota State Demographic Center [Dayton 2014] indicate that the population will increase by approximately 14% averaged across the 10 Rum River Basin counties. Individual county projections vary considerably from a negative growth for Aitkin County (–14%) to positive growth expected for all of the other counties ranging from 9% (Crow Wing County) to 24% (Benton County) and 32% in Sherburne County. Projected population increases along the mainstem Rum River counties were 20%for Mille Lacs, 20% for Isanti, and 16% for Anoka County.

3.3 Climate

Basic climate data were reviewed to: (1) define typical seasonal and annual cycles affecting runoff and water quality, (2) identify wet and dry patterns affecting pollutant loading dynamics, (3) assist implementation design considerations, and (4) help inform future performance monitoring efforts. Included in this assessment are typical monthly temperature and precipitation information (normals), annual precipitation, frost-free season lengths, dry and wet periods, and average summer temperatures. Climate variability for the Rum River Basin was assessed by using available long-term data for sites from the Midwest Regional Climate Center, the DNR gridded precipitation, and National Oceanic and

Atmospheric Administration's (NOAA) databases summarized for east-central Minnesota (Climate Division 6). Few monitoring stations with long-term climate data exist across the Rum River Basin; hence, interpolated data from the DNR's gridded precipitation network and the NOAA's Climate Division data were evaluated. Monthly normal for Milaca, Minnesota (USC00215392), and Minneapolis, Minnesota (MSPthr 9), are presented as monthly average precipitation as well as maximum, average, and minimum temperatures for the 1981 through 2010 period in Figures 3-1 and 3-2, respectively.

Figure 3-1. Observed Monthly Climate Normals for Milaca, Minnesota (USC 00215392), From 1981 to 2010 [Midwestern Regional Climate Center 2015].

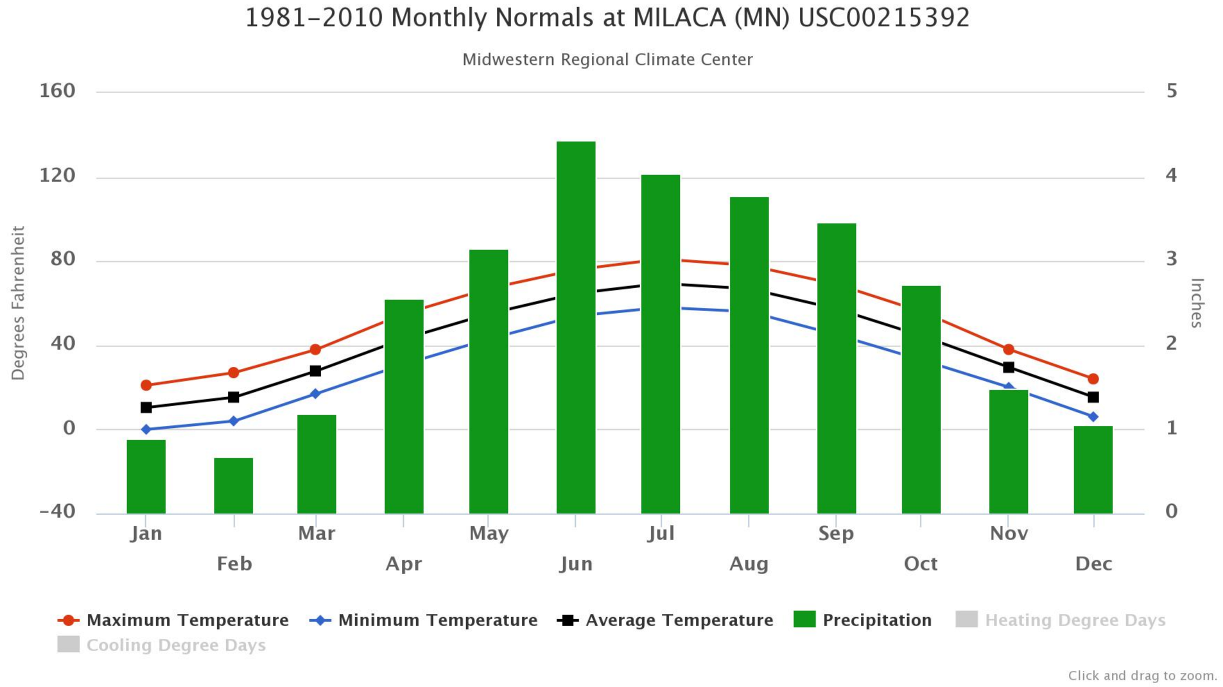
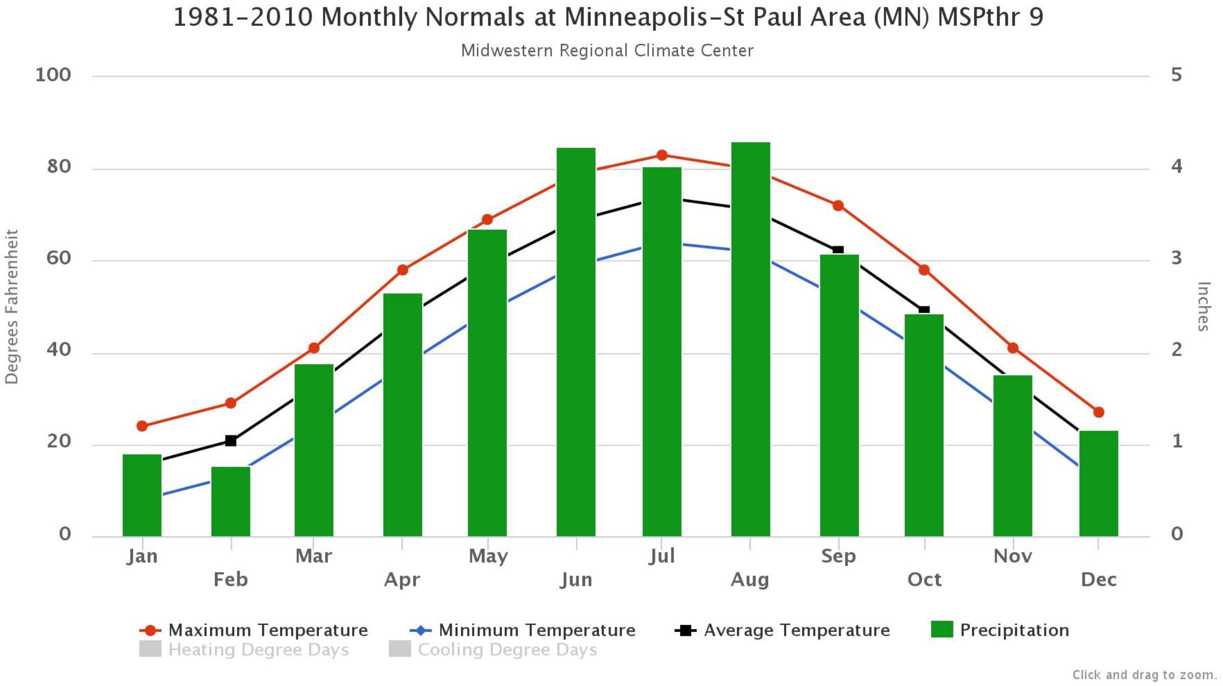


Figure 3-2. Observed Monthly Climate Normals for Minneapolis-St. Paul International Airport, Minnesota (USW 00014922), From 1981 to 2010 [Midwestern Regional Climate Center 2015].



Via the DNR's gridded precipitation network, the variability of annual precipitation across the basin was examined by using representative sites for the northern basin (Mille Lacs), central basin (Cambridge), and lower basin (Anoka), as shown in Figure 3-3. Annual precipitation has ranged from about 14 inches (1976) to nearly 45 inches [Cambridge 2002] across the basin, with generally similar annual precipitation patterns for Cambridge and Anoka and with generally lower annual totals for Mille Lacs. Over the TMDL time period (2006 through 2015), the annual precipitation average for the three basin sites was about 31.4 inches. These generalized average values differ from the more intensive precipitation station data from 1995 to 2015 used in developing the HSPF model for the Rum River Basin.

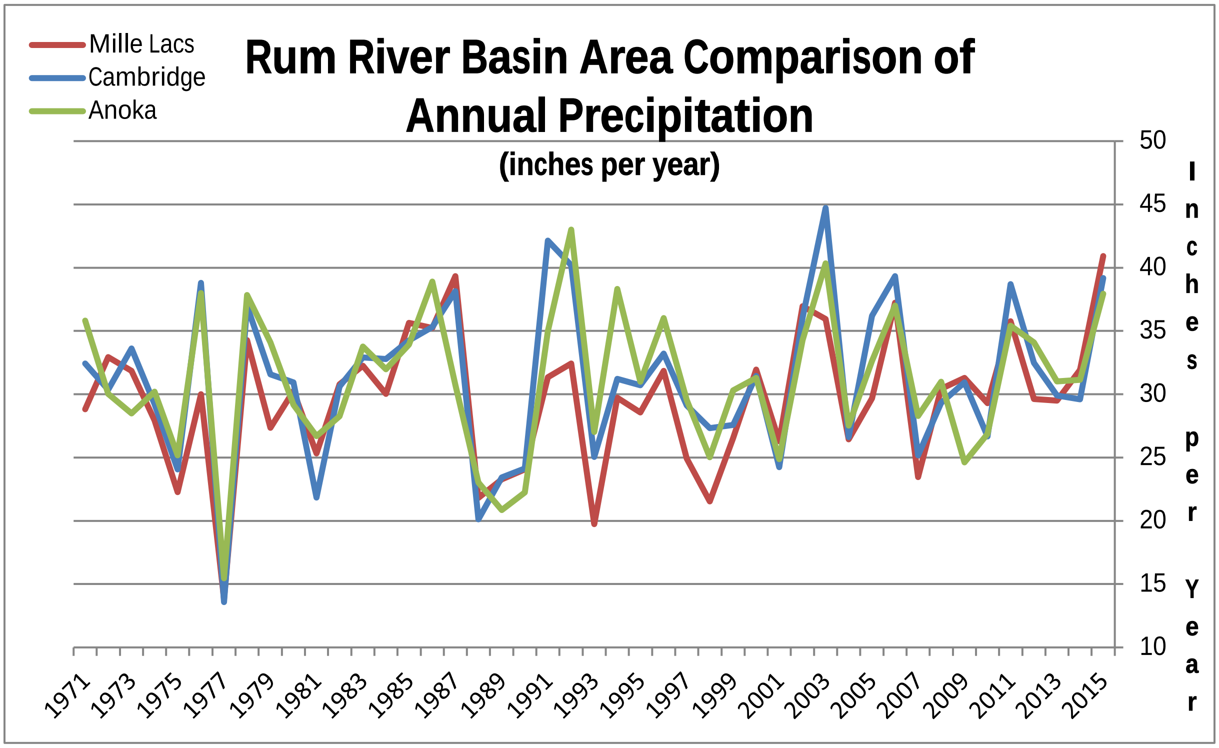


Figure 3-3. Comparison of Annual Precipitation (Inches) for Representative Sites of the North (Mille Lacs), Central (Cambridge), and Lower (Anoka) Rum River Basin [Minnesota Department of Natural Resources 2016].

A long-term overview (1895 through 2014) of annual precipitation variation and trends for Climate Division 6 covering east-central Minnesota, and dominated by the RRW, is depicted in Figure 3-4 from the NOAA's National Centers for Environmental Information [NOAA 2016a]. Using the smoothed time-series and rolling-averaged plots facilitates observation of longer periods of wet and dry precipitation patterns. From this data, considerable year-to-year variability in annual precipitation is evident, with a rolling pattern of multiyear averages noted by the smoothed binomial filter represented by the red line. A variable but generally increasing pattern of annual precipitation was noted since about 1990, particularly for the most recent years encompassing the TMDL study period (2006 through 2015).

Focusing on summer precipitation patterns, a similar NOAA plot for June through September is again presented for Climate Division 6 (east-central Minnesota) in Figure 3-5. In this figure, a long-term increase in growing-season precipitation was evident, but it was more muted than noted for annual precipitation and also quite variable. Over the TMDL period (2006 through 2015), growing-season precipitation ranged from about 11.25 inches to 21.55 inches with an average of approximately 14.9 inches. However, a similar NOAA plot of average growing-season temperatures, as depicted in Figure 3-6, showed a much larger increasing trend. Also discernable is a distinct increasing temperature pattern noted since about 1990 that encompassed the TMDL time period. On average, approximately 1.6 degrees warmer than the base period from 1901 to 2000 was noted.

Figure 3-4. Annual Precipitation for 1895–2014 From the National Oceanic and Atmospheric Administration [2016a] for Minnesota Climate Division 6.

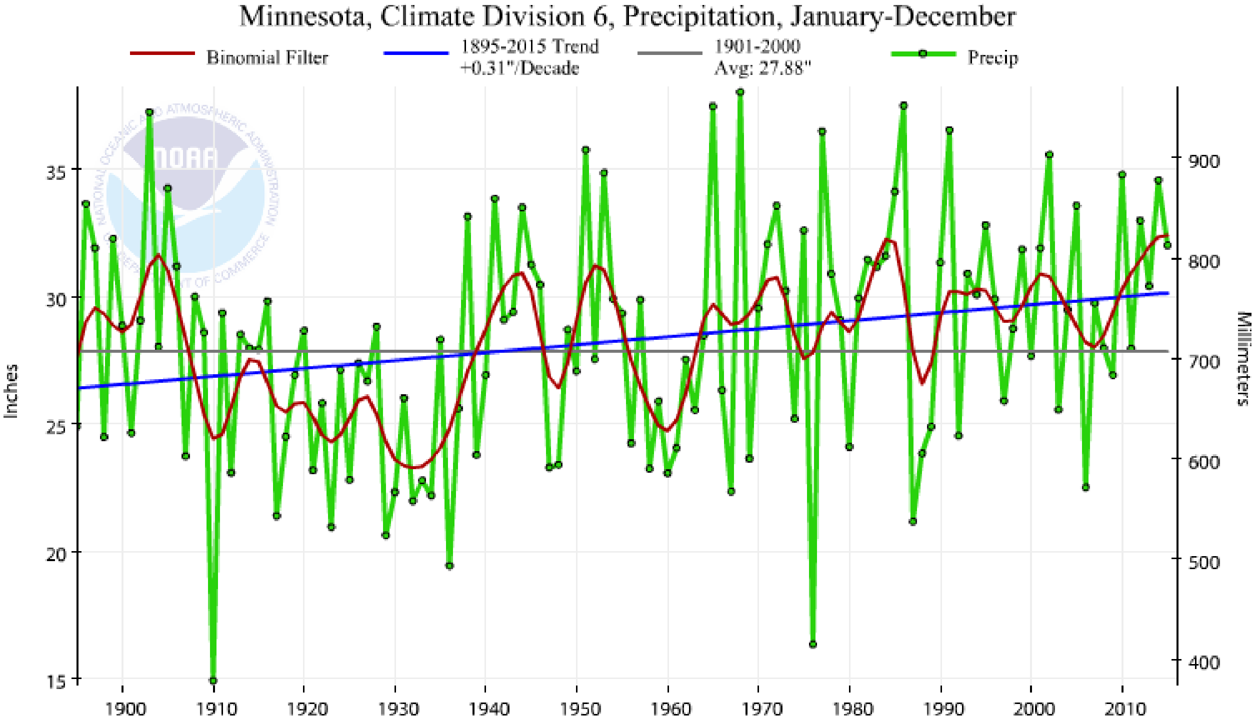


Figure 3-5. Growing-Season (June through September) Precipitation for 1895–2014 From the National Oceanic and Atmospheric Administration [2016a] for Minnesota Climate Division 6.

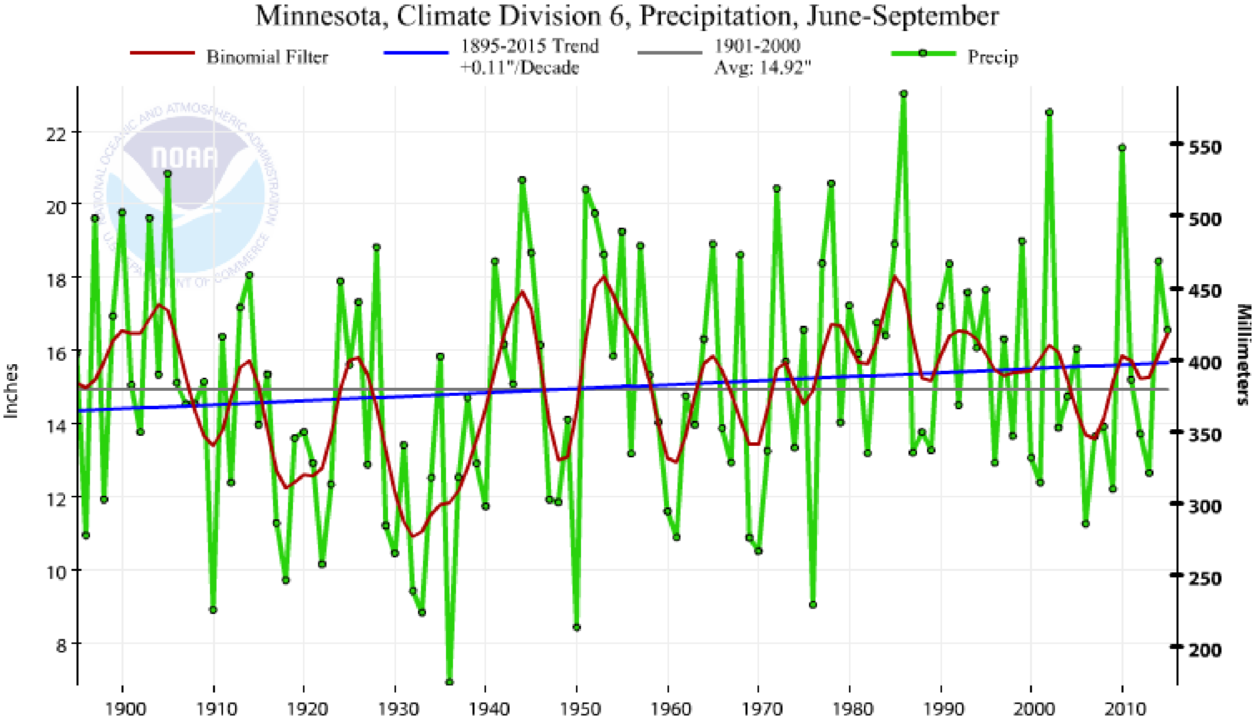
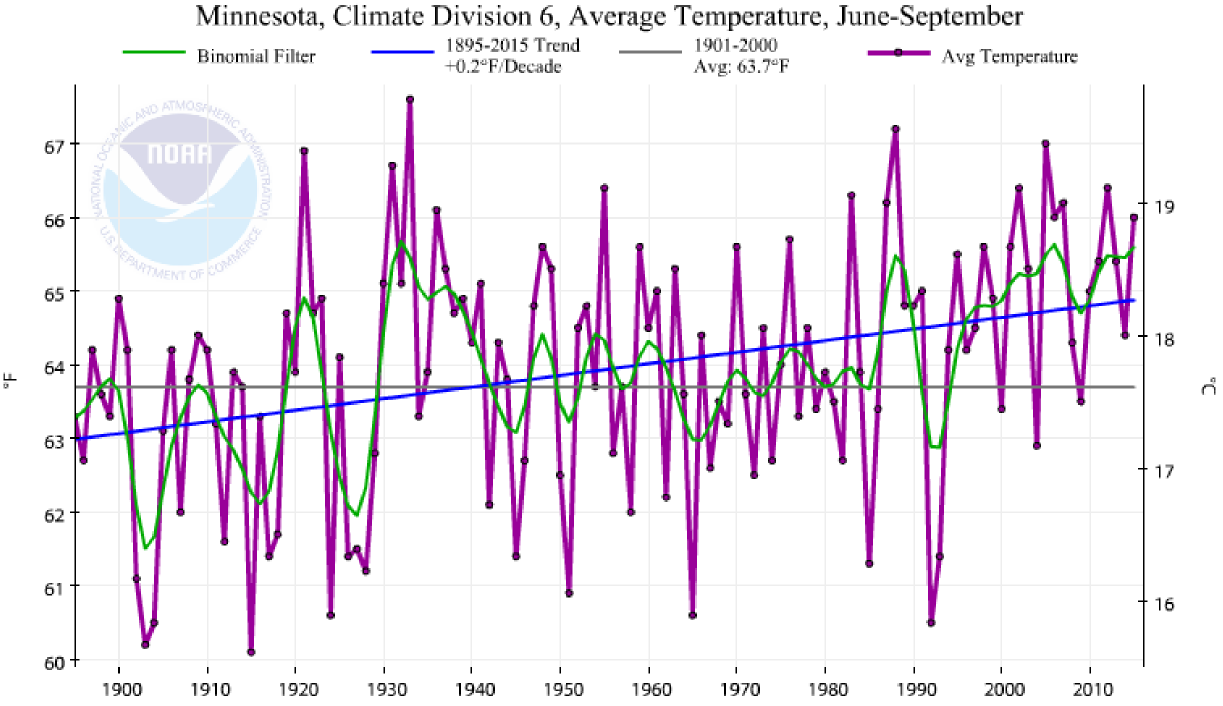


Figure 3-6. Growing-Season (June Through September) Temperature for 1895–2014 From the National Oceanic and Atmospheric Administration [2016a] for Minnesota Climate Division 6.



3.3.1 Characterization of Storm Events

NOAA, in cooperation with the MPCA, DNR State Climatology Office, and the Minnesota Department of Transportation (MnDOT), recently updated precipitation intensity and duration records for the entire state, which are referred to as Atlas 14. Storm-event totals, such as those reported in various media weather reports, are typically for 24-hour periods that have been summarized from data reported for stations representative of the north (Onamia), central (Cambridge), and lower (Anoka) reaches of the Rum River. A comparison of these 24-hour storm records that span the Rum River Basin is tabulated in Table 3-1, with increases in storm amounts noted from the northern basin (Onamia) to the central basin (Cambridge) and then to the lower basin (Anoka) across all recurrence intervals (1/1 year to 1/1,000 year occurrence). Back-to-back storms over several days often generate much larger totals associated with peak runoff events; therefore, frequencies of 10-day wet-period storms were summarized in Table 3-2. 10-day (wet) period precipitation amounts were noted to range from approximately 4.3 inches (annually) to 13.0 inches (1,000 year), with higher storm amounts at Anoka. From a flooding perspective, wet periods can have large cumulative storm totals that affect watershed runoff, agricultural producers, public safety, and pollutant loading. The succession of intense wind and rain storms experienced across the basin during the summer of 2016 reinforce the cumulative nature of these back-to-back storms.

Table 3-1. Atlas 14 Summaries of 24-Hour Precipitation Amounts (Inches) for Representative Rum River Basin Locations [National Oceanic and Atmospheric Administration, 2016b]

Rum River Location	24-Hour Storms									
	Average Recurrence Interval (years)									
	1	2	5	10	25	50	100	200	500	1,000
Onamia	2.34	2.71	3.37	3.97	4.85	5.58	6.35	7.19	8.36	9.31
Cambridge	2.4	2.8	3.52	4.15	5.1	5.87	6.7	7.58	8.81	9.8
Anoka	2.46	2.86	3.58	4.24	5.26	6.12	7.05	8.07	9.52	10.7

Table 3-2. Atlas 14 Summaries of 10-Day Wet Period Precipitation Amounts (Inches) for Representative Rum River Basin Locations [National Oceanic and Atmospheric Administration, 2016b]

Rum River Location	10-Day Wet Period									
	Average Recurrence Interval (years)									
	1	2	5	10	25	50	100	200	500	1000
Onamia	4.27	4.84	5.83	6.68	7.91	8.9	9.92	11	12.5	13.7
Cambridge	4.34	4.92	5.89	6.73	7.92	8.86	9.83	10.8	12.2	13.3
Anoka	4.39	4.98	5.97	6.84	8.07	9.07	10.1	11.2	12.7	13.9

3.3.2 Precipitation Variability: Wet and Dry Periods

A closer examination of year-to-year and monthly precipitation variability was evaluated by using synthetic data from the *DNR's Monthly Precipitation Data From a Gridded Database* [DNR 2016]. Data were summarized by month and year and are presented in Table 3-3 for the centrally located Spencer Brook Township near West Point in Isanti County, Minnesota. In this evaluation, the wet months (greater than 70th percentile months) were color-coded blue and dry months (less than 30th percentile months) were color-coded red. The in-between values (normal) are color-coded green. In the past 10 years, four "warm" seasons have been wet (e.g., precipitation greater than 70th percentile), four have been normal, and two have been dry (precipitation less than 30th percentile). Peak spring (April and May) and June precipitation events are of particular note for the potential to generate stormwater runoff from fertilized fields, growing crops with undeveloped canopies, and urban conveyance systems just before the peak growing season. The data from 2006 to 2015 also show numerous and substantial rotations between wet (blue color) and dry (red) monthly precipitation amounts, particularly during the period from June to September. Dry months tended to occur more commonly in the peak of the growing season (August and September) and fall months. Higher precipitation amounts that occur during July and August with established vegetative canopies and higher evaporative losses may not have peak runoff unless they are caused by extreme events and wet periods from back-to-back storm systems (as observed in 2016).

3.3.3 Frost-Free Season Length

Along with patterns of average summer ambient temperatures, variations of the frost-free season length were examined as they influence lake temperatures, algal growing-season length, and aquatic sediment reactions (kinetics). The frost-free season, as defined by the number of days between the last 32°F day of spring and the first 32°F day of autumn, were tabulated from Milaca, Minnesota (USC 00215392), as shown in Figure 3-7. While the Milaca dataset was limited by the number of missing years of data, the long-term pattern generally indicates a pattern of increasing frost-free periods. A much larger dataset for the Minneapolis-St. Paul International Airport, which is south of the RRW, was retrieved and plotted in Figure 3-8. The Minneapolis-St. Paul data indicate longer frost-free periods, which were approximately 30 days longer than most recently noted for Milaca and help underscore potential north-south climate gradients across the RRW.

3.3.4 Evaporation

Potential shallow lake annual evaporation estimated from pan evaporation measurements indicate a north-south gradient ranging from approximately 30 inches per year (in/yr) (Mille Lacs) to 34 in/yr (Anoka) [Farnsworth and Thompson 1982].

Table 3-3. Monthly Precipitation by Year (2006–2016) for Spencer Brook Township, Isanti County, Minnesota [DNR 2016]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	WARM
Period-of-Record Summary Statistics													
0.3	0.46	0.43	1.05	1.55	2.50	3.23	2.67	2.71	2.03	1.18	0.76	0.50	15.99
0.7	0.98	1.11	1.70	2.68	4.23	5.13	4.57	4.64	3.85	3.03	1.98	1.18	21.38
mean	0.83	0.82	1.45	2.30	3.62	4.35	3.82	3.82	3.22	2.29	1.47	0.93	18.83
1981 - 2010 Normals													
normal	0.86	0.82	1.67	2.69	3.45	4.49	4.23	4.32	3.72	2.78	1.76	1.12	20.20
Year-to-Year Data													
2016	**0.31**	**0.43**	**2.39**	**1.99**	**3.06**	**2.69 est**	**5.76 est**	–	–	–	–	–	–
2015	**0.18**	**0.52**	**0.43**	**1.97**	**4.51**	**3.91**	**5.15**	**5.44**	**1.81**	**3.90**	**2.76**	**1.79**	**20.82**
2014	**0.61**	**1.22**	**1.27**	**7.34**	**6.74**	**7.56**	**2.12**	**4.74**	**3.58**	**0.92**	**2.19**	**1.15**	**24.74**
2013	**0.54**	**1.13**	**2.25**	**1.99**	**4.09**	**5.74**	**2.79**	**0.83**	**3.56**	**3.99**	**0.85**	**1.86**	**17.01**
2012	**0.53**	**1.51**	**1.12**	**1.81**	**11.33**	**3.48**	**5.28**	**0.94**	**0.50**	**0.98**	**0.84**	**2.11**	**21.53**
2011	**1.26**	**0.72**	**1.75**	**3.16**	**6.60**	**4.16**	**8.39**	**4.95**	**0.55**	**0.86**	**0.28**	**0.47**	**24.65**
2010	**0.38**	**0.38**	**1.38**	**1.62**	**3.61**	**7.45**	**3.75**	**5.94**	**7.76**	**2.23**	**2.13**	**2.71**	**28.51**
2009	**0.41**	**0.96**	**1.82**	**1.10**	**0.86**	**3.17**	**2.78**	**7.43**	**0.75**	**5.45**	**0.55**	**1.92**	**14.99**
2008	**0.03**	**0.50**	**1.39**	**4.19**	**4.55**	**4.61**	**3.24**	**3.38**	**4.70**	**1.57**	**0.98**	**1.93**	**20.48**
2007	**0.84**	**1.37**	**2.40**	**2.61**	**1.90**	**2.76**	**1.89**	**4.75**	**4.33**	**5.16**	**0.02**	**1.94**	**15.63**
2006	**0.18**	**0.48**	**0.77**	**2.77**	**2.73**	**3.38**	**0.80**	**6.41**	**3.83**	**1.65**	**1.15**	**1.50**	**17.15**

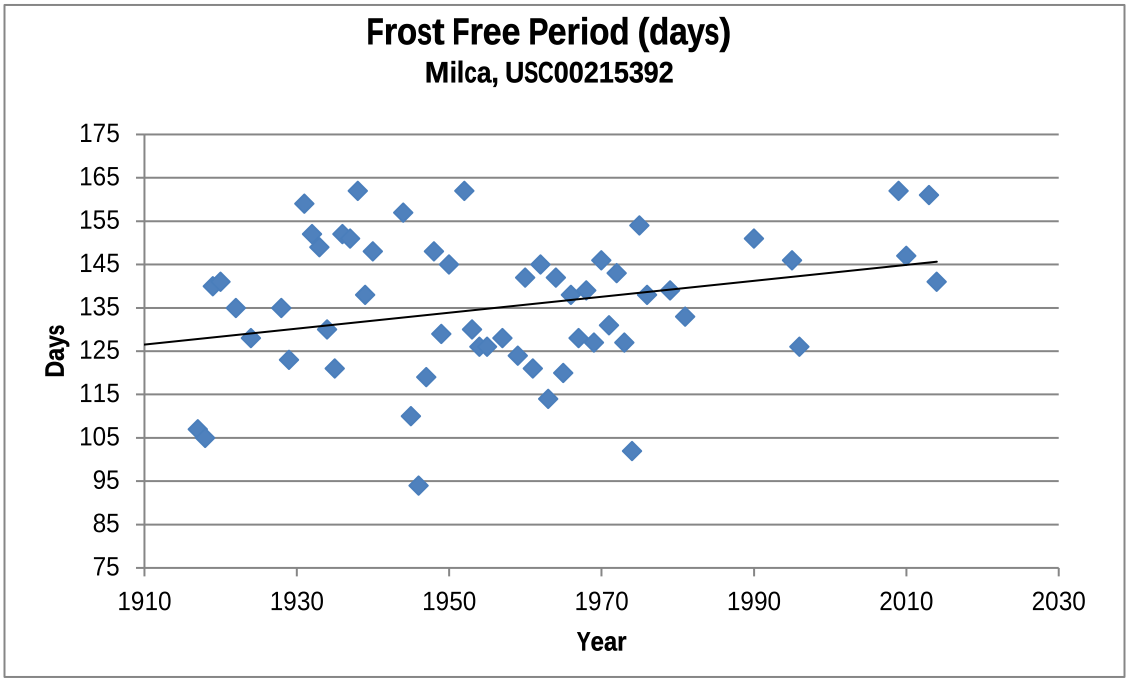
Note: Warm Season = May through September. Retrieved August 11, 2016.

Blue values = wet (or greater than 70th percentile)

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

Red values = dry (or less than 30th percentile)

Figure 3-7. Frost-Free Period (Days) for Milaca, Minnesota [Midwestern Regional Climate Center 2015].



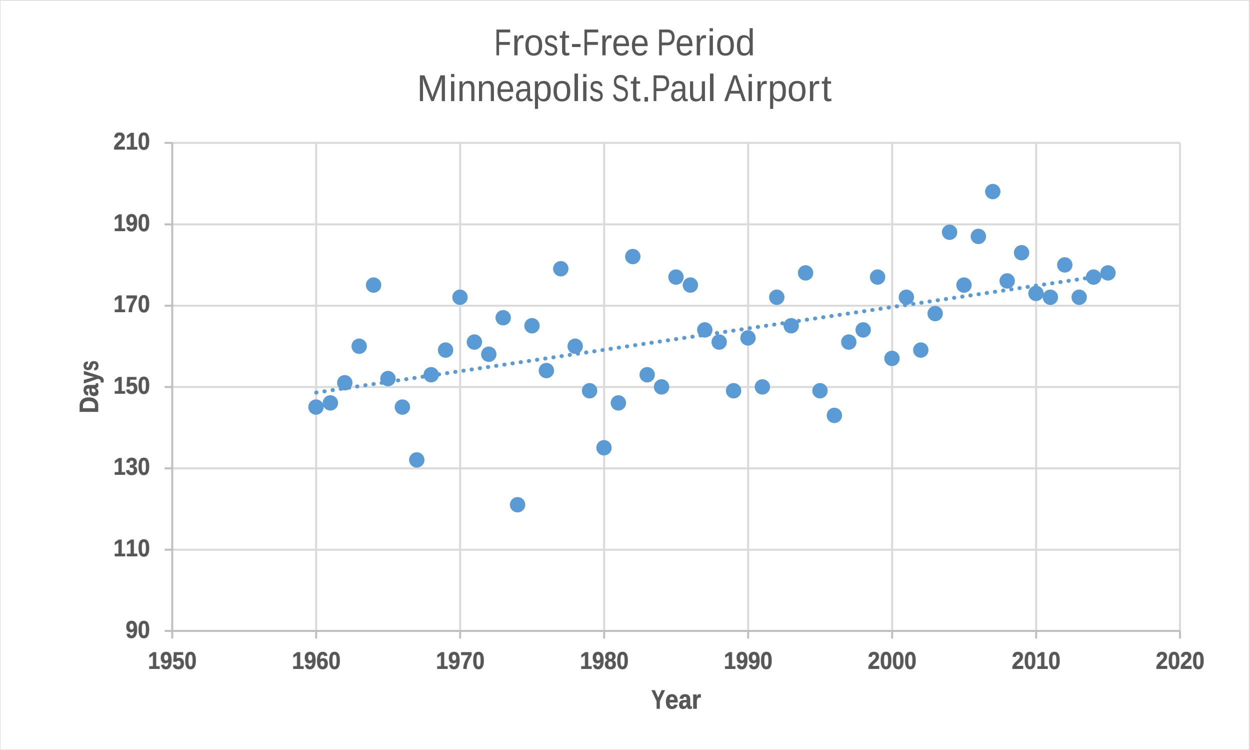


Figure 3-8. Frost-Free Period (Days) for Minneapolis-St. Paul International Airport, Minnesota [Midwestern Regional Climate Center 2015].

3.3.5 Climate Summary

Subtle north-south gradients were noted across the Rum River Basin as defined by storm precipitation intensities and durations, annual precipitation, evaporation, and frost-free periods with higher levels tracking south in the basin. Growing-season runoff can be expected to be affected by wide variations of month-to-month rainfall amounts, increasing average temperatures, and storm intensities. Storm-precipitation intensities for the typical 24-hour storm and multiday wet periods can be substantial with potential wide-ranging impacts that affect communities, agricultural producers, streams, lakes, wetlands, and associated aquatic habitats. Collectively, these basic climate and hydrologic cycle components vary considerably between years and seasonally, which potentially results in wide ranges of watershed runoff and the associated runoff-pollutant dynamics that should be factored into future restoration/protection and monitoring program design considerations.

3.4 Watershed Characteristics

3.4.1 Subwatersheds

Five stream reaches are impaired by *E. coli* bacteria, and one reach is impaired by low DO. Assessment Unit Identification (AUID), length, and drainage area are presented for the five *E. coli*-impaired reaches and one DO-impaired reach addressed in this TMDL, in Table 3-4. The stream impairments are shown in Figure 3-9.

Smaller feeder streams to these impaired stream reaches have not been identified as impaired, except for the West Branch of the Rum River *E.coli* impairment. In this case, the West Branch of the Rum River receives discharges from the large watershed of Estes Brook that is also impaired by *E.coli* bacteria. Hence, improving the water quality of the West Branch of the Rum River will require improving the upgradient Estes Brook via flow-network prioritized implementation strategies.

Table 3-4. Impaired Reach Watershed Areas and Locations and Areas

Impaired Reach	AUID #	Major Subwatershed (HUC 10)	Impairment	Reach Length (miles)	Drainage Area (acres)
Bogus Brook	07010207-523	Upper Rum River	*E. coli*	12.6	15,973
Cedar Creek	07010207-521	Cedar Creek	*E. coli*	28.6	51,711
Estes Brook	07010207-679	West Branch Rum River	*E. coli*	13.6	27,924
Seelye Brooke	07010207-528	Lower Rum River	*E. coli*	12.4	24,699
West Branch of the Rum	07010207-525	West Branch Rum River	*E. coli*	15.8	118,360
Trott Brook	07010207-680	Lower Rum River	DO	4.4	19,008

The Trott Brook-assessed reach (07010207-680) extends to the outlet of Trott Brook. However, the DO monitoring point is located at Nowthen Boulevard Northwest, upstream of where another unnamed drainage enters Trott Brook. As determined, the Trott Brook TMDL endpoint would be located approximately 800 feet downstream of Nowthen Boulevard Northwest at the HSPF model subwatershed outlet.

Impaired lake watersheds are shown in Figure 3-10. Figure 3-10 also shows pairing of impaired lakes including Skogman and Fannie Lakes, West and East Hunter Lakes, and South and North Stanchfield

Lakes. Note that North Stanchfield receives runoff from a large watershed that is not funneled through South Stanchfield Lake. In a similar manner noted for the West Branch of the Rum River, improving the water quality of downgradient lakes will require improving the upgradient lakes via flow-network prioritized implementation strategies.

3.4.2 Land Cover

Because land use is an important factor that affects runoff quantity and quality, the most current land cover data (2013) were used in developing the HSPF model for the Rum River Basin and each of the TMDLs described herein. Land cover data layers, as defined by the University of Minnesota Remote Sensing and Geospatial Analysis Laboratory [University of Minnesota 2016], were employed for this study and based on a 15-meter raster dataset of land cover and impervious surface classifications for 2013. The land cover classifications were created by using a combination of multitemporal Landsat 8 satellite remote-sensing data and Light Detection and Ranging (LiDAR) remote-sensing data with object-based image analysis [University of Minnesota 2016]. Thus, land surface and vegetation heights were employed to discern vegetation cover types to improve classification accuracies.

Land cover types determined by this process for the RRW are depicted in Figure 3-11 and consist of deciduous forest (26%), open water (15%), row crops (12%), grassland/managed grass (11%), forest/shrub wetlands (11%), emergent wetlands (10%), and developed (7%). Lower land cover percentages were noted for conifer forest, mixed forest, and pasture/hay with summary land covers for impaired streams listed in Table 3-5 and summary land covers for impaired lakes listed in Table 3-6. As stated previously, the upper one-third of the Rum River Basin is in the NLF ecoregion with generally better water quality because of higher amounts of forests, lakes, and wetlands. The Rum River flows into the NCHF portion of the watershed in southern Mille Lacs County, with land uses shifting to more intense land covers (agriculture and developed lands) along with forests, pasture/hay, and wetlands.

Figure 3-9. Impaired Streams and Drainage Areas to Impaired Streams.

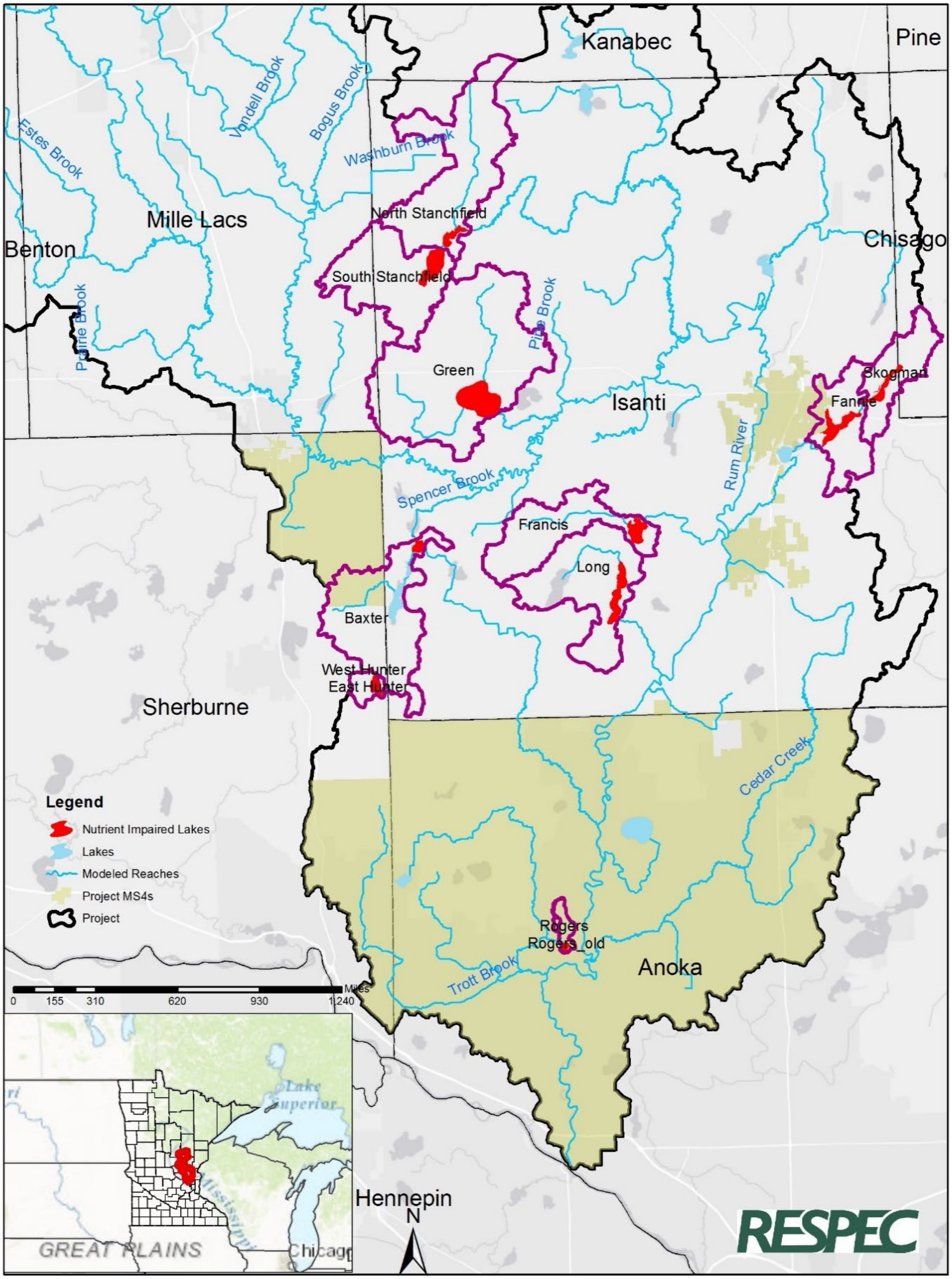


Figure 3-10. Impaired Lakes and Drainage Areas to Impaired Lakes.

Figure 3-11. Rum River Basin 2013 Land Cover Distribution by Subwatershed [University of Minnesota 2016].

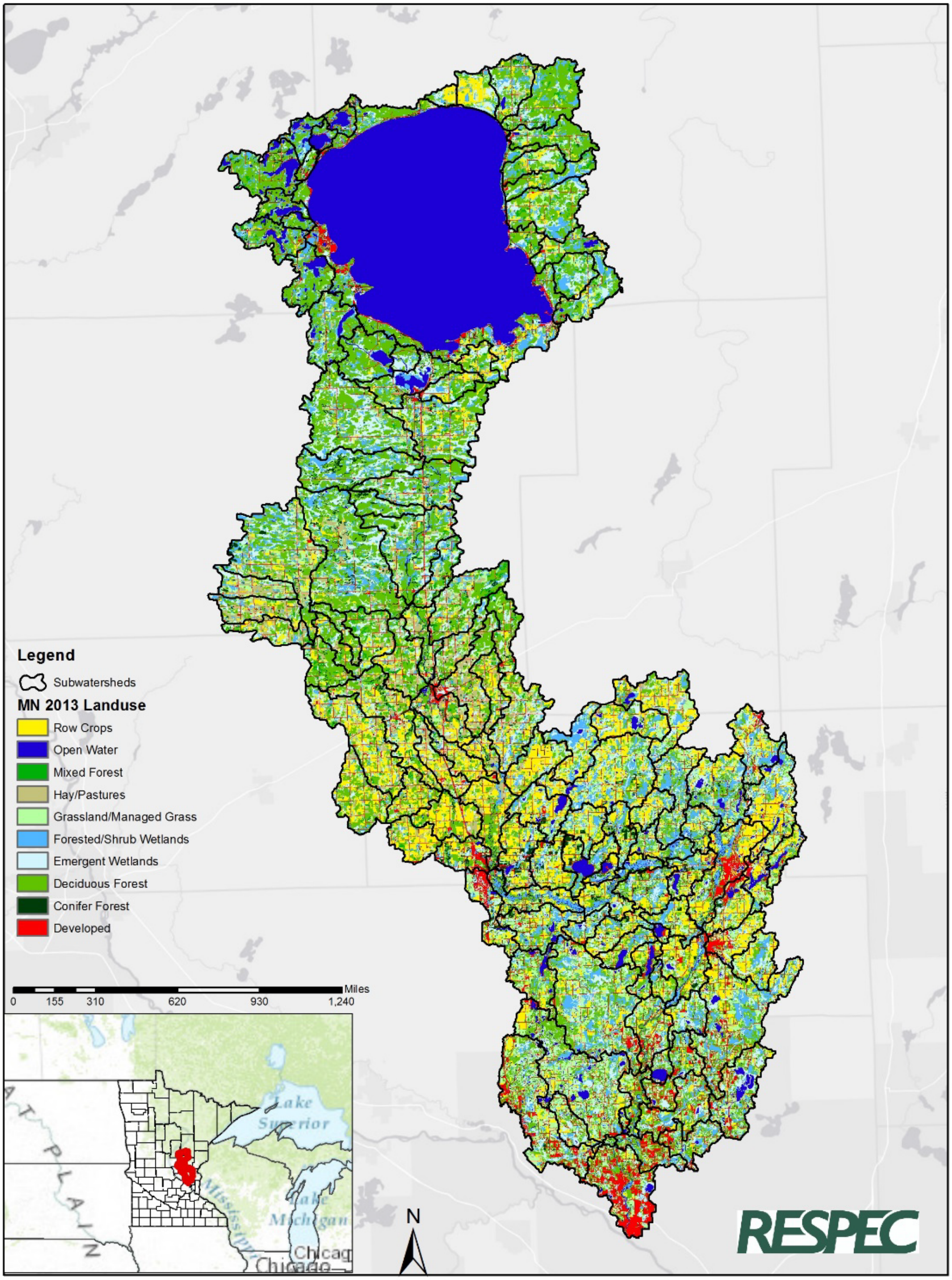


Table 3-5. Stream Watershed Land Cover Distribution by Impaired Stream [University of Minnesota 2016]

Impairment	Open Water (%)	Wetlands (%)	Forest (%)	Grassland/ Managed Grass (%)	Hay/ Pastures (%)	Row Crops (%)	Urban (%)
Bogus Brook	0.0	21.4	34.5	10.3	13.6	13.4	6.7
West Branch Rum River	0.2	16.5	32.6	10.7	12.8	20.5	6.6
Seelye Brook	2.0	32.0	28.1	21.3	0.3	9.1	7.2
Cedar Creek	3.9	27.9	26.7	17.8	0.6	11.3	11.6
Trott Brook	2.3	21.2	27.1	24.8	1.1	7.1	16.5
Estes Brook	0.1	13.7	29.4	10.2	10.8	28.6	7.1

Table 3-6. Lake Watershed Land Cover Distribution by Impaired Lake [University of Minnesota 2016]

Impairment	Open Water (%)	Wetlands (%)	Forest (%)	Grassland/ Managed Grass (%)	Hay/ Pastures (%)	Row Crops (%)	Urban (%)
North Stanchfield	5.8	35.2	15.4	10.0	0.4	28.3	4.9
Green	6.1	21.7	23.3	14.4	0.3	27.4	6.8
Fannie	10.0	16.4	22.6	15.7	0.0	23.8	11.4
Francis	6.5	23.4	25.8	11.8	0.0	24.6	7.8
Long	11.4	17.2	30.7	13.9	0.0	18.4	8.4
East Hunter	17.2	0.3	13.2	21.2	0.0	21.4	26.6
Baxter	6.9	15.8	33.8	24.3	0.0	9.4	9.7
South Stanchfield	9.1	24.3	17.7	10.0	0.8	31.6	6.4
Skogman	8.8	15.6	26.5	17.0	0.1	24.1	8.0
West Hunter	10.9	0.4	11.6	25.2	0.0	26.2	25.7

3.4.3 Soils

Watershed soils and their distributions are important factors to consider, because soils can significantly affect runoff and its quality from particle sizes, nutrients, interflow, and infiltration/groundwater recharge. For this purpose, Hydrologic Soil Groups (HSGs) defined by the Natural Resource Center of the U.S. Department of Agriculture were tabulated by four HSG soil groups (A, B, C, and D) summarized in Table 3-7. The project area consists of approximately 35% HSG A or A/D soils, 16% HSG B or B/D soils, 30% HSG C or C/D soils, and 1% HSG D soils (Figure 3-12). Dual HSG classification soils (notably HSG A/D and B/D soils) behave as HSG D soils when undrained. The Anoka Sand Plain is located along the lower one-third of the basin and may be expected to strongly influence runoff characteristics because of greater infiltration potentials. The extent of the RRW's aquatic ecoregions and the Anoka Sand Plain are shown in Figure 1-1. Urban and agricultural stormwater treatments that rely on infiltration and filtration practices will be facilitated in areas with HSG A and B soils. Hence, the distribution of the different land covers, soil types, and aquatic ecoregions are foundational aspects affecting (1) runoff quantity and quality and (2) future implementation of stormwater treatments within the RRW.

Table 3-7. General Description of Hydrologic Soil Groups [Natural Resources Conservation Service 2009]

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

3.4.4 Lake Characteristics

3.4.4.1 Lake Eutrophication and Physical Characteristics

Developing Minnesota's lake nutrient standards occurred in phases over three decades of monitoring and assessing a large cross section of lakes and lake types of Minnesota's aquatic ecoregions [Heiskary and Wilson 2005]. Distinct relationships were established between the causal factor (TP) and the response variables Chl-*a* and Secchi transparency. TP often has been found to be the limiting factor in freshwater lakes. As lake P concentrations increase, algal abundance increases, thereby resulting in higher Chl-*a* concentrations and reduced lake transparency. Based on these relationships, the Chl-*a* and Secchi standards are expected to be met by meeting the P target in each lake.

Supporting these standards are definitions described by the Minnesota State Legislature [2008], including the following definitions pertinent to the Rum River Basin Lake TMDLs:

- "M. "Lake" means an enclosed basin filled or partially filled with standing fresh water with a maximum depth greater than 15 feet. Lakes may have no inlet or outlet, an inlet or outlet, or both an inlet and outlet."
- "W. "Reservoir" means a body of water in a natural or artificial basin or watercourse where the outlet or flow is artificially controlled by a structure such as a dam. Reservoirs are distinguished from river systems by having a hydraulic residence time of at least 14 days. For purposes of this item, residence time is determined using a flow equal to the 122Q10 for the months of June through September."
- "CC. "Shallow lake" means an enclosed basin filled or partially filled with standing fresh water with a maximum depth of 15 feet or less or with 80% or more of the lake area shallow enough to support emergent and submerged rooted aquatic plants (the littoral zone). It is uncommon for shallow lakes to thermally stratify during the summer. The quality of shallow lakes will permit the propagation and maintenance of a healthy indigenous aquatic community and they will be suitable for boating and other forms of aquatic recreation for which they may be usable. Shallow lakes are differentiated from wetlands and lakes on a case-by-case basis. Wetlands are defined in Minn. R. 7050.0186, subp. 1a."

Minnesota's lake eutrophication standards for the NCHF ecoregion also include considering the effects of lake depth on water quality. Deep lakes that remain thermally stratified can be expected to have stable or declining surface water P concentrations over the summer-growing season. While deep-lake sediments may go anoxic, sediment-generated P (e.g., internal loading) can be less susceptible to mixing into surface waters because of thermal stratification. Conversely, shallow lakes are more prone to wind-mixing events and may have widely fluctuating P concentrations as inflow P is mixed with resuspended organic matter and lake sediment-generated P quantities. Reflective of the cumulative impacts of these factors, Minnesota's lake eutrophication standards for shallow lakes are higher than noted for deeper lakes for TP and Chl-*a* with reduced Secchi transparency.

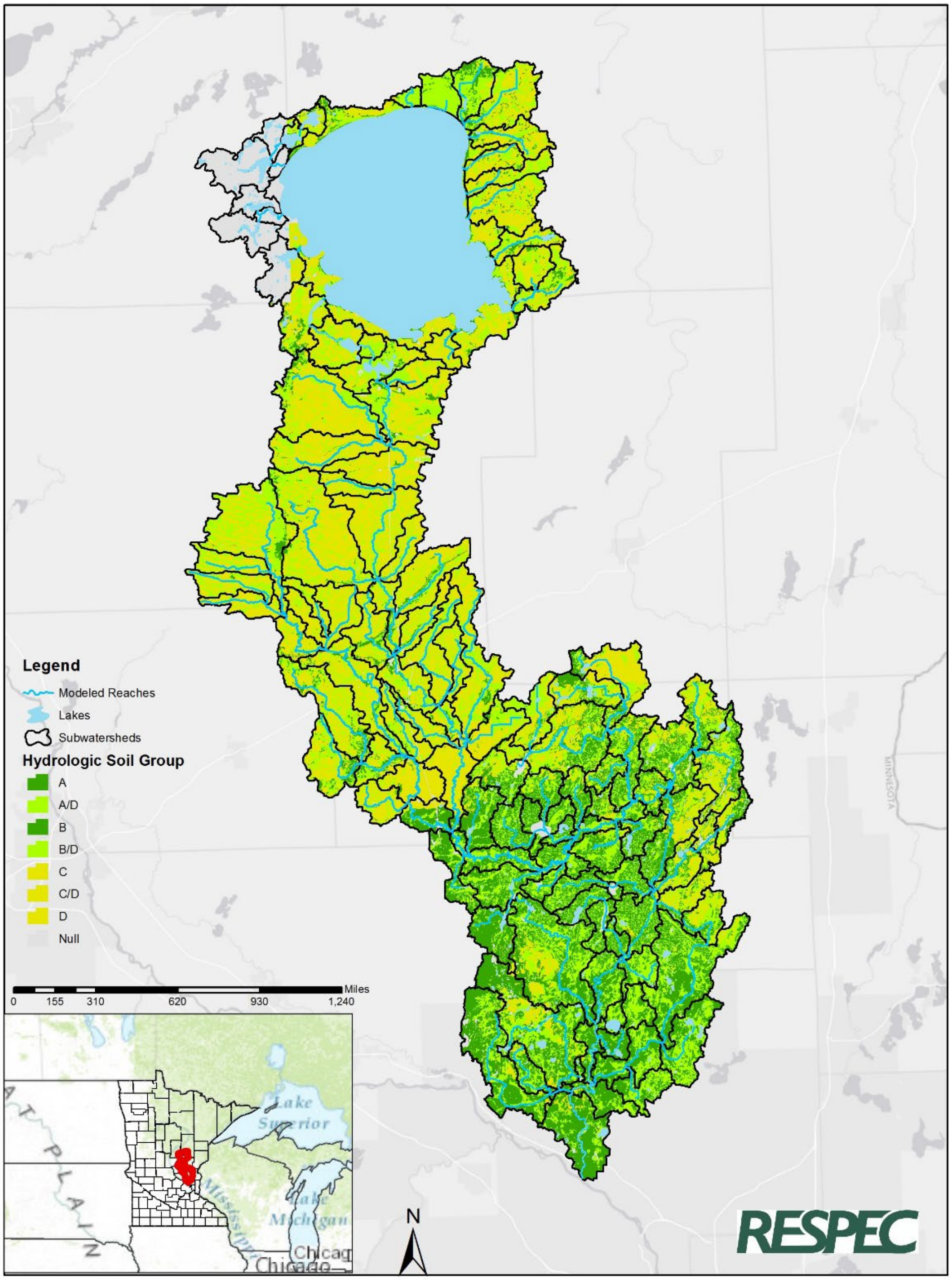


Figure 3-12. Hydrologic Soil Group Distribution Across Rum River Basin [Natural Resources Conservation Service 2016].

For a lake to be determined impaired, measured summer-average lake TP concentrations must show exceedances of the TP standard shown in Table 2-1 [Minnesota State Legislature 2008] along with one or both of the eutrophication response standards for Chl-*a* and Secchi transparency. Minnesota State

Legislature [2008] 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.

Internal loading of P may be an important P source for lakes with temporary thermal stratification that form an anoxic layer near the sediments. This may allow a P release from the lake’s sediments that can be periodically mixed into the surface waters and provide nutrients and light for algal growth. However, shallow, well-mixed or well-flushed lakes that maintain oxic conditions near the sediment-water interface over most of the summer may have lower internal loading rates [Nürnberg 1995]. Given these considerations, additional lake physical characteristics were assessed for the Rum River Basin TMDL lakes.

3.4.4.2 Lake Physical Characteristics

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].

$$\boldsymbol{Lake\ Geometry\ Ratio} = \frac{\boldsymbol{A^{0.25}}}{\boldsymbol{D_{max}}}$$

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

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:

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

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 four), intermediate (four to nine), or dimictic (greater than nine).

3.4.4.3 Shallow Lakes

Rum River Basin TMDL lakes assessed as shallow lakes included West and East Hunter, South and North Stanchfield, Baxter, Long, and Francis Lakes. TMDL assessments of adjacent and closely linked lakes included West and East Hunter, and South and North Stanchfield Lakes.

Lake morphometric and watershed characteristics for shallow lakes are noted in Table 3-8. Shallow lake-surface areas were noted to range from 55 acres (East Hunter Lake) to 398 acres (South Stanchfield), with maximum depths ranging from approximately 6 feet in West Hunter Lake to 17 feet in South Stanchfield Lake. South Stanchfield Lake has an estimated littoral area of 92% and, therefore, met the definition of a shallow lake. Hence, all of the lakes listed in Table 3-8 were assessed as shallow lakes by definition.

Corroborating evidence of shallow-lake classification was obtained by estimating Lake GRs and Osgood Index values. Estimated lake GRs ranged from 6.9 (South Stanchfield Lake) to 15.1 (Francis Lake), which is indicative of shallow-lake conditions (e.g., greater than a lake GR of 5.0). Calculated Osgood Index values ranged from 1.1 (Long Lake) to 3.2 (East Hunter Lake), which indicates that these are polymictic (well-mixed) lakes (e.g., values less than 4.0 Osgood Index value).

Table 3-8. Select Rum River Basin Total Maximum Daily Load Lake Morphometric and Watershed Characteristics for Shallow Lakes

Characteristic	West Hunter	East Hunter	South Stanchfield	Long	Francis	Baxter	North Stanchfield	Source
Lake Total Surface Area (acres)	60	55	398	382	264	88	143	ArcGIS, 2015 TMDL Lakes Layer
Mean Depth (ft)	5	5	8	4	5	5	4	Calculated, Lake volume/surface area
Maximum Depth (ft)	6	7	17	11	8.5	10	10.5	Lakefinder
Lake Volume (acre-ft)	360	385	3,088	1,681	1,320	440	634	Calculated
Littoral Area (acres)	58	54	366	382	264	88	143	Lakefinder
Percent Lake Littoral Surface Area (%)	97	98	92	100	100	100	100	Calculated
Watershed Area Including Lake Area (acres)	559	683	6,675	7,416	5,400	8,035	15,907	ArcGIS, 2015 TMDL Lake Drainage Layer
Watershed Area: Lake Area	9.3:1	12.4:1	16.8:1	19.4:1	20.5:1	91.3:1	111.2:1	Calculated
Osgood Index	3.1	3.2	1.9	1.1	1.5	2.6	1.8	Calculated
Geometry Ratio	12.1	10.2	6.9	10.5	15.1	8.0	8.6	Calculated
Water Residence Time (years)	0.71	0.58	0.07	0.16	0.42	0.08	0.048	Estimated

The ratio of total watershed area to lake-surface area (Ws:Ao ratio) was calculated with the majority of the lakes having Ws:Ao ratios less than 21:1. However, the Ws:Ao ratios for Baxter Lake (91.3:1) and North Stanchfield (111.2:1) are indicative of very large contributing areas relative the size of the lakes. For comparison, the average NCHF Ws:Ao ratio for lakes used in developing Minnesota Lake Eutrophication Analysis Procedure (MINLEAP) aquatic ecoregion eutrophication assessment was 9.6:1 [Wilson and Walker 1989].

Reinforcing the nature of these large watersheds, average annual runoff volumes calculated from HSPF modeling for the 2006 through 2015 period were used to estimate the water residence times (the time to completely fill the lake). The multiyear average flow estimated water residence times was calculated to be approximately 0.04 year or approximately 15 days for North Stanchfield Lake, thereby exceeding the 14-day water residence time noted in Minn. R. 7050.0150, subp. 4 [Minnesota State Legislature 2008]. The longest water residence time for the shallow lakes was 0.77 year for West Hunter Lake. Compared to NCHF lakes used in developing MINLEAP with water residence times ranging from 1 to 30 years [Wilson and Walker 1989], these shallow lakes have much shorter water residence times and may more quickly assume concentrations of dominant inflows.

3.4.4.4 Deep Lakes

TMDL lakes assessed as deep lakes included Green, Skogman, and Fannie Lakes, with surface areas ranging from 223 acres (Skogman Lake) to 833 acres (Green Lake), and maximum depths ranging from approximately 28 feet in Green Lake to 36 feet in Skogman Lake. Lake morphometric and watershed characteristics for deep lakes are noted in Table 3-9. Estimated Lake GRs ranged from 2.8 (Skogman Lake) to 5.0 (Green Lake), which indicates medium lake depths (e.g., less than or equal to a lake GR of 5.0). Calculated Osgood Index values were 2.2 (Fannie Lake), 2.7 (Green Lake), and 4.2 (Skogman Lake), which indicates that these lakes have polymictic (or well-mixed) characteristics (e.g., values less than or near 4.0 Osgood Index value). Thus, the three Rum River Basin TMDL deep lakes share characteristics of both deep and shallow lakes.

Table 3-9. Select Rum River Basin TMDL Lake Morphometric and Watershed Characteristics for Deep Lakes

Characteristic	Skogman	Fannie	Green	Source
Lake Total Surface Area (acres)	223	354	833	ArcGIS, 2015 TMDL Lakes Layer
Mean Depth (ft)	13	7.6	16	Calculated, Lake volume/surface area
Maximum Depth (ft)	36	33	28	Lakefinder
Lake Volume (acre-ft)(a)	2,839	2,702(a)	13,499	Calculated
Littoral Area (acres)	135	308	357	Lakefinder
Percent Lake Littoral Surface Area (%)	61	87	43	Calculated
Watershed Area Including Lake Area (acres)	3,384	7,340	15,887	ArcGIS, 2015 TMDL Lake Drainage Layer
Watershed Area: Lake Area	15.17:1	20.7:1	19.1:1	Calculated
Osgood Index	4.2	2.2	2.7	Calculated
Geometry Ratio	2.8	3.3	5.0	Calculated
Water Residence Time (years)	1.51	0.63	1.36	Estimated

(a) Lake volume less island volume.

The total Ws:Ao ratios were calculated as an indication of the relative size of the contributing watershed with a smaller range being estimated (e.g., 12.7:1 to 20.7:1) compared to most of the shallow lakes noted above. Runoff volumes calculated from HSPF modeling were used to estimate the lake water residence times (the time to completely fill the lake) that ranged from 0.63 year (Fannie Lake) to 1.15 years (Skogman Lake), and were more generally comparable to NCHF lakes used to develop MINLEAP with water residence times that ranged from 1 to 30 years [Wilson and Walker 1989].

3.5 Current/Historic Water Quality

3.5.1 Stream and Rum River Flows

Throughout the project area, several county, regional, state, and federal entities have been actively involved in gathering and reporting stream and river discharge flow data. A total of 12 stations throughout the RRW have discharge data available from 1995 to 2015. This dataset was used for calibrating the RRW hydrology model, which was the foundation of TMDLs addressed in this report. The sites range from small ephemeral streams to the fifth-order Rum River with an average flow of 889 cubic feet per second (cfs) with data from 1996 through 2015. Flow station data listed in Table 3-10 summarizes available data by stream reach, years of data, and mean flows. Although the RRW has several flow gauging stations, discharge data were widely unavailable for the impaired stream reaches and required using HSPF-modeled flows. More information on lake characteristics and more detailed water quality data are included in Appendices A through J.

Table 3-10. Locations Throughout the Rum River Watershed With Flow Data Available From 1995 to 2015

Site	Description	First Year Available	Final Year Available	Number of Days with Flow	Mean Flow (cfs)
21058001	Garrison Creek near Garrison	2004	2008	940	13
21003001	Thaines River near Isle	2004	2008	1,056	13
21059002 21059003	Seguchie Creek	2004	2006	858	8
21050001	Brandbury Creek near Onamia	2013	2015	569	78
21021001	Rum at Hwy 16	2003	2015	3,088	592
21022001	Tibbets Creek near Milaca	2013	2015	576	47
21045001	Estes Brook near Princeton	2013	2015	633	42
21040002	Rum West Branch	2004	2015	2,818	314
21067001	Stanchfield Creek	2013	2015	581	87
21089001	Cedar Creek Cooper	1996	1997	284	14
21095001	Rum River near St. Francis	1995	2015	7,670	773
Basin Outlet	Rum River Outlet at Anoka	1996	2013	6,575	889

3.5.2 Water Quality

Water quality data were downloaded from the MPCA Environmental Quality Information System (EQuIS) database, and all analyses were based on the 10-year period from 2006 through 2015 in developing the lake and stream TMDLs.

3.5.2.1 *E. coli*

E. coli data from 2006 through 2015 are summarized by stream reach in Table 3-11, which includes geometric mean concentrations by month for each impaired reach. Geometric means were above the 126 colony-forming units per 100 milliliter (cfs/mL) standard for every reach during at least 1 month between April and October. Monthly samples are shown for the West Branch, Cedar Creek, Seelye Brook, Bogus Brook, and Estes Brook in Figures 3-13 through 3-17, respectively. Monitoring sites for each impairment are shown in Figure 3-10.

Table 3-11. Monthly Geometric Mean *E. coli* Concentrations (org/100 mL) From 2006 to 2015

Monitoring Station	Impairment	Month	Number of Samples	Geometric Mean (org/100 mL)
S002-953	West Branch of the Rum	**April**	**5**	**48.7**
		May	4	95.2
		June	**9**	**224.9**
		July	**8**	**83.0**
		August	**9**	**241.3**
		September	2	893.8
		October	1	91.0
		November	1	54.0
S003-203	Cedar Creek	**June**	**5**	**230.0**
		July	**6**	**140.7**
		August	**5**	**67.4**
S003-204	Seelye Brook	**June**	**5**	**229.6**
		July	**6**	**102.9**
		August	4	140.7
S004-981	Bogus Brook	**June**	**5**	**166.3**
		July	**5**	**203.4**
		August	**5**	**218.0**
		October	1	330.0
S006-104	Estes Brook	June	4	331.5
		July	**6**	**298.0**
		August	**6**	**718.0**

org/100 mL = organisms per 100 mLs.

Geometric means shown in bold text have fiver or more samples during a month when the standard (126 org/100 mL) applies (April – October).

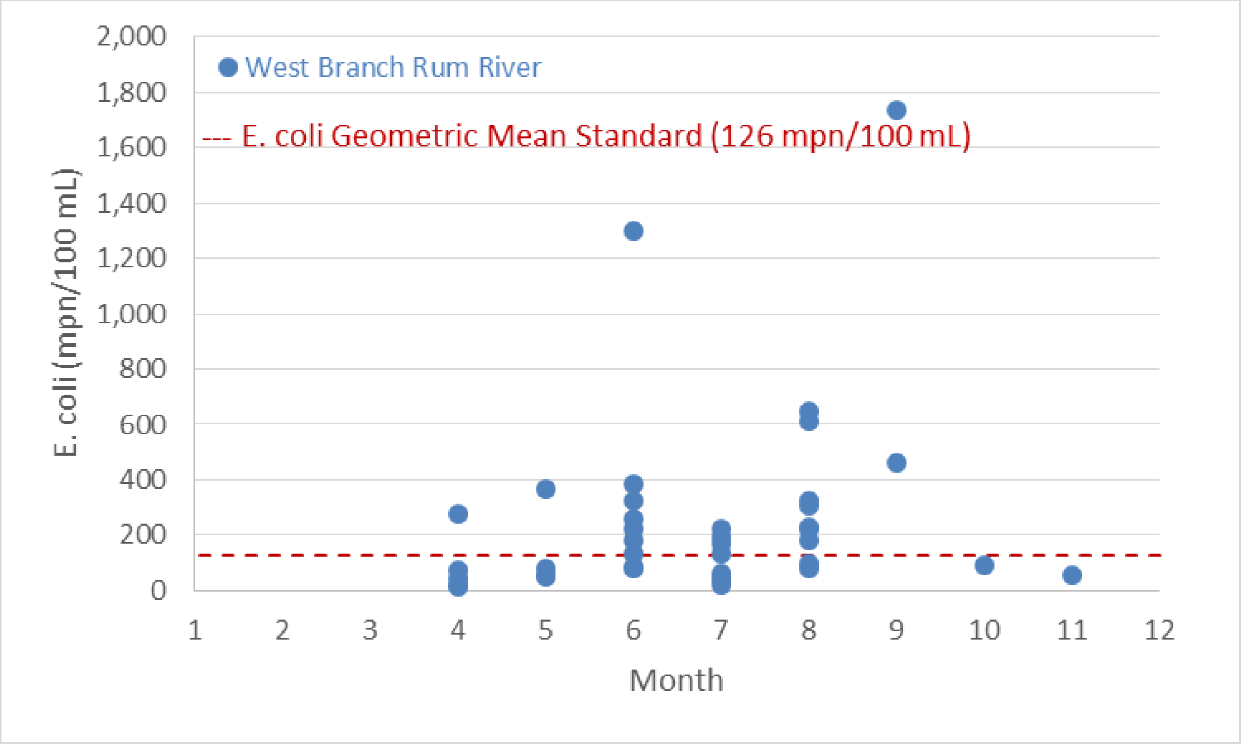
3.5.2.2 Dissolved Oxygen

Available Trott Brook DO monitoring data were summarized for Site S003-176 for the TMDL time period (2006 through 2015) and tabulated in Table 3-12 for open water months. Note that none of the DO measurements were taken before 9 a.m. and, therefore, may not reflect the lowest DO values of the diel (daily) cycles. Figure 3-18 depicts DO variability by month.

Note that Trott Brook's impaired reach (07010207-680) extends to the confluence with the Rum River, but was assessed based on the DO monitoring station located at Nowthen Boulevard Northwest (Ramsey, Minnesota). As determined, Trott Brook's TMDL endpoint would be located approximately 800 feet downstream of Nowthen Boulevard NW, above where other significant drainages contribute to the watershed unmonitored [Johnson, 2016a; Schurbon 2016].

During the 2013 growing season, the MPCA biological monitoring staff deployed YSI sonde sensors to continuously monitor Trott Brook DO concentrations [Johnson 2016b] along with water temperatures, specific conductance, and pH measures. During this deployment, the DO concentration fell below the state standard 5 milligrams per liter (mg/L) daily, with a daily flux of about 4–8 mg/L, which exceeded the state standard of 3.5 mg/L. Figure 3-19 shows the continuous DO and temperature data collected during the 2013 deployment [Johnson 2016b].

Figure 3-13. Single Sample *E. coli* Concentrations by Month in the West Branch of the Rum River (S002-953) From 2006 through 2015.



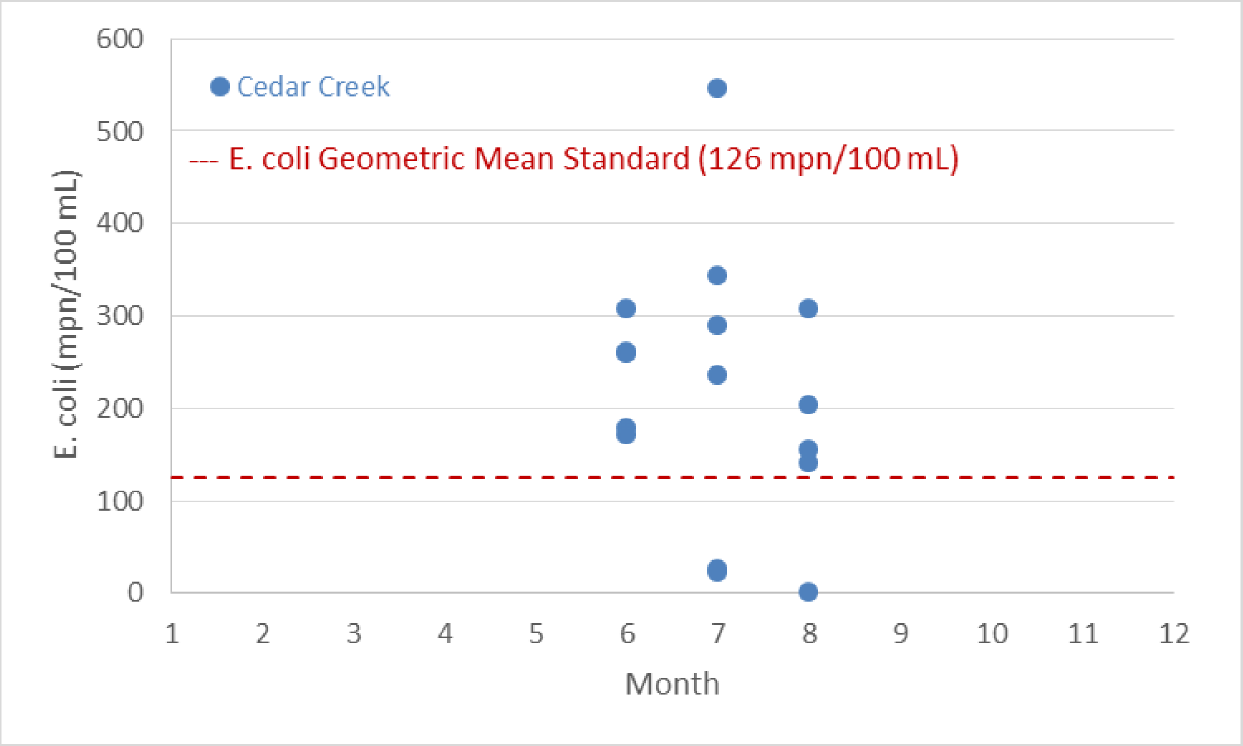


Figure 3-14. Single Sample *E. coli* Concentrations by Month in Cedar Creek (S003-203) From 2006 through 2015.

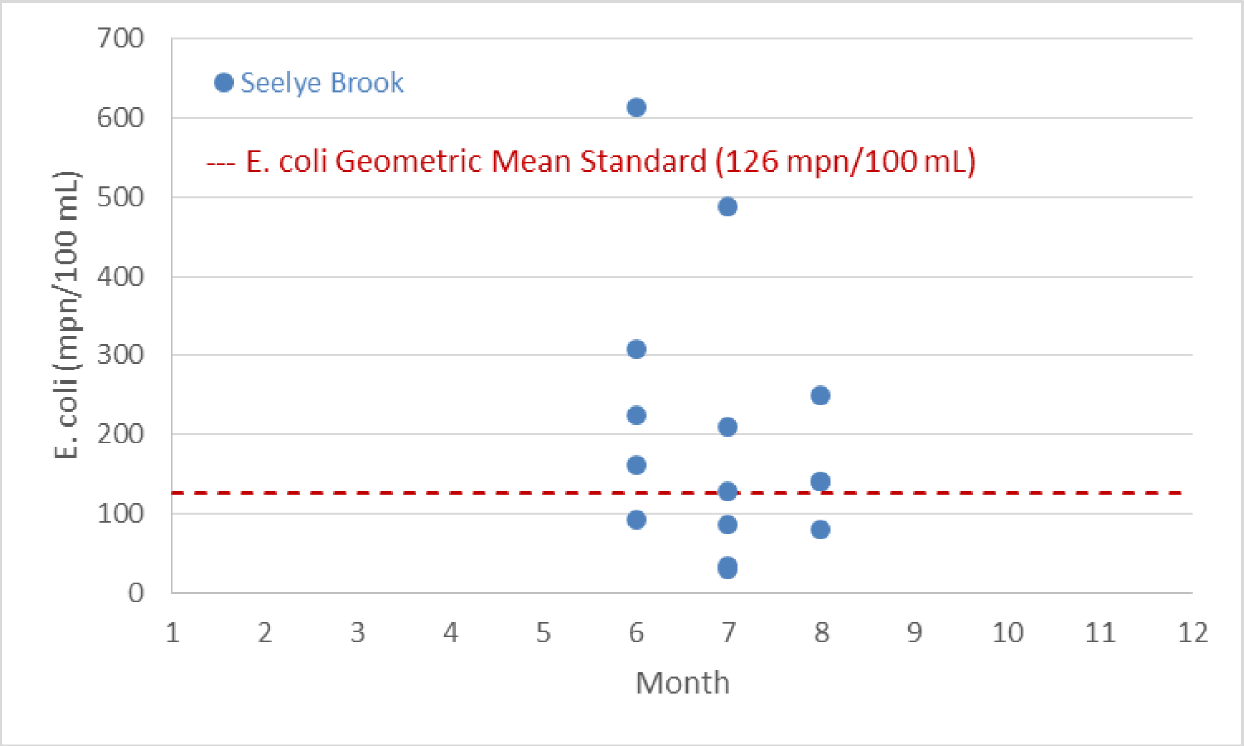


Figure 3-15. Single Sample *E. coli* Concentrations by Month in Seelye Brook (S003-204) From 2006 through 2015.

Figure 3-16. Single Sample *E. coli* Concentrations by Month in Bogus Brook (S004-981) From 2006 through 2015.

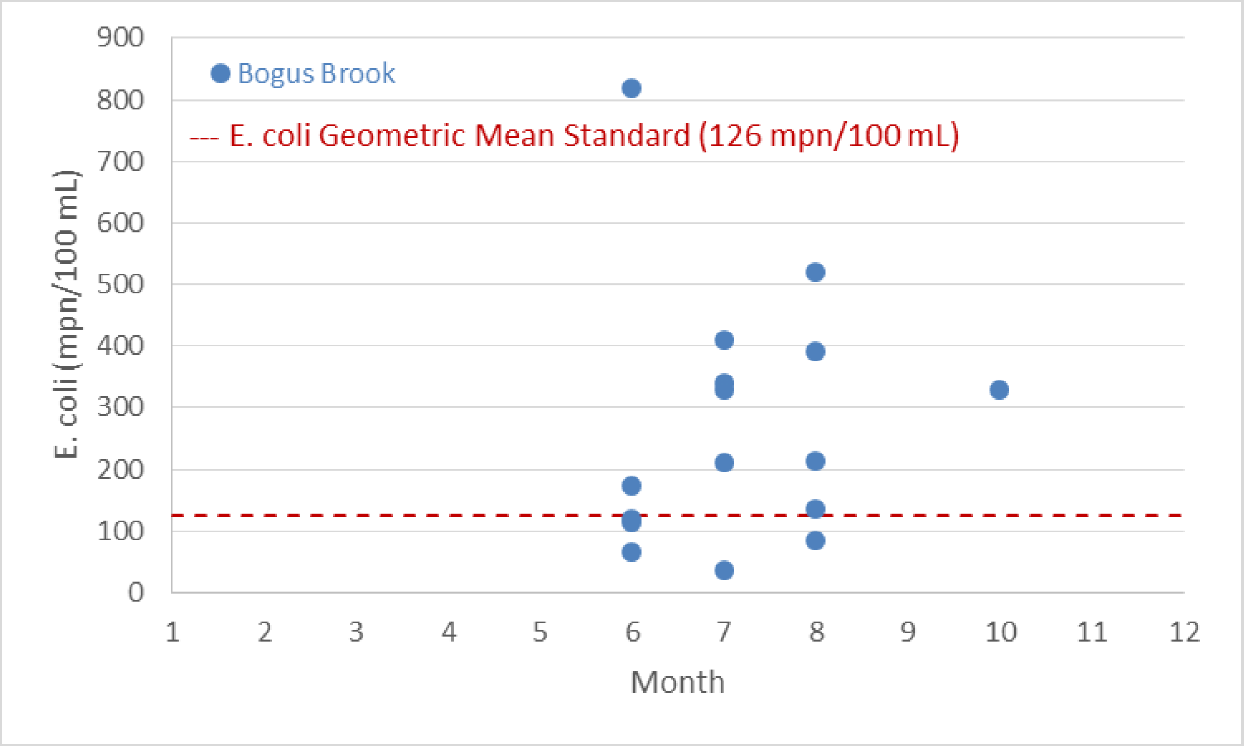


Figure 3-17. Single Sample *E. coli* Concentrations by Month in Estes Brook (S006-104) From 2006 through 2015.

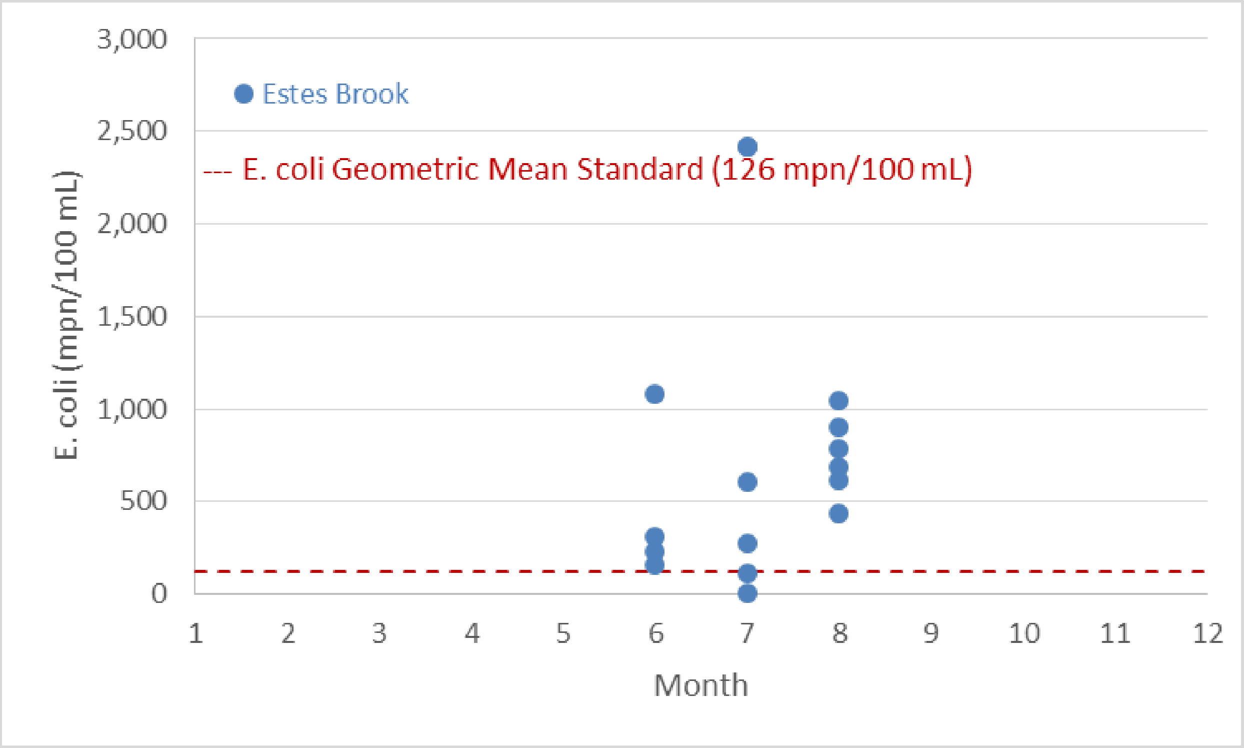


Table 3-12. Dissolved Oxygen Observed Data (S003-176) Measured From 2006 to 2015

Station	S003-176 (All Months)	S003-176 (April–November)
Number of Samples	33	32
Sample Date Range	3/31/2006	5/1/2006
	8/26/2014	8/26/2014
Minimum (mg/L)	2.0	2.0
Average (mg/L)	5.8	5.8
Maximum (mg/L)	10.0	10.0
Number Under 5 mg/L	11	11
Percent Under 5 mg/L	33%	34%

3.5.2.3 Nutrients

Lake-by-lake summaries have been prepared that include available data for water quality, bathymetry, lake-level fluctuations, DO and temperature profiles (changes by depth), select watershed characteristics, fisheries, and aquatic plant survey information. Table 3-13 summarizes the 10-year TMDL-period growing season mean TP, Chl-*a*, and Secchi Disk Depth (SDD) by impaired lake. The coefficient of variation (CV) for each parameter is also shown in Table 3-13. The number and temporal coverage of lake samples used in development of the TMDLs are listed in Appendix K.

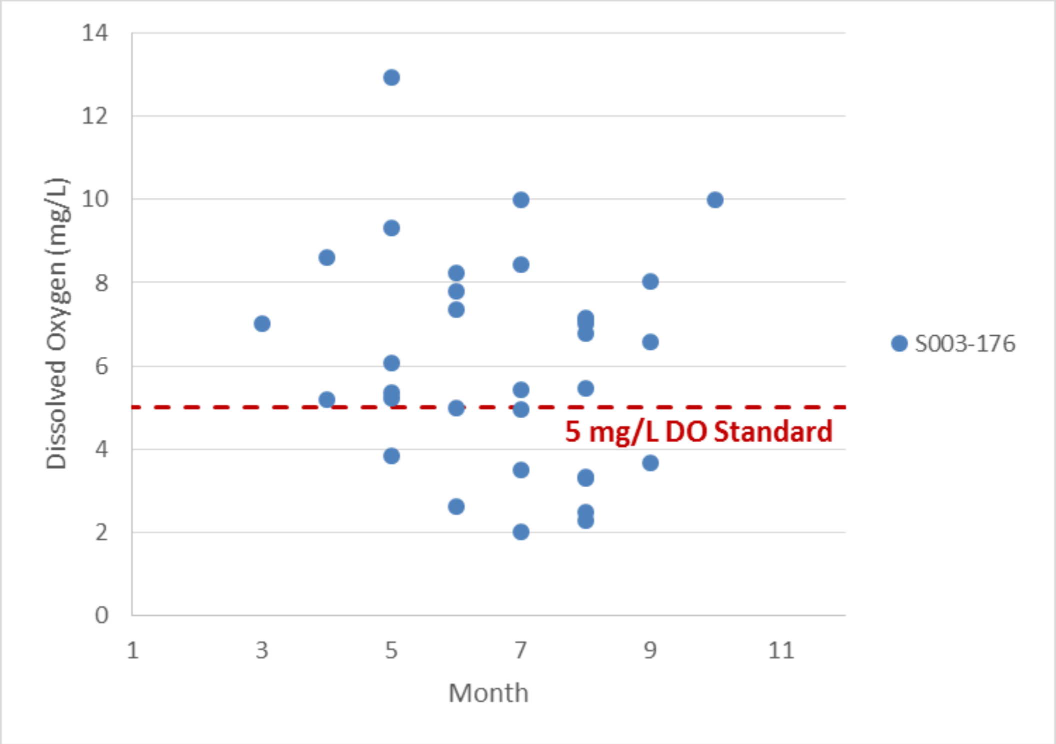


Figure 3-18. Seasonal Variation of Dissolved Oxygen Samples in Trott Brook from 2006 to 2015. The red dashed line indicates the 5 mg/L DO standard.

Figure 3-19. Continuous Dissolved Oxygen and Temperature Data Collected at Trott Brook Biological Monitoring Station 13UM044 on Nowthen Boulevard Northwest with a YSI Sonde for 11 days in 2013 [Johnson 2016b].

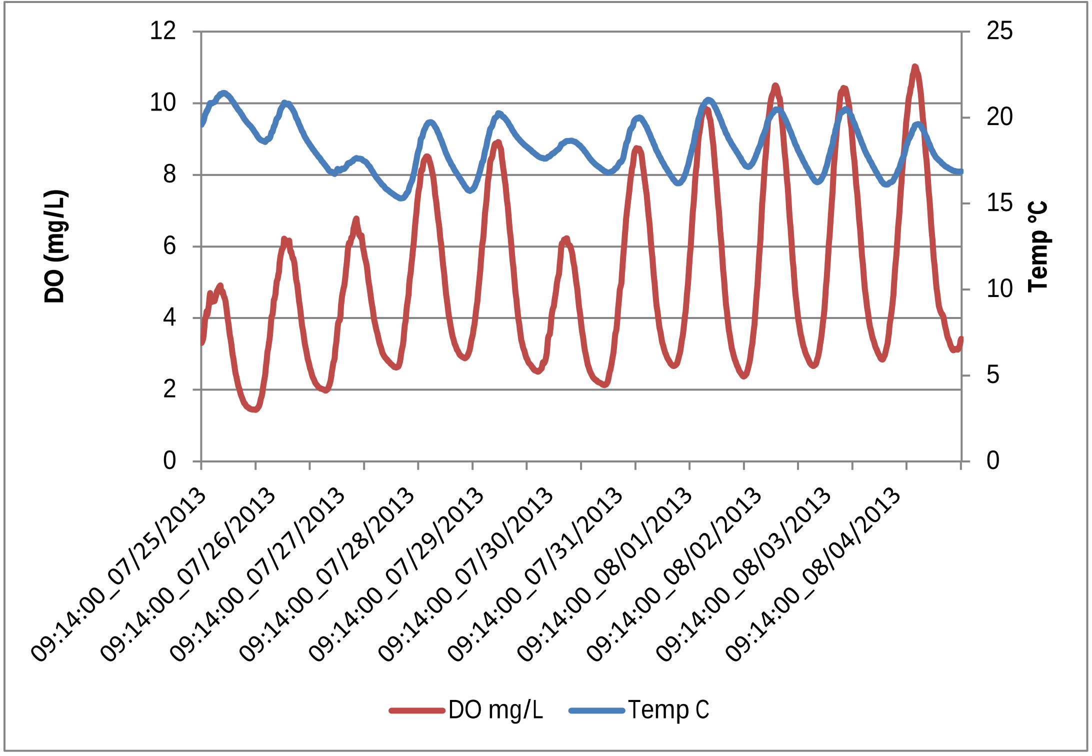


Table 3-13. Observed Lake Water Quality (Eutrophication Parameters) Averages for the Total Maximum Daily Load Time Period From 2006 to 2015.

Lake Name	10-Year Growing Season Observed Averages and CV Means					
	TP (ug/L)	CV	Chl-a (ug/l)	CV	SDD (m)	CV
Shallow Lakes						
Baxter	97.89	0.18	22.57	0.35	1.09	0.25
East Hunter	73.00	0.16	31.47	0.45	1.60	0.06
Francis	234.8[(a)]	NA[(a)]	108.63	0.32	0.51	0.06
Long	119.04	0.06	50.05	0.07	0.49	0.04
North Stanchfield	194.50	0.10	35.46	0.20	0.82	0.16
South Stanchfield	83.00	0.19	74.74	0.29	1.04	0.21
West Hunter	65.62	0.10	18.83	0.18	1.34	0.08
Deep Lakes						
Green	50.65	0.10	27.53	0.18	1.60	0.05
Fannie	44.11	0.07	25.56	0.16	1.69	0.05
Skogman	42.89	0.05	21.33	0.16	1.40	0.04

(a) Lake Francis's TPs data between 2006 and 2015 were unavailable and estimated derived from regression analysis.

The MINLEAP model developed by Wilson and Walker [1989] was employed to quickly compare observed lake water quality with values generally expected based on the lake's aquatic ecoregion, watershed size, lake-surface area, and mean depth. MINLEAP predictions generally describe observed water quality for the shallow lakes with very large contributing watershed areas (as noted for Baxter Lake) but substantially underpredict TP concentrations noted in North Stanchfield Lake. This suggests that watershed size is dominating P loading and needs to be incorporated in lake management considerations for these three shallow lakes. Predicted lake water quality for the remaining shallow lakes suggest that observed water quality exceeds (is worse) than MINLEAP-defined expectations. For the deep lakes, predicted water quality somewhat exceeds (is worse) observed values. However, MINLEAP does not factor upgradient lakes in a chain, such as Skogman Lake above Fannie Lake and, therefore, overestimates P concentrations in Fannie Lake. MINLEAP estimates indicate that the majority of the shallow lakes with typical watershed areas should have lower P and Chl-*a* concentrations than observed. Observed versus MINLEAP-predicted lake water quality is shown in Table 3-14.

Table 3-14. Observed Versus MINLEAP-Predicted Lake Water Quality

Lake Name	**Total Phosphorus (ug/L)**		**Chlorophyll-*a* (ug/L)**		**Secchi Clarity (m)**	
		MINLEAP		**MINLEAP**		**MINLEAP**
	Observed	**Predicted[(a)]**	**Observed**	**Predicted[(a)]**	**Observed**	**Predicted**
Shallow Lakes						
Baxter	97.89	98	22.57	53.6	1.09	0.7
North Stanchfield	194.5	104	35.46	57.9	0.82	0.7
Francis	234.8	69	108.63	32.3	0.51	1
Long	119.04	72	50.05	34.1	0.49	1
South Stanchfield	83	58	74.74	24.5	1.04	1.1
East Hunter	73	61	31.47	26.7	1.6	1.1
West Hunter	65.62	56	18.83	23.8	1.34	1.2
Deep Lakes						
Skogman	42.89	47	21.33	18	1.4	1.4
Fannie	44.11	62	25.56	27.6	1.69	1.1
Green	50.65	46	27.53	17.6	1.6	1.4

(a) Values in red indicate statistically significant differences based on T-Test at 95th percent.

3.6 HSPF Model Methodology

HSPF is a comprehensive watershed model of hydrology and water quality that includes modeling surface and subsurface hydrologic and water quality processes, which are linked and closely integrated with corresponding stream and reservoir processes. The framework can be used to determine the critical environmental conditions (e.g., certain flows or seasons) for the impaired segments by providing continuous flows and pollutant loads at any point within the system. HSPF simulates the fate and transport of modeled pollutants and can simulate subsurface concentrations in addition to surface concentrations (where appropriate). The following sections provide more detail on the source-assessment approach and provide the quantitative results of the source load assessment described in greater detail by Lupo [2016a; 2016b; 2016c].

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

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

Each of these components is described in the following section.

3.6.1 Gathering and Developing Time-Series Data

Data requirements for developing and calibrating an HSPF model application are both spatially and temporally extensive. The modeling period was from 1995 through 2015. Time-series data used in developing the model application included meteorological data, atmospheric deposition data, and point-source data. Precipitation, potential evapotranspiration, air temperature, wind speed, solar radiation, dew-point temperature, and cloud cover data are needed for HSPF to simulate hydrology (including snow-related processes).

3.6.2 Characterizing and Segmenting the Watershed

The Rum River Basin was delineated into 131 subwatersheds to capture hydrologic and water quality variability. The watershed was then segmented into individual land and channel pieces that are assumed to demonstrate relatively homogeneous hydrologic, hydraulic, and water quality characteristics. This segmentation provides the basis for assigning inputs and/or parameter values or functions to remaining portions of a land area or channel length contained in a model segment. The individual land and channel segments are linked together to represent the entire project area.

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

The University of Minnesota land cover categories [University of Minnesota 2015] were combined into 13 groups with similar characteristics and were integrated with riparian areas (Figure 3-20). The urban categories were divided into pervious and impervious areas based on an estimated percentage of effective impervious area. The term “effective” implies that the impervious region is directly connected to a local hydraulic conveyance system (e.g., open channel and river), and the resulting overland flow will not run onto pervious areas but, rather, will directly enter the reach network.

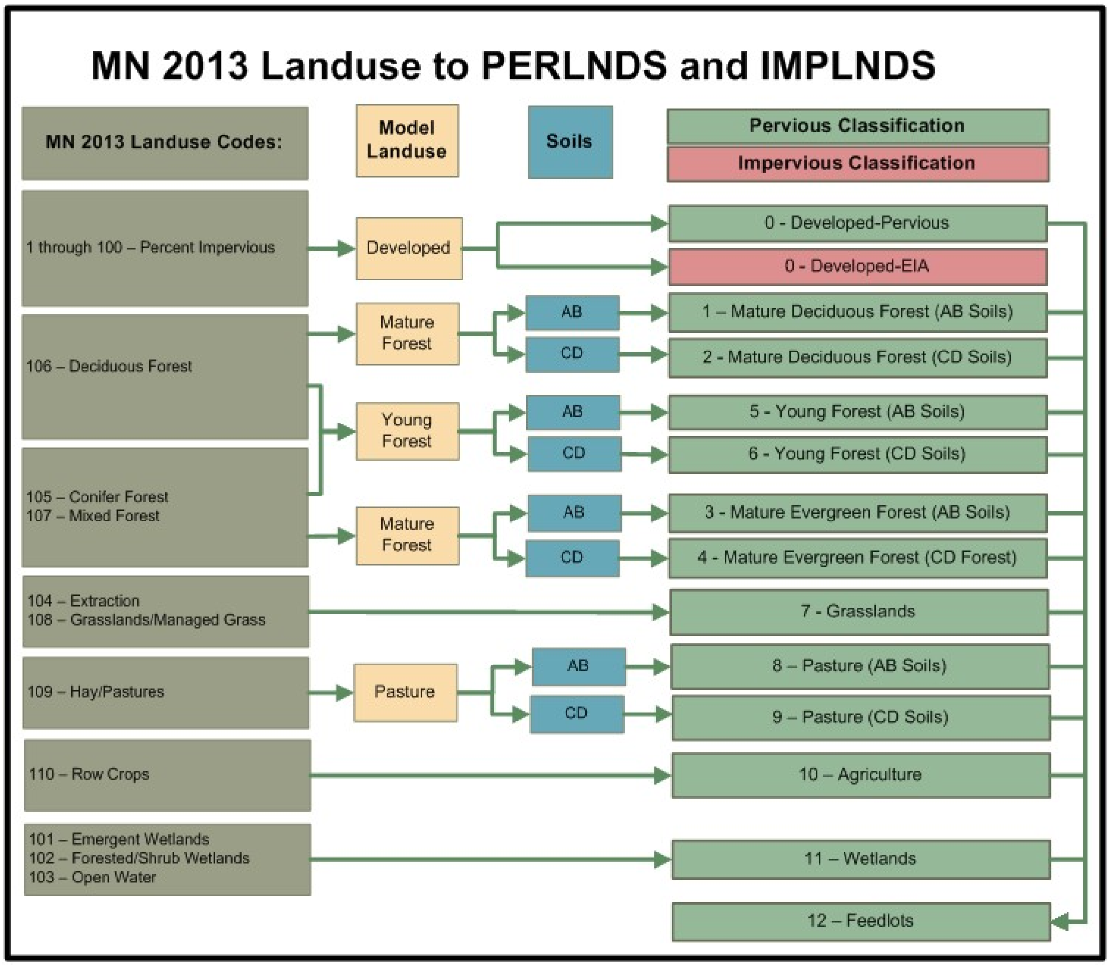


Figure 3-20. Land Cover Category Aggregation Schematic.

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

3.6.3 Calibrating and Validating the HSPF Model

Model calibration involved hydrologic and water quality calibration using observed flow and water quality data to compare to simulated results. Because water quality simulations depend highly on watershed hydrology, the hydrology calibration was completed first, followed by the sediment calibration, the temperature calibration, and finally the nutrient/oxygen/Chl-*a* calibration. The stream-discharge sites with time-series data were used for the calibration and validation. Data from all but the first year of the simulation period were used to calibrate the model. The initial year (1995) was simulated for the model to adjust to existing conditions. The 15-year simulation period included a range of dry and wet years. This range of precipitation improves the model calibration and validation and provides a model application that can simulate hydrology and water quality during a broad range of climatic conditions.

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

- Annual runoff
- Seasonal or monthly runoff
- Low- and high-flow distribution
- Individual storm hydrographs.

By iteratively adjusting calibration parameters within accepted ranges, the simulation results are improved until an acceptable comparison of simulated results and measured data is achieved. The procedures and parameter adjustments involved in these phases are more completely described in Donigian et al. [1984] and Lumb et al. [1994].

The hydrology calibration was evaluated using a weight-of-evidence approach based on a variety of graphical comparisons and statistical tests. The performance criteria are described in more detail in Donigian [2002]. Graphical comparisons included monthly and average flow volume comparisons, daily time-series data comparisons, and flow duration plots. Statistical tests included annual and monthly runoff errors, low-flow and high-flow distribution errors, and storm volume and peak flow errors. The calibration results for the primary mainstem gage ranked “very good” compared to the calibration and validation targets with a monthly coefficient of correlation of 0.90 and a daily coefficient of correlation of 0.84. The flow duration calibration curve at the primary calibration gage (Rum River near St. Francis, Minnesota) is shown in Figure 3-21.

The water quality calibration optimized alignment between the loads predicted to be transported throughout the system and the observed in-stream concentrations. Water quality data from monitoring sites were used to calibrate the model to observed conditions. Many parameters can be adjusted to calibrate water quality loads and concentrations. The TP concentration duration calibration curve at the most downstream mainstem calibration gage is shown in Figure 3-22. More detail information on the HSPF model application and model calibration results (hydrology and water quality) can be found in RRW project modeling memoranda [Lupo, 2016a; 2016b; and 2016c].

3.7 Pollutant Source Summary

Pollutant sources are summarized for *E. coli*, DO, and nutrient impairments in the following sections. The percent of *E. coli* produced in each impaired stream drainage area by source was estimated by using a GIS approach, while the sources of DO-consuming substances and nutrients were estimated by using the Rum River HSPF model application. The contributions of oxygen-demanding substances and nutrients from identified point and nonpoint sources in the DO-impaired streams and nutrient-impaired lakes were determined by using the Rum River HSPF model application. HSPF-generated runoff volumes were also used to identify the range of flows for the RRW and to generate flows for *E. coli* LDCs.

Figure 3-21. Flow Duration Calibration Curve at Primary Hydrology Calibration Site.

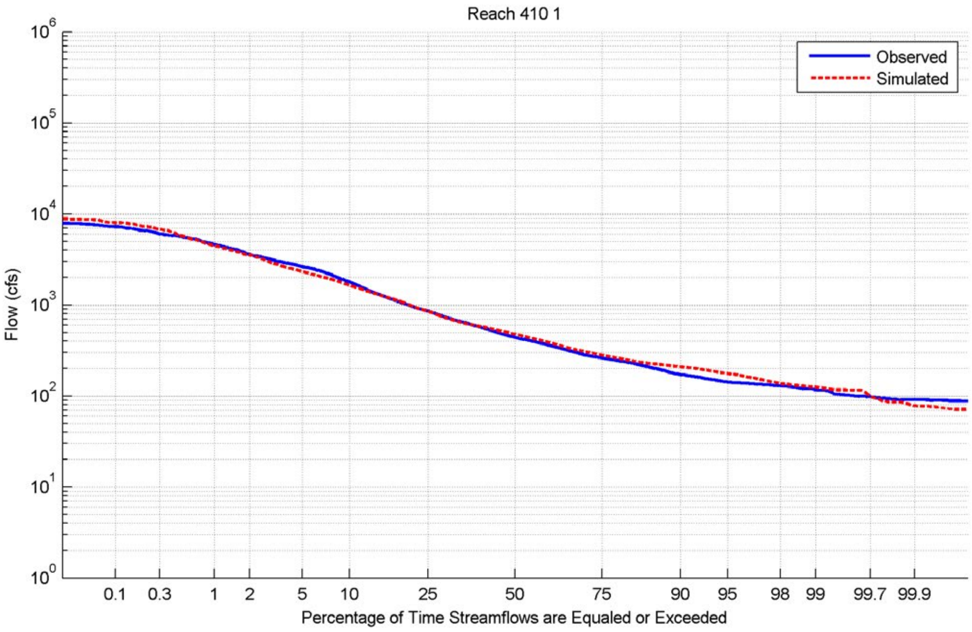
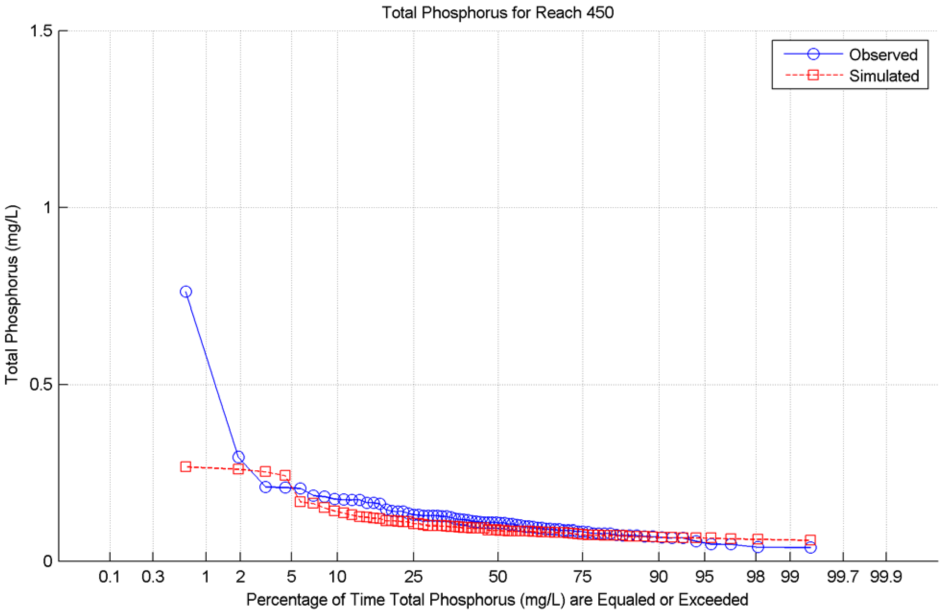


Figure 3-22. Total Phosphorus Concentration Duration Calibration Curve at Most Downstream Mainstem Calibration Site.



3.7.1 *E. coli*

Sources of bacteria-to-stream impairments can include livestock, wildlife, human, and pet sources. Bacteria from human and animal waste are naturally dispersed throughout the landscape, spread by humans, and/or treated in facilities. Once the bacteria are in the environment, their accumulation and delivery to the stream is affected by die-off and decay, surface imperviousness, detention time, ultraviolet exposure, and other mechanisms.

3.7.1.1 Permitted

Detailed information about specific permitted *E. coli* sources is included in Section 4 of this TMDL. Three permitted wastewater treatment facilities (WWTFs) are located in the RRW with allowable surface discharges contributing to an *E. coli*-impaired reach. Effluent from WWTFs is monitored and regulated but does contribute some *E. coli* to streams. No concentrated animal feeding operations (CAFOs) located in the RRW drain to an *E. coli*-impaired stream.

Multiple Municipal Separate Storm Sewer Systems (MS4s) are located with the watersheds of *E. coli*-impaired reaches. The Oak Grove City MS4 and Nowthen City MS4 contribute to the Seeyle Brook; and the Andover City MS4, East Bethel City MS4, Ham Lake MS4, Oak Grove City MS4, Saint Francis City MS4, Isanti City MS4, MnDOT, MS4, and Anoka County MS4 contribute to Cedar Creek. Human bacteria sources in MS4s can include cross connections between sanitary sewers and storm drain systems, leaks or overflows from sanitary sewer systems, and wet-weather discharges from centralized wastewater collection and treatment facilities in MS4 areas. Wildlife, decaying vegetation, eroded organic matter, and pet waste are other potential bacterial sources in MS4 areas. Pet waste that is not properly disposed of along a stream or near/within a stormwater conveyance system can be washed off during precipitation events [EPA 2001].

Land application of biosolids from WWTFs was not included in these TMDLs as a source of bacteria because of the rigorous monitoring and regulation associated with it. More information about land application of biosolids is available in the Sewage Sludge Management chapter (7401) of the Minnesota Administrative Rules [Minnesota State Legislature 2014].

E. coli is not typically contributed from construction stormwater. Also, no benchmark monitoring of bacteria or *E. coli* are required with industrial permits, and *E. coli* is not typically contributed from industrial stormwater.

3.7.1.2 Nonpermitted

Manure from livestock is a potential nonpermitted source of bacteria to streams. Livestock contribute bacteria loads directly by defecating in the stream and indirectly by defecating or through the spread of manure on cropland or pastures where bacteria can be washed off during precipitation events, snowmelt, or irrigation. Livestock in the project area mainly include cattle, poultry, hogs, horses, sheep, and goats. Livestock are grazed and confined in the areas draining to *E. coli*-impaired waterbodies. Over 114 active animal feeding operations (AFOs) are within the watersheds of impaired reaches. Manure spreading from livestock also contributes *E. coli* to waterbodies.

Wildlife (including waterfowl and large-game species) also directly contribute bacteria loads by defecating while wading or swimming in the stream, and contribute indirectly by defecating on lands that produce stormwater runoff during precipitation events. According to the Clean Water Legacy Act (CWLA), natural background means characteristics of the waterbody resulting from the multiplicity of factors in nature, including climate and ecosystem dynamics, that affect the physical, chemical, or biological conditions in a waterbody, but does not include measureable and distinguishing pollution that is attributable to human activity or influence. Bacteria loads from wildlife are considered natural background. Some BMPs that reduce loads from livestock and other sources can also reduce loads from wildlife.

Human bacteria sources in urban settings can include cross connections between sanitary sewers and storm drain systems, leaks or overflows from sanitary sewer systems, and wet-weather discharges from centralized wastewater collection and treatment facilities. These are generally non-permitted when they occur outside the specified MS4 areas. Outside of city domestic wastewater- coverage areas, septic systems can be a potential human source of bacteria loads. Pet waste is another potential source of bacteria from nonregulated communities of the watersheds.

3.7.1.3 Potential Sources

A GIS-based assessment was completed within each impaired drainage area to estimate populations of livestock, wildlife, humans, and pets. Animal populations were multiplied by average excretion rates obtained from the scientific literature. Reported literature values for fecal coliform excretion were converted to *E. coli* excretion by using a fecal coliform to *E. coli* ratio of 200:126 org/100 mL. Annual excretion estimates for livestock (excluding hogs) and wildlife were obtained from the *Bacteria Source Load Calculator: A Tool for Bacteria Source Characterization for Watershed Management* [Zeckoski et al. 2005], and bacterial estimates for humans and hogs were obtained from *Wastewater Engineering: Treatment, Disposal, Reuse* [Metcalf and Eddy 1991]. Annual excretion rates for dogs and cats were from *Identification and Evaluation of Nutrient and Bacterial Loadings to Maquoit Bay, New Brunswick and Freeport, Maine* [Horsley and Witten, Inc. 1996].

Domestic wastewater sewers within each *E.coli*-impaired drainage area were estimated by summing the 2010 population for all 2010 Census Block Centroid Population points falling within 2010 Census Urban Area. Points located within the urban areas were assumed to be connected to the WWTFs in applicable impairment drainage areas.

The number of people using septic systems was estimated by summing the 2010 population for all 2010 Census Block Centroid Population points falling outside of a 2010 Census Urban Area.

Pet populations were estimated by summing the households from the 2010 Census Block Centroid Population points within each applicable impairment drainage area and assuming 0.58 dogs (36.5% of households times 1.6 dogs per household) estimated 0.64 cats (30.4% of households times 2.1 cats per household) per household [American Veterinary Medical Association 2016].

The most recent MPCA feedlot data layer (April 15, 2015) with Animal Counts and Animal Units was obtained from the Minnesota Geospatial Commons. The layer was spatially joined to the drainage area of the impaired reaches, and the total number of birds, bovines, goats and sheep, horses, and pigs from active feedlots was calculated.

Deer were estimated by using average deer densities in deer-permit area boundaries. Boundaries and densities were provided from DNR [D'Angelo 2015]. Ducks and geese were estimated from the DNR and US Fish and Wildlife Service *2015 Waterfowl Breeding Population Survey and Subwatershed Waterbody Densities*. The *2015 Waterfowl Breeding Population Survey* was provided by the DNR [2015]. Coots and swans were also estimated. Coots were included in the duck population, while swans were included in the geese population.

Table 3-15 shows the total number (head) of each animal estimated for the purposes of this TMDL, the amount of bacteria produced by each animal per day, and the literature source used to estimate the amount of bacteria produced by each animal per day. In some cases, such as sheep and goats, the number was an average of the amount produced by sheep and goats because the number of each animal individually in the watershed is unknown. Table 3-16 shows estimated bacteria produced within the drainage area of each impaired stream from each animal and the percent that it makes up.

A majority of the bacteria produced in the Bogus Brook drainage area (78%) is produced by cattle. The remaining bacteria produced within the Bogus Brook drainage area is produced by humans, pets, wildlife, and horses. In the Cedar Creek drainage area, a majority of the bacteria produced is from humans and their pets (92%). The remaining bacteria produced in the Cedar Creek drainage area is from wildlife and hogs. A majority of the bacteria produced in the Estes Brook drainage area is produced by cattle (93%). The remaining bacteria produced in the Estes Brook drainage area is produced by humans, pets, and sheep/goats. In Seelye Brook, bacteria produced is diverse, with 44% produced by cattle, 20% produced by hogs, and 32% produced by humans and their pets. The remaining bacteria in Seelye Brook is produced by ducks. The West Branch of the Rum River drainage area includes the Estes Brook drainage area. The majority of the bacteria produced in the West Branch of the Rum River drainage area is produced by cattle (82%). The remaining bacteria produced in the West Branch of the Rum River drainage area is produced by humans and their pets, poultry, sheep and goats, hogs, and ducks. These estimates provide watershed managers with the relative magnitudes of total production by source and do not account for wash-off availability and delivery to the impaired reach or in-stream growth, and die-off dynamics.

Table 3-15. Total Number of Each Animal Producing Bacteria in Drainage Area and Bacteria Production Rates

Impairment	Total Humans		Total Pets		Total Livestock					Total Wildlife		
	Wastewater Treatment Plant	Subsurface Sewage Treatment Systems	Cats	Dogs	Cattle	Horses	Poultry	Sheep/ Goats	Hogs	Deer	Ducks	Geese
Bogus Brook	0	1,158	262	240	585	5	0	0	10	386	272	106
Cedar Creek	2,402	12,411	3,246	2,969	0	0	0	0	140	1,167	884	346
Estes Brook	0	1,307	159	145	3,654	14	301	310	42	328	238	93
Seelye Brook	2,167	2,692	1,071	980	724	17	190	0	1,010	649	441	172
West Branch Rum River	1,915	5,385	1,838	1,681	12,037	45	170,521	310	2,967	2,721	2,011	59
Bacteria Production Rate (cfu/day/head)	1.3E+09	1.3E+09	1.6E+09	3.2E+09	2.1E+10	2.7E+10	6.8E+07	7.6E+09	6.9E+09	2.2E+08	1.5E+09	5.0E+08
Source of Bacteria Production Rate	[Metcalf and Eddy, 1991]		[Horsley and Witten, Inc., 1996]		[Zeckoski et al., 2005]				[Metcalf and Eddy, 1991]	[Zeckoski et al., 2005]		

Table 3-16. Bacteria Produced in Each Impaired Stream Drainage Area by Source

Impairment		Total Humans		Total Pets		Total Livestock					Total Wildlife		
		Wastewater Treatment Plant	Subsurface Sewage Treatment Systems	Cats	Dogs	Cattle	Horses	Poultry	Sheep/Goats	Hogs	Deer	Ducks	Geese
Bogus Brook	Total Bacteria Produced (cfu/day)	0.0E+00	1.5E+12	4.1E+11	7.6E+11	1.2E+13	1.3E+11	0.0E+00	0.0E+00	6.9E+10	8.5E+10	4.1E+11	5.4E+10
Cedar Creek		3.0E+12	1.6E+13	5.1E+12	9.4E+12	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.7E+11	2.6E+11	1.3E+12	1.7E+11
Estes Brook		0.0E+00	1.6E+12	2.5E+11	4.6E+11	7.6E+13	3.7E+11	2.0E+10	2.3E+12	2.9E+11	7.2E+10	3.6E+11	4.7E+10
Seelye Brook		2.7E+12	3.4E+12	1.7E+12	3.1E+12	1.5E+13	4.5E+11	1.3E+10	0.0E+00	7.0E+12	1.4E+11	6.7E+11	8.7E+10
West Branch of the Rum River		2.4E+12	6.8E+12	2.9E+12	5.3E+12	2.5E+14	1.2E+12	1.2E+13	2.3E+12	2.1E+13	6.0E+11	3.0E+12	3.0E+10
Bogus Brook	Percent of Total Bacteria Produced (%)	0	9	3	5	78	1	0	0	0	1	3	0
Cedar Creek		8	44	14	26	0	0	0	0	3	1	4	0
Estes Brook		0	2	0	1	93	0	0	3	0	0	0	0
Seelye Brook		8	10	5	9	44	1	0	0	20	0	2	0
West Branch of the Rum River		1	2	1	2	82	0	4	1	7	0	1	0

3.7.2 Dissolved Oxygen

The water quality target for Trott Brook is the DO criteria. The pollutants of concern are constituents that reduce or lead to the reduction of DO in the listed reach. Oxygen is consumed by decomposition of organic matter (such as proteins, human and animal waste, and dead plant matter) and oxidation of inorganic ammonia. P (or in some cases nitrogen) can be a limiting nutrient to the production of algae and aquatic macrophytes, which die, decompose, and use oxygen in the water. One of the required elements of a TMDL is identifying the pollutants of concern. Conventionally, biochemical oxygen demand (BOD) (determined by the laboratory analysis) is used to define the oxygen demand of wastes and plant matter from water samples. Biochemical oxidation of organic material can be a slow process but, usually, the process is 95% complete within 20 days. During the initial portion of this period (from 6 to 10 days), oxygen is consumed to oxidize mostly carbonaceous matter. The hydrolysis of proteins in wastewater produces ammonia. After 6 to 10 days, the autotrophic bacteria which use oxygen to oxidize ammonia are present in sufficient numbers to exert a measureable oxygen demand. These two sources of oxygen demand are referred to as carbonaceous biochemical oxygen demand (CBOD) and nitrogenous biochemical oxygen demand (NBOD). The oxygen demand determined by continuing the BOD test until DO consumption is reduced to a negligible level is defined as the ultimate BOD of the wastewater. Most laboratories limit the Ultimate Biochemical Oxygen Demand (BODu) test to 20 days or 40 days. Inhabitation of nitrifying bacteria during the test results in the CBODu of the wastewater. Because of the time requirements of the BODu test, the oxygen demand from the 5-day CBOD test is commonly used to evaluate the organic waste load of wastewater.

Another source of oxygen demand in a stream reach can be the stream's sediments. Deposition of dead plant matter and debris, including algae and macrophytes, eroded organic soils, wastewater bypasses, and historic sludge deposits from old rudimentary wastewater treatment plants can result in organic benthic deposits. The aerobic decomposition of the surface layer of these deposits generates an oxygen demand during decomposition. Additionally, high spring-flow rates in the stream can scour these sediments and reduce the demand in a reach but may redeposit the sediment in a reduced velocity zone downstream. Sediment Oxygen Demand (SOD) is best determined using in situ testing but can also be approximated with laboratory analyses of sediment samples. In TMDL analyses, SOD is commonly determined through water quality models to avoid expensive and labor-intensive in situ monitoring.

Living material can also exude an oxygen demand on the water column. Algae, both suspended in the water (phytoplankton) and attached to rocks and wood debris on the streambed (periphyton), use oxygen during respiration. Hence, Minnesota's river nutrient standards include measures of algae, BOD, and daily (diel) oxygen fluctuation.

Natural background sources of oxygen-demanding substances are everywhere and include decaying material from forests and grasslands. In addition to oxygen-demanding substances, sources of low oxygen content (anoxic) water, such as groundwater and wetland drainage, can also reduce the DO concentration of a stream reach.

Legacy sources of sediments and nutrients to waterbodies may also influence present-day system oxygen demand via influencing alga/macrophyte growth, decay, and release of nutrients. A list of sources of low DO may include the following:

- CBOD

- NBOD
- SOD
- Nitrogen
- P
- Anoxic water
- Algal respiration.

3.7.2.1 Permitted

While Trott Brook Watershed did not contain permitted WWTFs or CAFOs, six MS4s that accounted for 91% of the total drainage area were noted. MS4s contributing to Trott Brook include the Elk River City MS4, Nowthen City MS4, Ramsey City MS4, Sherburne County MS4, and Anoka County MS4. MS4s can contribute oxygen-demanding substances from a variety of urban sources, such as decaying yard waste and soil erosion. Construction stormwater and industrial stormwater also have the potential to contribute to oxygen-demanding substances. Detailed information about specific permitted oxygen-demanding sources is included in Section 4.

Runoff from construction sites is a regulated source as defined by the MPCA's General Permit Authorization to Discharge Stormwater Associated with Construction Activity Under the National Pollutant Discharge Elimination System (NPDES)/State Disposal System (SDS) Permit (MNR100001). Permits are required for construction activities disturbing (1) one acre or more of soil; (2) less than one acre of soil if that activity is part of a "larger common plan of development or sale" that is larger than one acre; or (3) less than one acre of soil, but the MPCA determines that the activity poses a risk to water resources. Exposed soil surfaces can erode large quantities of suspended particles and oxygen-demanding materials from construction sites associated with soils, organic matter, and legacy sources. Industrial stormwater runoff is a regulated source as defined by the MPCA's reissued Multi-Sector Industrial Stormwater NPDES/SDS General Permit (MNR050000). The permit applies to facilities with Standard Industrial Classification Codes in 10 categories of industrial activities with the potential for significant materials and activities exposed to stormwater, which may leak, leach, or decompose and be carried offsite. Facilities can obtain a no-exposure exclusion if the site's operations occur under-roof. The permittee is required to develop and implement a Stormwater Pollution Prevention Plan (SWPPP) that details stormwater BMPs that are implemented to manage stormwater at the facility. Permitted facilities are also required to perform runoff sampling.

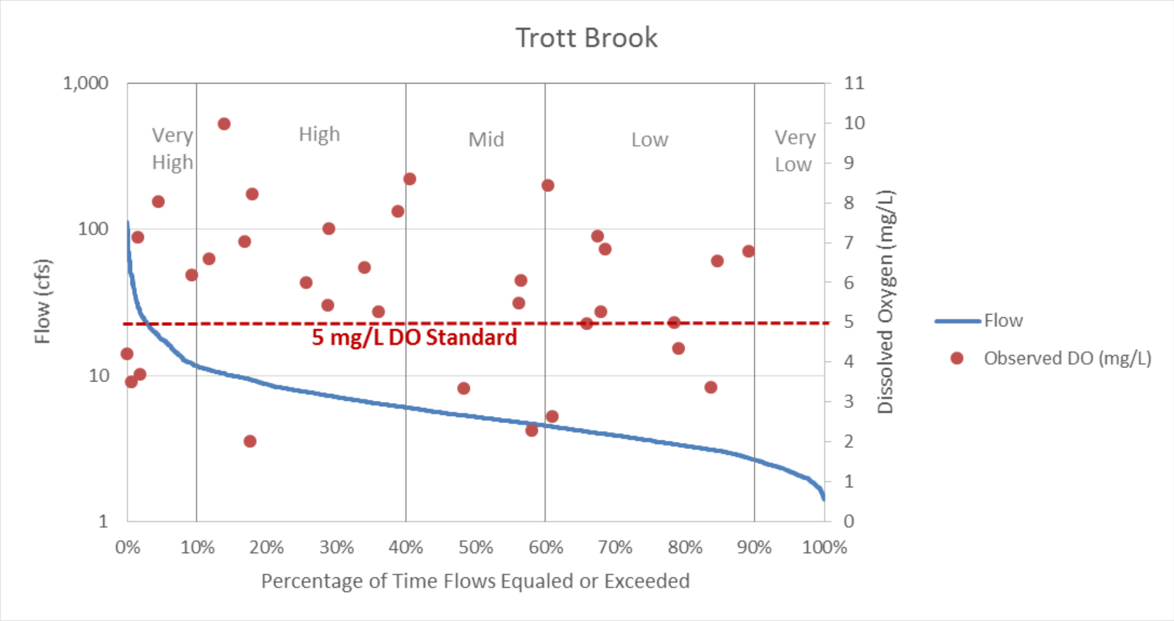
3.7.2.2 Nonpermitted

Approximately 9% of the drainage area is nonpermitted. Within this area, a mix of pasture/hay, row crops, forest, wetlands, and other land covers exist. These areas are likely to contribute to oxygen-demanding substances (CBOD and ammonia) via wash-off of nutrients, manure, and other organic materials from the land during precipitation events, as discussed at the beginning of Section 3.7. Two AFOs drain to Trott Brook above the TMDL endpoint, and both AFOs have less than 400 animal units. Manure from AFOs can also be washed off the land and can contribute oxygen-demanding materials to the stream.

3.7.2.3 Potential Sources

Available data for Trott Brook suggest that DO is not flow-dependent, with low values (e.g., below 5 mg/L) noted to occur across all flow zones, as shown in Figure 3-23. This indicates that low DO is a chronic condition and driven from persistent watershed sources. Figure 3-24 shows monitored 5-day biochemical oxygen demand (BOD_5) values plotted along the flow duration curve. These data indicate the BOD_5 levels do not appear to significantly increase during higher-flow runoff-related events. Similarly, monitored TP and Chl-*a* concentrations were plotted along the flow duration curve, as shown in Figures 3-25 and 3-26, respectively. Figures 3-25 and 3-26 indicate that TP and Chl-*a* also did not consistently increase with high flow. However, peak monitored ammonia concentrations were observed in high- and very high-flow zones, as shown in Figure 3-27.

Figure 3-23. Trott Brook (Site S003-176) Monitored Dissolved Oxygen Data Plotted on a Flow Duration Curve. The red dashed line indicates the 5 mg/L dissolved oxygen standard.



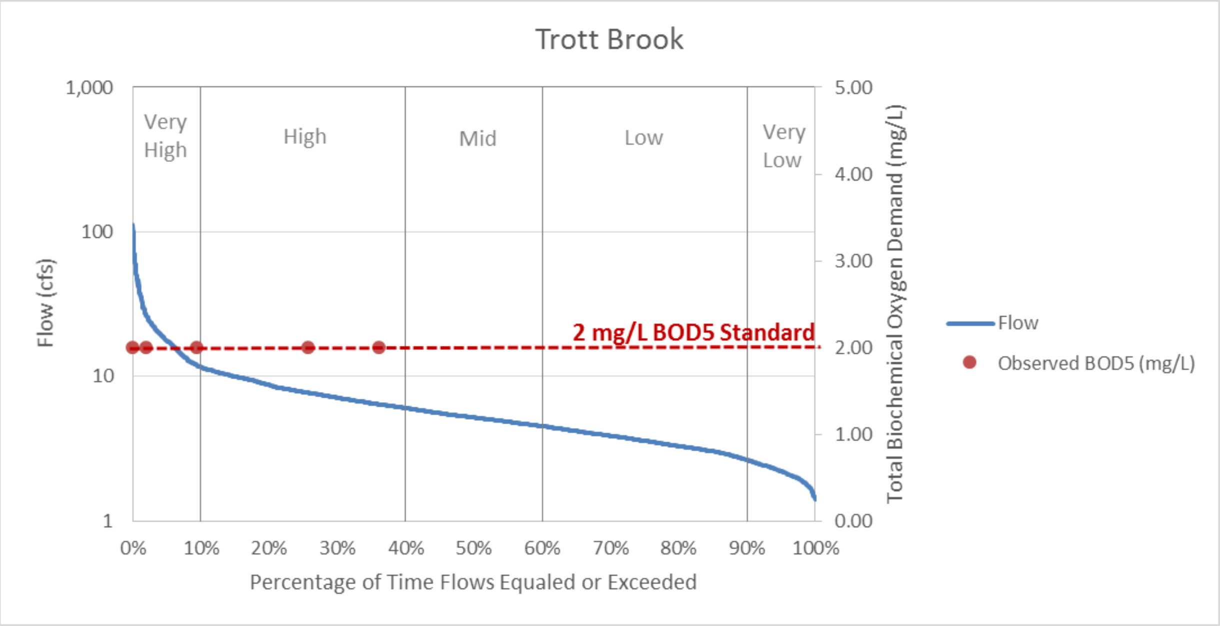


Figure 3-24. Trott Brook (Site S003-176) Monitored BOD_5 Concentrations Plotted on a Flow Duration Curve. The red dashed line indicates the 2 mg/L BOD_5 standard.

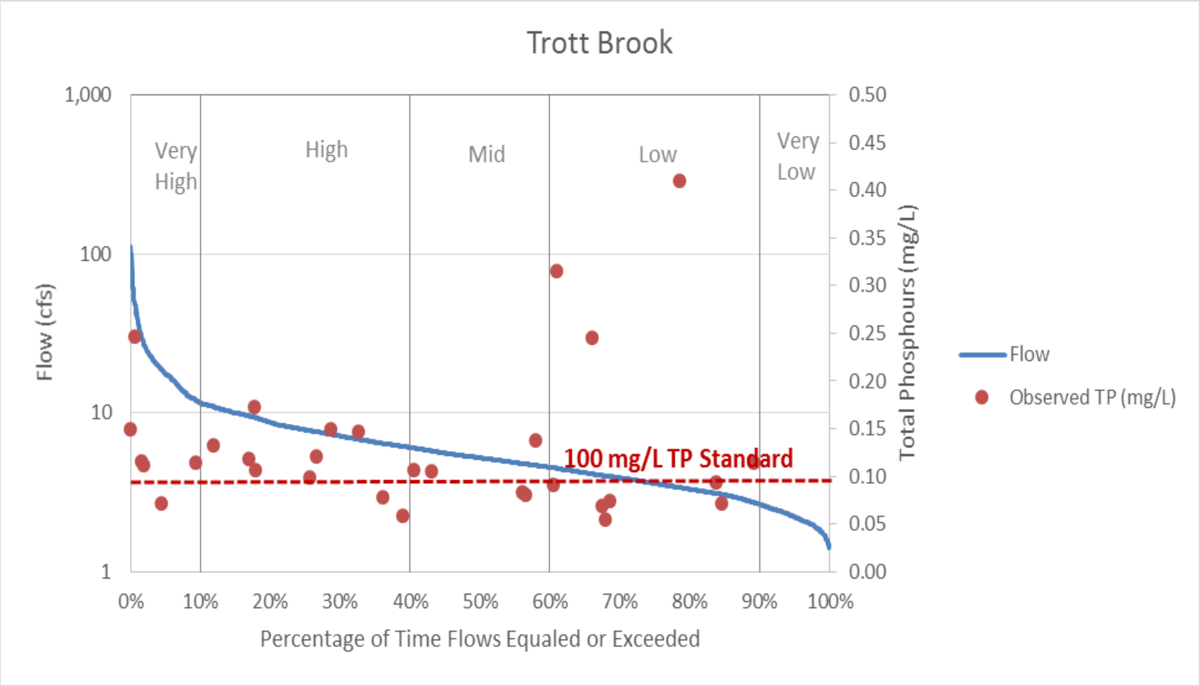


Figure 3-25. Trott Brook (Site S003-176) Monitored Total Phosphorus Concentrations Plotted on Flow a Duration Curve. The red dashed line indicates the 100 ug/L total phosphorus standard.

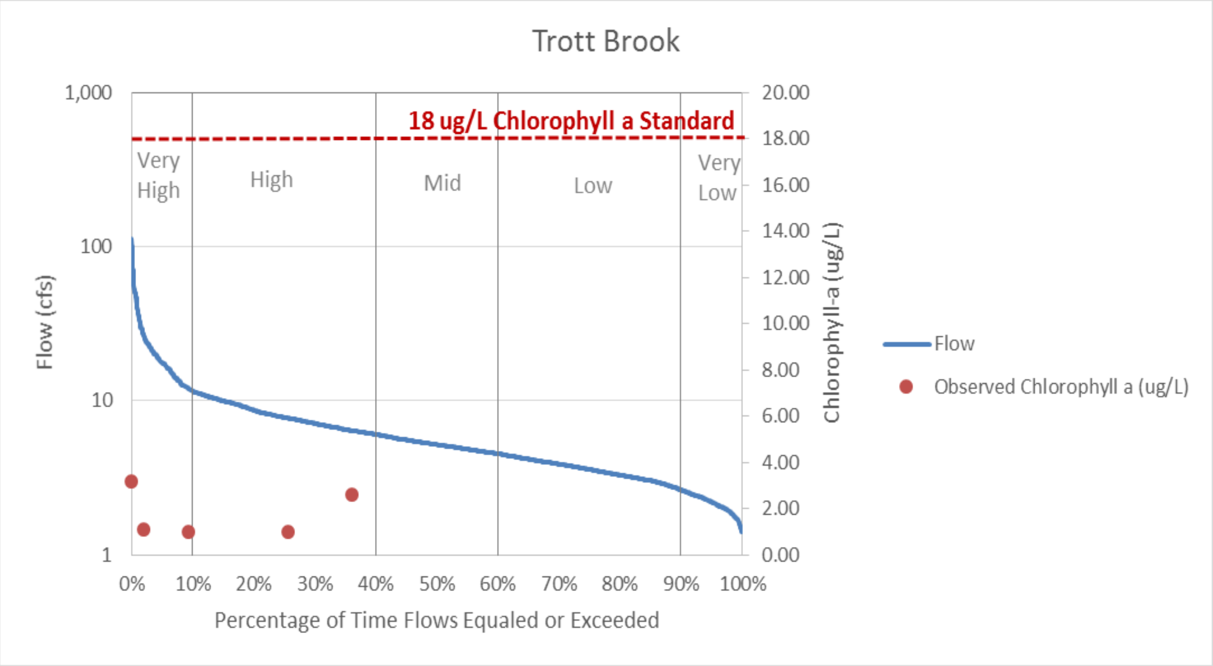
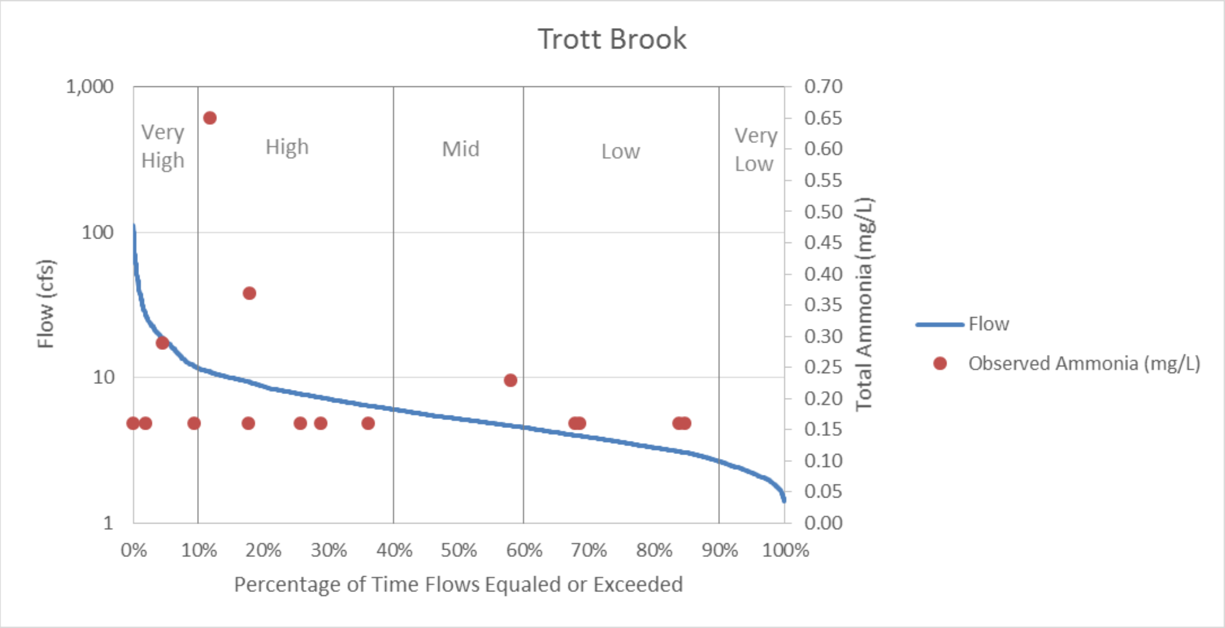


Figure 3-26. Trott Brook (Site S003-176) Monitored Chlorophyll-*a* Concentrations Plotted on a Flow Duration Curve. The red line indicates the 18 mg/L seston Chlorophyll-*a* standard.

Figure 3-27. Trott Brook (Site S003-176) Monitored Ammonia Concentrations Plotted on a Flow Duration Curve.



Other evidence of potential drivers of low DO was recently defined by the MPCA's RRW Stressor Identification Report [Johnson 2016b]. Extensive submerged aquatic plant and periphyton growth were noted with elevated TP concentrations that frequently exceed the Central River Nutrient Region standard of 100 micrograms per liter (µg/L). Also noted by Johnson [2016b] was the extent of channelization and recent land use changes to residential development along Trott Brook. These hydrologic changes and nearby wetland complexes may contribute to elevated TP and low DO concentrations.

SOD, CBOD, and NBOD are the sources that contribute to low DO concentrations in streams. The following general guidelines are based on chemical stoichiometry:

- 2.7 mg of oxygen is required to completely stabilize every milligram of carbon
- 3.43 mg of oxygen is required to completely stabilize every milligram of ammonia-nitrogen
  - (NH_4^++3/2O_2- à 2H^++H_2O+NO_2^-)
- 1.14 mg of oxygen is required to completely stabilize every milligram of nitrate-nitrogen
  - (NO_2^-+1/2O_2- à NO_3^-).

SOD can be a key contributor to low DO concentrations in streams and result in removing oxygen from overlying waters because of decomposition of settled organic matter. Stream SOD results in oxygen loss within streams because of aerobic decay of organic materials, enriched organic substrates in ditches/artificial drainage systems, and discharges from upgradient wetlands and lakes. SOD rates are defined in units of oxygen used per surface area per day (g-O_2/m^2/day). Higher SOD rates are typically associated with eutrophic systems with values exceeding 5 g-O_2/m^2/day.

This degradation of organic material can also result in the release of P into overlying waters [Price et al. 1994] and generate algal/organic matter further. High oxygen consumption (without replacement by reaeration or primary production) creates low oxygen conditions and, in severe cases, hypoxic or anoxic conditions that cause fish kills, invertebrate mortality, and species displacement. Increased oxygen depletion can affect fish and macroinvertebrate survival and propagation by increasing the potential for stress and disease that can, in turn, lead to a loss of diversity as more pollution-tolerant species replace more sensitive species. Hence, seasonality is an important factor affecting SOD rates, with warmer temperatures accelerating ambient chemical reaction rates that can influence aquatic DO concentrations.

Several factors affect SOD. Primary focus is often given to biological components, such as the organic content of the benthic sediment and microbial concentrations. Three of the most important parameters affecting SOD, as described in the literature, are temperature near the sediment-water interface, stream depth [Ziadat and Berdanier 2004], and the overlying water velocity [Truax et al. 1995]. Specifically, SOD increases linearly with velocity at low velocities (less than 10 centimeters per second (cm/s)) but becomes independent at high velocities [Makenthun and Stefan 1998]. Ziadat and Berdanier [2004] found that depth was the most important hydrologic variable effecting SOD in Rapid Creek, South Dakota. The base SOD rate changes throughout the year because of multiple factors, including DO concentration in the water column, seasonal benthic population changes, mixing rate of the overlying water, presence of toxic chemicals, and changes in temperature. Ambient temperatures increase in the summer-growing season when there are typically lower flows and stream velocities, which can increase the biologic activity and oxygen consumption at the sediment-water interface with minimal reaeration from water movement. Previously described basin climate patterns affecting SOD included dry/wet period variability, increasing ambient growing-season temperatures, and increasing frost-free periods. Sediment organic content is also a key factor that affects SOD rates.

Closely associated with SOD are oxygen-demand terms and methodologies borrowed from wastewater treatment for BOD_5 or biochemical oxygen demand (5-day laboratory method), which is represented as the sum of carbonaceous and nitrogenous oxygen demands (NODs). CBOD represents the oxygen equivalent (amount of oxygen) that microorganisms require to break down and convert organic carbon to CO_2 from carbonaceous organic matter. A second source is NBOD. A wide variety of microorganisms rapidly transform organic nitrogen to ammonia-nitrogen (NH_3-N). Bacteria then transform NH_3-N to nitrate through an oxygen-consuming process called nitrification. While these laboratory measures from sampled waters are appropriate, they do not adequately describe the cumulative oxygen depletions from upland ditches, drained wetlands, and eutrophic lakes; hence, a variety of SOD measurement methodologies employ a variety of in situ and laboratory core measurements. Lacking these assessments, alternative evaluations will be employed to approximate SOD.

Note that stream eutrophication standards (targets) were recently adopted for TP, Chl-*a*, diel DO flux, and biochemical oxygen. For Trott Brook (which is in the Central River Nutrient Region), these standards are TP (100 µg/L), Chl-*a* (seston) (18 µg/L), diel DO flux (3.5 mg/L), and BOD_5 (2 mg/L).

Water quality and flow data from the HSPF model were used to evaluate total oxygen demand (BOD decay, reach SOD, and NOD) as well as the effects of reaeration, phytoplankton, and benthic algae, as shown in Figure 3-28. The oxygen demand (SOD, BOD, and NOD) was calculated within the HSPF model and included total oxygen demand calculated over the simulation period for the model reach draining to Trott Brook. The HSPF model was also used to determine the contribution of oxygen-demanding substances from identified sources in the Trott Brook Watershed. Source-assessment modeling results were summarized by using the following categories: urban, mature forest, young forest, grassland, pasture/hay, agriculture, wetland, and feedlots. The majority of ammonia and BOD-related oxygen-demanding substances were distributed among five dominant source categories, with lesser amounts collectively represented by young forests, point sources, and pasture/hay sources, as depicted in Trott Brook source pie charts of Figure 3-29. Note that feedlot manure used on croplands is accounted in the agriculture category and not as feedlot loads in the HSPF model application source pie charts.

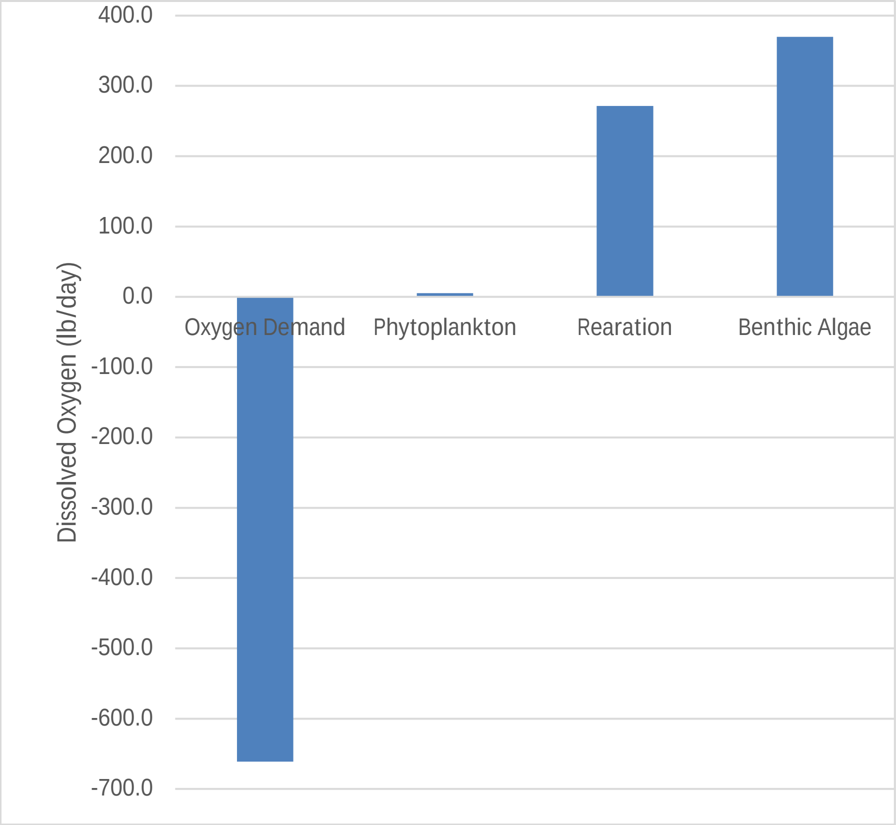


Figure 3-28. HSPF-Modeled Drivers of Dissolved Oxygen in Trott Brook.

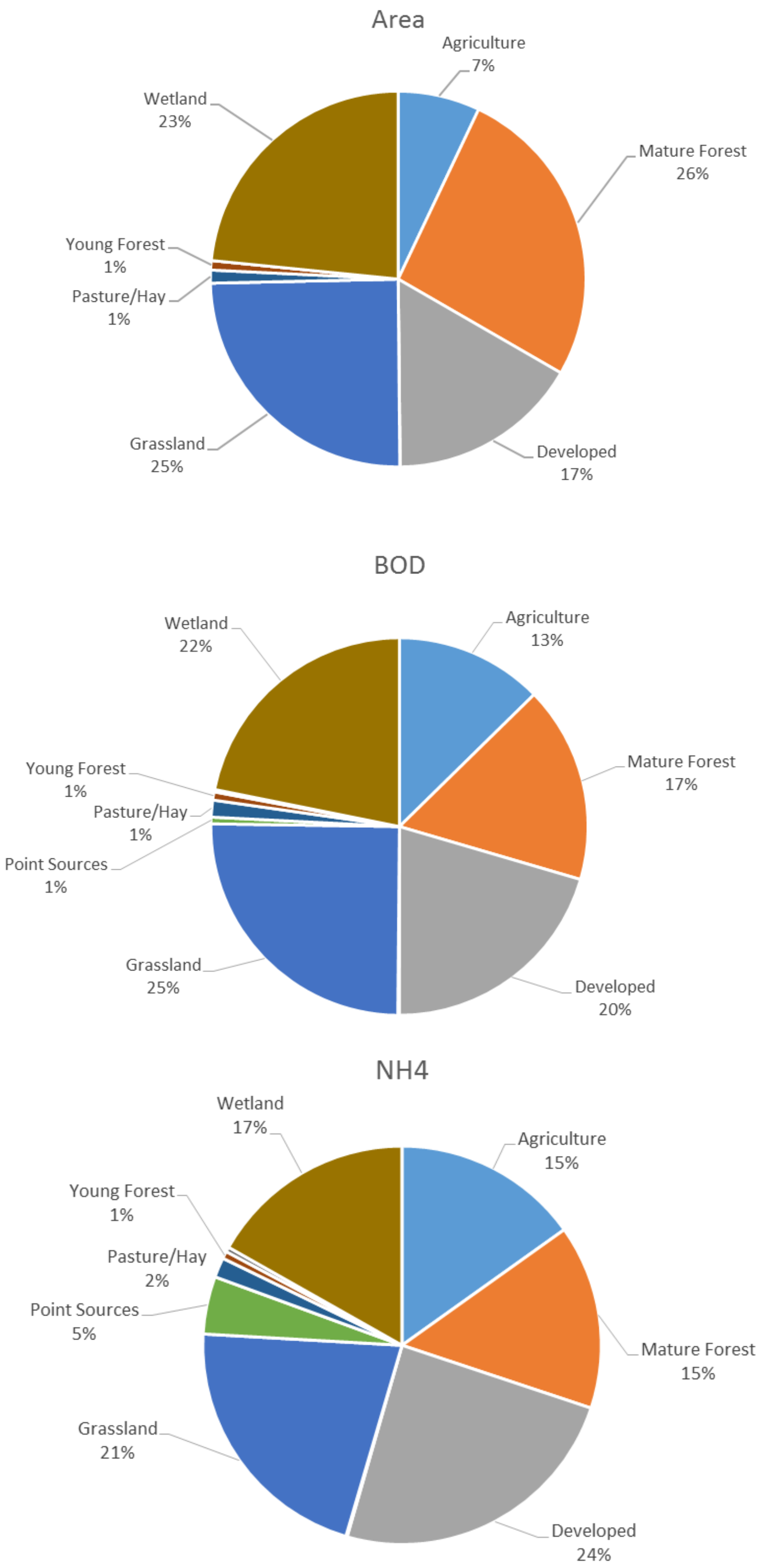


Figure 3-29. Trott Brook Watershed Oxygen Demand Source Summary Estimated by HSPF Modeling.

3.7.3 Nutrients

This TMDL study addresses nutrient impairment of 10 lakes of the RRW. P is the primary nutrient of concern in this TMDL because excess quantities typically drive a wide array of aquatic biological responses that can negatively affect established beneficial uses. High P concentrations are associated with elevated algal production, increased organic content and decay, and increased oxygen depletions that affect fish survival and propagation. Schupp and Wilson [1993] compared the relative abundance and presence of various fish across the spectrum of lake water quality by use of the Carlson Trophic State Index (TSI) [Carlson 1977], as depicted in Figure 3-30, which illustrates that the highest P concentrations (and TSI values) are associated with carp and black bullheads. Recreational uses are also affected as P concentrations increase and produce more algae and reduced water clarity. Increased algal abundance and reduced water clarity are negatively related to user preferences for swimmable conditions [Heiskary and Wilson 2005]. Heiskary and Walker [1988] further refined lake quality evaluations based on the frequency of extreme Chl-*a* concentrations or blooms as opposed to average summer Chl-*a* concentrations. Both Chl-*a* and transparency exhibit nonlinear responses to increased P concentrations. The observed frequency of Chl-*a* concentrations that exceed 30 ug/L (or severe nuisance conditions in Heiskary and Wilson [2005]) is quite low at P concentrations of about 30 ug/L and increases steadily to approximately 70% of the summer, with P concentrations of about 100--120 ug/L. Algal blooms in severe form are frequently dominated by cyanobacteria that can be periodically toxic. Hence, these interrelationships were the building blocks used to define lake P thresholds that became Minnesota's lake eutrophication standards and the targets for the lake nutrient TMDL allocations described herein.

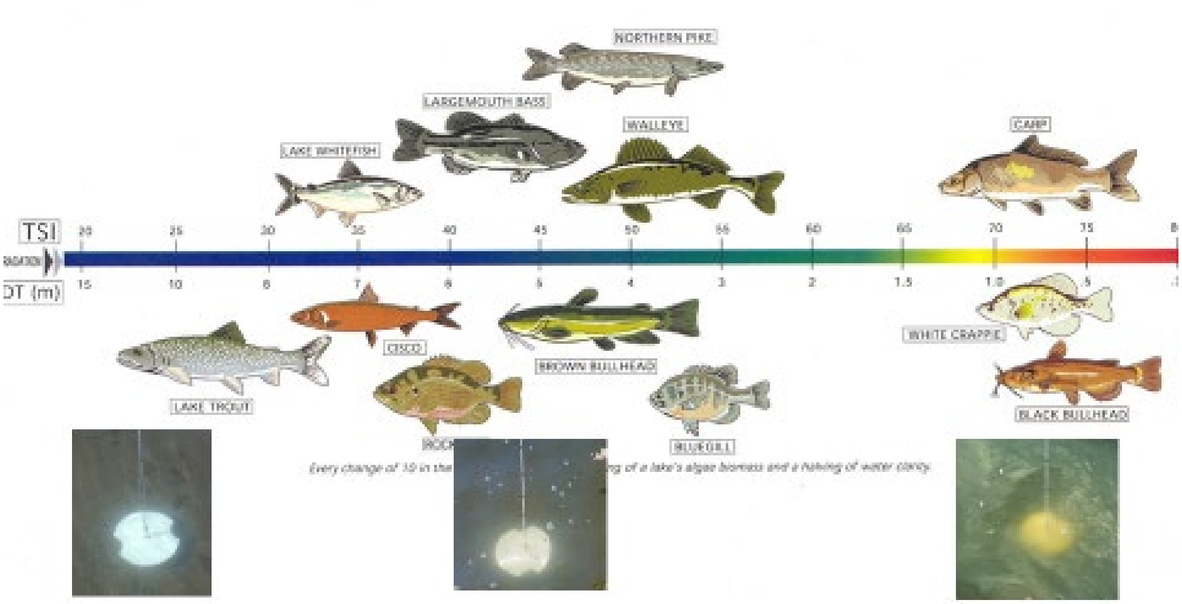


Figure 3-30. Lake Fish Species Relative to Carlson TSI (Top of the Bar) With Average Summer Secchi Transparency (Across the Bottom of the Bar in Meters) (MPCA Graphic Adapted From Schupp and Wilson [1993]).

One of the main components of a TMDL is identifying watershed P sources and the magnitude of their contributions to each lake.

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

3.7.3.1 Permitted

Permitted sources are by definition point sources or those that originate from a discrete, identifiable source within the watershed and are regulated by the NPDES and SDS Permits. These include the following:

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

Detailed information about specific permitted P sources is included in Chapter 4. Any industrial, municipal, or private-entity point source discharging treated wastewater to surface waters of Minnesota must have an NPDES/SDS Permit that specifies discharge location(s), volumes, and treated effluent quality. However, no WWTFs drain to the set of impaired lakes addressed in this TMDL.

The permitted CAFO (permit number MN0066184) located in the RRW is in the drainage area of Green Lake and is located approximately two miles north of the lake. The permit states "in the event of a discharge due to a storm event, as specified in Part IX.A.1.a, from chronic or catastrophic precipitation, from a discharge from a land application site, or any discharge due to noncompliance with the conditions of this Permit, the permittee shall report the discharge in a manner required under Part VIII.B.4.b." CAFOs are generally not allowed to discharge to surface water (with exceptions specified in the Permit), but manure from CAFO lagoons is spread locally and can be washed off during precipitation events to contribute to nutrient impairments.

Municipal stormwater permits are required for specified Phase II cities defined as MS4s by Permit (General Permit Authorization to Discharge Stormwater Associated with Small MS4s under the NPDES/SDS) Permit (MNR040000). MS4s are defined by the MPCA as conveyance systems (roads with drainage systems, municipal streets, catch basin, curbs gutters, ditches, man-made channel, and storm drains) that are owned or operated by a public entity such as a state, city, town, county, district, or other public body having jurisdiction. Multiple MS4s are located within the watersheds of nutrient-impaired lakes. The Cambridge City MS4 drains to Fannie Lake. The Baldwin Township MS4 drains to Baxter Lake. Winter thaws and rainfall events generate runoff within city areas that reach storm sewer conveyances largely influenced by the amounts and distribution of impervious areas associated with roof tops, sidewalks, driveways/parking lots, streets, and other compacted surfaces. Lawns, soils, grass clippings, organic debris, road-surface particles, vehicular debris, eroded soil particles, pet and wildlife wastes, and atmospheric deposition are all potential P-containing substances.

As previously mentioned in Section 3.7.2.1, runoff from construction sites is a regulated source as defined by the MPCA's General Permit Authorization to Discharge Stormwater Associated with Construction Activity under the NPDES/SDS Permit (MNR100001). Permits are required for construction activities disturbing: (1) one acre or more of soil, (2) less than one acre of soil if that activity is part of a 'larger common plan of development or sale" that is larger than one acre or (3) less than one acre of soil, but the MPCA determines that the activity poses a risk to water resources. Exposed soil surfaces can erode large quantities of suspended particles from construction sites, including P associated with soils, organic matter, and legacy sources. Industrial stormwater runoff is a regulated source as defined by the MPCA's reissued Multi-sector Industrial Stormwater NPDES/SDS General Permit (MNR050000) [MPCA 2015] and applies to facilities with Standard Industrial Classification Codes in 10 categories of industrial activities with the potential for significant materials and activities exposed to stormwater, and that may leak, leach, or decompose and be carried offsite. Facilities can obtain a no-exposure exclusion if the site's operations occur under-roof. The permittee is required to develop and implement a SWPPP that details stormwater BMPs that are implemented to manage stormwater at the facility. Permitted facilities are required to perform runoff sampling, which is compared to benchmark P concentrations as specified by the EPA. P monitoring is required if a nutrient-impaired waterbody is located within one mile of the facility. A search of the MPCA's Industrial Stormwater Database revealed that 16 industrial facilities exist in Cambridge, Minnesota, with five facilities having no-exposure exclusions.

3.7.3.2 Nonpermitted

P sources that are not required to have NPDES/SDS Permits include direct watershed runoff, loading from upland watershed tributaries, subsurface sewage treatment systems (SSTS), atmospheric deposition, and internal loading.

Direct watershed runoff occurs from precipitation and snowmelt events. Runoff from agricultural lands, feedlots, and urban lands and other land uses contributes P to waterbodies. For instance, decomposing organic material from forests and wetlands contribute P to waterbodies. P is also attached to sediment and is transferred with sediment into the stream during runoff events.

Loading from upland tributaries occurs from contributing areas outside of the direct lakeshed. These upstream loads are the result of upstream direct watershed runoff, SSTS, atmospheric deposition, scour/bank erosion, and other sources.

Homes and businesses in each impaired lake watershed are served by SSTSs. A desktop analysis was carried out to estimate the number of homes and cabins around each lake based on manual counting from the latest available Google Earth images for each lake's watershed. The counts were confirmed by county officials and reviewed by local lake groups (if possible). Assumptions and literature values were used to estimate total annual loading from septic systems.

Atmospheric deposition of P on the lake surface can be an important part of the P budget. Atmospheric deposition occurs as wet (carried by precipitation) and dry (dry particles carried as dust) deposition. Unlike other nonpoint sources such as watershed runoff or septic loading, atmospheric P deposition originates at least partly outside at the watershed and cannot be controlled. An atmospheric P deposition of 26.8 mg m^{-2}/yr [Twarowski et al. 2007] was used to quantify average annual total (wet + dry) deposition on the lake surface.

Lake nutrient cycling (or internal loading) refers to several processes that can result in releasing P into the water column, where it can be available to algal growth, as dissolved P forms. In general, lake P cycling can occur from the following types of processes:

1. P released from lake sediments in aerobic and anerobic conditions, as typically moderated by amounts of available iron and other factors such as legacy loading. The historical importance of dairy operations in the area suggests the possibility that manure and dairy cleaning operations may have enriched some sediment/wetland areas and, ultimately, lake sediments.
2. 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, can cause resuspension of nutrients, including P. Small particles (clay and silt) are most vulnerable to resuspension; these particles also have the largest specific area (surface area per mass) and, therefore, are capable of holding much more P per unit mass than larger particles (sand).
3. P released from 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 off in early- to mid-summer and is subject to rapid decay in warm water, thereby potentially contributing to summer P concentrations. In other instances, macrophytes can be effective at stabilizing sediment and limiting resuspension. However, peak macrophyte growth can increase pH and contribute to daily minimum DO concentrations at the sediment-water interface, which causes P release from sediments. Wave mixing of deeper waters can result in transport of sediment P into the surface waters.
4. High concentrations of TP and dissolved P from tributary and lakeshed runoff pulses can contribute to elevated in-lake concentrations and increased algal growth. The resulting increased biological growth, decay, and deposition may increase the pool of soluble/dissolved P in-lake shallow-lake sediments and, hence, may be temporally mistaken for traditional internal loading sources. Therefore, particular attention was paid to HSPF-generated TP and dissolved P loading rates to each lake.

Distinguishing internal versus external P loading is more difficult in shallow lakes that are more wind mixed vertically and subject to tributary-induced horizontal exchange (advective flows).

Simple methods for quantifying potential internal loading were developed by Nürnberg [1988; 1996] that are based upon statistical regression equations developed from measured sediment P release rates and sediment P concentrations from a set of North American lakes. This method estimates internal loading based on expected lake-sediment P release rates (RR), lake anoxic factor (AF) and the lake’s area. Lake-sediment samples were obtained during late July 2014 from Skogman, Baxter, Fannie, Francis, Green, South Stanchfield, and Long Lakes with laboratory analytical measurements of TP, bicarbonate dithionite extractable P (BD-P) and loss on ignition (organic matter). Iron- P and total P regression equations resulted in large ranges of estimated internal loading and are listed by lake in Table 3-17. BD-P-based estimates are lower than the North American lake TP-based regression values for the deep lakes but are greater for the shallow lakes. Considerable ranges of values were identified and ranged from negative to positive values that largely reflected the variable sediment chemistries, water residence times, and shallow nature of these lakes compared to lakes used in model development. Lastly, the shallow and highly flushed nature of most of these lakes complicates assessing internal loading based on broadly established relationships. Given these large uncertainties associated with the sediment chemistry-based internal loading, considerations of net summer increases and detailed mass balances (summary of income and outgo balances) were given greater significance in determining individual lake internal loading rates. Sediment data laboratory results are included in Appendix L.

Table 3-17. Range of Estimated Internal Loading (kilograms per year) Based on Sediment P Concentrations and Nürnberg [1988] Equations

Lake	Based on BD-P, North American Lakes (kg/yr)	Based on TP, North American Lakes (kg/yr)
Shallow Lakes		
Baxter	14	Very Low
Francis	66	Very Low
Long (2 samples)	40-50	Very Low to 63
South Stanchfield	Very Low	Very Low
Deep Lakes		
Fannie (2 samples)	Very Low to 171	193- 601
Skogman (2 samples)	29d–195	206- 643
Green	Very Low	Very Low

(a) Two sediment samples were obtained for Skogman, Fannie, and Long Lakes, and are represented as calculated ranges.

(b) Internal loading indicated as 'very low' means equations returned negative values.

3.7.3.3 Potential Sources

For the nutrient portion of this TMDL, sources are broken down by what is occurring within each impaired lake and how each potential source needs to be reduced within the TMDL development section (Chapter 4). The calibrated 1995 through 2015 RRW HSPF model was used to develop runoff volumes and P load estimates by source within each impaired lake's watershed. This included upland tributaries identified by reach number and direct drainage or lakeshed loading to each lake. Section 3.6 of this report details the HSPF model development that explicitly included regulated and nonregulated sources of P that were, in turn, incorporated into P loads for each lake. The HSPF-generated, lake-specific loadings along with permitted and nonpermitted sources discussed in Sections 3.7.3.1 and 3.7.3.2 were entered into BATHTUB to quantify each lake's loading capacity by source and to distribute the TMDL allocations and reductions Land cover categories represented in HSPF include developed, mature deciduous and evergreen forest, young forest, grasslands, pasture, agriculture, wetlands, and feedlots. Point sources, septic systems, and atmospheric deposition were also represented in HSPF. HSPF then incorporates the fate and transport of the P as it travels downstream.

4 TMDL Development: *E. coli*, Dissolved Oxygen, and Lake Nutrients

4.1 *E. coli*

LDCs, which represent the allowable daily *E. coli* load under a wide range of flow conditions, were used to represent the *E. coli*-loading capacity and allocations of each impaired reach. This approach results in a flow-variable target that considers the entire flow regime within the time period of interest. Five flow intervals were developed for each reach, and the loading capacity and allocations were developed for each flow interval. The five flow intervals were very high (0% to 10%), high (10% to 40%), mid (40% to 60%), low (60% to 90%), and very low (90% to 100%) in adherence to guidance provided by the EPA [2007].

4.1.1 Loading Capacity

The TMDL is the loading capacity of a reach and is the sum of the LA, the WLA, and a MOS, shown in Equation 4-1.

$$TMDL = \sum(WLA) + \sum(LA) + MOS + RC$$

LDCs were used to represent the loading capacity. The flow component of the loading capacity curve is the HSPF-simulated daily average flow at the outlet of each impaired reach, and the concentration component is geometric mean *E. coli* concentration criterion (126 most probable number per 100 milliliters [mpn/100 mL]). The loading capacities presented in the TMDL tables are the products of the median simulated flow in each flow interval, the applicable concentration criterion, and a unit conversion factor. The current load is based on the geometric mean of all observed samples in each flow zone. An LDC and TMDL summary table are provided for each *E. coli*-impaired reach in Section 4.1.5.

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

4.1.2 Wasteload Allocation Methodology

WLAs for TMDLs represent permitted WWTFs, permitted MS4s, and stormwater from industrial and construction permits.

4.1.1.1 Permitted Wastewater Treatment Facilities

The three permitted WWTFs contributing to an *E. coli*-impaired reach are shown in Table 4-1 along with the impairments to which each contributes. The WLAs were calculated as the product of the facility design flows or maximum permitted flow rates, the effluent concentration allowed, and a unit conversion factor. Loads from continuously discharging municipal WWTFs were calculated based on the average wet-weather design flow, which is equivalent to the wettest 30-days of influent flow expected over the course of a year. Loads from controlled municipal discharging WWTFs were calculated based on the maximum daily volume that may be discharged in a 24-hour period. The design flow, *E. coli* concentration limits used to calculate set WLAs, and the WLAs are included in Table 4-1. The WWTFs have fecal coliform regulations instead of *E. coli*. The *E. coli* standard of 126 org/100 mL was used to calculate the WLAs instead of the fecal coliform permit limit of 200 org/100 mL. The WLAs do not vary based on flow.

Table 4-1. Wastewater Treatment Facilities Design Flows and *E. coli* Wasteload Allocations

Impairment	Facility	Permit ID	Design Flow (mgd)	Effluent Concentration Limit (org/100 mL)	*E. coli* WLA (org/day)
West Branch of the Rum	Foreston WWTF	MNG580017	0.675	126	3.22E+09
Seelye Brook	Saint Francis WWTF	MN0021407	0.814	126	3.88E+09
Cedar Creek	Isanti Estates LLC	MN0054518	0.02	126	9.54E+07

mgd = million grams per day

4.1.1.2 Permitted Municipal Separate Storm Sewer Systems

Multiple regulated MS4s have portions of their municipal boundaries draining to an *E. coli*-impaired reach, as presented in Table 4-2. The percent area that all MS4s were contributing above the endpoint of each reach was determined, and the overall load allowed from each MS4 was calculated by using the percent of each MS4 area multiplied by the loading capacity after the MOS and NPDES portions of the WLAs were subtracted. Several nontraditional MS4s are located in Cedar Creek (MnDOT Metro District MS4 and the Anoka County MS4) and overlap with the city MS4s. Right-of-way areas and other areas owned by each nontraditional MS4 draining to their regulated areas were subtracted from city MS4 areas. Input was provided by Ham Lake City to slightly adjust the lower boundary of the Ham Lake City MS4 area.

Table 4-2. Wasteload Allocations for All Municipal Separate Storm Sewer Systems Communities That Contribute Directly to Impaired Reaches

Reach	MS4	Permit No.	Contributing Area (acres)	*E. coli* Allocation (% of Allowable Load)
Seelye Brook	Oak Grove City	MS400110	889	3.4
	Nowthen City	MS400069	760	2.9
	Saint Francis City	MS400296	6481	25.0
Cedar Creek	Oak Grove City	MS400110	9,358	18.0
	East Bethel City	MS400087	18,649	35.9
	Ham Lake City	MS400092	1,032	2.0
	Andover City	MS400073	4,411	8.5
	Saint Francis City	MS400296	618	1.2
	Isanti City	MS400287	260	0.5
	Anoka County	MS400066	16	< 0.5
	MnDOT	MS400170	14	< 0.5

4.1.1.3 Construction and Industrial Stormwater

The Minnesota Construction Stormwater Permit is MNR100001, and the Minnesota Industrial Stormwater Permit is MNR050000. *E. coli* is not typically contributed from construction stormwater; therefore, a construction stormwater WLA was not necessary. No benchmark monitoring of bacteria or *E. coli* are required with industrial permits, and *E. coli* is not typically contributed from industrial stormwater. Therefore, an industrial stormwater WLA was not necessary.

4.1.3 Margin of Safety

MOS is a portion of the TMDL that is set aside to account for the uncertainties associated with achieving water quality standards. MOS is usually expressed in terms of the percentage of the loading capacity that is set aside as an uncertainty-insurance measure. For *E. coli* TMDLs in the RRW, an explicit MOS was calculated for each impairment as 10% of the loading capacity. The calculation of the loading capacity is the product of monitored flow and the *E. coli* target concentration. Ten percent was considered an appropriate MOS because the LDC approach minimizes the uncertainty associated with developing TMDLs. Additionally, 10% is appropriate because no rate of decay or die-off rate of pathogen species was used in the TMDL calculations or in the creation of LDCs. As stated in EPA's Protocol for Developing Pathogen TMDLs (EPA 841-R-00-002), many different factors affect the survival of pathogens, including the physical condition of the water. These factors include, but are not limited to sunlight, temperature, salinity, and nutrient deficiencies. These factors vary depending on the environmental condition/circumstances of the water, and therefore it would be difficult to assert that the rate of decay caused by any given combination of these environmental variables was sufficient enough to meet the WQS of 126 cfu/100 mL. Thus, it is more conservative to apply the State's WQS as the MOS, because this standard must be met at all times under all environmental conditions.

4.1.4 Load Allocation Methodology

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

4.1.5 Total Maximum Daily Load Summary

The LDCs and *E.coli* TMDL tables are shown for each impaired reach in Figures 4-1 through 4-5 and Tables 4-3 through 4-7. Observed data are generally unavailable in the low-flow zone; the only impairment with observed data in the very low-flow zone is the West Branch of the Rum River. Based on available data, Bogus Brook reductions are needed in all flow zones. From available data, Cedar Creek and Estes Brook reductions are needed across all of the flow zones but the high-flow zone. Seelye Brook reductions are needed in the very high- and mid-flow zones, and in the West Branch of the Rum River, reductions are needed in all of the flow zones but the very high-flow zone. The percent load reductions needed to meet the loading capacity in each flow interval were calculated to provide the overall magnitude of the required reductions. Reduction magnitudes also help focus future management actions; if higher reductions are needed in a certain flow interval, management practices should focus on the sources that most likely influence concentrations in those flow conditions. Exceedances of the *E. coli* target during high flows are typically caused by larger area-induced indirect pollutant sources that reach surface waters through watershed runoff. Low-flow exceedances are typically caused by direct pollutant loads or sources in close proximity to the stream, such as direct defecation by wildlife or livestock in the stream channel or failing septic systems [EPA 2007]. To understand the overall reductions required across all of the flow zones, the current observed loads and loading capacities were flow weighted and were used to calculate a flow weighted required reduction. The overall reduction required is shown in the bottom row in Tables 4-3 through 4-7.

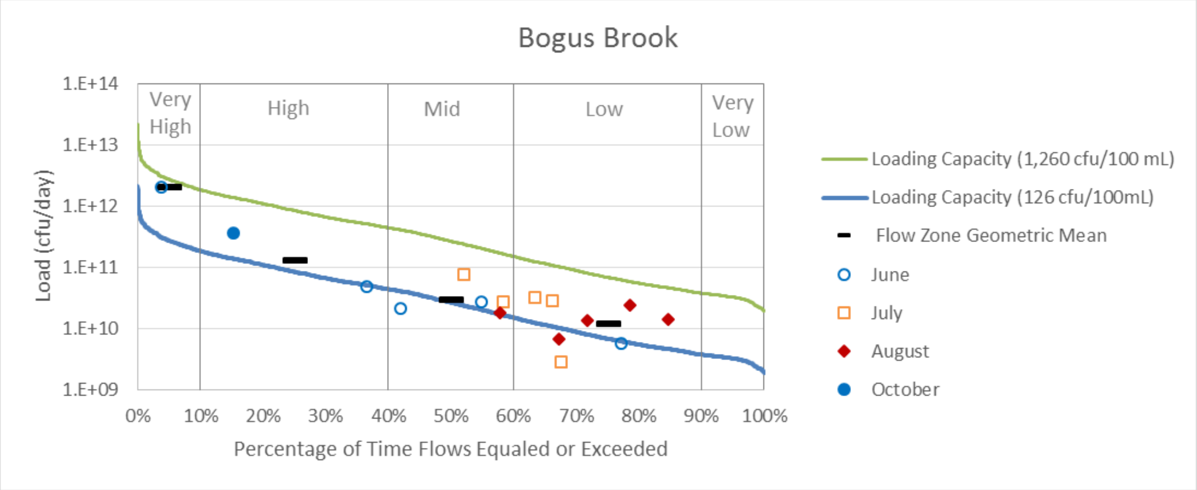


Figure 4-1. Bogus Brook *E. coli* Load Duration Curve.

Table 4-3. Bogus Brook *E. coli* Total Maximum Daily Load Summary

Bogus Brook		Flow Zone				
***E. coli* TMDL Component (billions of organisms/day)**		**Very High**	**High**	**Mid**	**Low**	**Very Low**
Total Daily Loading Capacity		270.25	83.92	26.61	6.81	3.23
Margin of Safety (MOS)		27.02	8.39	2.66	0.68	0.32
Wasteload Allocations	Permitted Wastewater Dischargers	–	–	–	–	–
	MS4s	–	–	–	–	–
Load Allocation		243.23	75.53	23.95	6.13	2.91
Total Current Load		1989.56	204.07	27.26	13.95	(a)
Reduction Required		86%	59%	2%	51%	*
Overall Reduction Required		78%				

(a) No data available to calculate current load.

Figure 4-2. Cedar Creek *E. coli* Load Duration Curve.

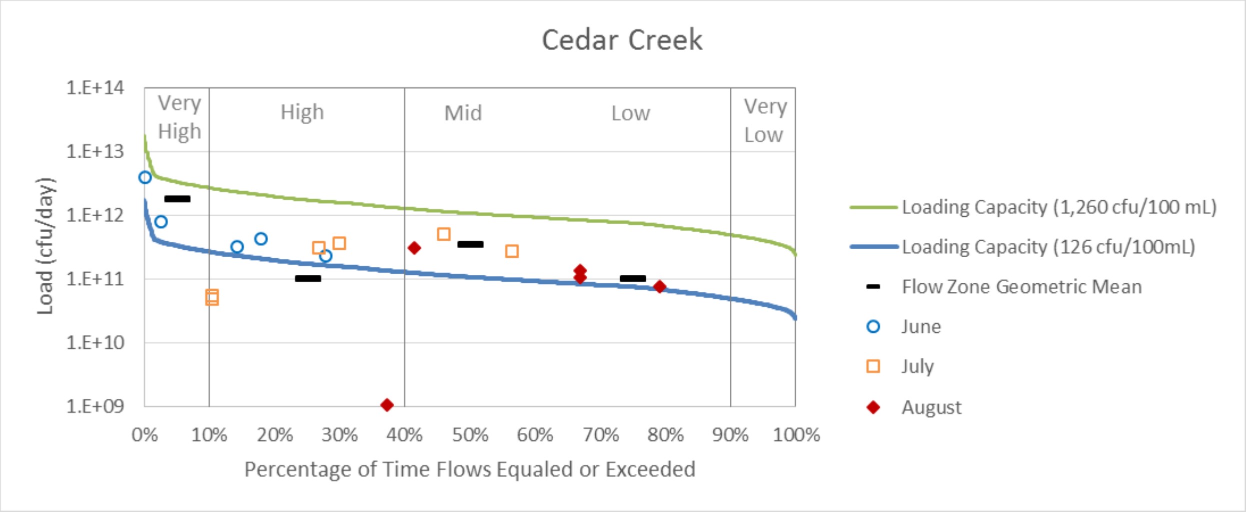


Table 4-4. Cedar Creek *E. coli* Total Maximum Daily Load Summary

Cedar Creek		Flow Zone				
***E. coli* TMDL Component (billions of organisms/day)**		**Very High**	**High**	**Mid**	**Low**	**Very Low**
Total Daily Loading Capacity		335.79	175.45	108.95	76.46	40.56
Margin of Safety		33.58	17.55	10.89	7.65	4.06
Wasteload Allocations	Permitted Wastewater Dischargers	0.10	0.10	0.10	0.10	0.10
	Andover City MS4	25.64	13.39	8.31	5.83	3.09
	East Bethel City MS4	108.39	56.62	35.14	24.65	13.06
	Ham Lake City MS4	6.00	3.13	1.95	1.36	0.72
	Oak Grove City MS4	54.39	28.41	17.64	12.37	6.56
	Isanti City MS4	1.51	0.79	0.49	0.34	0.18
	Saint Francis City MS4	3.59	1.88	1.16	0.82	0.43
	MnDOT MS4	0.08	0.04	0.03	0.02	0.01
	Anoka County MS4	0.10	0.05	0.03	0.02	0.01
Load Allocation		102.41	53.49	33.21	23.30	12.34
Total Current Load		1,798.35	101.49	348.82	104.66	(a)
Reduction Required		81%	0%	69%	27%	(a)
Overall Reduction Required		58%				

(a) No data available to calculate current load.

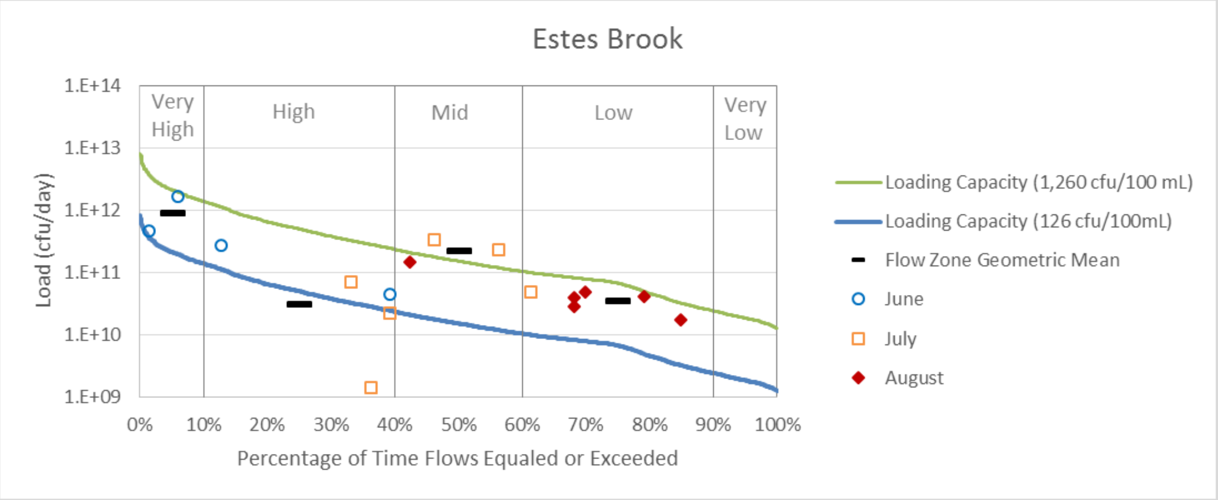


Figure 4-3. Estes Brook *E. coli* Load Duration Curve.

Table 4-5. Estes Brook *E. coli* Total Maximum Daily Load Summary

Estes Brook		Flow Zone				
***E. coli* TMDL Component (billions of organisms/day)**		**Very High**	**High**	**Mid**	**Low**	**Very Low**
Total Daily Loading Capacity		211.51	50.35	15.26	6.76	1.87
Margin of Safety		21.15	5.03	1.53	0.68	0.19
Wasteload Allocations	Permitted Wastewater Dischargers	–	–	–	–	–
	MS4s	–	–	–	–	–
Load Allocation		190.36	45.32	13.73	6.08	1.68
Total Current Load		893.52	30.94	226.87	35.41	(a)
Reduction Required		76%	0%	93%	81%	(a)
Overall Reduction Required		73%				

(a) No data available to calculate current load.

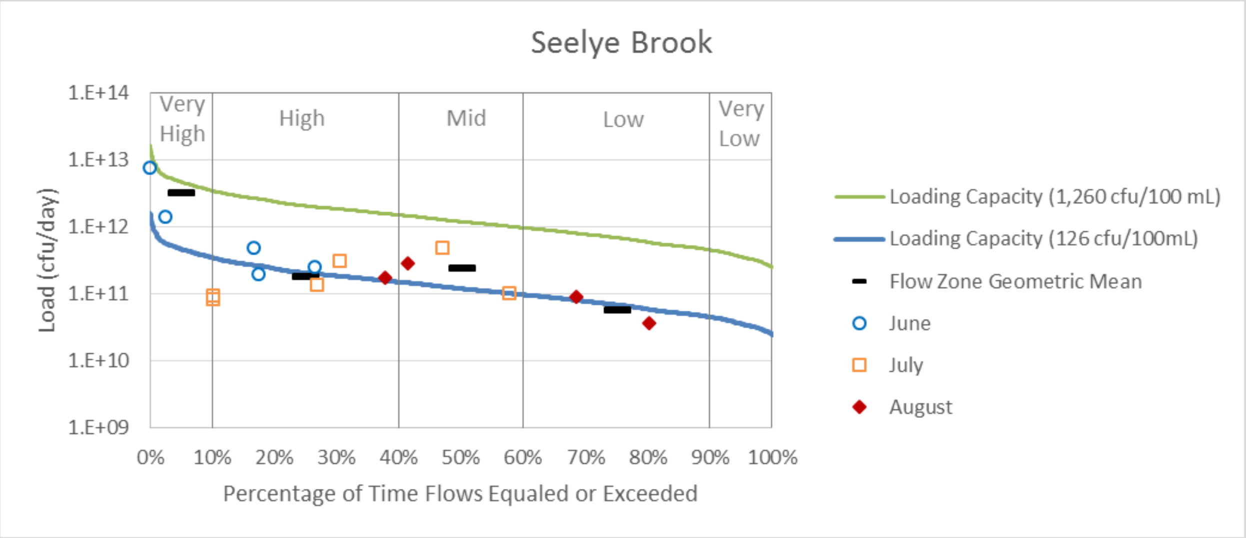


Figure 4-4. Seelye Brook *E. coli* Load Duration Curve.

Table 4-6. Seelye Brook *E. coli* Total Maximum Daily Load Summary

Seelye Brook		Flow Zone				
***E. coli* TMDL Component (billions of organisms/day)**		**Very High**	**High**	**Mid**	**Low**	**Very Low**
Total Daily Loading Capacity		470.22	208.24	120.44	69.50	36.34
Margin of Safety		47.02	20.82	12.04	6.95	3.63
Wasteload Allocations	Permitted Wastewater Dischargers	3.88	3.88	3.88	3.88	3.88
	Oak Grove City MS4	12.27	5.37	3.06	1.72	0.84
	Nowthen City MS4	14.35	6.28	3.58	2.01	0.99
	Saint Francis City MS4	104.73	45.84	26.10	14.65	7.20
Load Allocation		287.95	126.04	71.78	40.29	19.80
Total Current Load		3,331.95	186.66	248.29	58.37	(a)
Reduction Required		86%	0%	51%	0%	(a)
Overall Reduction Required		66%				

(a) No data available to calculate current load.

Figure 4-5. West Branch Rum River *E. coli* Load Duration Curve.

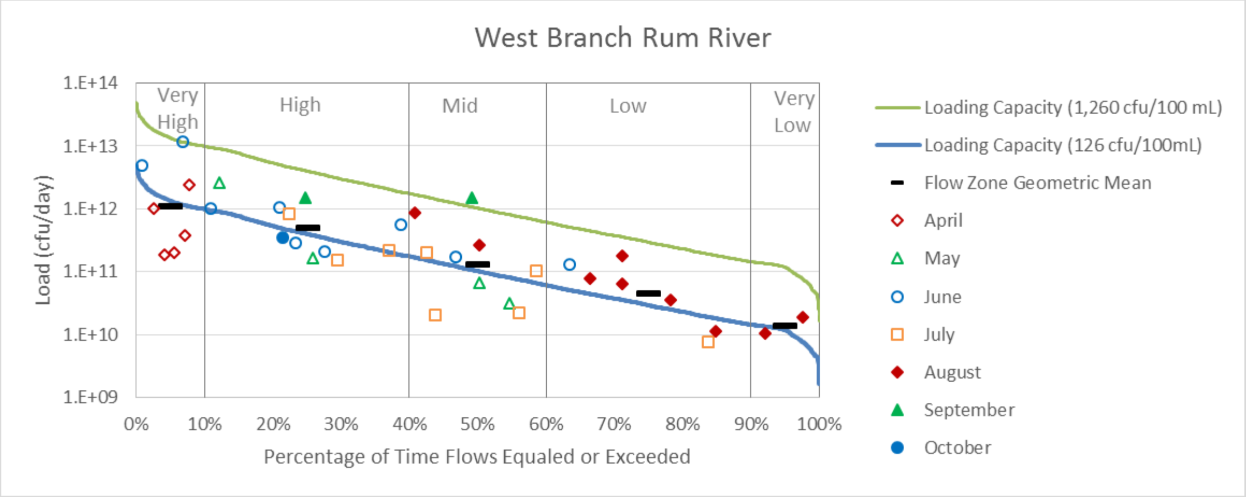


Table 4-7. West Branch Rum River *E. coli* Total Maximum Daily Load Summary

West Branch of the Rum River		Flow Zone				
E. coli TMDL Component (billions of organisms/day)		Very High	High	Mid	Low	Very Low
Upstream Boundary Condition (Estes Brook)		211.51	50.35	15.26	6.76	1.87
Total Daily Loading Capacity		1,343.33	398.83	103.10	29.46	11.85
Boundary Condition Adjusted Total Daily Loading Capacity		1,131.82	348.49	87.84	22.70	9.97
Margin of Safety		113.18	34.85	8.78	2.27	1.00
Wasteload Allocations	Permitted Wastewater Dischargers	3.22	3.22	3.22	3.22	3.22
	MS4s	–	–	–	–	–
Load Allocation		1,015.42	310.42	75.84	17.21	5.75
Total Current Load at Each Outlet		1,111.11	497.92	128.98	45.19	13.93
Reduction Required		0%	20%	20%	35%	15%
Overall Reduction Required		6%				

4.2 Dissolved Oxygen

The Trott Brook DO TMDL is required because it violates Minnesota's DO standard of 5 mg/L (daily minimum). For this TMDL, the daily minimum time series from HSPF during open water months (April through November) was used, and the loading capacity was set to achieve the 5 mg/L or higher during over 95% of simulation period. The numerical TMDL is the sum of the WLA, LA, and MOS. Since the DO standard applies, only 50% of the days at which the flow is equal to the 7Q10, which makes the 95% a conservative number.

4.2.1 Loading Capacity

The loading capacity in a DO TMDL is the maximum allowable oxygen demand that the stream can withstand and still meet water quality standards. To determine the loading capacity, oxygen demand rates were adjusted in the HSPF model until the model-predicted minimum daily DO in the impaired reach was below the 5.0 mg/L standard less than 5% of the time during open water months (April through November) from 2006 through 2016. The oxygen demand calculated by using the TMDL scenario was 332 pounds per day (lb/day), which represents a reduction of 50% from the current load of 661 lb/day.

4.2.2 Wasteload Allocation Methodology

TMDL WLAs are typically divided into three categories: NPDES point-source dischargers, permitted MS4s, and construction and industrial stormwater. The following sections describe how each of these WLAs was estimated.

4.2.2.1 Permitted Wastewater Treatment Facilities

No NPDES-permitted WWTF with surface discharges exist in the Trott Brook DO-impaired watershed.

4.2.2.2 Permitted Municipal Separate Storm Sewer Systems

Nearly all of the Trott Brook drainage area is located within an MS4. MS4s contributing to Trott Brook include the Elk River City MS4, Nowthen City MS4, Ramsey City MS4, Anoka County MS4, and Sherburne County MS4. Some nontraditional MS4s (the Anoka County MS4 and Sherburne County MS4) overlap the city MS4s. Right-of-way areas and other areas owned by each nontraditional MS4 draining to their regulated areas were subtracted from city MS4 areas. The overall load allowed from the MS4 was calculated by using the percent of MS4 area multiplied by the loading capacity after the MOS and NPDES portions of the WLAs were subtracted. MS4 allocations are shown in Table 4-8. The WLAs for each city were calculated by using the percent of the total allowable MS4 load. Input was provided by Sherburne County to slightly adjust the western boundary of the Elk River City MS4 area.

Table 4-8. Wasteload Allocations for Municipal Separate Storm Sewer Systems Contributing to Trott Brook

MS4	Permit No.	Contributing Area (acres)	Percent of MS4 Load	Allowable Oxygen Demand[a] (lb/day)
Elk River City	MS400089	10,479	63	171
Nowthen City	MS400069	1,610	10	26
Ramsey City	MS400115	4,440	27	72
Saint Francis City	MS400296	47	< 1	1
Sherburne County	MS400155	53	< 1	1
Anoka County	MS400066	36	< 1	1

(a) Oxygen demand accounts for the combination of SOD, NOD, and BOD.

4.2.2.3 Construction and Industrial Stormwater

Stormwater WLA includes loads from construction, industrial, and MS4 stormwater sources. Loads from construction stormwater are considered to be a small percent of the total WLA and are difficult to quantify.

The WLA for stormwater discharges from sites with construction activity reflects the number of construction sites greater than one acre that are expected to be active in the watershed at any one time, as well as the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in the state's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). If a construction site owner/operator obtains coverage under the NPDES/SDS General Stormwater Permit and properly selects, installs, and maintains all BMPs 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.

County estimates of the total area under construction were area weighted to estimate the areas under construction in the impaired waterbody watershed. The percentage of construction acres in each watershed was multiplied by the loading capacity (minus the MOS and NPDES portion of the WLAs) to determine the construction stormwater WLA. Average annual construction acres from 2006 through 2016 occurred on 0.22% of the watershed, and this percentage was rounded up to 0.25% to account for future growth.

Industrial stormwater is regulated by NPDES Permits if the industrial activity has the potential for significant materials and activities to be exposed to stormwater discharges. The WLA for stormwater discharges from sites with industrial activity reflects the number of sites in the watershed that require NPDES Industrial Stormwater Permit coverage, as well as the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at the industrial sites are defined in the state's NPDES/SDS Industrial Stormwater Multi- Sector General Permit (MNR050000) or NPDES/SDS General Permit for Construction Sand & Gravel, Rock Quarrying and Hot Mix Asphalt Production Facilities (MNG490000). If a facility owner/operator obtains stormwater coverage under the appropriate NPDES/SDS Permit and properly selects, installs, and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. Noted that all of the local stormwater management requirements must also be met.

The number of acres regulated under 2015 industrial permits was available from the MPCA Industrial Stormwater Permit data by county. County estimates of total industrial areas were area weighted to estimate the industrial areas in the impaired waterbody watershed. The percentage of industrial acres in each watershed was multiplied by the loading capacity (minus the MOS and NPDES portion of the WLAs) to determine the industrial stormwater WLA. Industrial permits in 2015 occurred on 0.6% of the watershed, and this percentage was rounded up to 0.65% to account for future growth.

To determine the load allowed from combined industrial and construction stormwater, the oxygen demand loading capacity in each flow zone (minus the MOS and NPDES portion of the WLAs) was multiplied by 0.009% to represent 0.25% from construction stormwater and 0.65% from Industrial Permits.

4.2.3 Margin of Safety

MOS is a portion of the TMDL that is set aside to account for uncertainties associated with achieving water quality standards. MOS is usually expressed in terms of percentage of the loading capacity that is set aside as an uncertainty-insurance measure. The MOS may be implicit (i.e., incorporated into the TMDL through conservative assumptions in the analysis), or explicit and expressed in the TMDL as a set-aside load. For this TMDL, an explicit 10% MOS was included to provide a reasonable safety factor. Oxygen demand for this TMDL was not measured directly because it was calculated by using model-predicted rates and variables. Thus, a 10% MOS accounts for the uncertainty in model-predicted loads and the uncertainty in how the stream may respond to changes in oxygen demand loading. Note that the TMDL was set to predict the stream meeting the DO standard 95% of the time; whereas, the standard only requires meeting the DO standard 50% of the time at the lowest 7-day average flow that occurs on average once every 10 years (7Q10). Because the delivery of oxygen-demanding materials that impact DO at the 7Q10 occurs during all flows, this TMDL was written for all flows and, therefore, is protective at the 7Q10. As such, an implicit MOS is also included.

4.2.4 Load Allocation Methodology

The LA represents the oxygen demand load allowed from nonpoint sources (such as direct runoff-related sources) and from the organic material and sediment that have settled into the bed and bank. The LA was calculated as the loading capacity minus the MOS and the WLA.

4.2.5 Total Maximum Daily Load Summary

Oxygen-demanding pollutants were systematically reduced through modeling throughout the impaired reach until the 5.0 mg/L DO standard was achieved 95% of the time. A 50% reduction was required. Final TMDL allocations for Trott Brook are presented in Table 4-9.

TMDL Component		Oxygen Demand[(a)] (lb/day)
Total Daily Loading Capacity		332
Margin of Safety		33
Wasteload Allocations	Permitted Wastewater Dischargers	–
	MS4s	272
	Construction and Industrial Stormwater	3
Load Allocation		24
Current Load		661
Required Reduction		50%

(a) Oxygen demand accounts for the combination of SOD, NOD, and BOD.

Table 4-9. Trott Brook Dissolved Oxygen Total Maximum Daily Load

4.3 Lake Nutrients

Loading capacity for impaired lakes was determined by using calibrated BATHTUB models based on HSPF loads and the growing-season monitored mean values for TP, Chl-*a*, and Secchi disk from 2006 to 2015. The allowable loading capacity (or the TMDL) is defined as the maximum allowable pollutant load that will allow water quality standards to be met. Loading capacities were defined by using the calibrated BATHTUB models and reducing source loads until achieving appropriate standards for each lake were achieved.

The TMDL equation is as follows:

$$\mathrm{TMDL} = \Sigma(\mathrm{WLA}) + \Sigma(\mathrm{LA}) + \mathrm{MOS} + \mathrm{RC} \tag{2-1}$$

where LA is load allocation, WLA is wasteload allocation, MOS is margin of safety, and RC is reserve capacity. The LA is the loading from nonpoint sources, while the WLA is the load from point sources and permitted discharges. The 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. The RC is a load-apportioned value to account for anticipated future growth or land use change.

Watershed loading to the lakes was derived by using the calibrated Rum River HSPF model [Lupo, 2016c]. Mean annual runoff and flow-weighted mean TP concentrations with mean coefficients of variation (CVMeans) for each tributary and lakeshed were used as inputs to each lake's BATHTUB model as defined in Section 4.3.1.

4.3.1 Lake Model

The publicly available lake modeling software BATHTUB (Version 6.1), developed by Dr. William W. Walker for the US Army Corps of Engineers, was employed to integrate watershed runoff with lake water quality. This peer-reviewed model has been successfully used in many Minnesota lake studies as well as throughout the US for over 30 years. BATHTUB uses steady-state annual water and nutrient mass balances to model advective transport, diffusive transport, and nutrient sedimentation [Walker 2006]. Lake responses (e.g., Chl-*a* concentration or SDD) are predicted by empirical relationships developed by Walker [1985]. BATHTUB allows users to specify single lake segments (lake bays) or multiple segments with complicated flow routing; lake response is calculated for each lake segment based on morphometry and lake fetch data entered by the user. The cumulative annual P load from all external watershed and internal lake sources has been empirically related to lake recreation period (e.g., growing season) conditions [Walker 1996]; it is expressed as average summer TP, Chl-*a,* and Secchi transparency. This is the basis of predictive models such as BATHTUB, which includes statistical analyses to account for variability and uncertainty.

4.3.1.1 Representation of Lake Systems in BATHTUB Models

Each of the lakes was represented by a single lake segment as defined by lake-surface area, mean depth, and length of fetch. Lakes in series or those that are joined or in close proximity were assessed separately. HSPF-derived for the TMDL period (2006 through 2015) average annual water and P inputs to each lake were entered for all upgradient tributaries and each lake's immediate drainage areas (lakesheds). Additionally, lake-specific estimated SSTS (septic) contributions were added. For Fannie Lake, estimated contributions for MS4were also added. Annual precipitation and evaporation used in these models were 0.77 meters per year (m/year) and 0.75 m/year, respectively, for all lakes based on HSPF climate station average values. Observed lake water quality data (TP, Chl-*a*, SDD, and conservative substances) are entered as growing season (June–September) mean and CVMean values for the TMDL period. Tributary inflows to each lake segment included mean annual flow volume in cubic hectometers (hm^3); pollutant concentrations are entered as flow-weighted mean concentrations and CVMeans.

Lakes in series included West/East Hunter, South/North Stanchfield, and Skogman/Fannie Lakes. TMDL allocations for upgradient lakes were determined separately with corresponding reductions incorporated into the downstream lake TMDL allocation. Hence, the inclusion of explicit MOS in the upstream lake offers an implicit MOS for the downstream lakes.

BATHTUB includes several model choices for predicting TP, Chl-*a*, SDD, and other lake responses with selected models listed by lake in Appendix M. Additionally, a complete listing of inputs and modeling coefficients are included in the Appendix M.

4.3.1.2 Modeling Sequence

Lake modeling was conducted to determine (1) present-day P loads that result in exceeding lake standards and (2) allowable P loads and reductions that are required to achieve water quality standards. Modeling of present-day conditions was completed for each lake and calibrated to the most recent and available water quality data (growing-season averages). Each of the lake's BATHTUB models was calibrated by adjusting calibration coefficients and/or internal loading rates. The calibration coefficient adjustments were relatively minor for all of the Rum River TMDL lakes.

4.3.2 Loading Capacity

The loading capacity for each lake TMDL was determined by adjusting tributary, lakeshed, internal, and SSTS loads to achieve a targeted average P concentration of 59 ug/L for the shallow lakes or 39 ug/L for the deep lakes. For this purpose, tributary and lakeshed loads were either reduced toward or to the Central River Nutrient Region river concentration of 100 ug/L. The SSTS allocation was set to zero P loading and assumed 100% future compliance to county SSTS regulations.

Baxter and North Stanchfield Lakes required exceptional reductions of average inflow P concentrations to levels less than the Central River Nutrient Region P concentration (100 ug/L) and more consistent with North River Nutrient Region concentrations (e.g., 50 to 60 ug/L). These shallow highly flushed lakes have very large watersheds and, as a result, lake concentrations will mirror watershed runoff quality.

4.3.2.1 Subsurface Sewage Treatment System Loading

A desktop analysis was conducted to estimate the number of lakeshore homes and cabins around each lake. These numbers were verified by county officials. The percent of homes occupied year-round and seasonally, average house size, noncompliance rates, and P retention rates of complying and noncomplying septic systems are included in Table 4-10. An estimate of annual TP loss per capita of 1 kilogram (kg) [Heiskary and Wilson 2005] was used to estimate mean annual TP loading to septic systems.

Table 4-10. Subsurface Sewage Treatment System Information

Lake	Year-Round Residences	Seasonal Residences	Average Household Size	Noncompliance Rate (%)	TP Loss Rate (%)
West Hunter	24	0	2.9	3	75
East Hunter	17	0	2.9	3	75
South Stanchfield	9	1	2.69	15	50
North Stanchfield	10	0	2.69	15	25
Long	139	77	2.69	15	75
Francis	19	26	2.69	15	75
Baxter	5	0	2.69	15	75
Skogman	57	15	2.69	15	50
Fannie	60	21	2.69	15	25
Green	103	61	2.69	15	75

HSPF septic-loading estimates are based on large-scale county data and, therefore, are not appropriately detailed for a TMDL in small lakesheds. Refined estimates of septic system loading were developed independently for each direct impaired lakeshed. HSPF lakeshed septic system P loads were replaced with these refined estimates.

4.3.2.2 Atmospheric Loading

An atmospheric P deposition of 26.8 milligrams per meter squared per year(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 24.9 and 29.0 kilograms per hectare per year (kg/ha/yr), respectively.

4.3.2.3 Internal Loading: Cumulative Weight-of-Evidence Approach

Growing-season lake water quality is largely determined by annual P loading rates from all sources. However, historical excessive P loading can accumulate in-lake sediments and influence present-day lake P concentrations. This process is called internal loading, meaning P that is recycled from enriched sediments back into lake waters, which increases lake P and algal concentrations. This typically occurs when low or no oxygen conditions occur along the sediment-water interface and can be enhanced by other factors such as low-sediment iron, calcium or aluminum content, invasive macrophyte species, and rough fish. Internal loading may also occur with oxygenated sediments but at reduced rates. Assessments of growing-season lake TP dynamics, lake mixing, DO concentrations, and mass-balance unexplained residuals were conducted to evaluate each lake’s potential for significant internal loading.

- **Growing-season lake P dynamics**: Net increases in surface-water TP concentrations (growing-season means) were tabulated. Progressive increases in monthly mean P concentrations reflect both internal and external (watershed) loading sources that affect shallow lakes with limited dilution and subject to resuspension potential. The HSPF modeling also provides estimates of dissolved P loading from lakeshed and tributary sources, which can directly influence shallow-lake concentrations and can be misidentified as internal loading.

- **Lake mixing**: Lake mixing was evaluated by calculating lake GR and Osgood Index values for each lake. All of the shallow lakes were assessed as polymictic (well-mixed) lakes.
- **DO concentration**: Shallow lakes noted to experience depleting deeper water DO concentrations to values of 2 mg/L or less included Baxter Lake and Lake Francis. Long Lake exhibited substantial oxygen depletion with depth on most monitored dates, but DO concentrations were greater than 2.0 mg/L. All three of the deep lakes (Skogman, Fannie, and Green) were noted to develop thermoclines and experience typical declining summer oxygen values in their hypoliminions to concentrations less than 2.0 mg/L.
- **Mass-balance unexplained residuals.** BATHTUB modeling was conducted for each lake based on HSPF inputs from watershed sources along with reported Minnesota atmospheric P deposition and estimated P loading from septic tanks. The unexplained residual or P loads needed to balance the income and outgo budgets was assigned as internal load.

Based on these evaluations, lakes with explicit allocations for internal loading included Lake Francis, Long Lake, North Stanchfield Lake, and East Hunter Lake. Internal loading for all other lakes included implicit values incorporated into developing the BATHTUB model.

4.3.3 Wasteload Allocation Methodology

40 C.F.R. § 130.2(h) states that a WLA is "the portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution." Components of the WLAs include permitted point sources, MS4s, and industrial and construction stormwater facilities.

4.3.3.1. Permitted Wastewater Treatment Facilities

No WWTFs drain to any of the nutrient-impaired lakes addressed in this TMDL.

4.3.3.2 Permitted Municipal Separate Storm Sewer Systems

A small portion (430 acres) of the city of Cambridge drains to Fannie Lake. The city of Cambridge is a regulated MS4 by NPDES permit (MNR040000). Other Phase II MS4s do not exist in the watersheds of the other Rum River Basin Lake TMDLs defined herein.

4.3.3.3 Construction and Industrial Stormwater

Stormwater WLA includes loads from construction, industrial, and MS4 stormwater sources. Loads from construction stormwater are considered to be a small percent of the total WLA and are difficult to quantify.

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 (MNR100001). If a construction site owner/operator obtains coverage under the NPDES/SDS General Stormwater Permit and properly selects, installs and maintains all BMPs required under the permit, including those related to impaired waters discharges and any applicable additional requirements found in Appendix A of the Construction General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local construction stormwater requirements must also be met.

County estimates of the total area under construction were area weighted to estimate the areas under construction in the impaired waterbody watershed. The percentage of construction acres in each watershed was multiplied by the loading capacity (minus the MOS and NPDES portion of the WLAs) to determine the construction stormwater WLA.

Industrial stormwater is regulated by NPDES Permits if the industrial activity has the potential for significant materials and activities to be exposed to stormwater discharges. The WLA for stormwater discharges from sites where there is industrial activity reflects the number of sites in the watershed for which NPDES Industrial Stormwater Permit coverage is required, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at the industrial sites are defined in the state's NPDES/SDS Industrial Stormwater Multi- Sector General Permit (MNR050000***)*** or NPDES/SDS General Permit for Construction Sand & Gravel, Rock Quarrying and Hot Mix Asphalt Production facilities (MNG490000). If a facility owner/operator obtains stormwater coverage under the appropriate NPDES/SDS Permit and properly selects, installs and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. It should be noted that all local stormwater management requirements must also be met.

The number of acres regulated under 2015 industrial permits was available from the MPCA Industrial Stormwater Permit data by county. County estimates of total industrial areas were area weighted to estimate the industrial area in each impaired waterbody watershed. The percentage of industrial acres in each watershed was multiplied by the loading capacity (minus the MOS and NPDES portion of the WLAs) to determine the industrial stormwater WLA.

4.3.4 Margin of Safety

A MOS is a portion of the TMDL that is set aside to account for the uncertainties associated with achieving water quality standards. A MOS is usually expressed as an explicit percentage of the loading capacity that is set aside as an uncertainty-insurance measure. The MPCA noted that a MOS of 10% is reasonable because of the results of the generally good calibration of the HSPF and BATHTUB models for pollutant loading (Sections 3.6 and 4.3.1). The calibration results indicate that the models adequately characterize the waterbodies and, therefore, an additional MOS is not needed. An explicit 10% MOS was included for the majority of the lakes to ensure that water quality goals are met.

An explicit 5% MOS was assigned to the shallow Baxter, Francis, and Long Lakes. Management of these lakes will present substantial challenges due to their shallow nature, water level fluctuations and relatively large contributing drainage areas. As a result, the water residence times for Baxter, Francis and Long Lakes were estimated to be 0.08 year, 0.42 year and 0.16 year and TMDL allocations as defined for these lakes required inflow streams to generally be near or lower than the Central River Nutrient Region P Standard. Requiring a higher MOS would result in stream targets that would be substantially less than the Central River Nutrient Region P Standard and may not be attainable.

Lakes that are joined or in close proximity include West Hunter/East Hunter, South/North Stanchfield, and Skogman/Fannie Lakes. The TMDL allocations for the upgradient lakes were determined separately and assume future compliance to lake water quality standards and were incorporated into the downstream lake TMDL allocations. Hence, including an explicit MOS in the upstream lake offers an implicit MOS for the downstream lake. Lastly, the endpoint targets for each lake are 1 µg/L below the lake eutrophication P standards and offers a slight implicit MOS for each lake.

4.3.5 Load Allocation Methodology

The LA for each lake was apportioned from the loading capacity (TMDL) minus the MOS and the WLAs. The LA includes all nonregulated sources or those that do not require NPDES permit coverage as well as unregulated watershed runoff, internal loading, and atmospheric deposition.

4.3.6 Total Maximum Daily Load Summary

The TMDL allocation tables for each of the impaired lakes are summarized below. The allowable load was determined by BATHTUB modeling to achieve the specified lake targets. From this allowable load, the MOS was subtracted to determine the new total load, which was used to apportion the WLAs and LAs. The following tables summarize the existing and allowable loads, the TMDL allocations, and the required reductions by allocation category. Allocation table values reflect the following conventions in reporting significant digits:

- Pounds per year values were rounded to the nearest 0.1.
- Categorical construction and industrial stormwater loading of pounds-per-day values were reported to four significant digits so that values greater than zero were listed in the tables.
- The LA category loading of pounds per day was reported to two significant digits.

Reductions required to achieve lake standards are listed in Table 4-11 and range from 21% in Skogman Lake to 86% in the highly impacted Lake Francis. Sequential improvement of water quality will be realized for lakes in series (i.e., joined or in close proximity), as noted for West/East Hunter, South/North Stanchfield and Skogman/Fannie Lakes.

4.3.6.1 Shallow Lake Total Maximum Daily Load Allocation Tables

The TMDL tables for shallow lakes are shown in the same order as Table 4-10 for Tables 4-12 through Figure 4-18.

4.3.6.2 Deep Lake Total Maximum Daily Load Allocation Tables

The TMDL tables for deep lakes are shown in the same order as in Table 4-10 in Tables 4-19 through 4-21.

Lake/Type	Required TMDL Reductions (%)
Shallow Lakes	
West Hunter	22
East Hunter	32
South Stanchfield	44
North Stanchfield	75
Long	61
Francis	86
Baxter	42
Deep Lakes	
Skogman	21
Fannie	22
Green	39

Table 4-11. Required Reductions for Lake Total Maximum Daily Loads

Table 4-12. West Hunter Lake Nutrient Total Maximum Daily Load

West Hunter Lake Load Allocation		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Margin of Safety 10%				**17.86**	**0.05**		
Wasteload	Construction Stormwater	0.40	< 0.01	0.40	< 0.01	0.00	—
	Industrial Stormwater	1.56	< 0.01	1.56	< 0.01	0.00	—
	Total WLA	**1.96**	**0.01**	**1.96**	**0.01**	**0.00**	**—**
Load	Lakeshed	181.99	0.5	144.46	0.39	37.53	21
	SSTS	8.82	0.02	0.00	0.00	8.82	100
	Atmospheric Deposition	14.30	0.04	14.30	0.04	0.00	—
	Total LA	**205.11**	**0.56**	**158.76**	**0.43**	**46.35**	**23**
Total Load (WLA + LA)		**207.07**	**0.57**	**160.72**	**0.44**	**46.35**	**22**
Loading Capacity (WLA + LA + MOS)				**178.57**	**0.49**		

Table 4-13. East Hunter Lake Nutrient Total Maximum Daily Load

East Hunter Lake Load Allocation		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Margin of Safety 10%				**15.95**	**0.04**		
Wasteload	Construction Stormwater	0.40	< 0.01	0.40	<0.01	0.00	—
	Industrial Stormwater	1.59	< 0.01	1.59	< 0.01	0.00	—
	Total WLA	**1.99**	**0.01**	**1.99**	**0.01**	**0.00**	**—**
Load	West Hunter Discharge	80.33	0.22	62.21	0.17	18.12	23
	Lakeshed	11.16	0.03	10.57	0.02	0.59	5
	Internal Load	97.45	0.26	55.81	0.15	41.64	43
	SSTS	6.62	0.02	0.00	0.00	6.62	100
	Atmospheric Depositional	13.00	0.04	13.00	0.04	0.00	—
	Total LA	**208.56**	**0.57**	**141.59**	**0.38**	**66.97**	**32**
Total Load (WLA + LA)		**210.55**	**0.58**	**143.58**	**0.39**	**66.97**	**32**
Loading Capacity (WLA + LA + MOS)				**159.53**	**0.44**		

Table 4-14. South Stanchfield Lake Nutrient Total Maximum Daily Load

South Stanchfield Lake Load Allocation		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Margin of Safety 10%				**158.34**	**0.43**		
Wasteload	Construction Stormwater	0.43	< 0.01	0.43	< 0.01	0.00	—
	Industrial Stormwater	2.08	0.01	2.08	0.01	0.00	—
	Total WLA	**2.51**	**0.01**	**2.51**	**0.01**		**—**
Load	Lakeshed	2,431.28	6.66	1,327.42	3.63	1,103.86	45
	SSTS	6.62	0.02	0.00	0.00	6.62	100
	Atmospheric Deposition	95.14	0.26	95.14	0.26	0.00	—
	Total LA	**2,533.04**	**6.94**	**1,422.56**	**3.89**	**1,110.48**	**44**
Total Load (WLA + LA)		**2,535.55**	**6.95**	**1,425.07**	**3.90**	**1,110.48**	**44**
Loading Capacity (WLA + LA + MOS)				**1,583.41**	**4.34**		

Table 4-15. North Stanchfield Lake Nutrient Total Maximum Daily Load

North Stanchfield Lake Load Allocation		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Margin of Safety 5%				**116.06**	**0.32**		
Wasteload	Construction Stormwater	1.58	<0.01	1.58	<0.01	0.00	—
	Industrial Stormwater	8.32	0.02	8.32	0.02	0.00	—
	Total WLA	**9.90**	**0.02**	**9.90**	**0.02**	**0.00**	**—**
Load	South Stanchfield Outlet	1,443.83	3.96	734.40	2.01	709.43	49
	North Stanchfield Trib 315	1,861.82	5.10	1,171.30	3.21	690.52	37
	Lakeshed	727.45	2.00	255.24	0.71	472.21	65
	SSTS	4.41	0.01	0.00	-	4.41	100
	Internal Load	4,671.18	12.80	0.00	0.00	4,671.18	100
	Atmospheric Deposition	34.30	0.09	34.30	0.09	0.00	—
	Total LA	**8,742.99**	**23.96**	**2,195.24**	**6.02**	**6,547.75**	**75**
Total Load (WLA + LA)		**8,752.89**	**23.98**	**2,205.14**	**6.04**	**6,547.75**	**75**
Loading Capacity (WLA + LA + MOS)				**2,321.20**	**6.36**		

Table 4-16. Long Lake Nutrient Total Maximum Daily Load

Long Lake Load Allocation		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Margin of Safety 5%				**63.59**	**0.17**		
Wasteload	Construction Stormwater	0.59	< 0.01	0.59	< 0.01	0.00	—
	Industrial Stormwater	3.41	0.01	3.41	0.01	0.00	—
	Total WLA	**4.00**	**0.01**	**4.00**	**0.01**	**0.00**	**—**
Load	Tributary 367	851.38	2.33	544.84	1.49	306.54	36
	Lakeshed	821.23	2.25	457.62	1.26	363.61	44
	Internal Loading	1248.23	3.42	110.13	0.30	1138.10	91
	SSTS	108.05	0.30	0.00	0.00	108.05	100
	Atmospheric Deposition	91.60	0.25	91.60	0.25	0.00	—
	Total LA	**3,120.49**	**8.55**	**1,204.19**	**3.3**	**1,916.30**	**61**
Total Load (WLA + LA)		**3,124.49**	**8.56**	**1,208.19**	**3.31**	**1,916.30**	**61**
Loading Capacity (WLA + LA + MOS)				**1,271.78**	**3.48**		

Table 4-17. Lake Francis Nutrient Total Maximum Daily Load

Lake Francis Load Allocation		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Margin of Safety 10%				**94.77**	**0.26**		
Wasteload	Construction Stormwater	1.17	< 0.01	1.17	< 0.01	0.00	—
	Industrial Stormwater	6.69	0.02	6.69	0.02	0.00	—
	Total WLA	**7.86**	**0.02**	**7.86**	**0.02**	**0.00**	**—**
Load	Tributary 359	1,120.04	3.07	700.7	1.92	419.34	37
	Local Watershed	123.06	0.34	81.15	0.23	41.91	34
	SSTS	82.11	0.22	0.00	0.00	82.11	100
	Atmospheric Deposition	63.23	0.17	63.23	0.17	0.00	—
	Internal load	4,739.64	12.99	0.00	0.00	4,739.64	100
	Total LA	**6,128.08**	**16.79**	**845.08**	**2.32**	**5,283.00**	**86**
Total Load (WLA + LA)		**6,135.94**	**16.81**	**852.94**	**2.34**	**5,283.00**	**86**
Loading Capacity (WLA + LA + MOS)				**947.71**	**2.60**		

Table 4-18. Baxter Lake Nutrient Total Maximum Daily Load

Baxter Lake Load Allocation		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Margin of Safety 5%				**61.38**	**0.17**		
Wasteload	Baldwin MS4	227.56	0.62	170.93	0.47	56.63	25
	Construction Stormwater	1.08	<0.01	1.08	< 0.01	0.00	—
	Industrial Stormwater	4.59	0.01	4.59	0.01	0.00	—
	Total WLA	**233.23**	**0.63**	**176.60**	**0.48**	**56.63**	**24**
Load	Tributary 272	941.40	2.58	833.91	2.28	107.54	11
	Lakeshed	171.20	0.48	107.24	0.31	63.93	37
	SSTS	4.41	0.01	0.00	-	4.41	100
	Atmospheric Deposition	21.19	0.06	21.19	0.06	0.00	—
	Internal load	788.46	2.16	27.24	0.07	761.23	97
	Total LA	**1,926.66**	**5.29**	**989.58**	**2.72**	**937.08**	**49**
Total Load (WLA + LA)		**2,159.89**	**5.92**	**1,166.18**	**3.20**	**993.71**	**46**
Loading Capacity (WLA + LA + MOS)				**1,227.56**	**3.37**		

Table 4-19. Skogman Lake Nutrient Total Maximum Daily Load

Skogman Lake Load Allocation		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Margin of Safety 10%				**84.32**	**0.23**		
Wasteload	Construction Stormwater	0.23	< 0.01	0.23	< 0.01	0.00	—
	Industrial Stormwater	0.66	< 0.01	0.66	< 0.01	0.00	—
	Total WLA	**0.89**	**< 0.01**	**0.89**	**< 0.01**	**0.00**	**—**
Load	Local Watershed	868.00	2.38	704.81	1.93	163.19	19
	SSTS	41.90	0.11	0.00	0.00	41.90	100.00
	Atmospheric Deposition	53.18	0.15	53.18	0.15	0.00	—
	Total LA	**963.08**	**2.64**	**757.99**	**2.08**	**205.09**	**21**
Total Load (WLA + LA)		**963.97**	**2.64**	**758.88**	**2.08**	**205.09**	**21**
Loading Capacity (WLA + LA + MOS)				**843.20**	**2.31**		

Table 4-20. Fannie Lake Nutrient Total Maximum Daily Load.

Fannie Lake Load Allocation		Existing TPLoad		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Margin of Safety				**135.85**	**0.37**		
Wasteload	Cambridge MS4	143.06	0.39	123.04	0.34	20.02	14
	Construction Stormwater	0.36	< 0.01	0.36	< 0.01	0.00	—
	Industrial Stormwater	1.49	< 0.01	1.49	< 0.01	0.00	—
	Total WLA	**144.91**	**0.40**	**124.89**	**0.35**	**20.02**	**14**
Load	Tributary 352	272.32	0.75	196.07	0.54	76.25	28
	Lakeshed	1,046.49	2.86	826.06	2.25	220.43	21
	SSTS	30.87	0.08	0.00	0.00	30.87	100
	Atmospheric Deposition	75.64	0.21	75.64	0.21	0.00	—
	Total LA	**1,425.32**	**3.9**	**1,097.77**	**3.00**	**327.55**	**23**
Total Load (WLA + LA)		**1,570.23**	**4.30**	**1,222.66**	**3.35**	**347.57**	**22**
Loading Capacity (WLA + LA + MOS)				**1,358.51**	**3.72**		

Table 4-21. Green Lake Nutrient Total Maximum Daily Load

Green Lake Load Allocation		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Margin of Safety 10%				**319.17**	**0.87**		
Wasteload	Construction Stormwater	0.90	< 0.01	0.90	< 0.01	0.00	—
	Industrial Stormwater	5.04	0.01	5.04	0.01	0.00	—
	Total WLA	**5.94**	**0.01**	**5.94**	**0.01**	**0.00**	**—**
Load	Tributary 281	1,820.84	4.99	1,085.74	2.97	735.10	40
	Tributary 283	1,290.18	3.53	809.92	2.22	480.26	37
	Local Watershed	1,286.36	3.53	771.81	2.12	514.55	40
	SSTS	110.25	0.30	0.00	0.00	110.25	100
	Atmospheric Deposition	199.15	0.55	199.15	0.55	0.00	—
	Total LA	**4,706.78**	**12.90**	**2,866.62**	**7.86**	**1,840.16**	**39**
Total Load (WLA + LA)		**4,712.72**	**12.91**	**2,872.56**	**7.87**	**1,840.16**	**39**
Loading Capacity (WLA + LA + MOS)				**3,191.73**	**8.74**		

5 Seasonal Variation

Monthly precipitation, flows, and pollutant concentrations vary seasonally. Average monthly precipitation in the project area is generally the highest in spring (May and June), as shown in Figure 5-1. Short-duration, high-intensity rainstorms are common during the summer months. These localized summer storms can cause significant runoff with the potential of increasing pollutant concentrations for a relatively short time period, particularly from spring and early-summer events. Occasionally, large events can occur during the drier, late summer that have significant wash-off of pollutants while not significantly increasing stream flow.

Monthly average flows in the RRW were typically highest during the late-spring and early-summer months (April, May, and June) and lowest during winter months (December, January, and February), as shown in Figure 5-2.

5.1 *E. coli*

The highest average and median *E. coli* concentrations in the Rum River-impaired streams varied by site; however, data were primarily available in June, July, and August at most sites. The highest bacteria loads occur when flows are highest (typically in June), as shown in the *E. coli* LDCs. Figures of bacteria in impaired reaches by month are shown in Section 3.5. Bacteria concentration geometric means tend to be higher during summer months. The LDC approach to develop the TMDL allocations for five flow zones accounts for the seasonal variability in flow and *E. coli* loads (e.g., the high-flow zone contains flows that primarily occur in the spring). The TMDL is seasonal because the *E. coli* criterion applies from April through October. Occasionally, large events can occur during the drier, late summer that have significant wash-off of *E. coli* while not significantly increasing stream flow.

5.2 Dissolved Oxygen

DO seasonality is shown in Section 3.5. Trott Brook dropped below 5 mg/L from May through September. The combination of higher precipitation washing off organic materials and warmer temperatures during these months likely contribute to the lower DO concentrations.

5.3 Nutrients

Lake water quality varies seasonally with the critical conditions occurring during the summer recreational season. Developing Minnesota's lake nutrient standards occurred in phases over three decades of monitoring and assessing a large cross section of lakes and lake types of Minnesota's aquatic ecoregions [Heiskary and Wilson 2005]. Seasonal variation has been factored into the development of Minnesota's lake standards based on swimmable and fishable beneficial uses for the summer recreation period of June through September [Heiskary and Wilson 2005]. Distinct relationships were established between the causal factor (TP) and the response variables Chl-*a* and Secchi transparency. TP has often been found to be the limiting factor in freshwater lakes; as lake P concentrations increase, algal abundance increases to result in higher Chl-*a* concentrations and reduced lake transparency. Based on these relationships, the Chl-*a* and Secchi standards are expected to be met by meeting the P target in each lake. Reducing P loads defined by these TMDLs will achieve water quality standards for the critical conditions.

Figure 5-1. Monthly Average Annual Precipitation (2006–2015) From Site DNR 714 in Zimmerman, Minnesota.

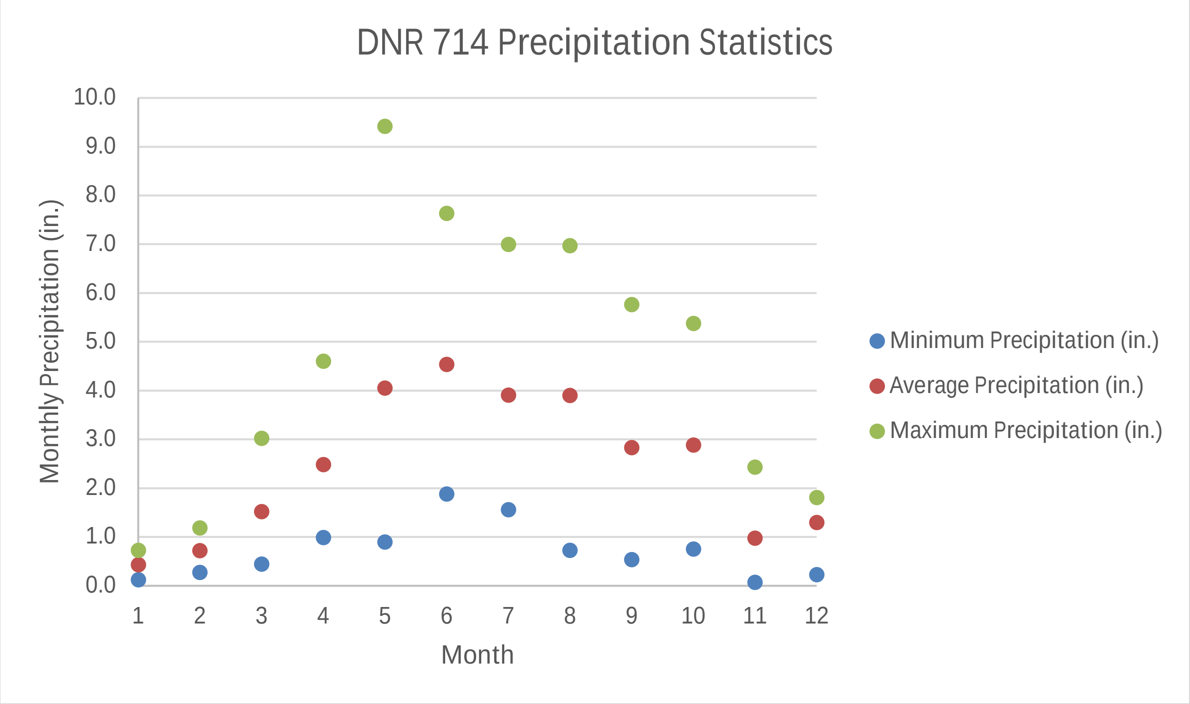
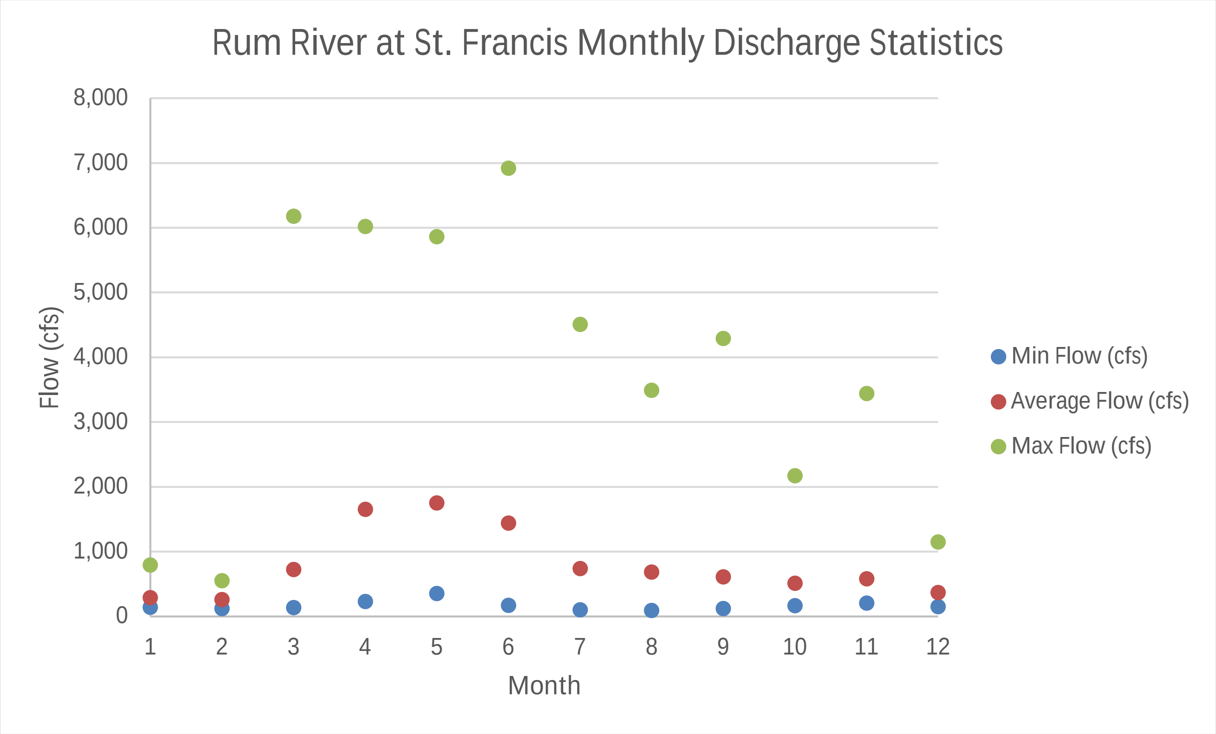


Figure 5-2. Monthly Average Annual Flow (2006–2015) From Rum River at St. Francis (21095001).



6 Future Growth Considerations

6.1 New or Expanding Permitted MS4 Waste Load Allocation Transfer Process

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

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

Load transfers will be based on methods that are consistent with those used in setting the allocations in this TMDL (a land-area basis). In cases where the WLA is transferred from or to a regulated MS4, the permittees will be notified of the transfer and have an opportunity to comment.

6.2 New or Expanding Wastewater Treatment Facilities

The MPCA, in coordination with the EPA Region 5, has developed a streamlined process for setting or revising WLAs for new or expanding WWTFs to waterbodies with an EPA approved TMDL [Minnesota Pollution Control Agency 2012]. This procedure will be used to update WLAs in approved TMDLs for new or expanding WWTFs whose permitted effluent limits are at or below the in-stream target and will ensure that the effluent concentrations will not exceed applicable water quality standards or surrogate measures. The process for modifying any and all WLAs will be handled by the MPCA – input and involvement by the EPA – once a permit request or reissuance is submitted. The overall process will use the permitting public notice process to allow for the public and EPA to comment on the permit changes based on the proposed WLA modification(s). Once any comments or concerns are addressed and the MPCA determines that the new or expanded wastewater discharge is consistent with the applicable water quality standards, the permit will be issued and any updates to the TMDL WLA(s) will be made. For more information on the overall process, visit the MPCA's TMDL Policy and Guidance webpage (*https://www.pca.state.mn.us/water/tmdl-policy-and-guidance*).

6.3 Reserve Capacity

The RC is the portion of the loading capacity directed to growth of existing and new future load sources. Demographic growth of the TMDL region (e.g., middle and southern portions of the Rum River Basin) is expected to result primarily from shifts in agricultural to developed land classes. As such, nutrient and sediment-related pollutants are expected to decline, particularly with community attention to better stormwater management such as low-impact development (LID) and Minimal Impact Design Standards (MIDS) performance standards for new, redevelopment, and linear developments. Hence, RC allocations were not derived for TMDLs defined herein.

7 Reasonable Assurance

An important part of the TMDL implementation strategy is to provide reasonable confidence or assurance that the TMDL allocations (1) were properly developed, documented, and calibrated and (2) will be implemented by local, state, and federal entities. TMDL allocations described herein have been based on the best and latest available information, including land cover that was incorporated into an updated Rum River Basin HSPF model and subject to rigorous state oversight. Lake modeling was accomplished by using widely accepted standard assessment and quality control methods. TMDL goals defined by this study are consistent with objectives defined in local county water plans that will be further refined by MPCA's Rum River Basin WRAPS. The 10 Rum River Basin counties and the Mille Lacs Band of Ojibwe representatives have been active participants in the TMDL planning and development process, and most have decades of water quality management experience. Stakeholder meetings have been conducted to provide comment/feedback and support, including local governmental units receiving TMDL allocations. Future water quality restoration efforts will be led by the Rum River Basin local and county entities and the Mille Lacs Band of Ojibwe. Funding resources may be obtained from the following state and/or federal programs:

- Minnesota Clean Water, Land, and Legacy Funds
- EPA funding such as Section 319 grants
- Natural Resources Conservation Services (NRCS) cost-share funds
- Local governmental funds and utility fees
- Local and lake association related resources.

7.1 Nonregulatory

At the local level, the Rum River counties, county soil and water conservation districts (SWCDs), and the Mille Lacs Band of Ojibwe have a long history of completing water quality improvement projects with well-developed infrastructure (i.e., technical assistance, administrative support, and fiscal oversight) in place. The implementation strategies described in Chapter 9 have been demonstrated to be effective in reducing pollutant loads to Minnesota streams and lakes. Performance monitoring will continue to guide adaptive management, including evaluating progress-to-goals in achieving water quality standards and established beneficial uses.

Recent watershed projects include Rum River bank stabilization projects in Anoka County and multiple lakeshore restorations in Anoka, Isanti, Crow Wing, Aitkin, and Millie Lacs Counties. Also, new stormwater treatment areas were added to older neighborhoods of Isanti County, and the Mille Lacs County Local Water Resource Management Plan was adopted in 2006. Funding sources included Long Lake Grants, the Rum River Grant, and the Clean Water Fund. The Legacy Amendment allocates 33% of its sales tax revenue to the Clean Water Fund, which is spent to protect, enhance, and restore water quality. Projects funded by the Clean Water Fund can be found online (*http://www.legacy.leg.mn/projects/project/10*). Minnesota has a new buffer rule that establishes new perennial vegetation buffers on public lands of up to 50 feet along rivers, streams, and ditches that will help filter out P, nitrogen, and sediment.

7.2 Regulatory

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

8 Monitoring Plan

Tracking progress toward achieving the TMDL load reductions will primarily rely on monitoring each impaired watershed for (1) BMP implementation and (2) tracking attainment to lake and stream water quality standards. Each of the 10 RRW SWCDs will track and report implementation projects annually within their jurisdictions. Therefore, existing tools, such as the pollutant reduction calculators and input into Minnesota Board of Soils and Water Resources' (BWSR) web-based eLINK tracking system [Minnesota BWSRs 2016a] and other methods of tracking will be used to report on progress. BMP effectiveness may be estimated by BWSR and MPCA calculators based on BMP designs, construction, and operation and maintenance considerations.

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

9 Implementation Strategy Summary

Rehabilitation actions within the impaired river reach and lake watersheds will require cooperative planning and implementation by: nonregulated, and regulated entities, such as local governments, with partnering counties; SWCDs; regional, state, and federal agencies; and funding sources. Pollutant reductions can be achieved primarily by using BMPs, land use changes, benchmark assessments, and monitoring to identify critical areas.

9.1 Permitted Sources

9.1.1 Phase II Municipal Separate Storm Sewer Systems

Phase II MS4 NPDES-permitted stormwater communities are required by permit (the General Permit Authorization to Discharge Stormwater Associated With small MS4s Under the NPDES/SDS Permit [MNR040000]) to develop and implement an SWPPP. This Permit requires MS4s to develop regulatory mechanisms, including enforcement of construction sites under the MPCA's general permit to Discharge Stormwater Associated with Construction Activity (MN R100001) and post-construction stormwater management. MS4s are also required to inventory and map the storm sewer system and implement a minimum of six control measures (public education and outreach, public participation and involvement, illicit discharge detection and elimination, construction site runoff controls, post-construction stormwater runoff controls and pollution prevention, and good housekeeping measures). Measurable goals must be specified for each of the six minimum control measures, including public participation and involvement in reviewing the SWPPPs. Routine inspection and maintenance of the MS4 conveyance system is required. Additionally, the MS4 permit requires regulated communities to provide reasonable assurance that progress is being made toward achieving all TMDL WLAs approved by the EPA before the effective date of the General MS4 permit issued at five-year intervals. MS4s must determine that the WLA(s) are being and, if not, a compliance schedule is required. The compliance schedule includes interim milestones (expressed as BMPs) that are not one of the six minimum control measures and that will be implemented over the current 5-year permit term. As MS4 management activities occur across 10-year capital budgetary cycles, a long-term implementation strategy and target date for full compliance to the WLAs must be included.

9.1.2 Baseline Year

Several cities (Elk River, Nowthen, Oak Grove, Ramsey, East Bethel, Ham Lake, Andover, Saint Francis, Isanti, and Cambridge), one township (Baldwin), counties (Anoka and Sherburne), and MNDOT have MS4 loads allocated in these TMDLs. For MS4s in these TMDLs, the baseline year will be the beginning of the TMDL time period (2006). A baseline year is used because the effects of BMPs are not always immediate. BMPs implemented since 2006 will qualify toward MS4 load reductions for these TMDLs. Appropriate implementation strategies and MS4 BMPs are further defined in the WRAPS report.

9.1.3 Construction Stormwater

The WLA for stormwater discharges from sites with construction activity reflects the number of construction sites greater than one acre that are expected to be active in the watershed at any one time, as well as the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in the state's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). If a construction site owner/operator obtains coverage under the NPDES/SDS General Stormwater Permit and properly selects, installs, and maintains all BMPs 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. Note that all local construction stormwater requirements must also be met.

9.1.4 Industrial Stormwater

The WLA for stormwater discharges from sites with industrial activity reflects the number of sites in the watershed that require NPDES Industrial Stormwater Permit coverage, as well as the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at the industrial sites are defined in the state's NPDES/SDS Industrial Stormwater Multi- Sector General Permit (MNR050000***)*** or NPDES/SDS General Permit for Construction Sand & Gravel, Rock Quarrying and Hot Mix Asphalt Production Facilities (MNG490000). If a facility owner/operator obtains stormwater coverage under the appropriate NPDES/SDS Permit and properly selects, installs, and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local stormwater management requirements must also be met.

Facilities can obtain a no-exposure exclusion if the site’s operations occur under-roof. The permittee is required to develop and implement an SWPPP that details stormwater BMPs to be implemented to manage stormwater at the facility. Permitted facilities are required to perform runoff sampling that compares to benchmark P concentrations as specified by the EPA. P monitoring is required if a nutrient-impaired waterbody is located within one mile of the facility.

9.1.5 Wastewater

Permitted NPDES facilities drain to multiple *E. coli*-impaired reaches. Facilities are not allowed to discharge fecal coliform concentrations above 200 cfu/100 mL. Data for Isanti Estates (which drains to Cedar Creek) and the Foreston WWTF (which drains to the West Branch of the Rum River) were tabulated (2006 through 2015) to evaluate bacteria concentrations. The calculated monthly geometric mean at Isanti Estates exceeded 200 cfu/100 mL for 5 of the 67 months (7.5% of the time). Isanti Estates is currently working with the MPCA to maintain compliance. All available calculated monthly geometric means at the Foreston WWTF were below 200 cfu/100 mL. No fecal coliform data were available from the Saint Francis WWTF.

No NPDES-permitted WWTFs discharge to the DO-impaired Trott Brook reach nor to any of the nutrient-impaired lakes addressed in this TMDL.

One CAFO is located in the Green Lake Watershed. However, CAFOs are not allowed to discharge to surface water (with permit specified exceptions) and were not given a WLA.

9.2 Nonregulated Sources

Nonregulated rehabilitation actions within the impaired river reach and lake watersheds will require cooperative planning and implementation by: partnering counties; SWCDs; and regional, state, and federal agencies.

9.2.1 *E. coli*

BMPs that are expected to reduce *E. coli* loads to impaired streams are identified below, with details provided by *The Agricultural BMP Handbook for Minnesota* [Miller et al. 2012] and *Minnesota Stormwater Manual* [MPCA 2016]. Cost, targets, and other BMP information will be further discussed in the Rum River WRAPS Report.

- Animal access control—offstream watering and fencing will aid in restricting animal access to stream and sensitive stream bank areas and allow growth of riparian vegetation.
- Buffers and streambank stabilization—riparian vegetation helps to filter pollutants and stabilize banks. 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) [Minnesota State Legislature 2015b]. Details of the buffer implementation are being developed. The Clean Water Legacy Fund included $5 million to BWSR for local government implementation in the state fiscal year 2016-2017 biennium. The SWCDs will be identifying the priority for placing perennial vegetation buffers along small streams and headwater areas.
- Manure management—proper manure management will assist in reducing manure-related organic matter from being carried in runoff. Manure management techniques include applying at recommended rates, controlling manure stockpile runoff, avoiding manure application near open inlets, and avoidance of winter manure spreading.
- Pasture management—rotational grazing, off-stream watering, and maintenance of riparian vegetation will aid in keeping bacteria from entering stream systems.

- Pet waste management—ensure that local ordinances are being followed by using public education and enforcement of pet waste regulations.
- Channelization and Artificial Drainage— exporting organic substrates, nutrients, and bacteria to downstream segments of the flow network will increase. Targeted monitoring of potential critical areas or specific areas of concern are considered in the WRAPS monitoring plan.
- County SSTS (septic system) compliance and inspection programs—RRW county ordinances have been developed to protect human health and the environment and need the public's support. Upgrades of noncompliance systems may be required to obtain building permits and upon property sale. County support via the Rum River WRAPS process may result in designating grants or loans to help in upgrading old and failing septic systems. Failing and noncompliant SSTSs adjacent to lakes, streams and associated drainages should receive the highest priority.
- Education—public education on the benefits of the above practices should continue with RRW-partnering counties to provide core materials for reinforcing messages aimed at target audiences.

9.2.2 Dissolved Oxygen

BMPs that are expected to reduce oxygen-demanding substances in Trott Brook are identified below. Cost, targets, and other BMP information will be further discussed in the Rum River WRAPS Report.

- Urban BMPs—urban BMPs and pollutant removal calculators are detailed by the MPCA website and the Minnesota Stormwater Manual [Minnesota Pollution Control Agency 2016] and include source, rate, and volume controls, and minimizing impervious sources. Reducing nutrients such as P and organic materials (BOD) discharged to public waters are the primary concerns. Source controls act to reduce residential/commercial erosion areas, fertilizer use, and organic debris from lawns (grass clippings and leaves) and pet wastes. Community use of lawn-waste recycling and street sweeping are examples. Primary urban BMPs reduce stormwater pollutants via filtration, infiltration, sedimentation, and chemical treatments. The voluntary MIDS practices are particularly amendable for use in areas with highly infiltrating soils of the Anoka Sand Plain. MIDS is based on LID—an approach to stormwater management that mimics a site's natural hydrology as the landscape is developed. Using the LID approach, storm water is managed on site and the rate and volume of predevelopment storm water reaching receiving waters is unchanged. The calculation of predevelopment hydrology is based on present-day native soil and vegetation [Minnesota State Legislature 2015c]. This program will provide assistance with reviewing and updating existing stormwater-related ordinances to better protect and restore water resources. The program could also streamline compliance under the state's NPDES Construction Permit (which applies to all grading activities that disturb more than an acre), because this permit has stricter requirements for impaired waters and has greater antidegradation restrictions.
- Agricultural BMPs—a wide array of agricultural BMPs as defined by *The Agricultural BMP Handbook for Minnesota* [Miller et al. 2012] will be effective in reducing delivery of DO-demanding substances to Trott Brook. These include practices that will reduce overall runoff from agricultural land and those that reduce nutrient and BOD loads from agricultural land.

Some agricultural BMPs that should be considered include buffer strips, nutrient management, livestock exclusion/fencing, feedlot runoff control, and others as specified by *The Agricultural BMP Handbook for Minnesota.*

- Buffers and streambank stabilization—riparian vegetation helps to filter pollutants and stabilize banks. A 50-foot average buffer width with a 30-foot minimum width has been recently required along public waters [Minnesota State Legislature 2015b]. Details of the buffer implementation are being developed. The Clean Water Legacy Fund included $5 million in state fiscal years 2016-2017 to BWSR for local government implementation. The SWCDs will be identifying the priority for placing perennial vegetation buffers along small streams and headwater areas.
- Channelizing Upland Wetland Complexes and Stream Channel Modifications—may affect stream DO dynamics may be affected by exporting nutrients and organic matter to downstream segments of the flow network. Monitoring potential critical areas or specific areas that discharge low DO should be undertaken.
    - Targeted monitoring to further identify high loading sources of DO-demanding substances should be considered. For example, sequential monitoring (grab sampling of upstream and downstream discharge locations from a post-summer storm event) of wetland complexes may be considered by this type of monitoring that will be detailed in the Rum River Watershed WRAPS Report.
- Lake Restorations—water quality will be improved by reducing nutrients and algal concentrations and corresponding organic matter discharged to downstream portions of the flow network.
- Urban Source, Rate, and Volume Control Practices—this BMP will be effective in reducing DO-demanding substances that discharge to Trott Brook.
- Education—public education on the benefits of the above practices should continue with RRW-partnering counties to provide core materials for reinforcing messages aimed at target audiences.

9.2.3 Nutrients

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

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

- Riparian vegetation helps to filter pollutants and stabilize banks. A 50-foot average buffer width with a 30-foot-minimum width has been recently required along public waters [Minnesota State Legislature 2015b]. Details of the buffer implementation are being developed. The Clean Water Legacy Fund included $5 million in state fiscal years 2016-2017 to BWSR for local government implementation. The SWCDs will be identifying the priority for placing perennial vegetation buffers along small streams and headwater areas.
- Encouraging and tracking implementation of urban BMPs, as detailed by the *Minnesota Stormwater Manual* and MIDS, will cover the spectrum of source, rate, and volume controls that will substantially reduce developed land's pollutant loadings of BOD and related sediment losses, nutrients, and bacteria. Proper site designs, construction, and maintenance are key components for effective performance of urban BMPs.
- Encouraging and tracking implementation of agricultural BMPs, as detailed by *The Agricultural BMP Manual for Minnesota*, will substantially reduce agricultural lands' pollutant loadings of BOD and related sediment losses, nutrients, and bacteria. Proper site designs, construction and maintenance are key components for effective performance of agricultural best practices.
- Internal loading can comprise an important portion of the P income to impaired lakes and legacy source-impacted wetlands. Internal P loading is typically the result of excessive historical watershed loading and a recommended first step is to reduce watershed P loading as much as possible. This includes reducing runoff from shore lands, developed land, noncompliant SSTSs, and other upland sources (potentially including wetlands). Wetland pulsing is possible from the succession of dry and wet periods and resulting shifting water levels that can induce P release from legacy sources. During dry periods, water levels recede and provide greater oxygen concentrations for aerobic digestion of organic substrates, including mobilization of various dissolved and particulate P forms [Dunne et al. 2010]. Upon refilling during wet periods, growing-season oxygen concentrations can quickly be depleted, which results in releasing digested P concentrations that depend on other factors, such as sediment iron, aluminum, and calcium. The extent of this occurrence from watershed wetland complexes is generally not known but can be initially characterized by relatively simple P monitoring, such as sequential diagnostic grab sampling of upgradient and downgradient waters following summer storm events.
- Whole lake treatment by alum can be very effective in reducing lake internal loading of P for 10 to 30 years. Following alum treatment, a white alum band is deposited along the top of the lake's sediments serving to trap released P. However, effectiveness in shallow lakes may be reduced because of wind mixing and disruption of the sediment's alum layer [Cooke et al. 1986]. After reducing watershed P loading sources, the appropriateness of a whole lake alum treatment can be assessed by a detailed feasibility study. Mobilization and treatment costs could amount to about $1,000 per acre depending on dosage requirements and alum costs.
- Hypolimnetic treatments such as ferric chloride, aeration, and oxygenation.

    - A recommended total iron to TP concentration ratio of 3:1 for lake bottom water has been used to control lake sediment released P. If the total iron to TP ratio is less than 3:1, then iron is likely not effectively reducing sediment-liberated P concentrations. In the latter case, iron augmentation of lake sediments may be required by using ferric chloride or similar iron compounds. The details, including oxygen supply rates, would have to be determined by an engineering design study.
    - High oxygen depletion rates can be expected to accompany elevated lake productivity (e.g., algal concentrations). Replenishing oxygen supplies via oxygenation of bottom waters may be a viable option in some cases. This would require installing a series of pipes and diffusers on the lake bottom along with required pump house and oxygenation system on land. The details, including oxygen supply rates, would have to be determined by an engineering design study. Lake aeration (without oxygenation) will require careful examination if intended for something other than reduced winter fish kill potential. Whole lake aeration during the growing season can result in increased P concentrations that feed increased algal growth and potentially degrade lake quality.
- Public education about the benefits of the above practices should continue with RRW partnering counties providing core materials for reinforcing messages aimed at targeted audiences.

9.3 Cost

The CWLA requires that a TMDL include an overall approximation of the cost to implement a TMDL [Minn. Stat. 2007, § 114D.25]. The cost estimate for this TMDL includes implanting buffers along the National Hydrology Dataset (NHD) flowlines in impaired drainage areas (50 foot buffers on both sides of approximately 690 stream miles at approximately $200 per acre after cost share [Shaw 2016]), alum treatment on impaired lake acres (approximately 2,900 acres at $1,000 per acre [Kretsch 2016]), septic updates around impaired lakes (70% replacement of approximately 660 septic systems at $10,000 a system), and MIDS on high- and medium-intensity developed lands (approximately 1,570 acres at $5,000 per acre) [Minnesota Board of Water and Soil Resources 2016b]. The initial estimate for implementing the Rum River WRAPS is approximately $9,100,000 for nonpoint-source implementation such as stream buffers, lake chemical treatments, and SSTS updates, and approximately $7,800,000 for implementation of MIDS in medium- and high-intensity developed areas. Urban BMP costs estimated in this overview are primarily based on construction and maintenance costs. Land areas required for constructed BMPs generally require 2% to 5% of the watershed drainage area, and land costs are not generally included because they can vary. This estimate is by nature, a very general approximation with considerable uncertainties associated with design complexity, local regulatory requirements, unknown site constraints, and BMP choices with widely variable costs per water quality volume treated. This is a large-scale estimate and many other implementation strategies will likely be used in addition to or in replacement of general practices used in this estimate.

9.4 Adaptive Management

The list of implementation elements and the more detailed WRAPS report that will be prepared following this TMDL assessment will focus on adaptive management as illustrated in Figure 9-1. Continued monitoring and “course corrections” that respond to monitoring results are the most appropriate strategy for attaining the water quality goals established in this TMDL. Management activities will be changed or refined to efficiently meet the TMDL and provide the groundwork for delisting the impaired waterbodies.

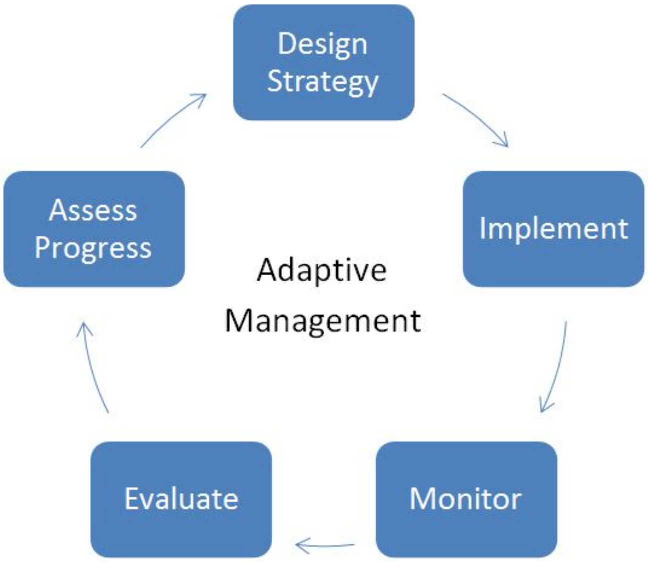


Figure 9-1. Adaptive Management Cycle.

10 Public Participation

Efforts to facilitate public education, review, and comment with development of the Rum River TMDLs included meetings with local groups in the watershed on the assessment findings, and a 30-day public notice period for public review and comment of the draft TMDL document. All input, comments, responses, and suggestions from public meetings and the public notice period were addressed or were taken into consideration in developing the TMDL. The draft TMDL report was made available at https://www.pca.state.mn.us/public-notices. Regular updates regarding the TMDL process with the Rum River Basin WRAPS team included meetings to discuss TMDL processes and results.

- A meeting was held with the city of Cambridge officials on July 26, 2016, to review the draft Fannie Lake modeling, TMDL allocations, and the city's urban stormwater ordinances and BMPs.
- A second MS4 meeting was held on September 22, 2016, to review the draft TMDL allocations, their development, and to receive comments and suggestions. Participating MS4 entities included officials from the cities of Ramsey, St. Francis, Andover, Isanti, Oak Grove, Ham Lake, and East Bethel and the counties of Anoka and Isanti.
- A public and stakeholder meeting was held on October 19, 2016 to present the draft TMDL report and allocations before public notice and receive public comments and concerns.

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Appendix A: Baxter Lake (30-0114-00)

Land Cover

Land cover defined by the University of Minnesota [2016] is summarized for the Baxter Lake Watershed in Table A-1 with the majority of the land cover consisting of forests (33.8%), wetlands (15.8%), and open water (6.9%). The more intense land uses (urban and row crops) covered a similar amount of area (9.7% and 9.4%, respectively), with grasslands/managed grass covering the remaining 24.3% of the watershed.

Table A-1. Baxter Lake Watershed Land Cover

Impairment	Open Water (%)	Wetlands (%)	Forest (%)	Grassland/ Managed Grass (%)	Hay/ Pastures (%)	Row Crops (%)	Urban (%)
Baxter	6.9	15.8	33.8	24.3	0.0	9.4	9.7

Physical Characteristics

Baxter Lake (30-01114-00) is located between Blue and Tennyson Lakes in the Spencer Brook Drainage of Isanti County in the southwestern portion of the Rum River Hydrologic Unit Code (HUC) 8. Near-shore substrates are predominantly sand. Development is very low for an Isanti County lake. From a regulatory standpoint, Baxter Lake is categorized as a shallow NCHF ecoregion lake. Select lake morphometric and watershed characteristics are listed in Table A-2. Baxter Lake has one public access that is maintained by Isanti County and includes parking for approximately six boat trailers. Baxter Lake is classified as a shallow lake. Figure A-1 shows an aerial imagery of Baxter Lake.

Water Quality

Monitoring data for the TMDL period were collected in 2013 and 2014 and are summarized in Table A-3 as average growing-season values for TP, Chl-*a*, and Secchi transparency (Secchi). Corresponding Minnesota NCHF shallow lake water quality standards are also included. Mean values for TP and Chl-*a* are above the water quality standard, while the mean Secchi disk depth (SDD) meets the water quality standard. This data indicates that Baxter Lake exceeds the P standard (by over 60%) and will require substantial reductions to achieve lake standards. Extreme high values of TP and Chl-*a* were 173 micrograms per liter (µg/L) and 64.3 µg/L, respectively, while the lowest Secchi reading was below 1 meter (m). Individual growing-season averages from available data were plotted in Figures A-2 through A-4 and show that both years exceed the P standard while Chl-*a* exceeds and then meets the standard in 2013 and 2014, respectively. The short water residence times likely influence the lake’s algal response.

Multiyear growing-season mean monthly water quality observations are summarized in Figures A-5 through A-7 for data available from 2006 through 2014. Plots of this mean monthly data indicate 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 approximately 45 µg/L to 160 µg/L from June through August and decline to 135 µg/L in September. Based on lake volume and stated concentrations, a mean increase of approximately 96 kilograms (kg) of TP in Baxter Lake is observed between June and September and is P from all external (watershed loading and septic systems) and internal sources. In a similar fashion, multiyear mean monthly Chl-*a* concentrations increase from June through August from approximately 2 µg/L to 45 µg/L with a decline to approximately 36 µg/L in September. Average monthly Secchi readings decline from approximately 2.0 m in June to 0.5 m in August, followed by a slight increase to approximately 0.75 m in September. The number of samples annually are shown in Table A-4. Error bars in annual and monthly P and Secchi plots indicate standard error.

Table A-2. Baxter Lake Select Lake Morphometric and Watershed Characteristics

Characteristic	Baxter Lake	Source
Lake-Surface Area (acres)	88	DNR LakeFinder
Number of Islands	0	
Percent Lake Littoral Surface Area	100	DNR LakeFinder
Drainage Area, Including Lake acres (ac)/square kilometers (km^2)	8,035 ac/32.5 km^2	Model Subwatersheds
Watershed Area to Lake Area Ratio	91:1	Calculated
Wetland Area (% of watershed)	15.8	University of Minnesota [2016]
Number of Upland Lakes	2	US Geological Survey topographic maps
Number of Perennial Inlet Streams	1	US Geological Survey topographic maps
Lake Volume (acre-feet (ac-ft)/cubic hectometers (hm^3))	440 ac-ft/0.5 hm^3	Calculated
Mean Depth (ft/m)	5 ft/1.5 m	Calculated
Annual Lake-Level Fluctuations (ft):typical, maximum	NA	DNR Lake-Level Data
Maximum Depth (ft/m)	10 ft/3.1 m	DNR LakeFinder
Maximum Fetch Length (miles (mi)/kilometers (km))	0.53 mi/0.85 km	Measured in Google Earth
Lake Geometry Ratio	8.0	Calculated
Osgood Index	2.6	Calculated
Estimated Water Residence Time (years/days)	0.083 year/30 days	Calculated
Public Access	1	Isanti County
Shore Land Properties	5	Counted from topographic maps

Dissolved Oxygen and Temperature Summary

DO and temperature data monitored by depth were examined to better define lake-mixing patterns that affect biological responses and lake P dynamics. Available data from 2013 and 2014 are plotted in Figures A-8 and A-9 for temperature and DO, respectively.

Figure A-1. Baxter Lake Aerial Imagery.

Figure A-1. Baxter Lake Aerial Imagery.

Table A-3. TMDL Period Total Phosphorus, Chlorophyll-a, and Secchi Transparency Growing-Season Means for Baxter Lake

Parameter	Minimum	Mean	Maximum	Standard Deviation	Lake Standards
TP (µg/L)	33	97.9	173	53.2	≤60
Chlorophyll-*a* (µg/L)	1.4	22.6	64.3	23.4	≤20
Secchi disk depth (m)	0.3	1.1	2.5	0.8	≥1.0

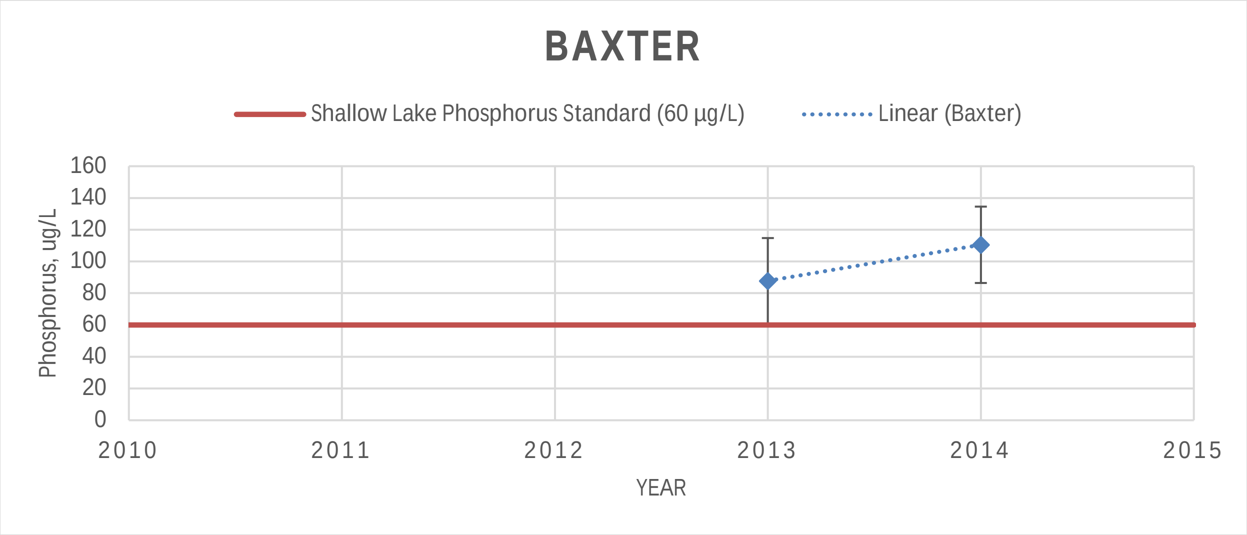


Figure A-2. Annual Growing-Season Mean of Total Phosphorus Concentrations for Baxter Lake.

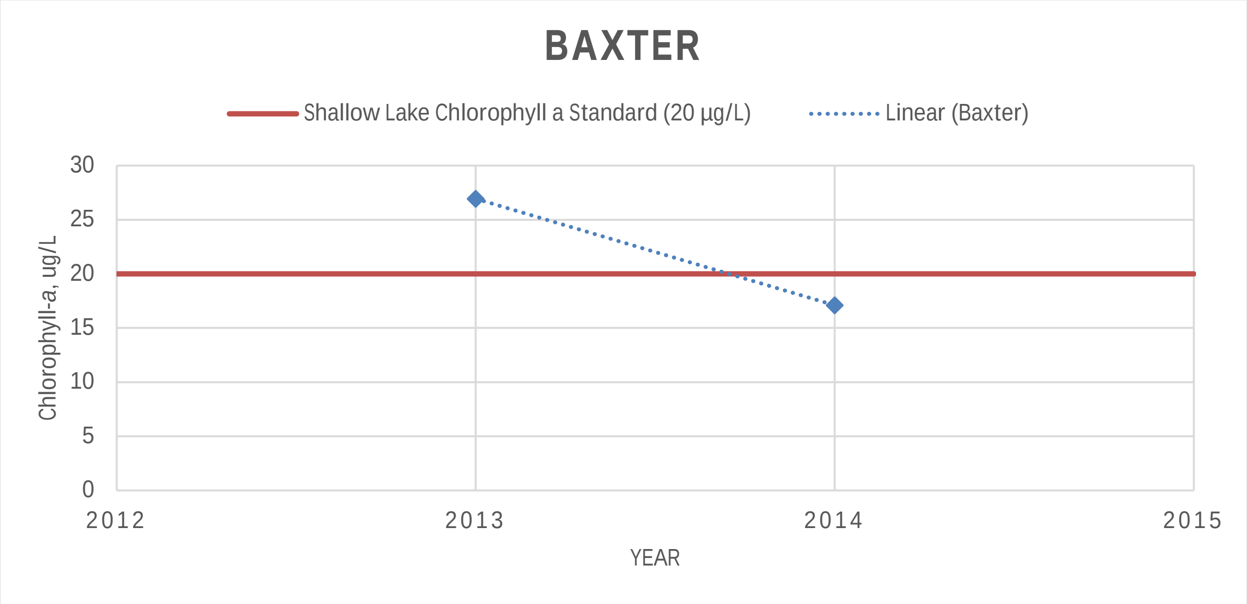


Figure A-3. Annual Growing-Season Mean of Chlorophyll-*a* Concentrations for Baxter Lake.

Water-temperature profiles as depicted in Figure A-8 indicate well-mixed conditions as temperatures are relatively similar going from the surface to depth. The July 10, 2013, profiled temperatures varied the most with the surface and 3-meter values differing by 5°C. Peak monitored summer bottom water temperatures (July through September) ranged from approximately 15° to 23°C.

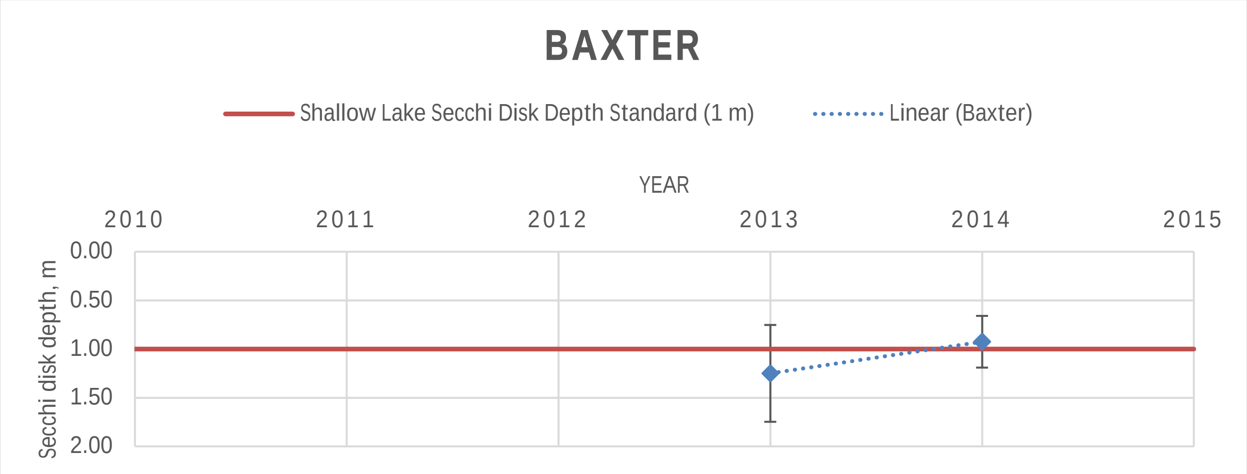


Figure A-4. Annual Growing-Season Mean of Secchi Transparency for Baxter Lake.

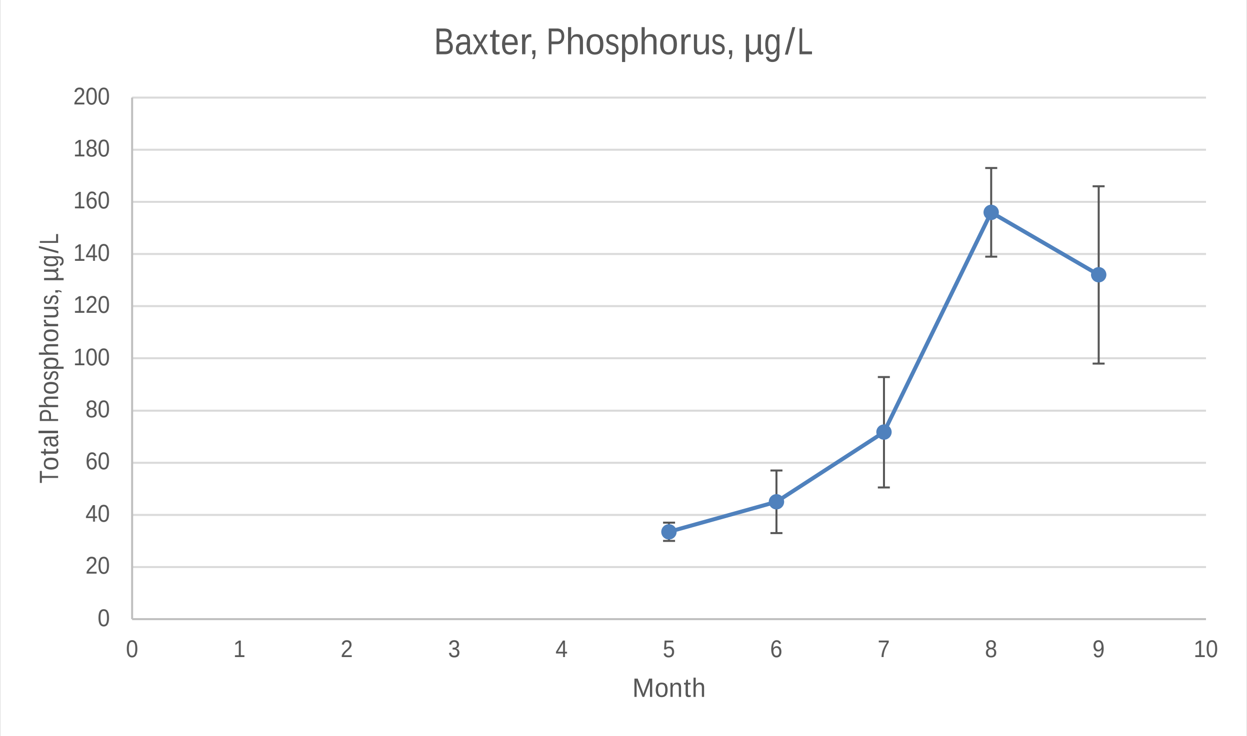


Figure A-5. Growing-Season Monthly Mean of Total Phosphorus for Baxter Lake (All Available Data Between 2006–2015).

The DO profile data shown in Figure A-9 typically exhibited substantial concentration losses with depth, which indicates large oxygen depletion rates are occurring. Baxter Lake exhibited clinograde-like oxygen patterns with values decreasing with depth. Values less than 5 mg/L were observed on several dates. The DO profiles generally show a difference of approximately 5 mg/L or more between the maximum and minimum measured DO concentrations.

Aquatic Plants

A qualitative survey of aquatic plants along the south shore of Baxter Lake was performed on July 1, 2013, by the DNR. This report found 14 species of submersed, free-floating, floating-leaf, emergent plants. The exotic invasive species, curly-leaf pondweed (*Potamogeton Crispus*) was present.

The areal coverage of curly-leaf pondweed was not available. The aquatic plant survey identified nine wetland habitat species.

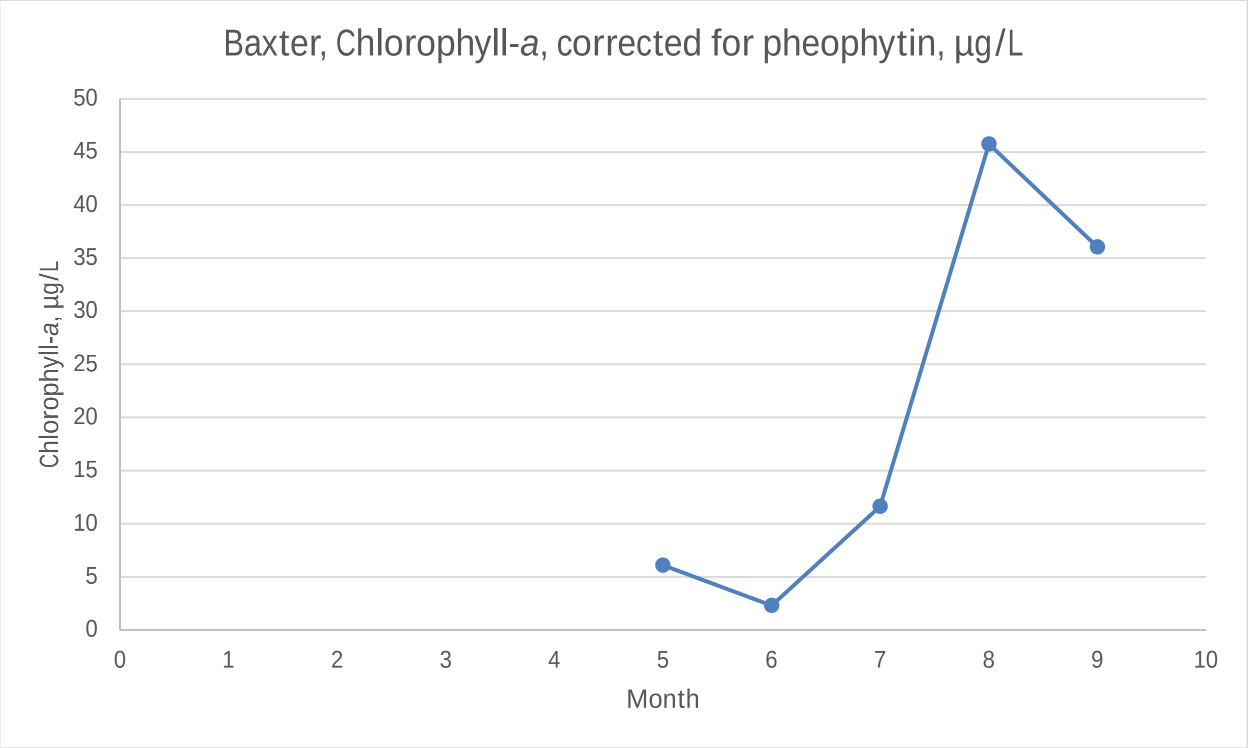


Figure A-6. Growing-Season Monthly Mean of Chlorophyll-*a* for Baxter Lake (All Available Data Between 2006–2015).

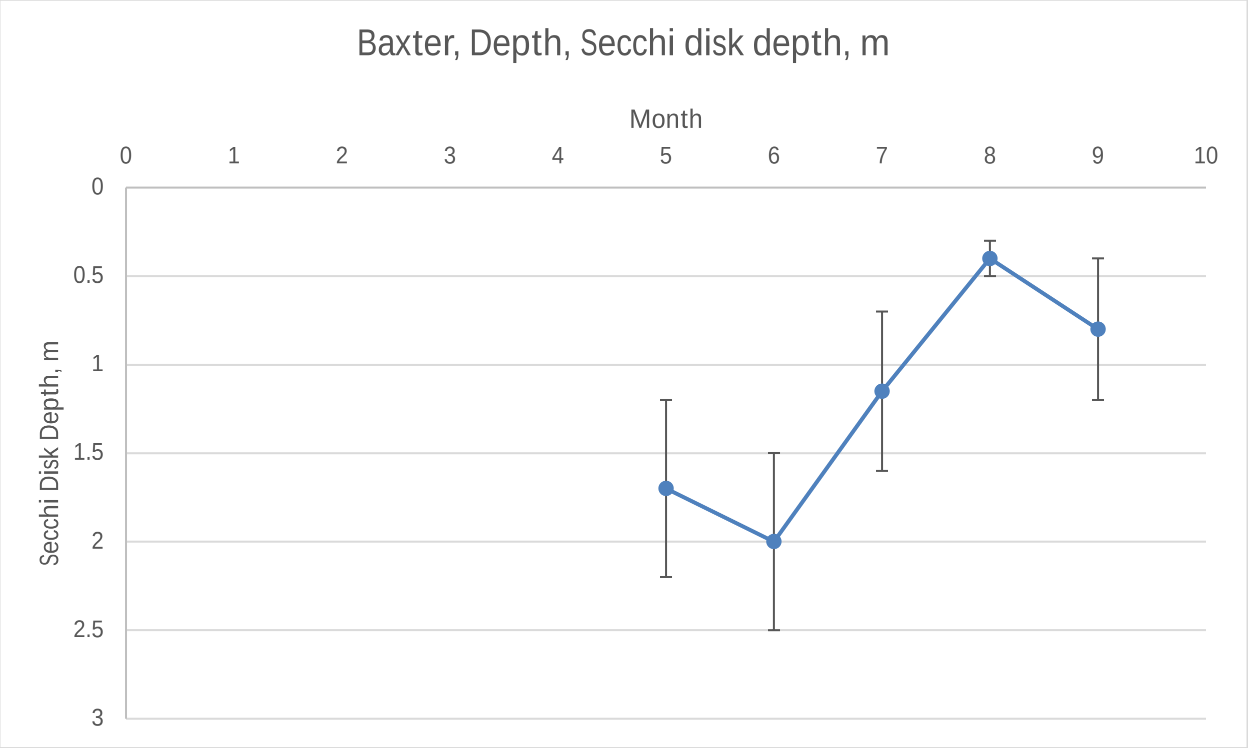
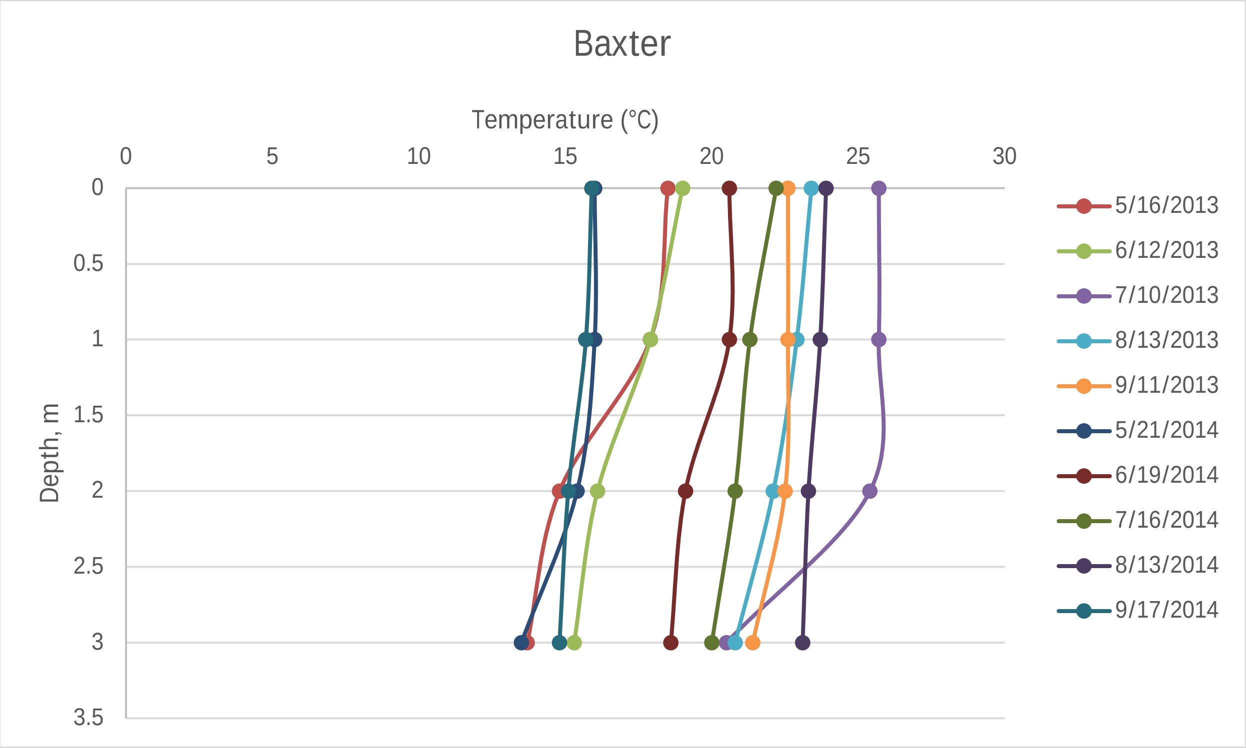


Figure A-7. Growing-Season Monthly Mean of Secchi Transparency for Baxter Lake (All Available Data Between 2006–2015).

Table A-4. Total Phosphorus, Chlorophyll-a, and Secchi Transparency Number of Samples Annually for Baxter Lake

Lake	Constituent	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
Baxter	TP								5	4		9
	Chl-*a*								5	4		9
	Secchi								4	4		8

Figure A-8. Lake Temperature Profiles for Baxter Lake.



Fisheries

The DNR Fisheries surveyed Baxter Lake in late August 2010 noted common carp and black bullheads at relatively moderate catch rates for both standard trap nets and gillnets. Fishing pressure was noted for black crappies, which were abundance as were largemouth bass and bluegills.

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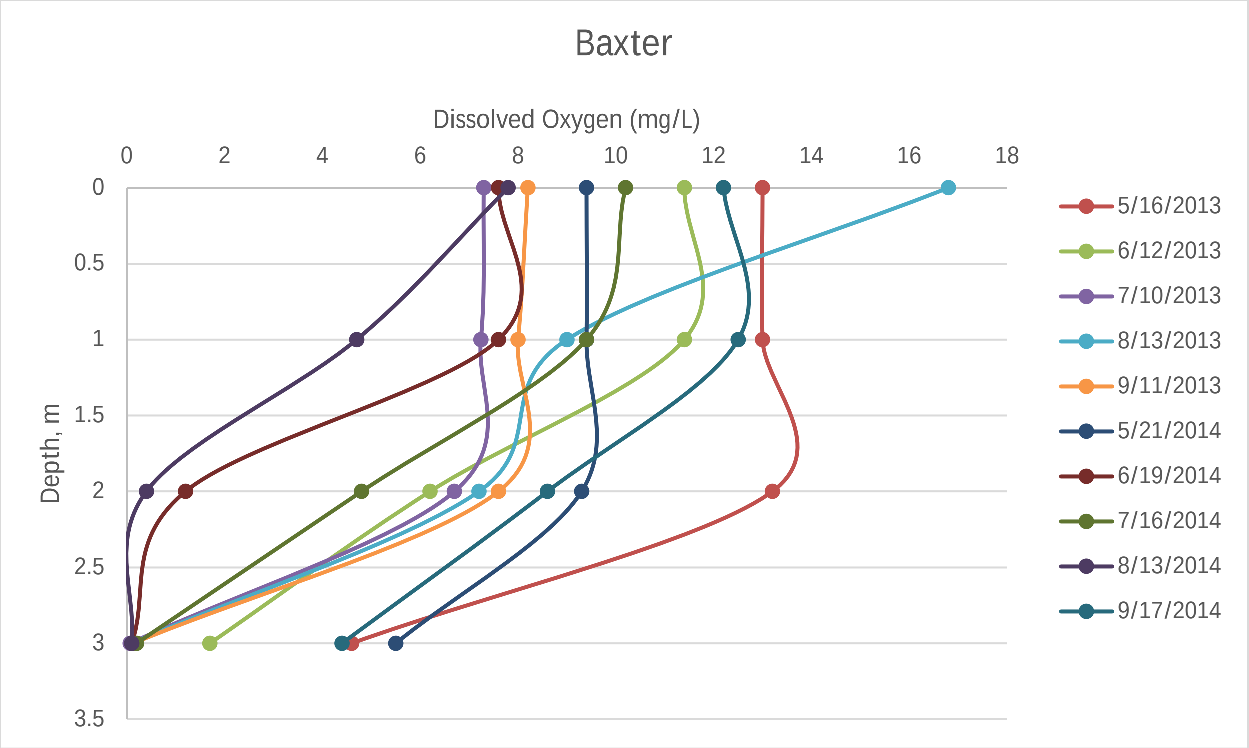


Figure A-9. Dissolved Oxygen Profiles for Baxter Lake.

Appendix B: West Hunter Lake (71-0022-00) and East Hunter Lake (71-0023-00)

Land Cover

Land cover defined by the University of Minnesota [2016] is summarized for the West and East Hunter Lake Watersheds in Table B-1. Very similar land cover percentages are noted for these paired lakes. Urban and row cropland covers comprise the majority of land covers in both watersheds, followed by grassland/managed grass, forests, and open water. Wetlands comprise a very small percentage (0.3% to 0.4%) of each watershed.

Table B-1. West and East Hunter Lakes Watershed Land Cover

Impairment	Open Water (%)	Wetlands (%)	Forest (%)	Grassland/ Managed Grass (%)	Hay/ Pastures (%)	Row Crops (%)	Urban (%)
East Hunter	17.2	0.3	13.2	21.2	0.0	21.4	26.6
West Hunter	10.9	0.4	11.6	25.2	0.0	26.2	25.7

Physical Characteristics

West Hunter Lake (71-0022-00) and East Hunter Lake (71-0023-00) are located in eastern Sherburne County, approximately four miles west of Zimmerman, Minnesota. These lakes are in the southwestern portion of the Rum River Hydraulic Unit Code (HUC) 8. West Hunter Lake discharges into East Hunter Lake via two narrow channels that are approximately 32 feet wide and 48 feet long. As such, these lakes have been assessed in tandem. Both lakes have a history of oxygen depletion with winterkills being experienced every 5 to 7 years, according to Minnesota Lakefinder. Curly-leaf pondweed (*Potamogeton Crispus*) has been noted to occur over less than 3% of West Hunter surface area but covers about 92% of East Hunter Lake. Watershed area to lake-surface area ratios of about 9.3:1 and 12.4:1 were estimated for West and East Hunter Lakes, respectively. Smaller watershed to lake-surface area ratios suggest that these watersheds may respond more quickly to watershed restoration actions.

From a regulatory standpoint, West and East Hunter Lakes are categorized as shallow NCHF ecoregion lakes. Select lake morphometric and watershed characteristics are listed in Table B-2, and lake bathymetry for both lakes are depicted in Figure B-1. Table B-2 lists standard limnological and watershed characteristics. Mean lake depth was calculated from DNR lake bathymetric maps. West Hunter Lake has one public access maintained by the DNR, with four vehicle/trailer parking spaces and a public dock. Lake-level fluctuation data was not available for these lakes. Both West and East Hunter Lakes are classified as shallow based on Lake GR values of 12.1 and 10.2, respectively, and polymictic based on an Osgood Index Values of 3.1 and 3.2, respectively.

Table B-2. West Hunter and East Hunter Lakes Select Lake Morphometric and Watershed Characteristics

Characteristic	West Hunter Lake	East Hunter Lake	Source
Lake-Surface Area (acres)	60	55	DNR LakeFinder
Number of Islands	0	0	
Percent Lake Littoral Surface Area	97	98	DNR LakeFinder
Drainage Area, Including Lake acres (ac)/square kilometers (km^2)	559 ac /2.3 km^2	683 ac /2.8 km^2	Model Subwatersheds
Watershed Area to Lake Area Ratio	9.3:1	12.4:1	Calculated
Wetland Area (% of watershed)	0.4	0.3	University of Minnesota [2016]
Number of Upland Lakes	0	1	US Geological Survey topographic maps
Number of Perennial Inlet Streams	1	West Hunter	US Geological Survey topographic maps
Lake Volume (acre-feet (ac-ft)/cubic hectometers (hm^3))	360 ac-ft/0.44 hm^3	385/0.47	DNR LakeFinder
Mean Depth (ft/m)	5 ft/1.5 m	5/1.5	DNR LakeFinder
Annual Lake-Level Fluctuations (ft):typical, maximum	NA	NA	DNR Lake Levels
Maximum Depth (ft/m)	6 ft/1.8 m	7 / 2.1	DNR LakeFinder
Maximum Fetch Length (miles (mi)/kilometers (km))	0.63 mi/1.02 km	0.6/0.98	Measured in Google Earth
Lake Geometry Ratio	12.1	10.2	Calculated
Osgood Index	3.1	3.2	Calculated
Estimated Water Residence Time (years/days)	0.71 year	0.58 year	Calculated
Public Access	1	(via West Hunter)	DNR
Shore Land Properties	24	17	Counted from topographic maps

Water Quality

Monitoring data for the Total Maximum Daily Load (TMDL) period were available from 2008, 2009, and 2010 sampling efforts that are summarized in Table B-3 as average growing-season values for TP, Chl-*a*, and Secchi. Corresponding Minnesota NCHF shallow lake water quality standards are also tabulated. Mean growing-season values for TP and Chl-*a* are above the water quality standard for East Hunter Lake. West Hunter Lake's average summer TP exceeds the lake standard, while average Chl-*a* and Secchi values during the TMDL period did not. Peak monitored Chl-*a* concentrations for West Hunter (e.g., 41.2 micrograms per liter (ug/L)) are substantially less than encountered in East Hunter Lake (e.g., 183 ug/L). TMDL allocations for East Hunter Lake will require quantification of West Hunter Lake's water and P mass balances. The number of samples annually are shown in Table B-4.

Figure B-1. West Hunter and East Hunter Lakes Bathymetry and Aerial Imagery.

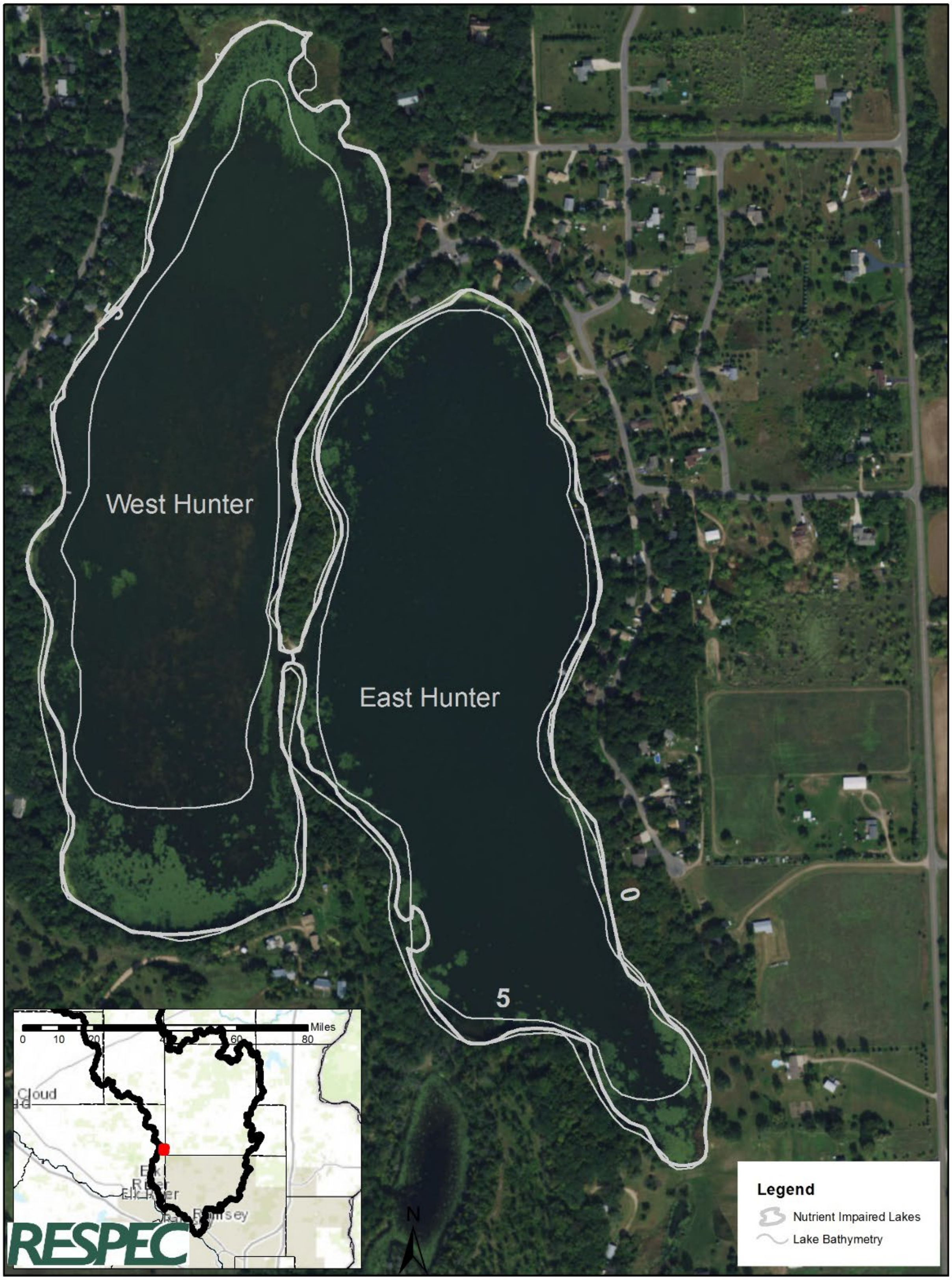


Table B-3. Total Maximum Daily Load Period Total Phosphorus, Chlorophyll-*a*, and Secchi Transparency Growing-Season Means for West Hunter Lake and East Hunter Lake With Corresponding Lake Standards

Parameter	Minimum	Mean	Maximum	Sample Number	Standard Deviation	NCHF Shallow-Lake Standards
West Hunter Lake						
TP (µg/L)	31.0	65.6	114.0	13	22.8	≤ 60
Chlorophyll-*a* (µg/L)	5.8	18.8	41.2	13	12.4	≤ 20
Secchi Disk Depth (m)	0.6	1.34	1.9	12	0.4	≥ 1.0
East Hunter Lake						
TP (µg/L)	26.0	73.0	182.0	12	41.6	≤ 60
Chlorophyll-*a* (µg/L)	2.9	31.5	183.0	12	49.1	≤ 20
Secchi disc depth (m)	1.2	1.6	2.2	11	0.3	≥ 1.0

Table B-4. Total Phosphorus, Chlorophyll-*a*, and Secchi Transparency Number of Samples Annually for West Hunter and East Hunter Lakes

Lake	Constituent	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
East Hunter	TP			5	5	2						12
	Chl-*a*			5	5	2						12
	Secchi			5	5	1						11
West Hunter	TP			5	6	2						13
	Chl-*a*			5	6	2						13
	Secchi			5	5	2						12

West Hunter Lake

Data from 2008 to 2010 were summarized as mean growing-season values in Figures B-2 through B-4 to summarize West Hunter Lake's year-to-year variability of key lake water quality parameters. Mean summer TP values showed a less stable pattern than indicated in East Hunter Lake with values initially around the lake standard of 60 µg/L and then increasing to about 95 µg/L in 2010 (note that two samples were obtained in 2010). Corresponding average growing-season Chl-*a* varied in a similar fashion with a peak value noted in 2010 of about 37 ug/L with a corresponding low Secchi value of approximately 2 feet noted in 2010.

Multiyear mean growing-season monthly water quality observations for West Hunter Lake are summarized in Figures B-5 through B-7 from 2008 through 2010. Plots of this mean monthly data show general declines in TP values from June through August with some minor increases in September. Chl-*a* showed similar declines through August, followed by a peak in September. Algal species data were not available to discern a prevalence of cyanobacterial levels. Secchi values increased from June and remained steady through September.

East Hunter Lake

Data from 2008 through 2010 were depicted as mean growing-season values by year in Figure B-8 through Figure B-10 for key lake water quality parameters. While mean summer TP values were remarkably stable over this time (averaging approximately 75 ug/L), the corresponding Chl-*a* varied considerably with a mean growing-season range of about 50 to 15 ug/L, with lower values noted in the most recent years. A somewhat different picture emerged based on average summer Secchi, with values generally declining from approximately 6 feet to 4.5 feet over this same time period.

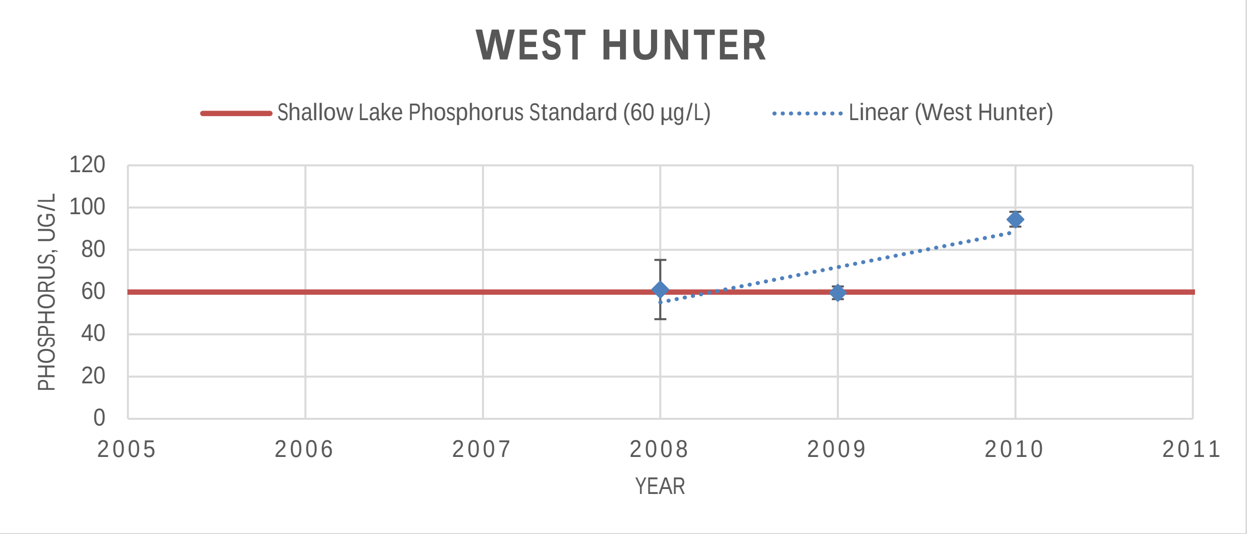


Figure B-2. Annual Growing-Season Mean of Total Phosphorus Concentrations for West Hunter Lake.

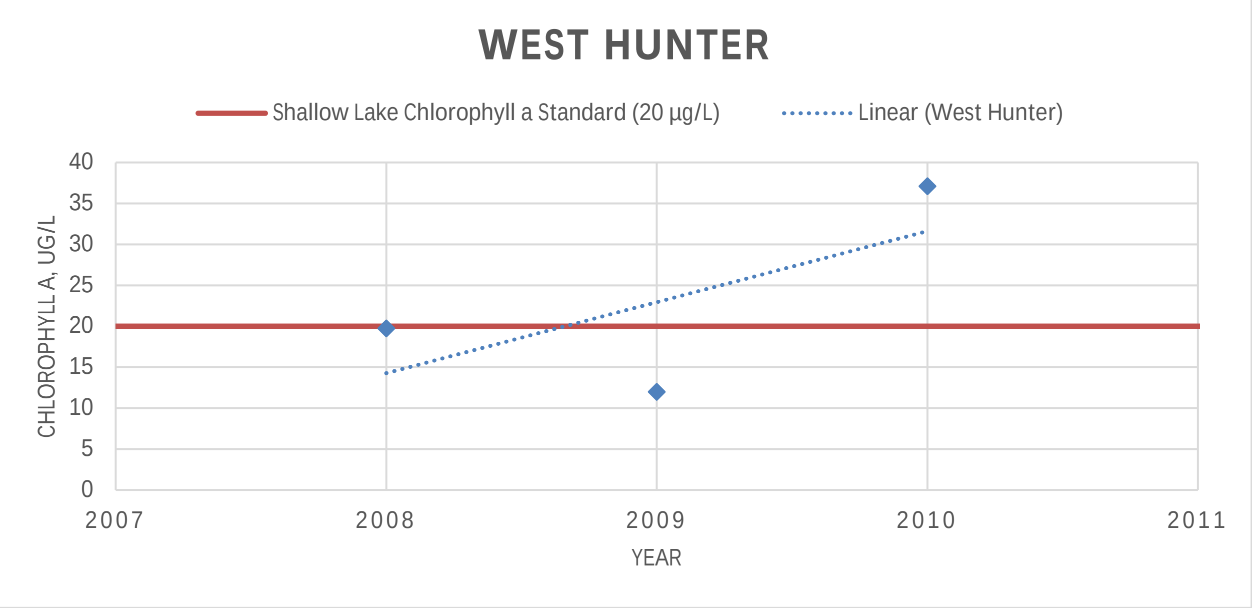


Figure B-3. Annual Growing-Season Mean of Chlorophyll-*a* Concentrations for West Hunter Lake.

Multiyear mean monthly growing-season water quality observations for East Hunter Lake are summarized in Figure B-11 to Figure B-13 for 2008, 2009, and 2010 (two observations). Plots of this mean monthly data show short peaks in TP and Chl-*a* concentrations from June through August, with sharp declines noted in September. The multiyear mean growing-season monthly P concentrations increase from approximately 70 µg/L to 100 µg/L from June through August and decline to about 55 µg/L in September. Mean monthly P values reflect all external (watershed loading and septic systems) and internal sources. In a similar fashion, multiyear mean monthly Chl-*a* concentrations increase sharply from June through August from approximately 15 µg/L to 65 µg/L, with a decline to approximately 18 µg/L in September. Correspondingly, average monthly Secchi transparencies decline from approximately 1.75 m in June to 1.25 m in August, followed by a slight increase to approximately 1.5 m in September.

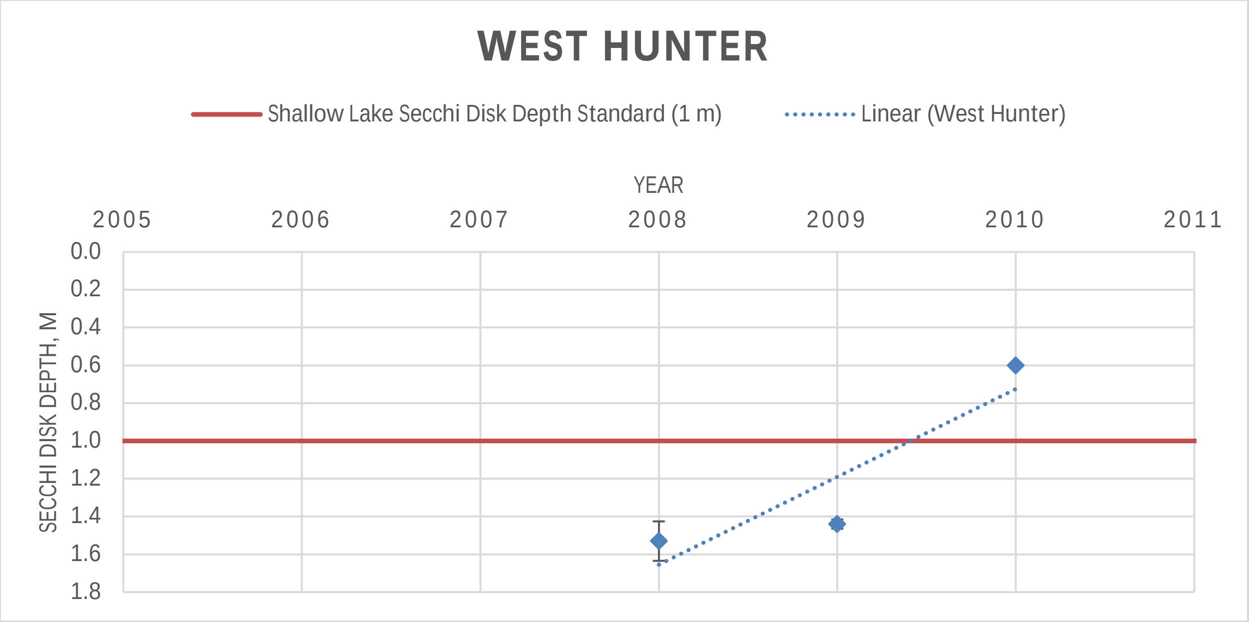


Figure B-4. Annual Growing-Season Mean of Secchi Transparency) for West Hunter Lake.

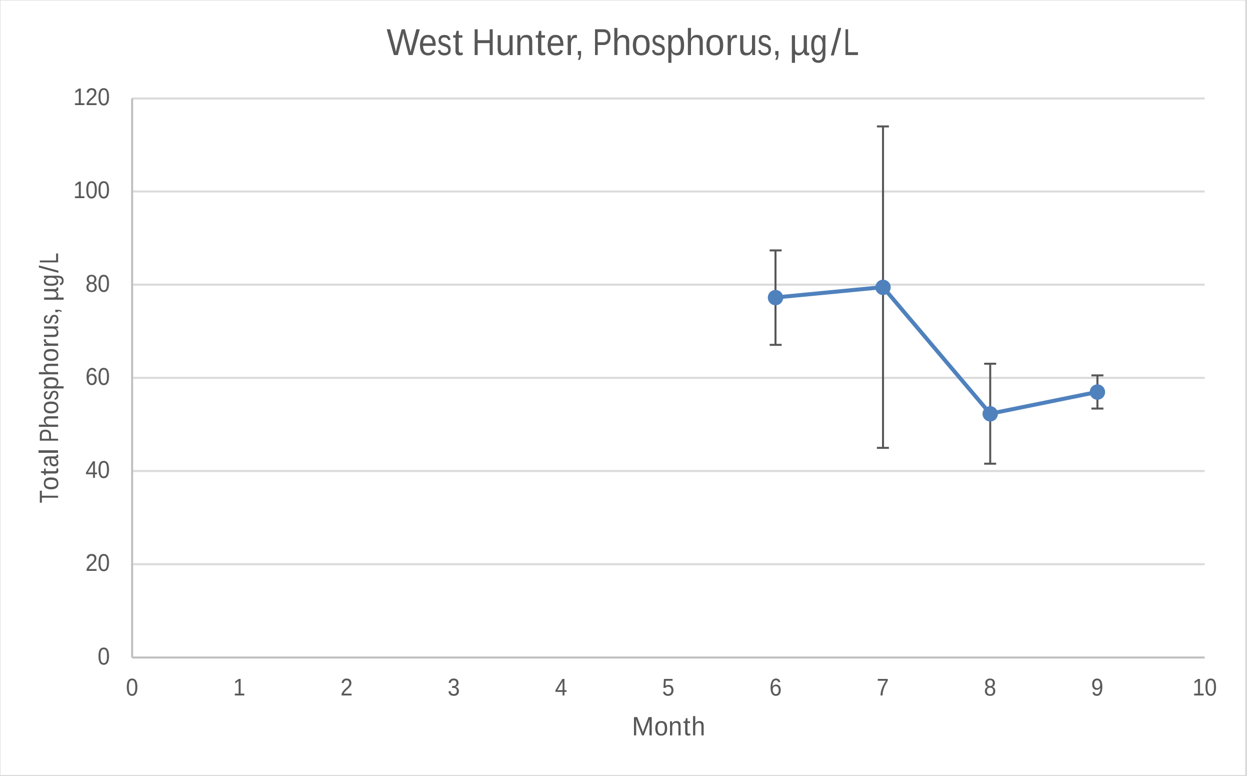


Figure B-5. Growing-Season Monthly Mean of Total Phosphorus for West Hunter Lake (All Available Data Between 2006–2015).

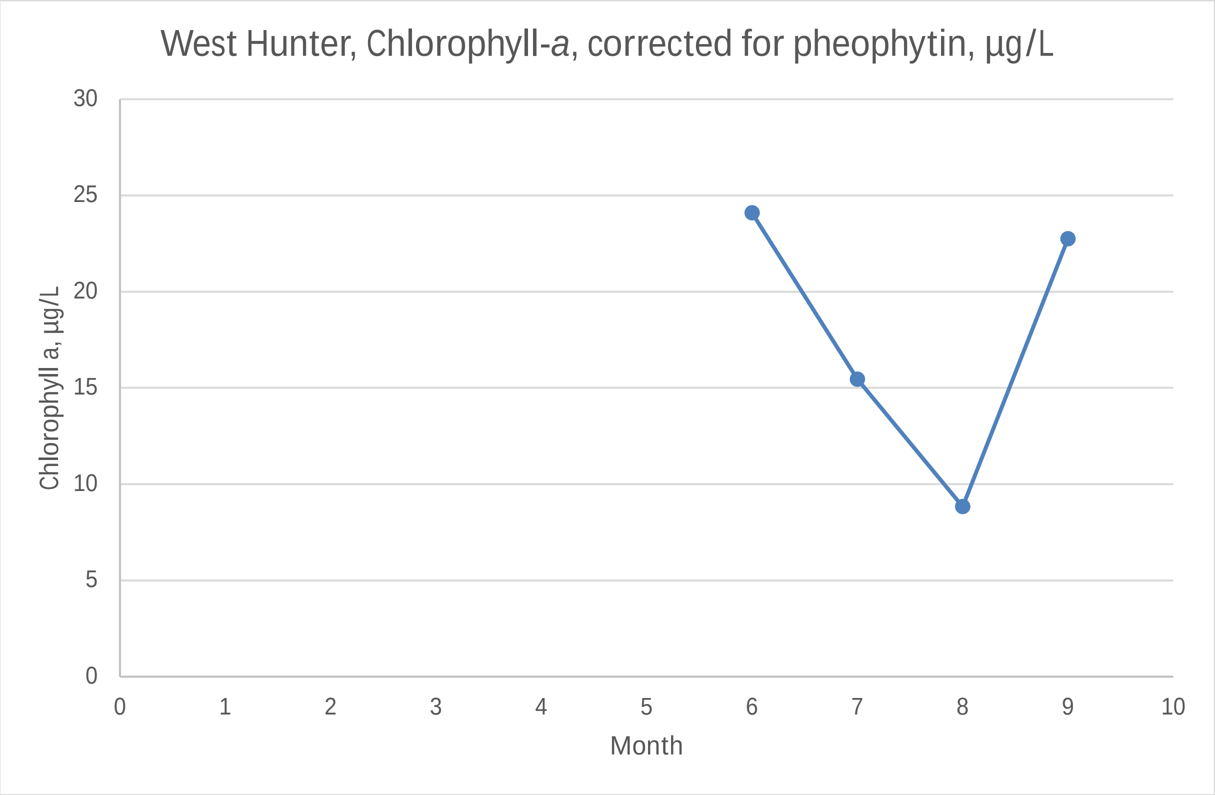
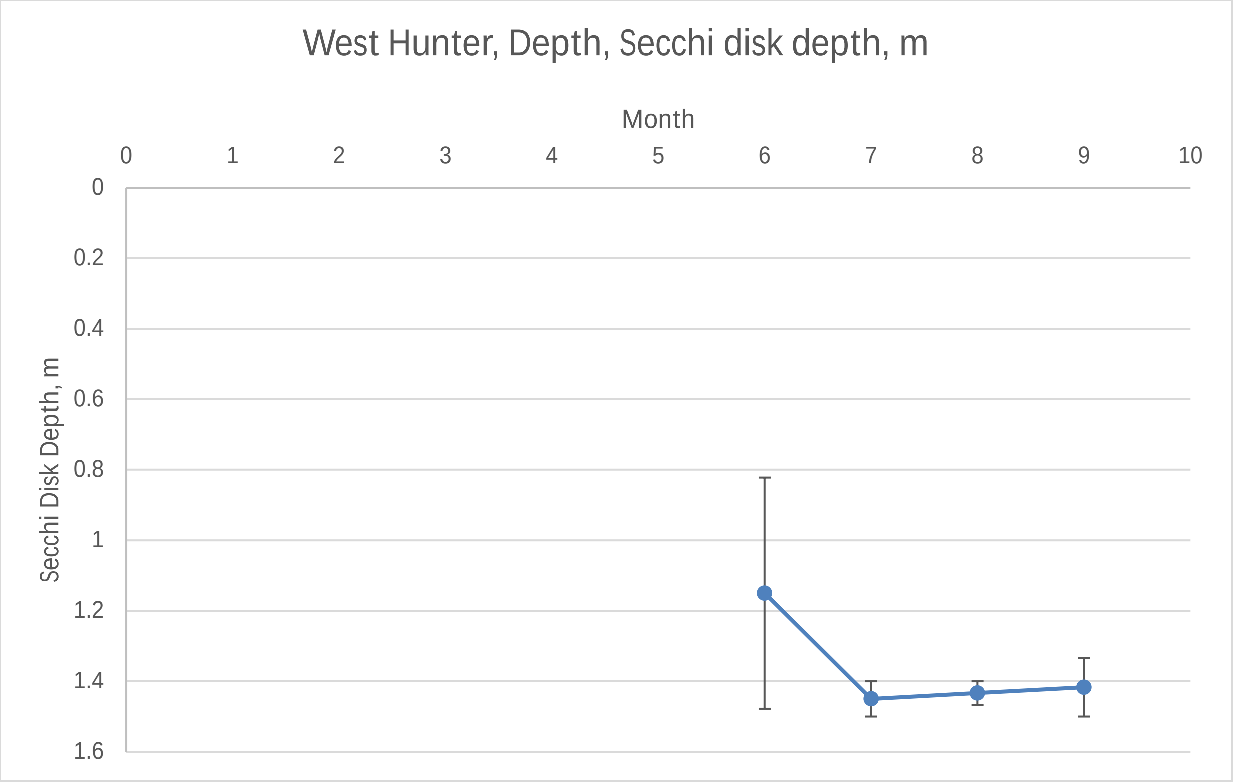


Figure B-6. Growing-Season Monthly Mean of Chlorophyll-*a* for West Hunter Lake (All Available Data Between 2006–2015).

Figure B-7. Growing-Season Monthly Mean of Secchi Transparency for West Hunter Lake (All Available Data Between 2006–2015).



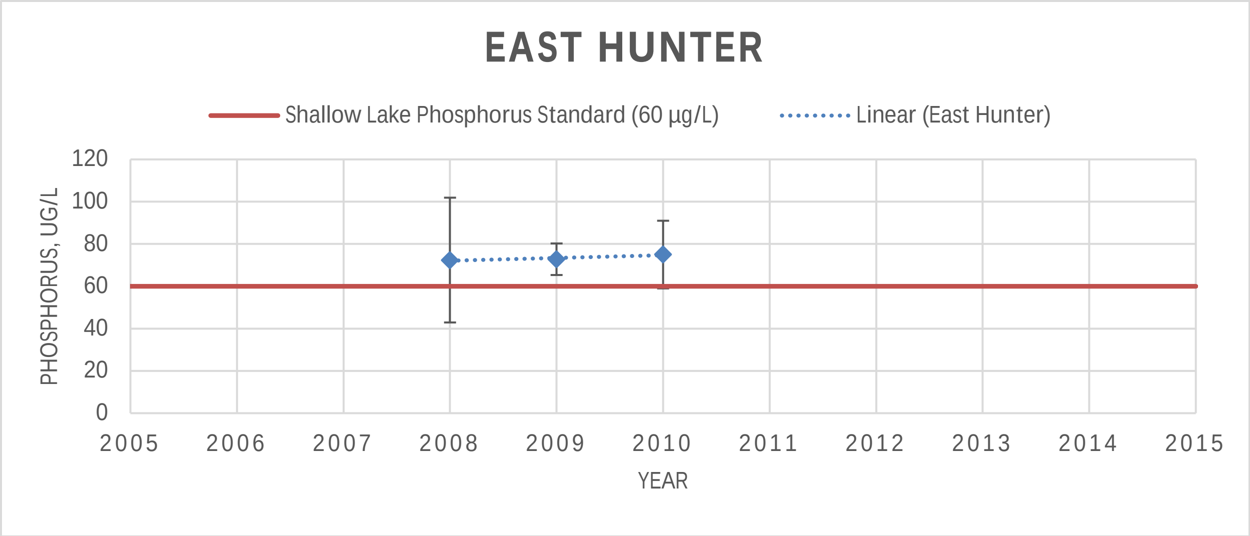


Figure B-8. Annual Growing-Season Mean of Total Phosphorus Concentrations for East Hunter Lake.

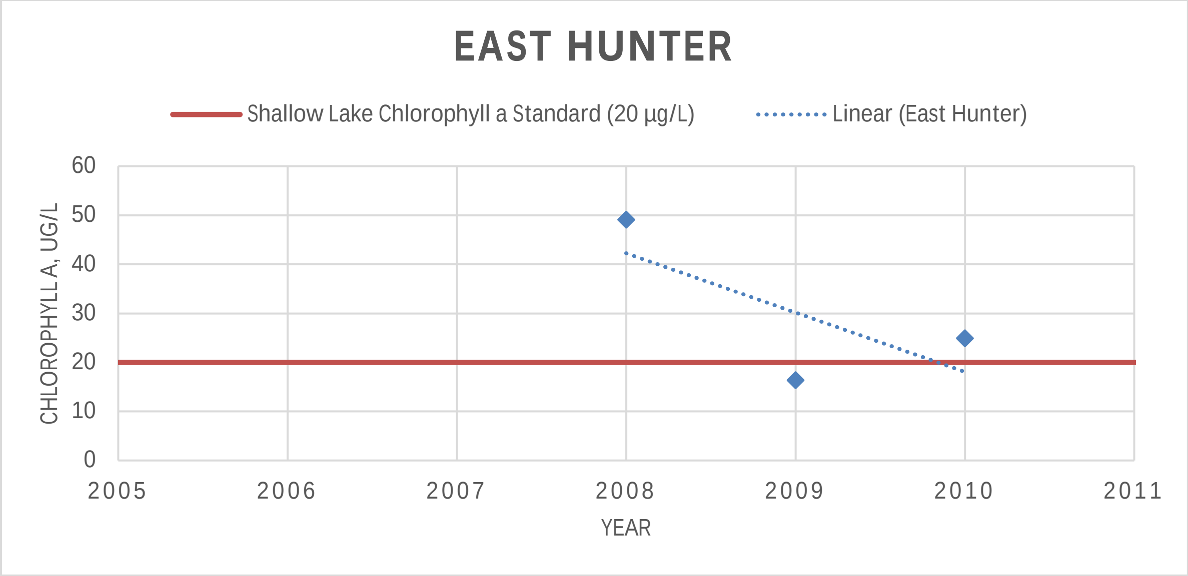


Figure B-9. Annual Growing-Season Mean of Chlorophyll-*a* Concentrations for East Hunter Lake.

Dissolved Oxygen and Temperature Data Summary

The DO and temperature data monitored by depth were examined to better define lake-mixing patterns that affect biological responses and lake P dynamics.

West Hunter Lake

Available data from 2008 and 2009 are plotted in Figures B-14 and B-15 for temperature and DO, respectively. Water-temperature variation by depth profiles are shown in Figure B-14, with data indicating relatively well-mixed or polymictic conditions with similar temperatures from the surface to depth. Peak monitored summer bottom water temperatures (July through September) ranged from approximately 20° to 25°C.

The growing-season DO profile data typically exhibited similar concentrations with depth except for two June dates where oxygen loss with depth was noted in Figure B-15. Lake bottom water temperature and

DO concentrations relate to the potential for internal loading of P and are, thus, important parameters for characterizing in-lake nutrient dynamics. As noted for the growing-season monthly P plots, these DO profiles indicate a lower probability of substantial anoxic (low or no oxygen) moderated internal loading potentials.

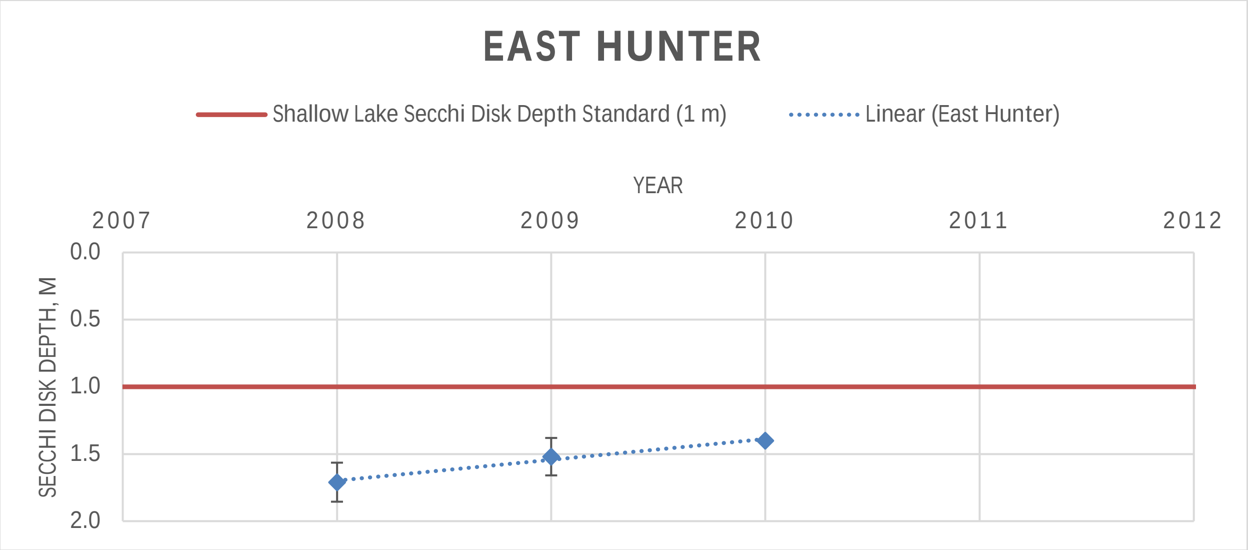


Figure B-10. Annual Growing-Season Mean of Secchi Transparency for East Hunter Lake.

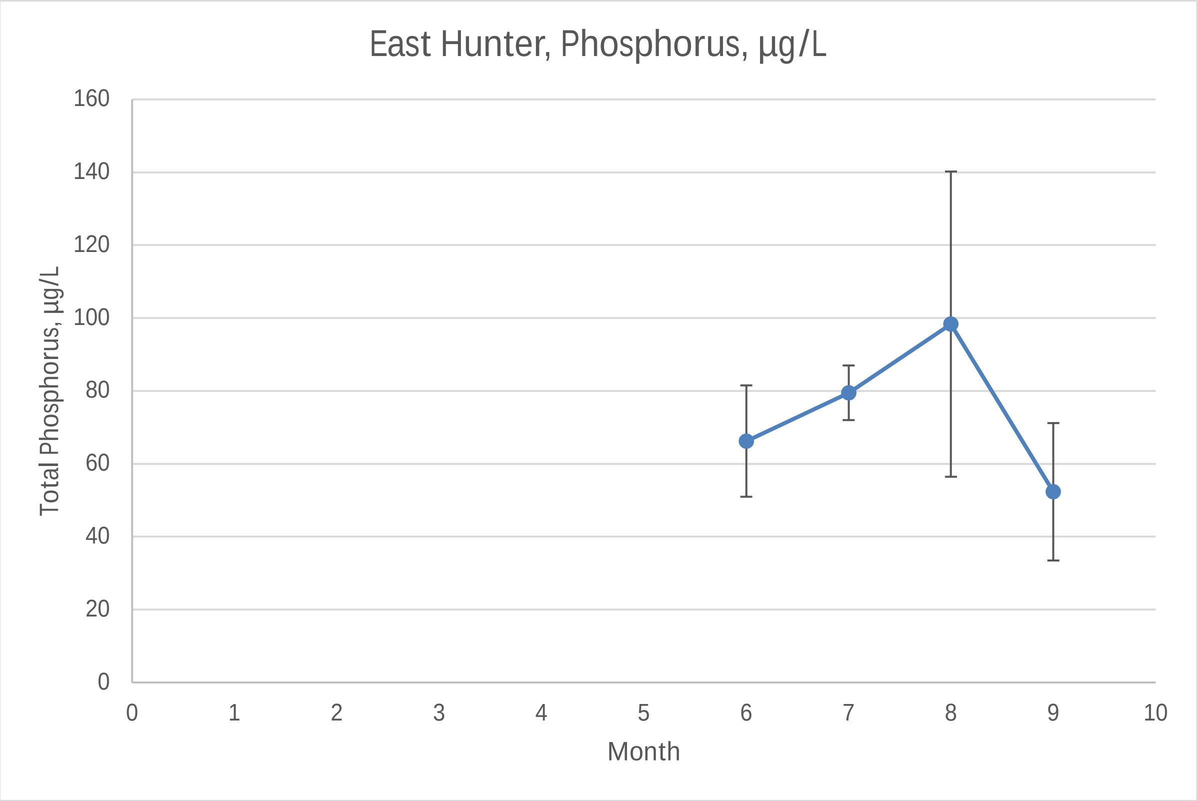


Figure B-11. Growing-Season Monthly Mean of Total Phosphorus for East Hunter Lake (All Available Data Between 2006–2015).

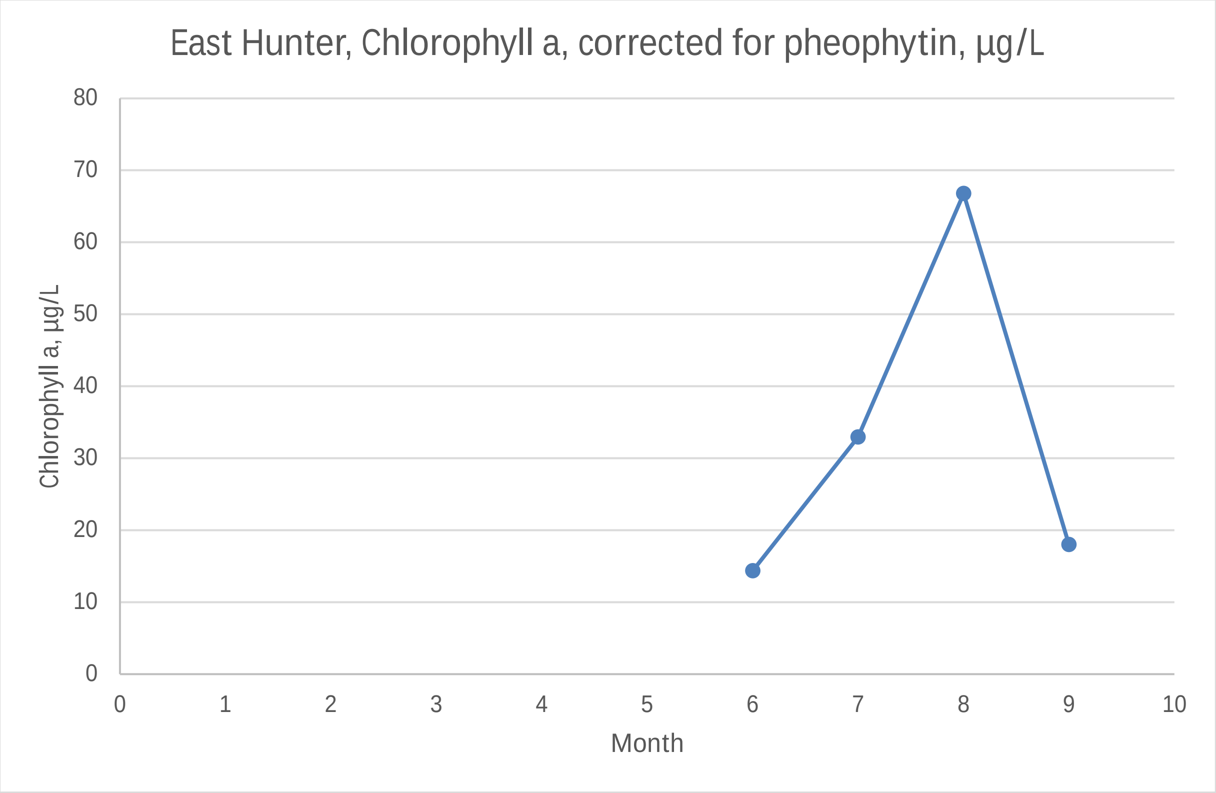


Figure B-12. Growing-Season Monthly Mean of Chlorophyll-*a* for East Hunter Lake (All Available Data Between 2006–2015).

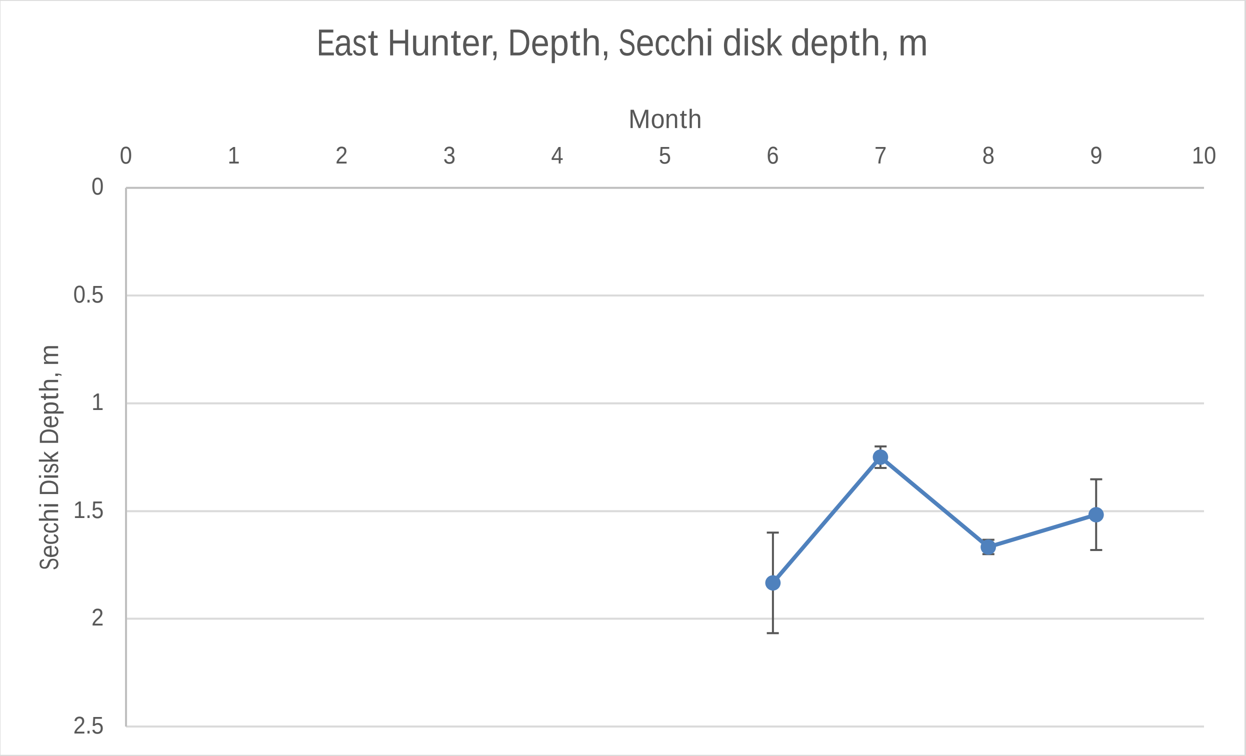


Figure B-13. Growing-Season Monthly Mean of Secchi Transparency for East Hunter Lake (All Available Data Between 2006–2015).

Figure B-14. Lake Temperature Profiles for West Hunter Lake.

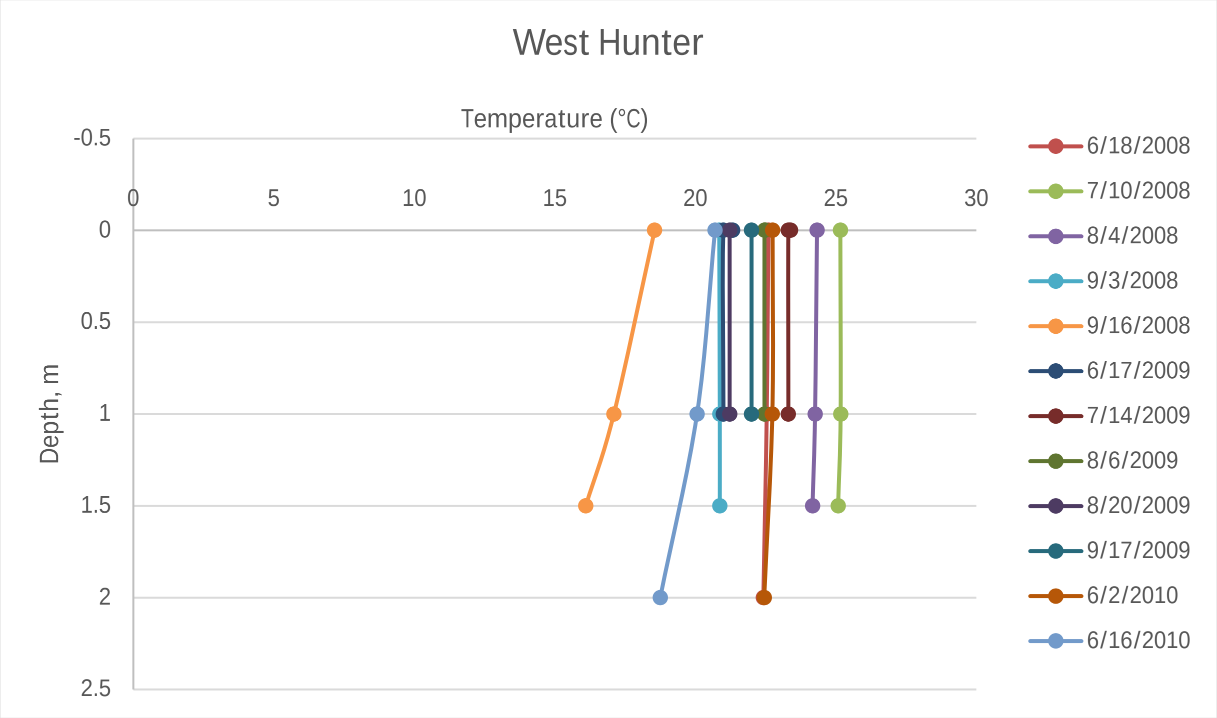
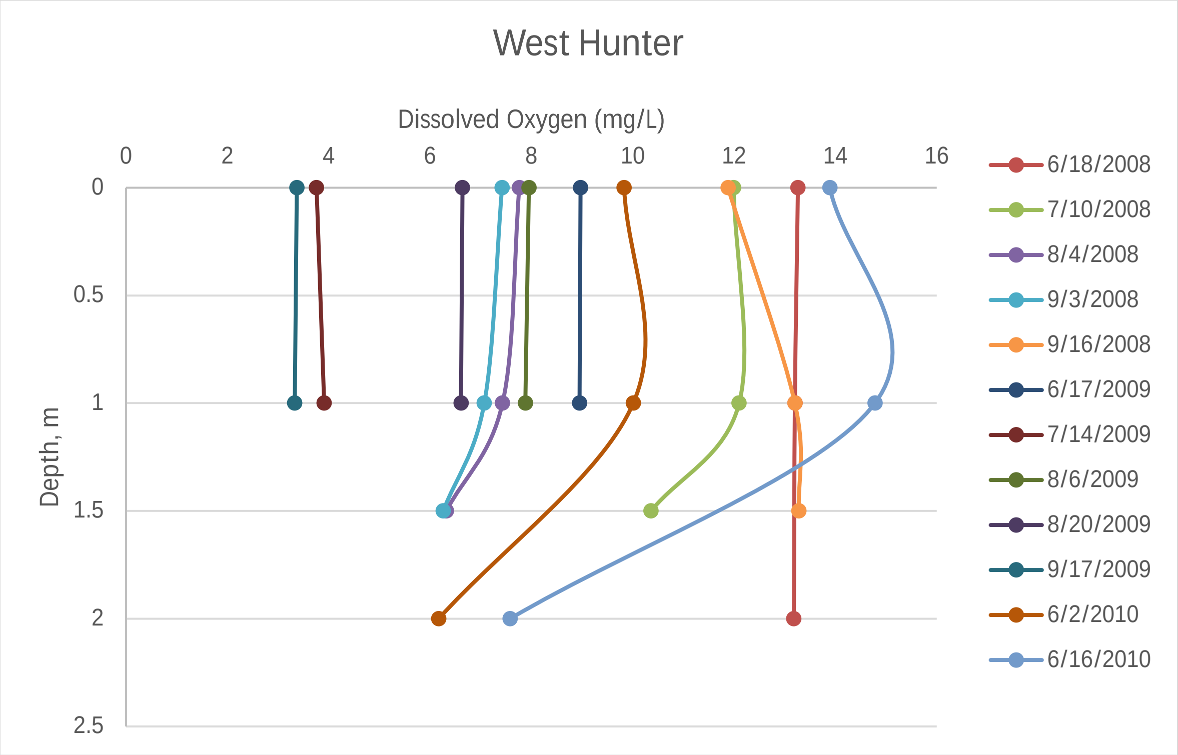


Figure B-15. Dissolved Oxygen Profiles for West Hunter Lake.



East Hunter Lake

Available data from 2008 through 2010 are plotted in Figures B-16 and B-17 for temperature and DO, respectively. Water-temperature variation by depth profiles are shown in Figure B-16 with data indicating relatively well-mixed or polymictic conditions and similar temperatures from the surface to depth. Peak monitored summer bottom water temperatures (July through September) ranged from approximately 20° to 25°C.

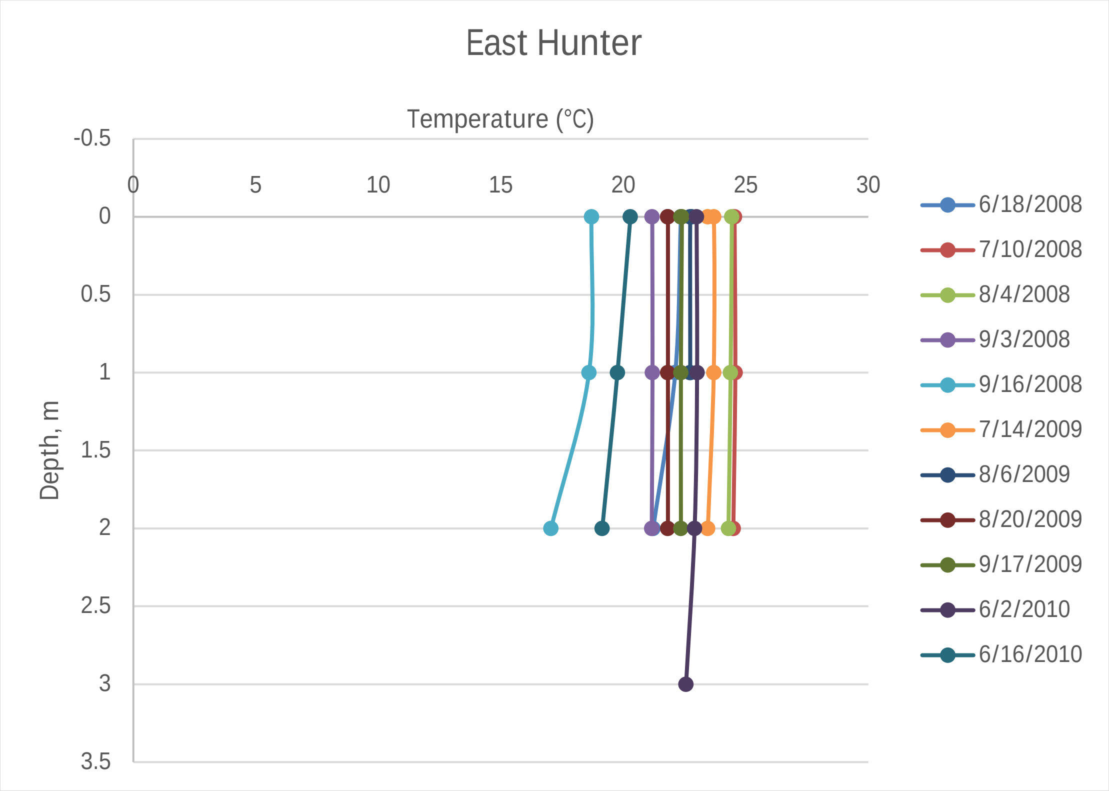


Figure B-16. Lake Temperature Profiles for East Hunter Lake.

The growing-season DO profile data typically exhibited similar concentrations with depth except for two dates with large oxygen losses noted, as shown in Figure B-17. Also noted by DNR Fisheries managers are the periodic winter fish kills attributed to low DO. Hence, these two shallow lakes are prone to seasonal DO depletion periods. Lake bottom water temperature and DO concentrations relate to the potential for internal loading of P and are, thus, important parameters for characterizing in-lake nutrient dynamics.

Aquatic Plant Survey

A Minnesota biological survey of aquatic plant species was conducted on the northwestern shore of West Hunter Lake that detailed shoreline plants. In total, the aquatic plant community appears to be diverse with 19 species of submersed, free-floating, floating-leaf, and emergent plants as well as 12 species of shoreline plants identified. Curly-leaf pondweed was noted to cover a minor surface area in West Hunter but dominates the early summer in East Hunter Lake [DNR 2016]. Coontail and northern water milfoil were noted as being the most abundant.

Fisheries

The DNR conducted a fisheries survey on both West and East Hunter Lakes on June 11, 2007, and noted that both lakes have a history of winterkill on the order of every five to six years. Hence, the DNR has placed a priority on oxygen depletion management and restocking. The primary fisheries management species is largemouth bass, which had an excellent population in the 2007 survey, along with bluegills, which lacked size. Common carp were not noted in the fish surveys. Northern pike were not noted in 1987 but by 2007, increased to ranges at or above normal ranges for similar lakes. Black bullheads were abundant but at reduced levels from 1987.

Figure B- 17. Dissolved Oxygen Profiles for East Hunter Lake.

References

Minnesota Department of Natural Resources, 2013. *Minnesota Biological Survey List of Plant Species Observed at West Hunter Lake*, prepared by the Minnesota Department of Natural Resources, St. Paul, MN.

University of Minnesota, 2016. “Metadata, Minnesota Land Cover Classification and Impervious Surface Area by Landsat and LiDAR: 2013 Update - Version 1,” *umn.edu*, retrieved June 1, 2016, from *http://portal.gis.umn.edu/map_data_metadata/LandCover_MN2013.html*

Appendix C: Skogman Lake (30-0022-00)

Land Cover

Land cover defined by the University of Minnesota [2016] is summarized for the Skogman Lake Watershed in Table C-1. Row crops and grassland/managed grass comprise 24.1% and 17.0% of the watershed, respectively, while urban lands cover about 8% of the watershed. Wetlands and forests comprise 15.6% and 26.5%, respectively, with open water covering about 8.8%.

Table C-1. Skogman Lake Watershed Land Cover

Impairment	Open Water (%)	Wetlands (%)	Forest (%)	Grassland/ Managed Grass (%)	Hay/ Pastures (%)	Row Crops (%)	Urban (%)
Skogman	8.8	15.6	26.5	17.0	0.1	24.1	8.0

Physical Characteristics

Skogman Lake's watershed (30-0022-00) is located in Isanti and Chisago Counties in the southeastern portion of the Rum River Hydraulic Unit Code (HUC) 8. The lake has an elongated configuration about 1.8 miles in length and oriented from the northeast to the southwest. The lake is much narrower with an average width on the order of less than 0.17 mile. The lake's discharge flows a distance of about 0.4 mile before it reaches the downstream Fannie Lake. Select lake morphometric and watershed characteristics are listed in Table C-2, with lake bathymetry depicted in Figure C-1.

Skogman Lake is located in the NCHF ecoregion and, from a regulatory standpoint, was categorized as a deep NCHF ecoregion lake. Table C-2 lists select lake and watershed characteristics. Lake volume and mean depth were calculated from the DNR lake bathymetric map. Skogman Lake has one public accesses maintained by the DNR with dock and vehicle parking. DNR lake-level program data indicate that fluctuations of one to two feet are relatively common. Lake levels are shown in Figure C-2.

Water Quality

As paired lakes, data for both Skogman and Fannie Lake are listed for comparative purposes in Table C-3. Fannie and Skogman Lakes' monitoring data for the TMDL period were available from 2006 to 2015 for paired TP, Chl-*a*, and Secchi transparency (Secchi) data (9 samples) and from 2006 through 2015 for Secchi measurements (71 measurements for Fannie Lake and 80 measurements for Skogman Lake) as summarized in Table C-3. Corresponding growing-season averages for TP, Chl-*a*, and Secchi as well as lake standards are summarized in Table C-3. P growing-season averages for both lakes narrowly exceed the P standard, which suggests modest reductions in P loading are required to attain water quality standards. Chl-*a* values greatly exceed the corresponding standard for both lakes, while average Secchi values do not exceed the standard thresholds. The long-term data plots indicate slightly improving patterns based on average summer TP (Figure C-3), Chl-*a* (Figure C-4), and Secchi transparency (Figure C-5). The longer and more extensive Secchi dataset reflect broader time period cycles with an overall improving pattern. The number of samples annually are shown in Table C-4.

Table C-2. Fannie and Skogman Lakes Select Lake Morphometric and Watershed Characteristics

Characteristic	Skogman	Fannie	Source
Lake-Surface Area (acres)	223	354	DNR LakeFinder
Number of Islands	0	1	
Percent Lake Littoral Surface Area	61	87	DNR LakeFinder
Drainage Area, Including Lake acres (ac)/square kilometers (km^2)	3,384 ac/13.7 km^2	7,340 ac/29.7 km^2	Model Subwatersheds
Watershed Area to Lake Area Ratio	15.2:1	20.7:1	Calculated
Wetland Area (% of watershed)	15.6	16.4	University of Minnesota [2016]
Number of Upland Lakes	3+	4+	US Geological Survey topographic maps
Number of Perennial Inlet Streams	1	3	US Geological Survey topographic maps
Lake Volume (acre-feet (ac-ft)/cubic hectometers (hm^3))	2,839 ac-ft/3.5 hm^3	2,701.6 ft/3.3 hm^3	DNR LakeFinder
Mean Depth (ft/m)	12.7 ft/3.9 m	7.6 ft/2.3 m	DNR LakeFinder
Annual Lake-Level Fluctuations (ft):typical, maximum	1–2 ft	NA (Old data, 2.2 ft noted)	DNR Lake Levels
Maximum Depth (ft/m)	36 ft/11 m	33 ft/10 m	DNR LakeFinder
Maximum fetch length (miles (mi)/kilometers (km))	1.8 mi/2.9 km	1.7 mi/2.7 km	Measured in Google Earth
Lake Geometry Ratio	2.8	3.3	Calculated
Osgood Index	4.2	2.2	Calculated
Estimated Water Residence Time (years/days)	1.5 years	0.6 year	Calculated
Public Access	1	2	DNR, Isanti Township
Shore Land Properties	“72	81	Isanti County

Available data have been averaged by growing-season month and is summarized in Figures C-6 through C-8. Plots of mean monthly data from 2006 show relatively stable TP concentrations from June through September with slight declines noted in Chl-*a* averages for September. Mean monthly Chl-*a* concentrations increase from June through August from approximately 7 micrograms per liter (µg/L) to 35 µg/L with a decline to approximately 27 µg/L in September. Correspondingly, average monthly Secchi declines from approximately 2.25 meters (m) in June to 1.25 m in September. Without additional lake P data and with the general improving Secchi measures, no internal loading component was calculated in the lake P balances.

Dissolved Oxygen and Temperature Data Summary

The DO and temperature data monitored by depth were examined to better define lake-mixing patterns that affect biological responses and lake P dynamics. Available data from 1981 to 2004 are plotted in Figures C-9 and C-10 for temperature and DO, respectively.

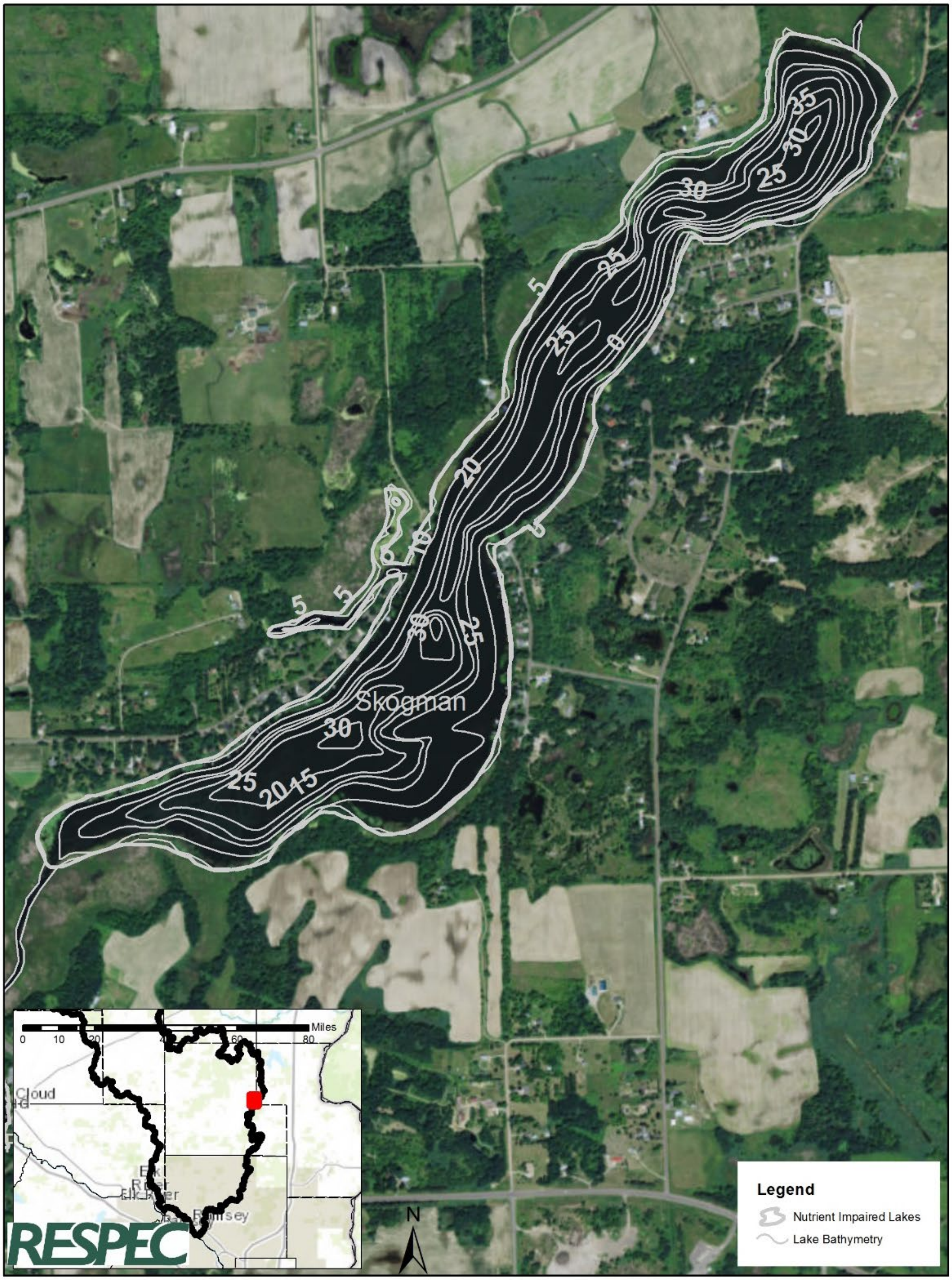


Figure C-1. Skogman Lake Bathymetry and Aerial Imagery [DNR 2015].

Figure C-2. Skogman Lake Water Level Records from DNR LakeFinder.

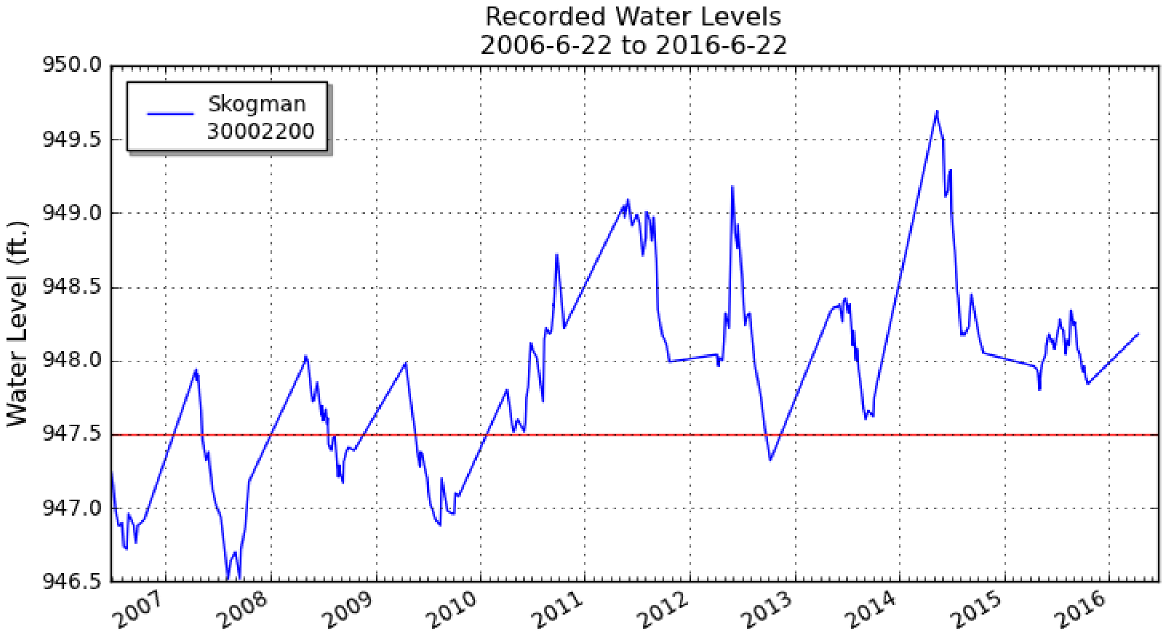


Table C-3. Total Maximum Daily Load Period Total Phosphorus, Chlorophyll-*a*, and Secchi Transparency Growing-Season Means for Skogman and Fannie Lakes

Parameter	Minimum	Mean	Maximum	Standard Deviation	Sample Number	Lake Standards
Skogman						
TP (µg/L)	33.0	42.9	53.0	6.5	9	≤ 40
Chlorophyll-*a* (µg/L)	5.0	21.3	35.0	10.2	9	≤ 14
Secchi disk depth (m)	0.9	1.4	4.3	0.5	71	≥ 1.4
Fannie						
TP (µg/L)	29	44.1	59	9.6	9	≤ 40
Chlorophyll-*a* (µg/L)	5.0	25.6	36.0	12.0	9	≤ 14
Secchi disk depth (m)	0.6	1.7	4.1	0.7	80	≥ 1.4

Water-temperature variation by depth profiles are shown in Figure C-9 with data indicating a weak summer thermocline at about 4 to 6+ m in depth. Peak monitored summer bottom water temperatures (July through September) ranged from approximately 12° to 18°C. DO concentrations were noted to decline in clinograde fashion with depth on all but one date with available data to below 2.0 mg/L (Figure C-10).

Aquatic Plants

A Minnesota biological survey of aquatic plant species was conducted on the eastern and western lakeshore areas of Skogman Lake on June 26, 2013, that detailed submersed, free-floating, floating-leaf, emergent, and shoreline plants. Nineteen species of aquatic plants were noted, including the invasive submerged species curly-leaf pondweed (*Potamogeton crispus*). Twenty-one species of shoreline plants associated with wetland habitats were noted, including the invasive species purple loosestrife (*Lythrum salicaria).*

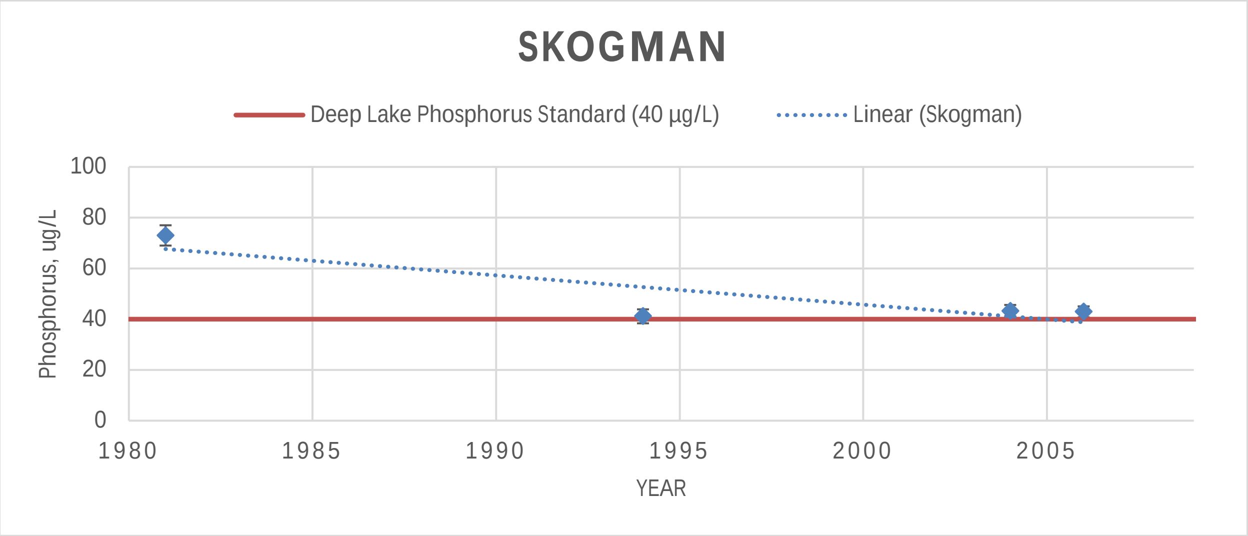


Figure C-3. Annual Growing-Season Mean of Total Phosphorus Concentrations for Skogman Lake.

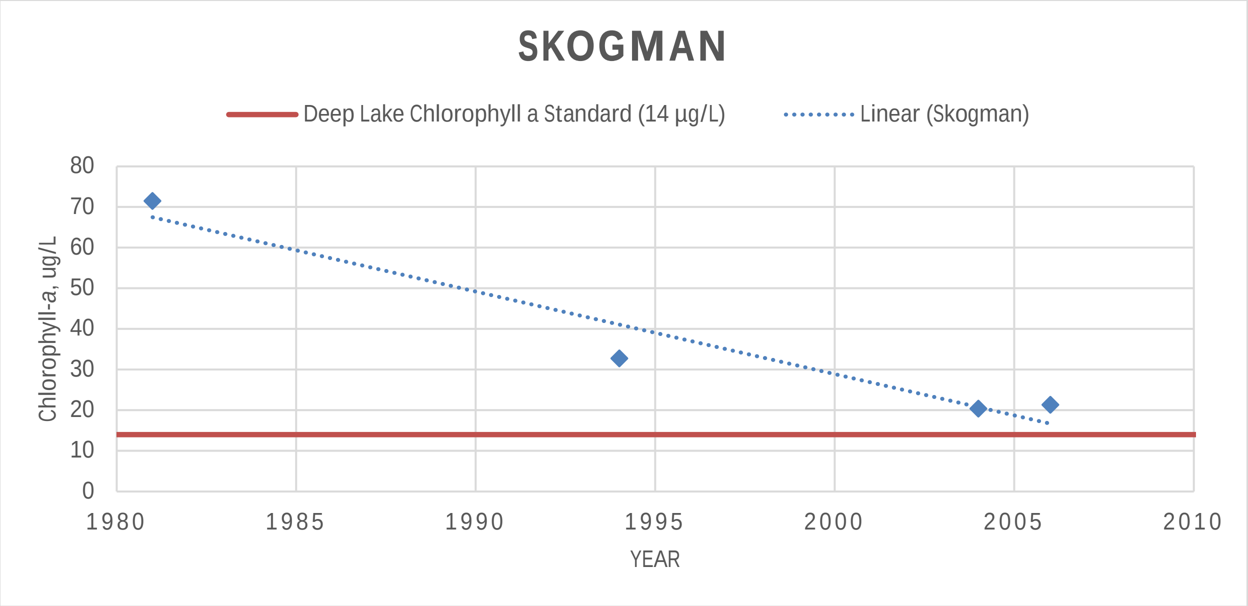


Figure C-4. Annual Growing-Season Mean of Chlorophyll-*a* Concentrations for Skogman Lake.

Fisheries

Skogman Lake is a bass-panfish lake that is managed primarily for walleye and is a DNR Lake Class 34. A fisheries survey was conducted in July 2013 with high catch rates for northern pike and low catch rates for walleye.

References

Minnesota Department of Natural Resources, 2013. *Minnesota Biological Survey List of Plant Species Observed at Skogman Lake*, prepared by the Minnesota Department of Natural Resources, St. Paul, MN.

University of Minnesota, 2016. "Metadata, Minnesota Land Cover Classification and Impervious Surface Area by Landsat and LiDAR: 2013 Update - Version 1," *umn.edu*, retrieved June 1, 2016, from *http://portal.gis.umn.edu/map_data_metadata/LandCover_MN2013.html*

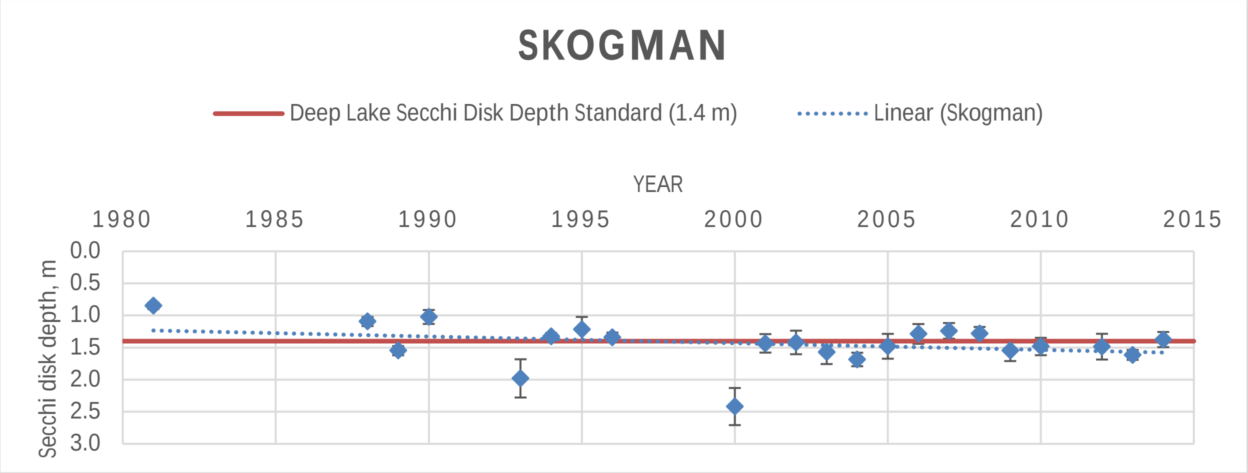


Figure C-5. Annual Growing-Season Mean of Secchi Transparency for Skogman Lake.

Table C-4. Total Phosphorus, Chlorophyll-*a*, and Secchi Transparency Number of Samples Annually for Skogman Lake

Lake	Constituent	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
Skogman	TP	9										9
	Chl-a	9										9
	Secchi	22	7	5	7	6		7	7	4	6	71

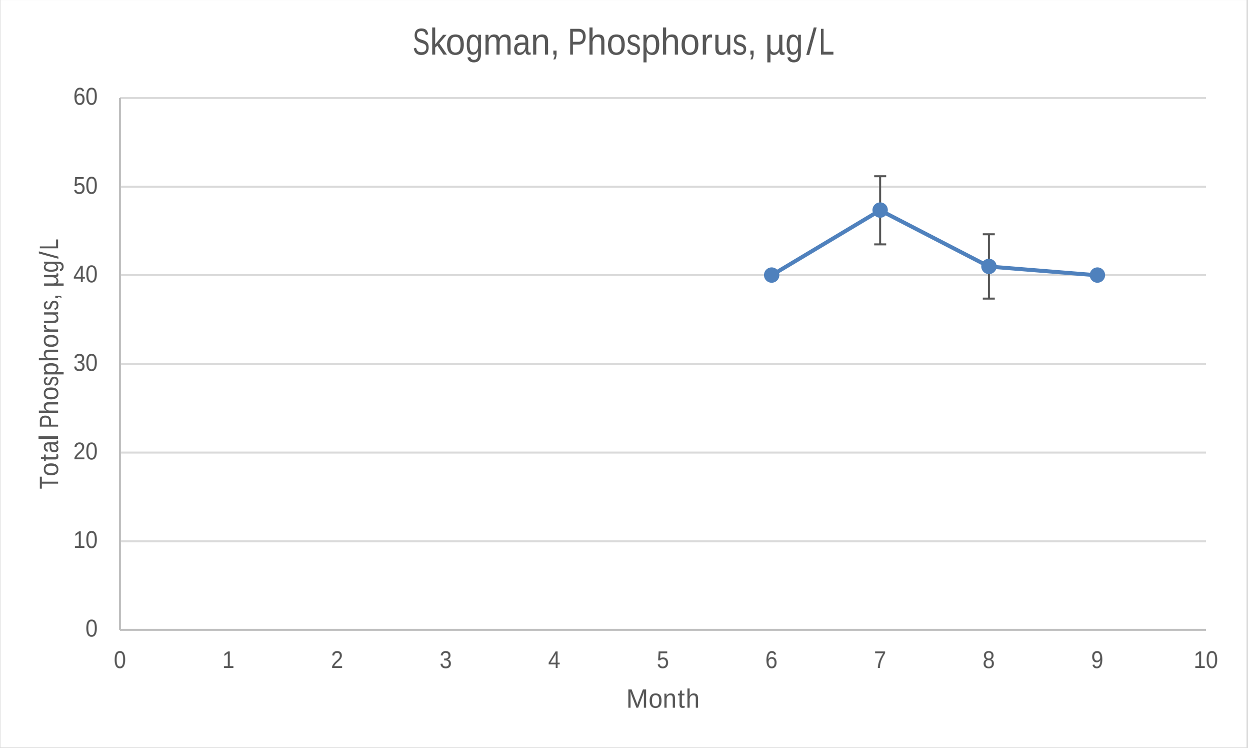


Figure C-6. Growing-Season Monthly Mean of Total Phosphorus for Skogman Lake (All Available Data Between 2006–2015).

Figure C-7. Growing-Season Monthly Mean of Chlorophyll-*a* for Skogman Lake (All Available Data Between 2006–2015).

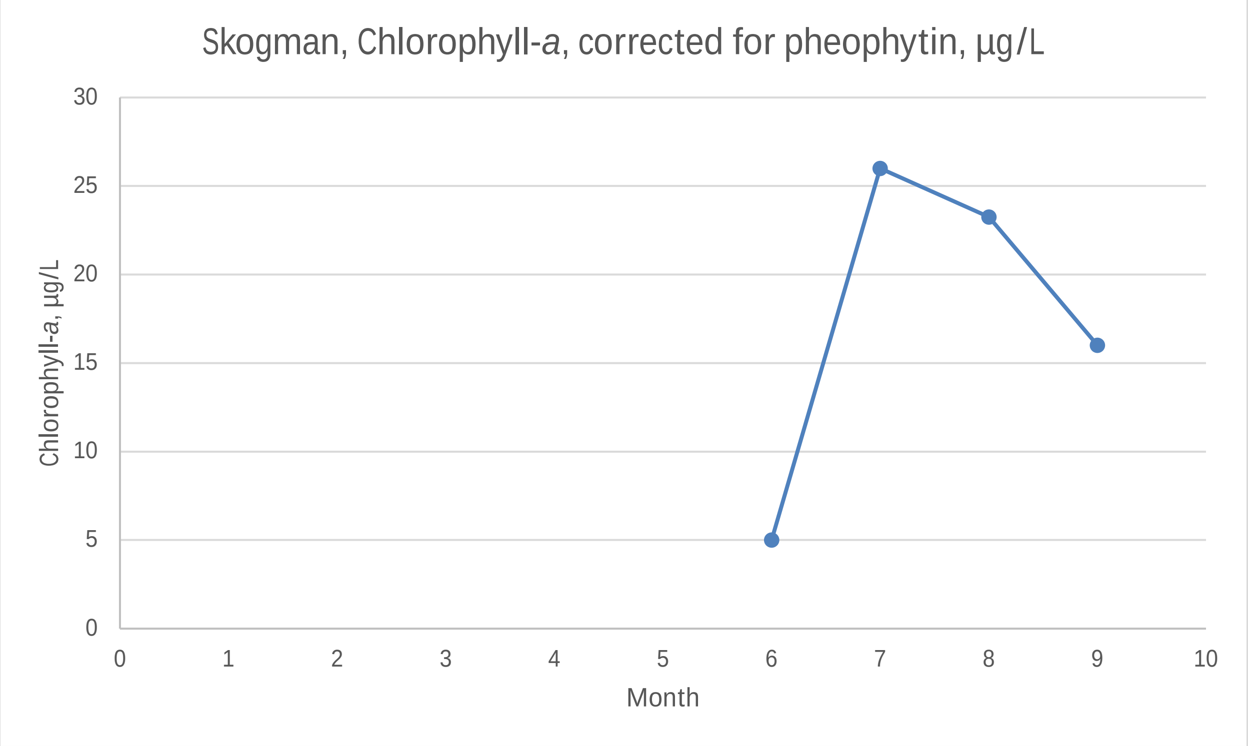
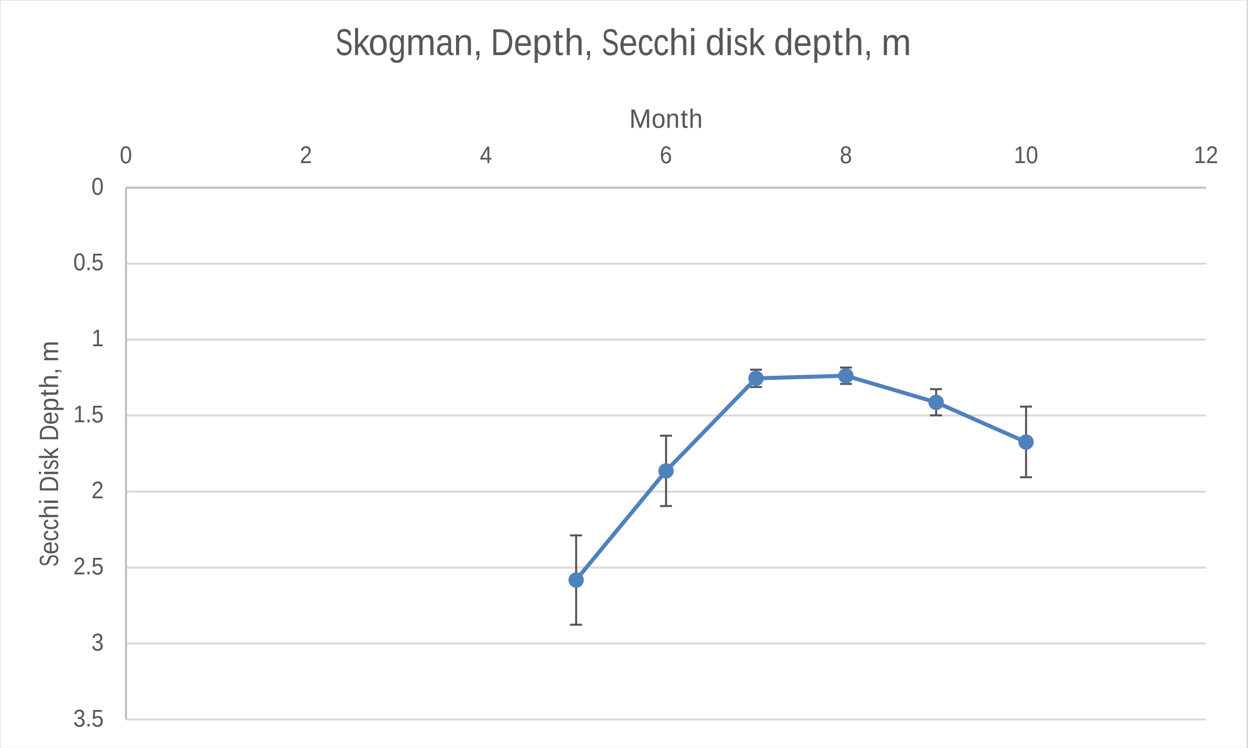


Figure C-8. Growing-Season Monthly Mean of Secchi Transparency for Skogman Lake (All Available Data Between 2006–2015).



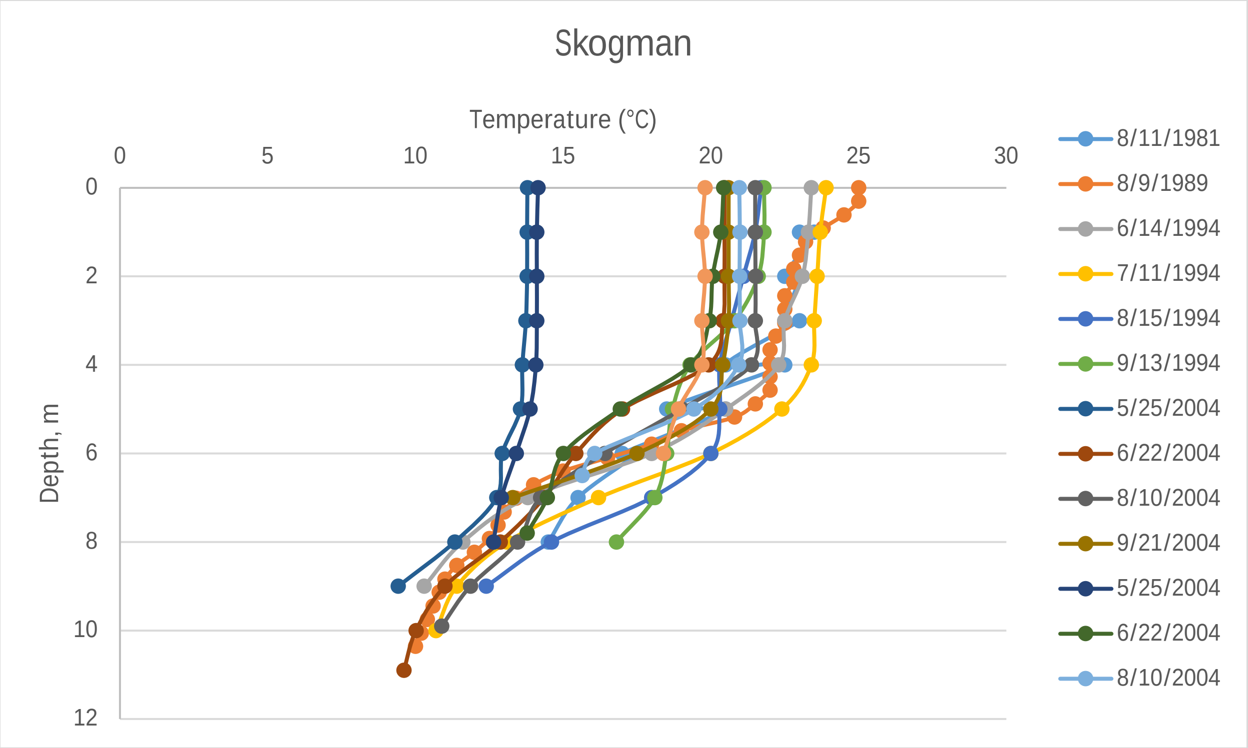


Figure C-9. Lake Temperature Profiles for Skogman Lake.

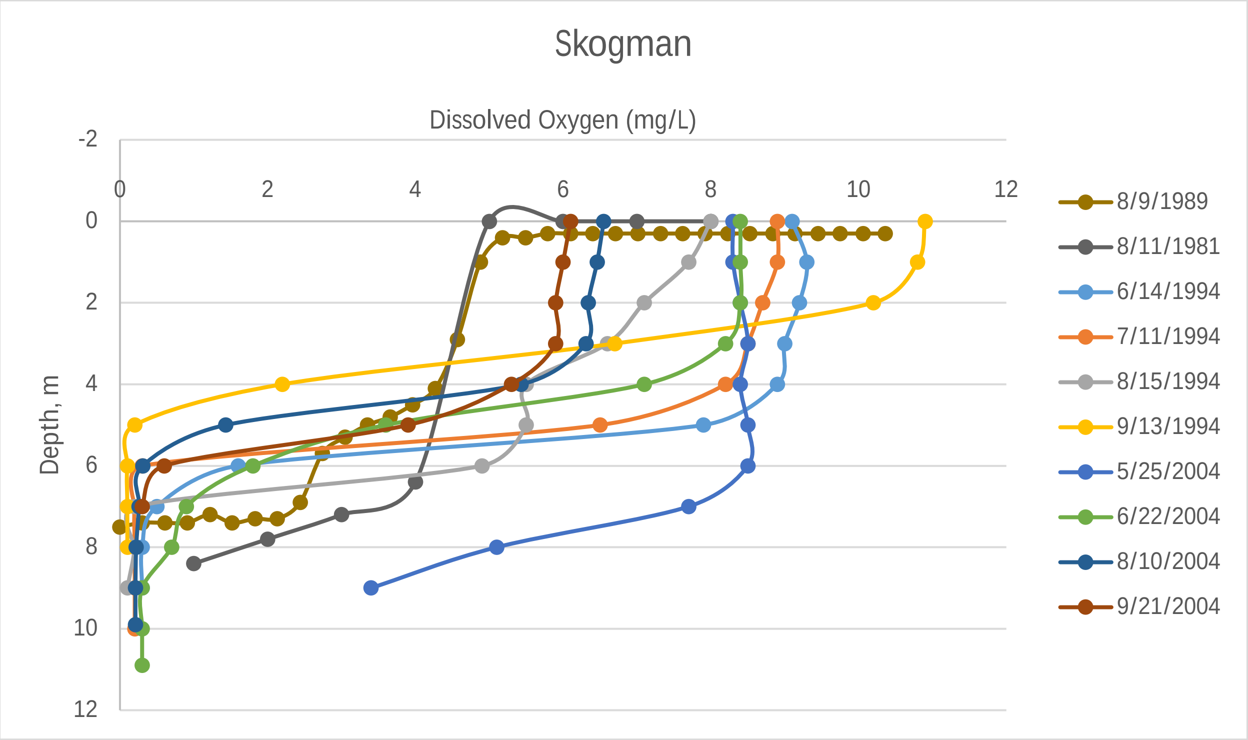


Figure C-10. Dissolved Oxygen Profiles for Skogman Lake.

Appendix D: Fannie Lake (30-0043-00)

Land Cover

Land cover defined by the University of Minnesota [2016] is summarized for the Fannie Lake Watershed in Table D-1. Row crops and grassland/managed grass comprise 23.8% and 15.7% of the land cover in the Fannie drainage area, respectively, while urban lands cover about 11.4% of the watershed. Wetlands and forests comprise 16.4% and 22.6% of the land cover, respectively, with open water covering about 10%. The higher percentage of urban cover reflects the more intense lakeshore development as well as portions of the city of Cambridge on the northwestern portion of the watershed.

Table D-1. Fannie Lake Watershed Land Cover

Impairment	Open Water (%)	Wetlands (%)	Forest (%)	Grassland/ Managed Grass (%)	Hay/ Pastures (%)	Row Crops (%)	Urban (%)
Fannie	10.0	16.4	22.6	15.7	0.0	23.8	11.4

Physical Characteristics

Lake Fannie (30-0043-00) is located in Isanti County in the southeastern portion of the Rum River Hydraulic Unit Code (HUC) 8. Portions of its western watershed include the city of Cambridge, which was issued a NPDES as a MS4 Permit (MS400250). The lake has a Y-shaped configuration with primary flow paths from Skogman Lake's discharge into the northeast bay and from the city of Cambridge into the northern bay. An island structure is located at the base of the two bays, as shown in Figure D-1. The lake's discharge exits from its southwestern corner to the flowage that, in turn, enters Elms Lake and Florence Lake before discharging into the Rum River. Information about fish passage through the system was not available.

Lake Fannie is located in the NCHF ecoregion and, from a regulatory standpoint, was categorized as a deep NCHF ecoregion lake. Table D-2 lists standard limnological and watershed characteristics. Bathymetry data were obtained from the DNR lake bathymetric map, and the lake volume and mean depth were determined by electronic planimetry. The island volume was subtracted when determining total lake volume. Fannie Lake has two public accesses maintained by: (1) Isanti Township with four vehicle/trailer parking spaces and (2) DNR access with a dock and vehicle parking. Recent lake-level fluctuation data were not available. Data from the 1980s indicate a 2.2-foot range of values.

Water Quality

Fannie and Skogman Lakes' monitoring data for the TMDL period were available from 2006 for paired TP, Chl-*a* and Secchi transparency (Secchi) data (nine samples) and from 2006 to 2015 for Secchi measurements. A total of 71 Secchi measurements for Fannie Lake and 80 Secchi measurements were taken for Skogman Lake. Corresponding growing-season averages for TP, Chl-*a*, and Secchi as well as lake standards are summarized in Table D-3. P growing-season averages for both lakes narrowly exceed the P standard. However, Chl-*a* values greatly exceed the corresponding standard for both lakes, while average Secchi values do not exceed the standard thresholds. As previously noted for Skogman Lake, the longer and more extensive Secchi dataset indicate higher transparency values (improving pattern) in recent years. Long-term data plots are shown in Figures D-2 through D-4. The number of samples annually are shown in Table D-4.

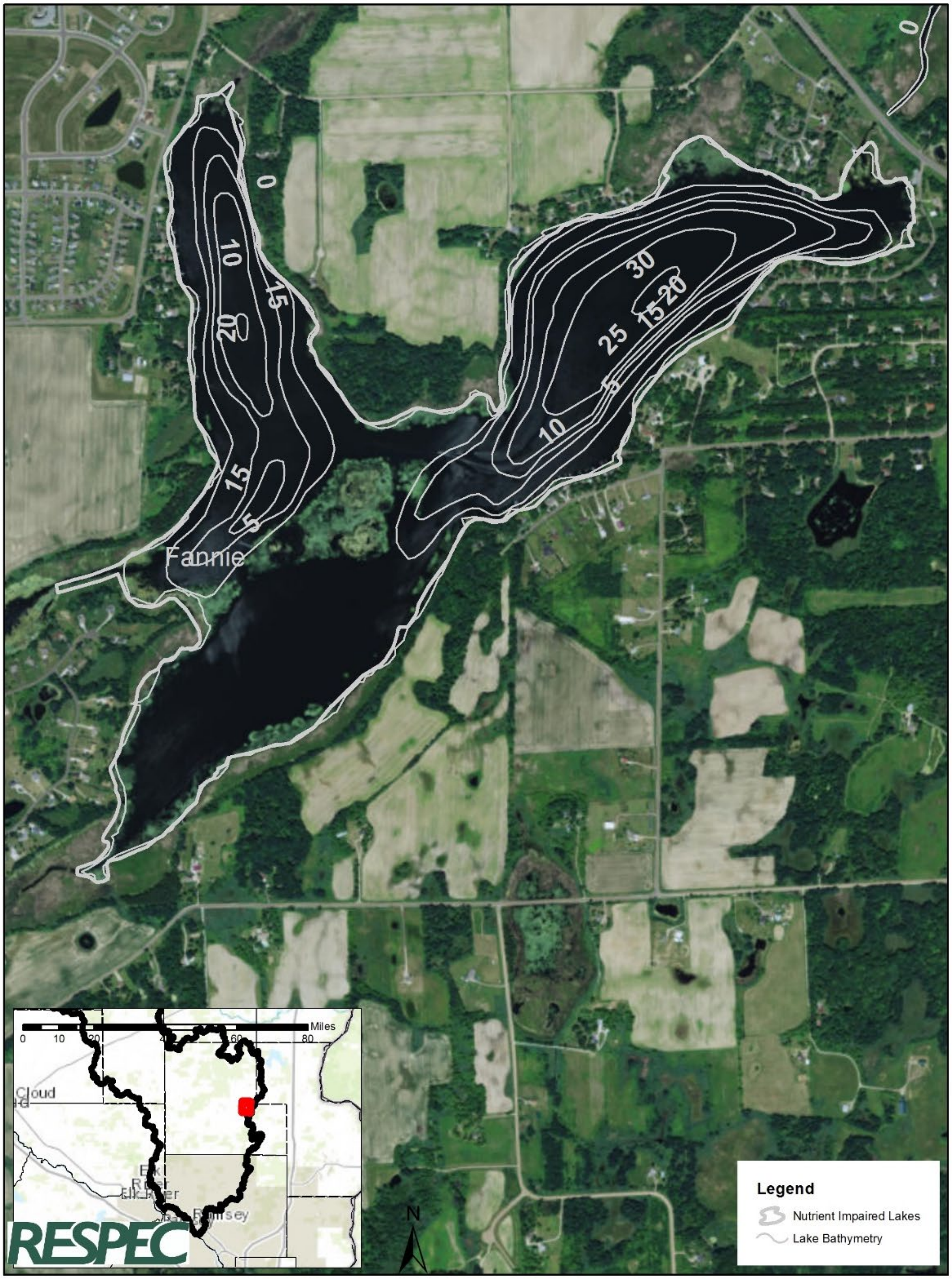


Figure D-1. Fannie Lake Bathymetry and Aerial Imagery.

Table D-2. Fannie and Skogman Lakes Select Lake Morphometric and Watershed Characteristics

Characteristic	Skogman	Fannie	Source
Lake-Surface Area (acres)	223	354	DNR LakeFinder
Number of Islands	0	1	
Percent Lake Littoral Surface Area	61	87	DNR LakeFinder
Drainage Area, Including Lake acres (ac)/square kilometers (km^2)	3,384 ac/13.7 km^2	7,340 ac/29.7 km^2	Model Subwatersheds
Watershed Area to Lake Area Ratio	15.2:1	20.7:1	Calculated
Wetland Area (% of watershed)	15.6	16.4	University of Minnesota, 2016
Number of Upland Lakes	3+	4+	US Geological Survey topographic maps
Number of Perennial Inlet Streams	1	3	US Geological Survey topographic maps
Lake Volume (acre-feet (ac-ft)/cubic hectometers (hm^3))	2,839 ac-ft/3.5 hm^3	2,701.6 ac-ft/3.3 hm^3	DNR LakeFinder
Mean Depth (ft/m)	12.7 ft/3.9 m	7.6/2.3	DNR LakeFinder
Annual Lake-Level Fluctuations (ft):typical, maximum	1–2 feet	NA (Old data, 2.2 feet noted)	DNR Lake Levels
Maximum Depth (ft/m)	36 ft/11 m	33/10	DNR LakeFinder
Maximum Fetch Length (miles (mi)/kilometers (km))	1.8/2.9	1.7/2.7	Measured in Google Earth
Lake Geometry Ratio	2.8	3.3	Calculated
Osgood Index	4.2	2.2	Calculated
Estimated Water Residence Time (years/days)	1.5 years	0.6 year	Calculated
Public Access	1	2	DNR, Isanti Township
Shore Land Properties	72	81	Isanti County

Multiyear growing-season mean monthly water quality observations are depicted in Figures D-5 through D-7 for TP, Chl-*a*, and Secchi, respectively. Plots of mean monthly data from 2006 show increasing TP concentrations from June through September with slight declines noted in Chl-*a* averages for September. The increase in growing-season monthly P concentrations from about 33 micrograms per liter (µg/L) to 55 µg/L from June through September corresponds to a mean increase of 73 kilograms (kg) of TP in Fannie Lake in 2006; this is P from all external (watershed loading and septic systems) and internal sources. Mean monthly Chl-*a* concentrations increase from June through August from approximately 7 µg/L to 34 µg/L with a decline to approximately 28 µg/L in September. Correspondingly, average monthly Secchi declines from approximately 2.25 meters (m) in June to 1.25 m in September. Without additional lake P sediment data and with the general improving Secchi pattern, no internal loading component was calculated in the BATHTUB lake P balances.

Table D-3. Total Maximum Daily Load Period Phosphorus, Chlorophyll-a, and Secchi Transparency Growing-Season Means for Fannie Lake

Parameter	Minimum	Mean	Maximum	Standard Deviation	Sample Number	Lake Standards
Skogman						
TP (µg/L)	33.0	42.9	53.0	6.5	9	≤ 40
Chlorophyll-*a* (µg/L)	5.0	21.3	35.0	10.2	9	≤ 14
Secchi disk depth (m)	0.9	1.4	4.3	0.5	71	≥ 1.4
Fannie						
TP (µg/L)	29	44.1	59	9.6	9	≤ 40
Chlorophyll-*a* (µg/L)	5.0	25.6	36.0	12.0	9	≤ 14
Secchi disk depth (m)	0.6	1.7	4.1	0.7	80	≥ 1.4

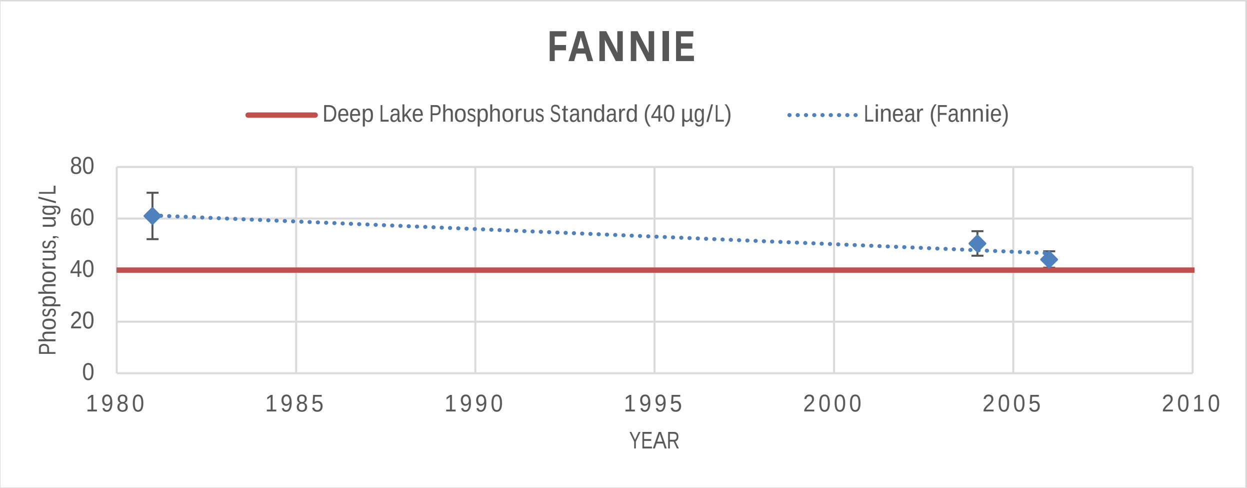


Figure D-2. Annual Growing-Season Mean of Total Phosphorus Concentrations for Fannie Lake.

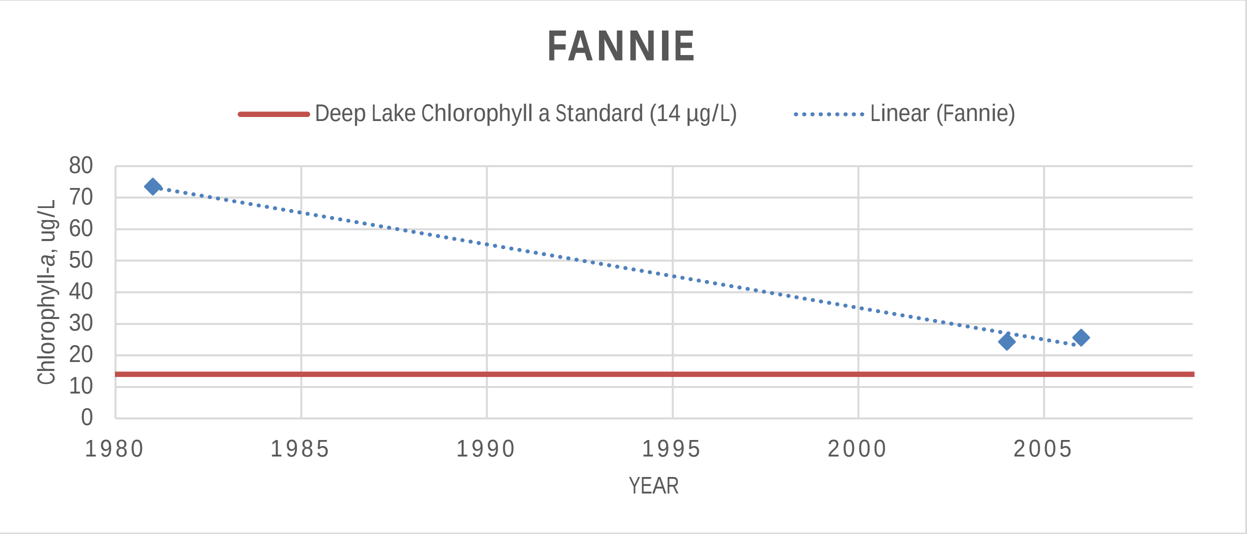


Figure D-3. Annual Growing-Season Mean of Chlorophyll-*a* Concentrations for Fannie Lake.

Figure D-4. Annual Growing-Season Mean of Secchi Transparency for Fannie Lake.

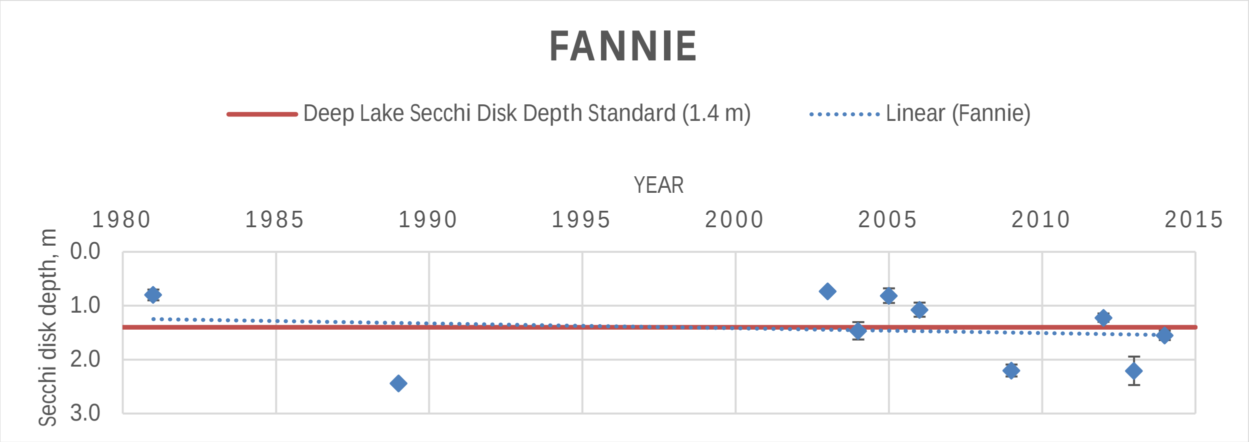


Table D-4. Total Phosphorus, Chlorophyll-*a*, and Secchi Transparency Number of Samples Annually for Fannie Lake

Lake	Constituent	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
Fannie	TP	9										9
	Chl-*a*	9										9
	Secchi	15			11			14	13	14	13	80

Dissolved Oxygen and Temperature Data Summary

The DO and temperature data monitored by depth were examined to better define lake-mixing patterns that affect biological responses and lake P dynamics. Available data from 2008 and 2009 are plotted in Figures D-8 and D-9 for temperature and DO, respectively.

Water-temperature variation by depth from historical data is shown in Figure D-8 with data indicating thermal stratification as temperatures decline with depth. The summer thermocline in this dimictic lake was noted about 6 to 7 m in depth. Peak monitored summer bottom water temperatures (July through September) ranged from approximately 12° to 17°C and were much cooler than noted for the shallow lakes of this study. Growing-season DO concentrations shown in Figure D-9 were noted to steeply decline with depth to values less than 5.0 mg/L and approaching zero in the bottom levels.

Aquatic Plant Survey

A Minnesota biological survey of aquatic plant species was conducted on the eastern and western lakeshore areas of Skogman Lake on June 26, 2013, that detailed submersed, free-floating, floating-leaf, emergent, and shoreline plants. Nineteen species of aquatic plants were noted, including the invasive submerged species curly-leaf pondweed (*Potamogeton crispus*). Twenty-one species of shoreline plants associated with wetland habitats were noted, including the invasive species purple loosestrife (*Lythrum salicaria*).

Fisheries

Based on physical, chemical and biological similarities, the DNR has developed lake classes. Fannie Lake is a DNR Lake Class 35 and is managed for walleye, northern pike, and panfish. Survey data from June 24, 2013, indicate high catch rates with normal growth for northern pike. Yellow perch were noted to be above 25th percentile levels. Walleye catch rates were noted to have fallen below normal class ranges and the DNR management plan. Black, yellow, and brown bullhead catch rates were on the low end of the normal range. Common carp were not noted on the survey.

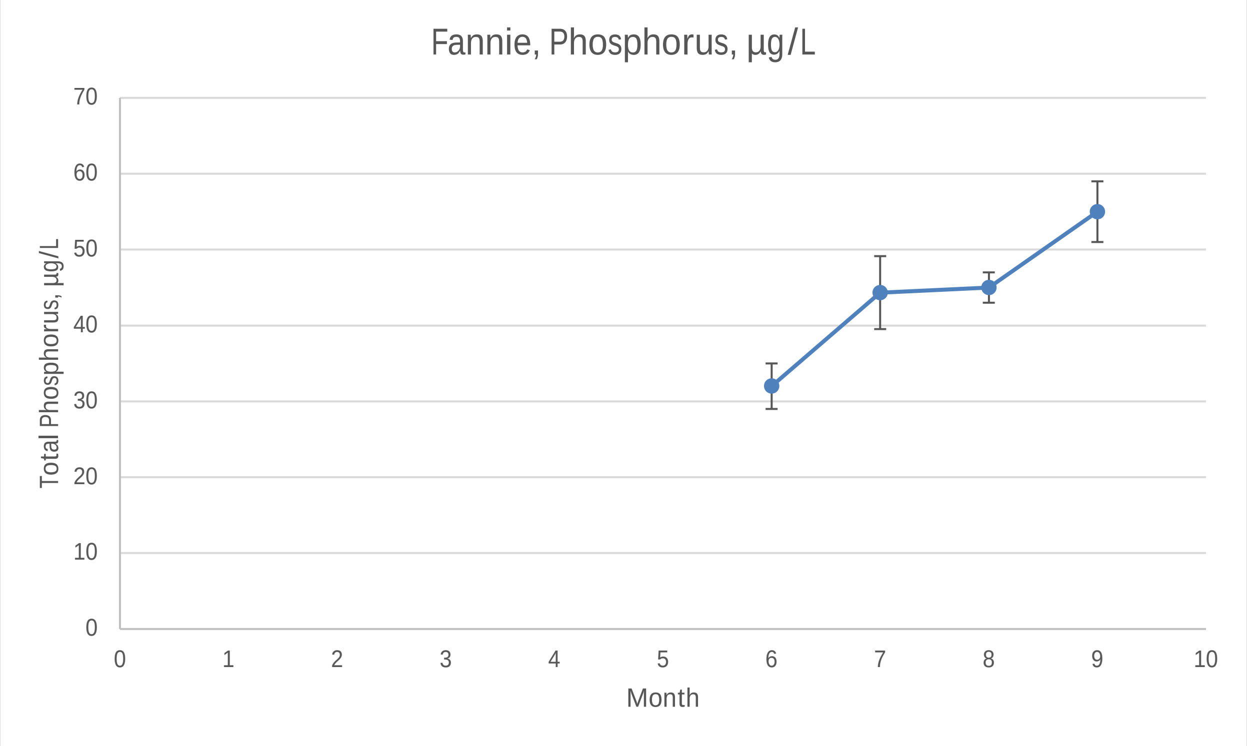


Figure D-5. Growing-Season Monthly Mean of Total Phosphorus for Fannie Lake (All Available Data Between 2006–2015).

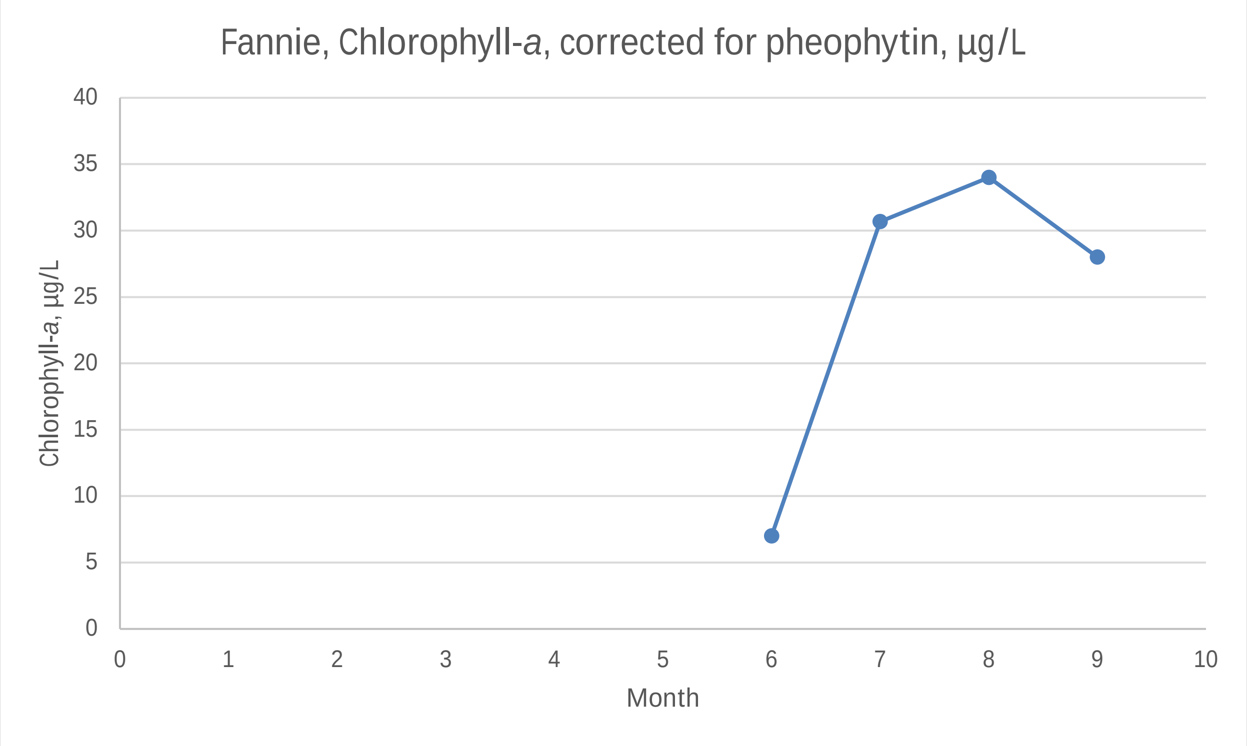


Figure D-6. Growing-Season Monthly Mean of Chlorophyll-*a* for Fannie Lake (All Available Data Between 2006–2015).

Figure D-7. Growing-Season Monthly Mean of Secchi Transparency for Fannie Lake (All Available Data Between 2006–2015).

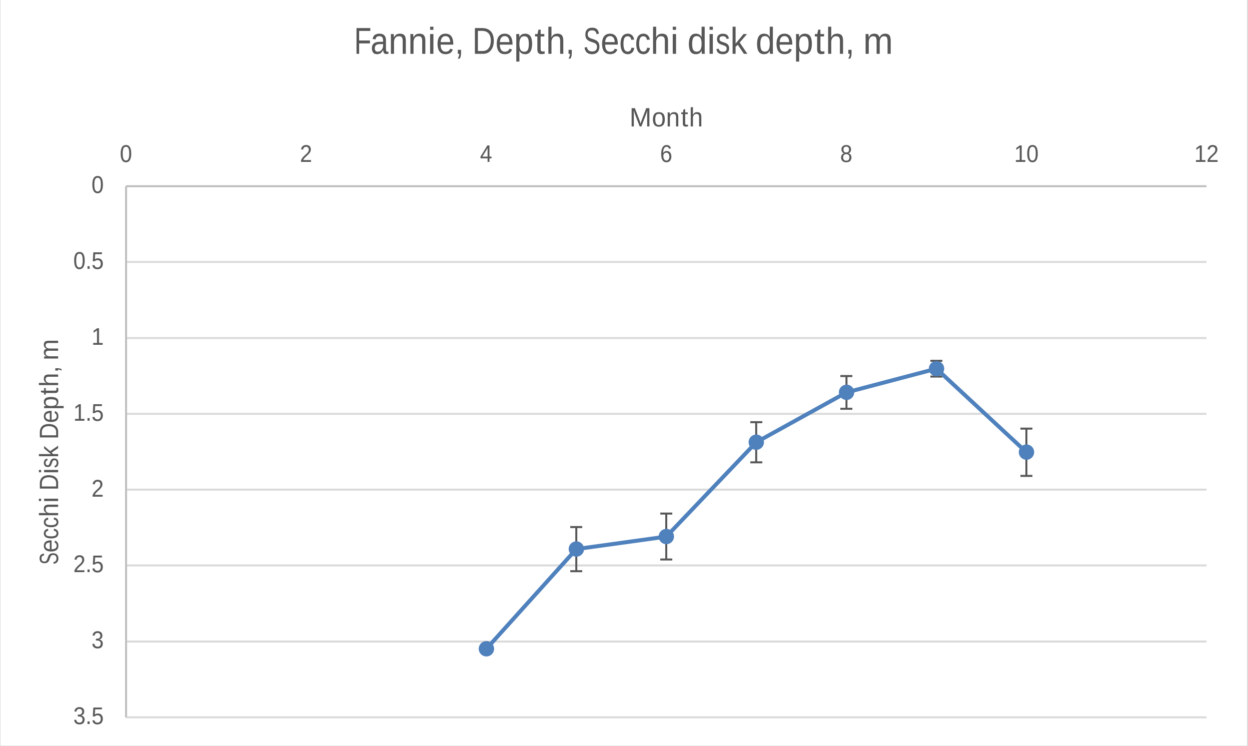


Figure D-8. Lake Temperature Profiles for Fannie Lake.

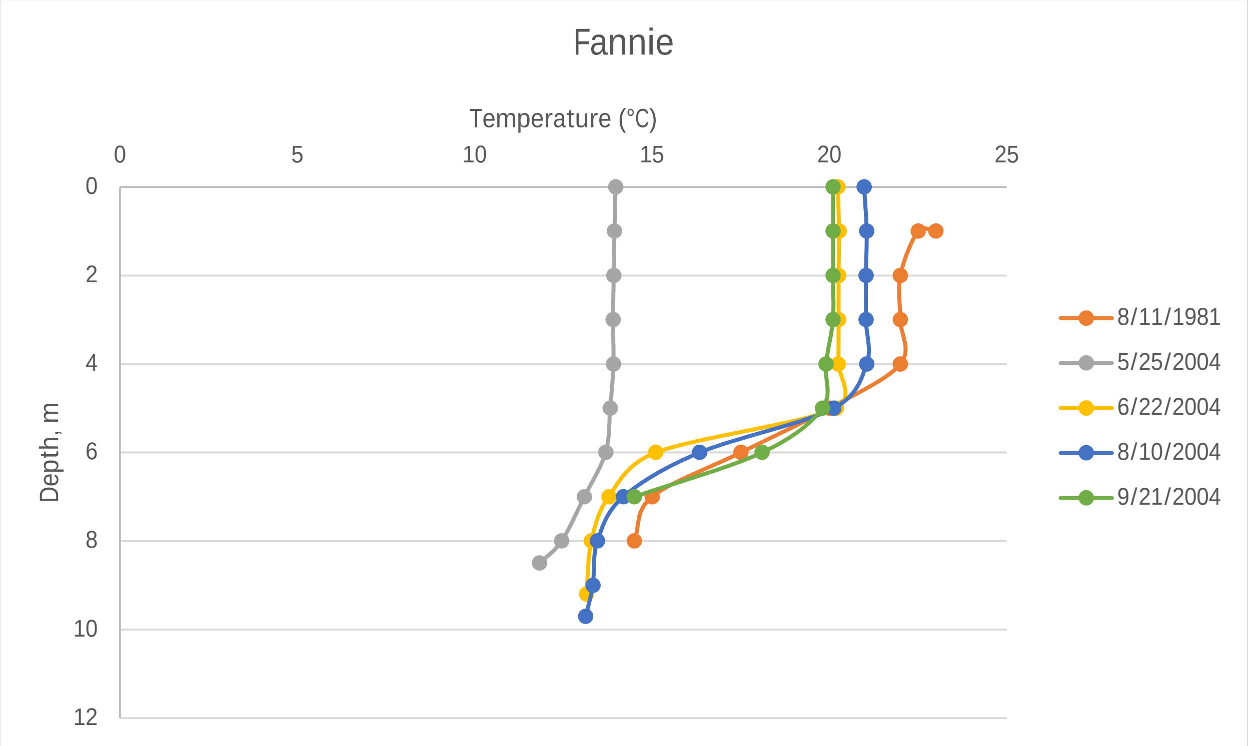
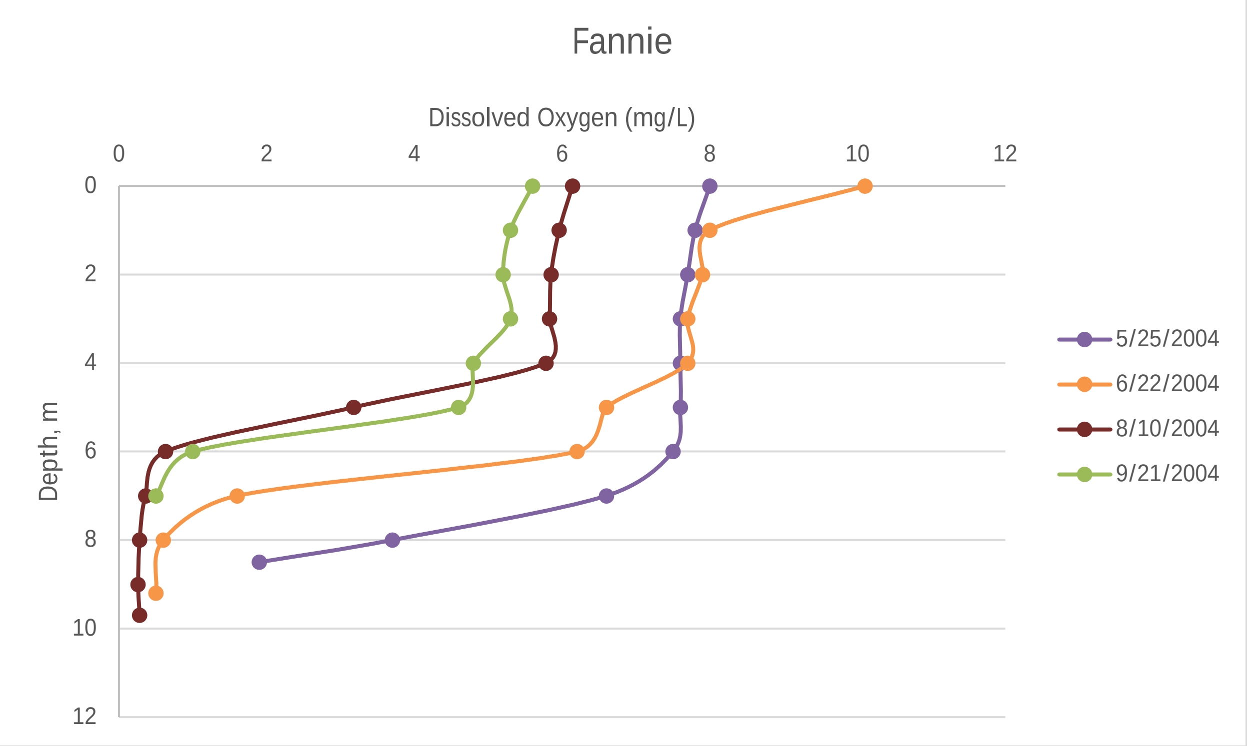


Figure D-9. Dissolved Oxygen Profiles for Fannie Lake.



References

University of Minnesota, 2016. "Metadata, Minnesota Land Cover Classification and Impervious Surface Area by Landsat and LiDAR: 2013 Update - Version 1," *umn.edu*, retrieved June 1, 2016, from *http://portal.gis.umn.edu/map_data_metadata/LandCover_MN2013.html*

Appendix E: Francis Lake (30-0080-00)

Land Cover

Land cover defined by the University of Minnesota [2016] is summarized for the Francis Lake Watershed in Table E-1. Row crops and grassland/managed grass comprise 24.6% and 11.8% of the watershed, respectively, while urban lands cover about 7.8% of the watershed. Wetlands and forests comprise 23.4% and 25.8% of the watershed, respectively, with open water covering about 6.5%.

Table E-1. Francis Lake Watershed Land Cover

Impairment	Open Water (%)	Wetlands (%)	Forest (%)	Grassland/ Managed Grass (%)	Hay/ Pastures (%)	Row Crops (%)	Urban (%)
Francis	6.5	23.4	25.8	11.8	0.0	24.6	7.8

Physical Characteristics

Lake Francis (30-0080-00) is located in Isanti County in the south-central portion of the Rum River Hydraulic Unit Code (HUC) 8 about 4.3 miles west of the city of Isanti, Minnesota. Lake Francis is a shallow lake located in the NCHF ecoregion. Select lake morphometric and watershed characteristics are listed in Table E-2. Figure E-1 depicts the lake's bathymetry and an aerial imagery, and Figure E-2 shows lake-level fluxuations.

Water Quality

Francis Lake monitoring data for the TMDL period included Chl-*a* data from 2013 (four samples) and 102 Secchi depth measurements. TP data were not available for the TMDL time period. As a result, TP and Secchi data from 1995 to 2000 sampling efforts were regressed to develop a mean TP value of 235 micrograms per liter (ug/L) for the TMDL time period. Growing-season averages for TP (derived), Chl-*a*, and Secchi greatly exceed (violate) state standards, as summarized in Table E-3. While historical lake average values indicate extremely elevated TP and Chl-*a* values, the longer and more extensive Secchi dataset indicate slightly improved (increased) transparency values in recent years to values similar to those previously noted in the 1980s. However, the average Secchi remains below (worse) than the standard of 1.0 meter (m) or 3.3 feet (ft). Nonetheless, this increasing pattern suggests that lake conditions may be subtly improving. Long-term data are shown in Figures E-3 through E-5.

Available data were converted into growing-season mean monthly water quality observations as depicted in Figures E-6 and E-7. P monthly means were not plotted because of data lacking during the TMDL time period. Chl-*a* monthly mean values increase sequentially during the summer months to a peak of over 180 µg/L. Correspondingly, average monthly Secchi transparencies vary from approximately 0.6 m in June to 0.3 m in July and increase to about 0.7 m in September.

Francis Lake TP monthly growing-season means were not plotted because of the lack of data. The number of samples annually are shown in Table E-4.

Table E-2. Francis Lake Select Lake Morphometric and Watershed Characteristics

Characteristic	Lake Francis	Source
Lake-Surface Area (acres)	264	DNR LakeFinder
Number of Islands	0	
Percent Lake Littoral Surface Area	100	DNR LakeFinder
Drainage Area, Including Lake acres (ac)/square kilometers (km^2)	5,400 ac/21.9 km^2	Model Subwatersheds
Watershed Area to Lake Area Ratio	20.5:1	Calculated
Wetland Area (% of watershed)	23.4	University of Minnesota [2016]
Number of Upland Lakes	0	US Geological Survey topographic maps
Number of Perennial Inlet Streams	1	US Geological Survey topographic maps
Lake Volume (acre-feet (ac-ft)/cubic hectometers (hm^3))	1,320 ac-ft/1.6 hm^3	DNR LakeFinder
Mean Depth (ft/(m)	5 ft/1.5 m	DNR LakeFinder
Annual Lake-Level Fluctuations (ft):typical, maximum	0.4 feet	DNR Lake Levels
Maximum Depth (ft/m)	7 feet	DNR LakeFinder
Maximum Fetch Length (miles (mi)/kilometers (km))	0.9 mi/1.46 km	Measured in Google Earth
Lake Geometry Ratio	15.1	Calculated
Osgood Index	1.5	Calculated
Estimated Water Residence Time (years/days)	0.4 year	Calculated
Public Access	1	Bradford Township
Shore Land Properties	45	US Geological Survey topographic maps

Dissolved Oxygen and Temperature Data Summary

The DO and temperature data monitored by depth were examined to better define lake-mixing patterns that affect biological responses and lake P dynamics. Available data from 1996 to 2000 are plotted in Figures E-8 and E-9, respectively, for temperature and DO.

Water-temperature variation by depth profiles are shown in Figure E-8 with data indicating well-mixed conditions with similar temperatures from the surface to depth. Peak monitored summer bottom water temperatures (July through September) ranged from approximately 20° to 25°C.

DO concentrations typically declined with depth and frequently declined to less than 5.0 milligrams per liter (mg/L) during the summer and winter periods, as shown in Figure E-9. As a result, partial winter fish kills have been noted by DNR Fisheries managers.

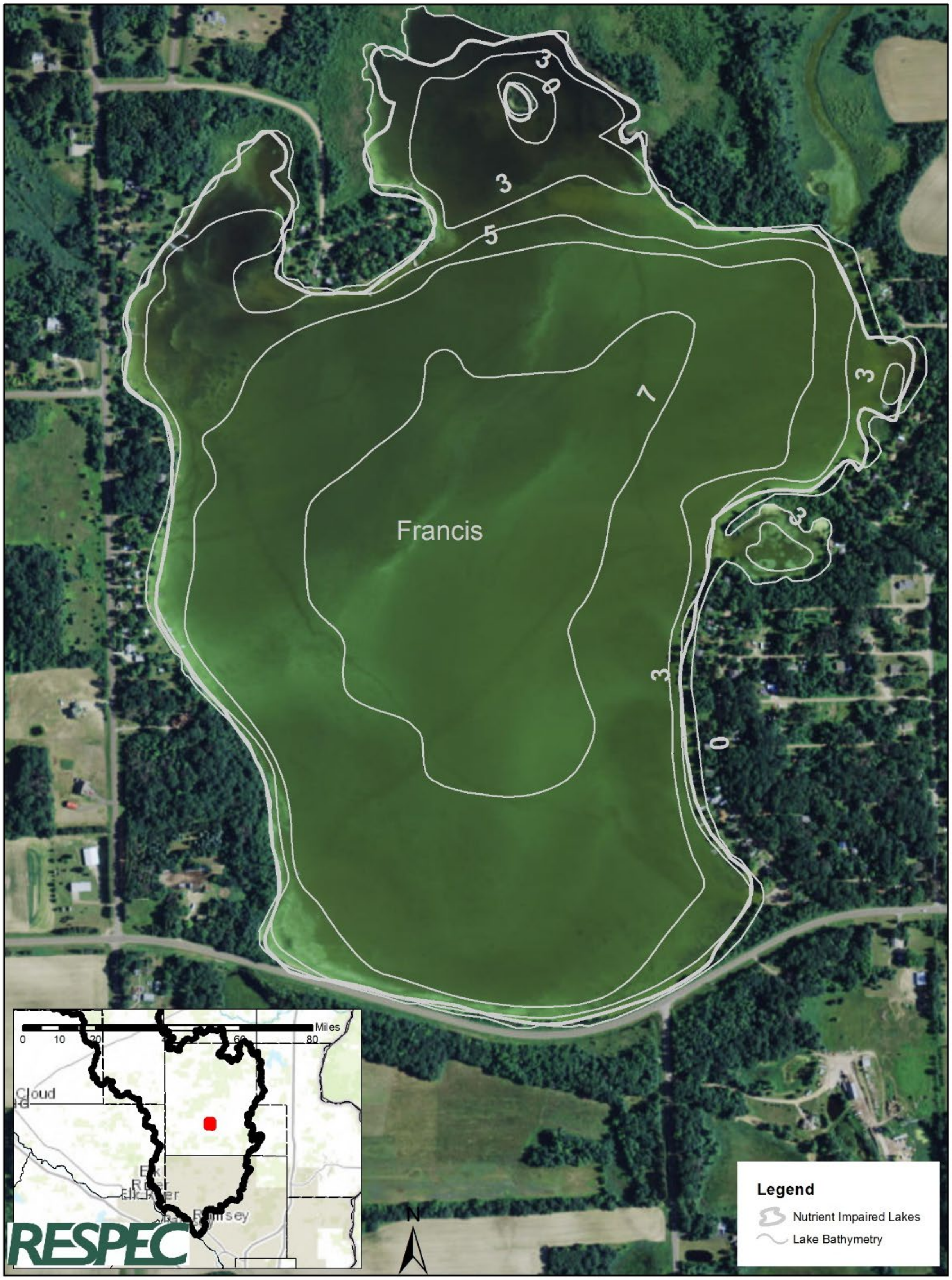


Figure E-1. Francis Lake Aerial Imagery and Lake Bathymetry

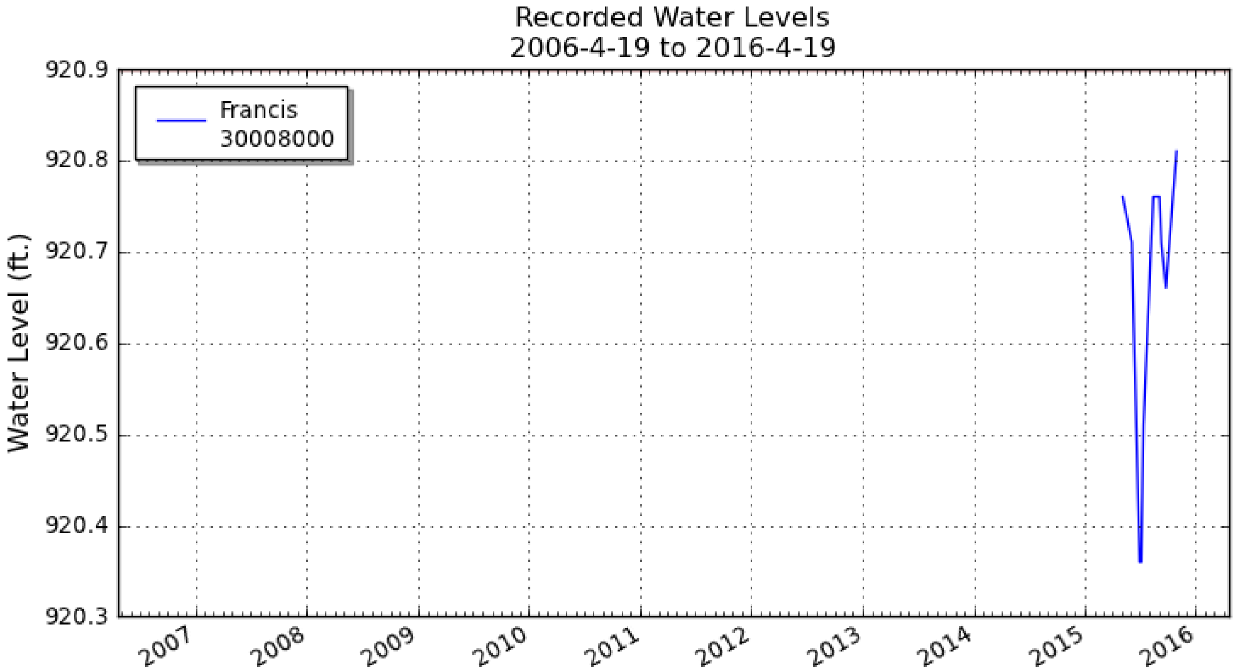


Figure E-2. Francis Lake Lake-Level Measures (DNR Lake-Level Program Plot).

Table E-3. Total Maximum Daily Load Period Total Phosphorus, Chlorophyll-*a*, and Secchi Transparency Growing-Season Means for Francis Lake

Parameter	Minimum	Mean	Maximum	Standard Deviation	Sample Number	Lake Standards
TP (µg/L)		235 Derived			0	≤ 60
Chlorophyll-*a* (µg/L)	14.5	108.3	181.0	69.3	4	≤ 20
Secchi disk depth (m)	0.15	0.5	1.2	0.3	102	≥ 1.0

Aquatic Plants

A Minnesota biological survey of aquatic plant species was conducted on the northwestern shore of Francis Lake on June 25, 2013, that detailed submersed, free-floating, floating-leaf, emergent and shoreline plants. In total, the aquatic plant community appears to be quite limited, with 8 aquatic species identified and 13 species of shoreline plants. The exotic invasive species, curly-leaf pondweed (*Potamogetagon Crispus*) was noted in this survey.

Fisheries

Francis Lake has been noted to have partial fish kills because of low winter oxygen concentrations. The lake has an excellent black crappie, bluegill, and northern pike fishery that is partly attributed to repopulation via migration from the Rum River. Common carp, white sucker, and black bullhead populations were noted. The DNR reports that summer angling pressure is low, while winter angling pressure has been high in recent years.

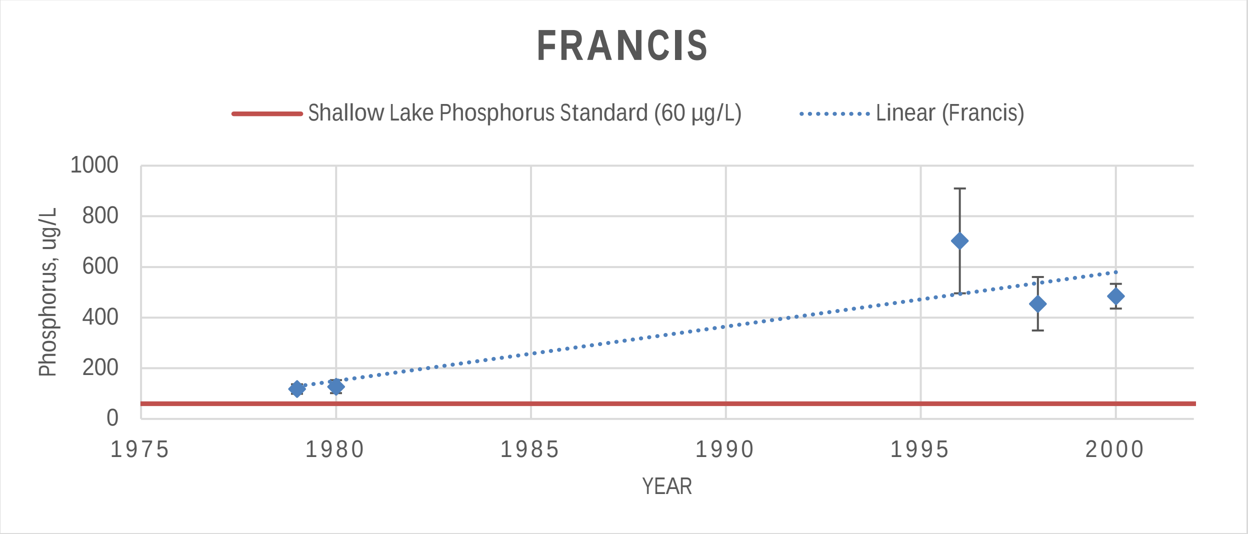


Figure E-3. Annual Growing-Season Mean of Total Phosphorus Concentrations for Francis Lake.

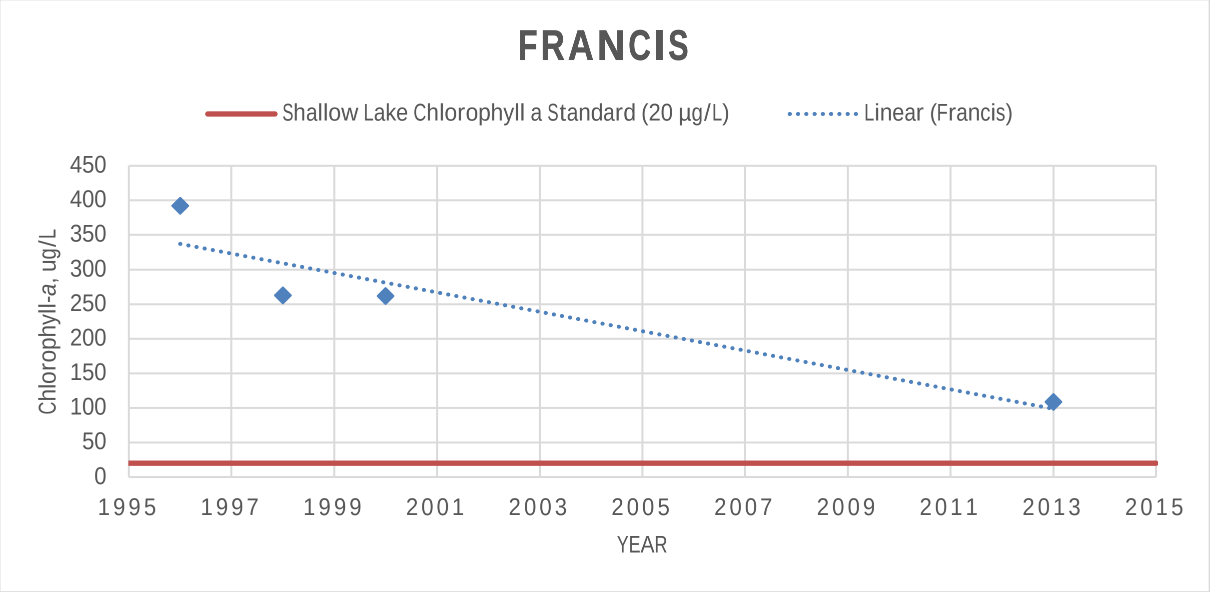


Figure E-4. Annual Growing-Season Mean of Chlorophyll-a Concentrations for Francis Lake.

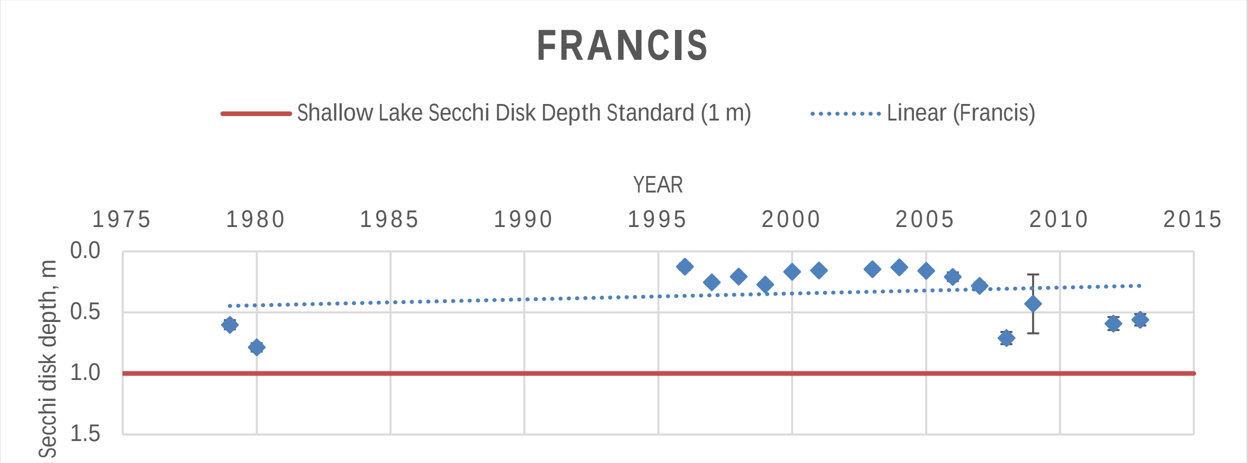


Figure E-5. Annual Growing-Season Mean of Long-Term Secchi Transparency for Francis Lake (Annual Growing-Season Means).

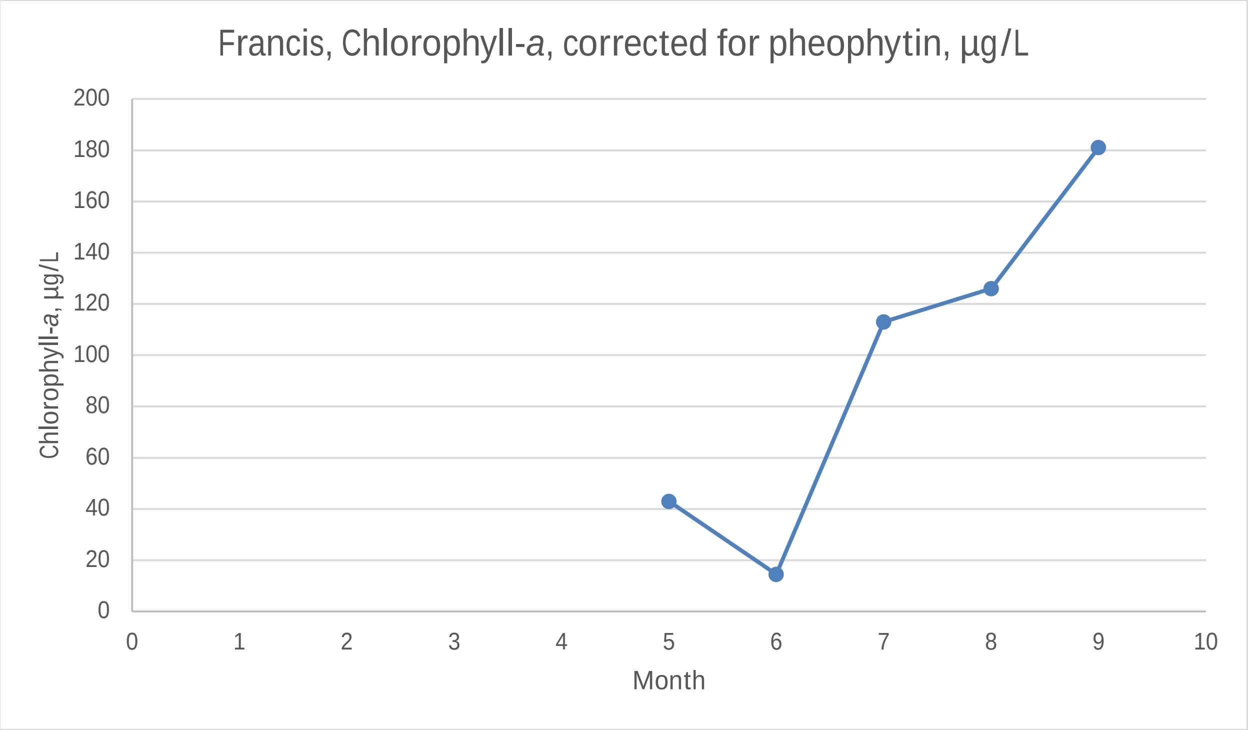


Figure E-6. Growing Monthly-Season Mean of Chlorophyll-a for Francis Lake (All Available Data Between 2006–2015).

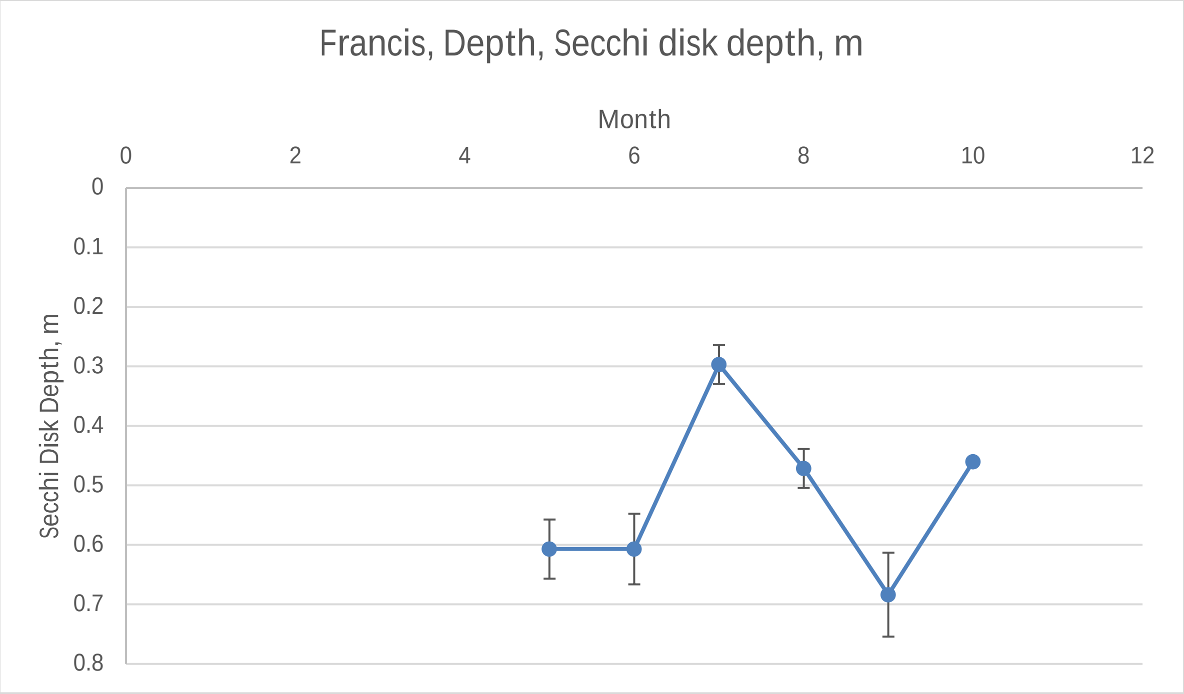


Figure E-7. Growing Monthly-Season Mean of Secchi Transparency for Francis Lake (All Available Data Between 2006–2015).

Table E-4. Total Phosphorus, Chlorophyll-a, and Secchi Transparency Number of Samples Annually for Francis Lake

Lake	Constituent	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
Francis	TP											0
	Chl-*a*								4			4
	Secchi	9	12	9				34	38			102

Figure E-8. Lake Temperature Profiles for Francis Lake.

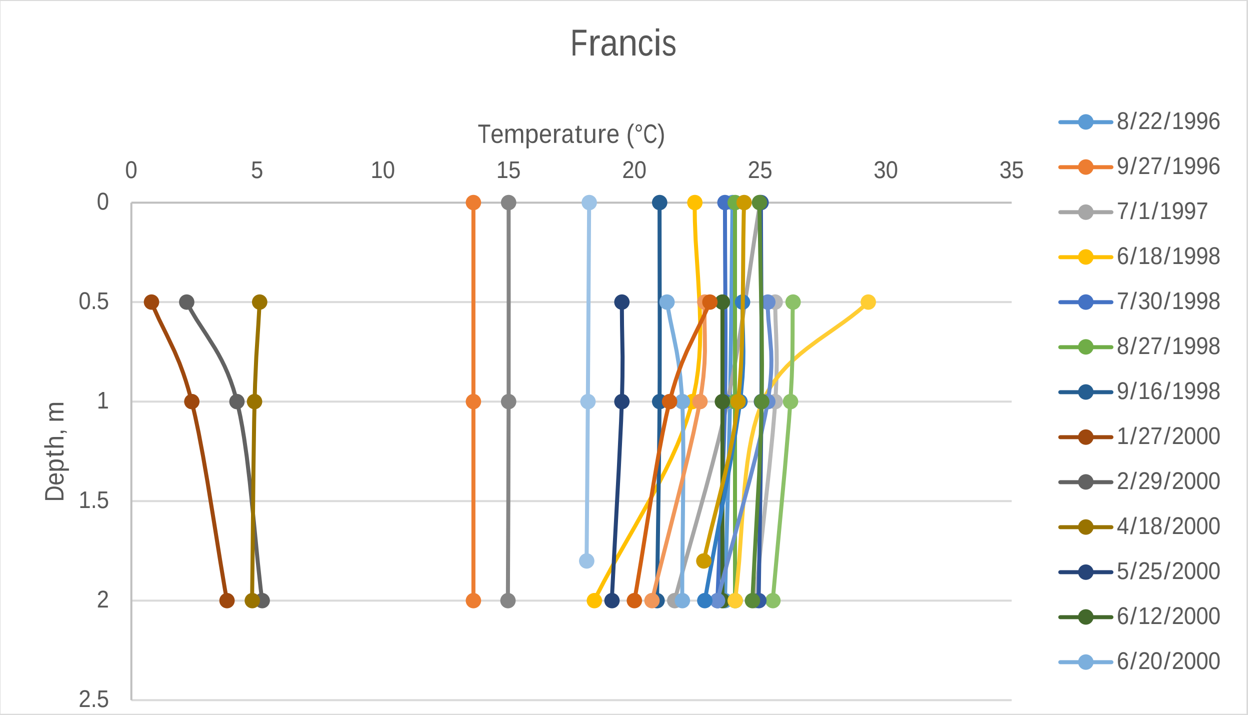
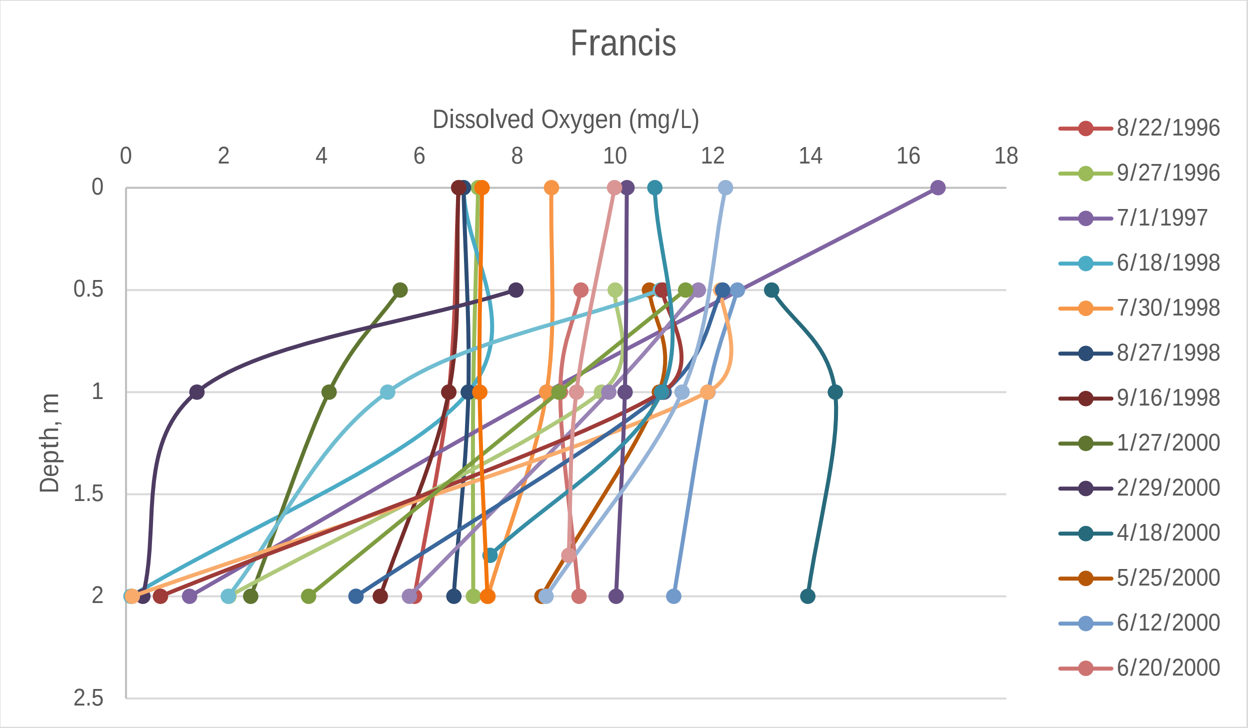


Figure E-9. Dissolved Oxygen Profiles for Francis Lake.



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University of Minnesota, 2016. “Metadata, Minnesota Land Cover Classification and Impervious Surface Area by Landsat and LiDAR: 2013 Update - Version 1,” *umn.edu*, retrieved June 1, 2016, from *http://portal.gis.umn.edu/map_data_metadata/LandCover_MN2013.html*

Appendix F: Green Lake (30-0136-00)

Land Cover

Land cover as defined by the University of Minnesota [2016] for the Green Lake Watershed is summarized in Table F-1. Row crops and grassland/managed grass comprise 27.4% and 14.4% of the watershed, respectively, while urban lands cover about 6.8% of the watershed. Wetlands and forests comprise 21.7% and 23.3% of the watershed, respectively, with open water covering approximately 6.1%.

Table F-1. Green Lake Watershed Land Cover

Impairment	Open Water (%)	Wetlands (%)	Forest (%)	Grassland/ Managed Grass (%)	Hay/ Pastures (%)	Row Crops (%)	Urban (%)
Green	6.1	21.7	23.3	14.4	0.3	27.4	6.8

Physical Characteristics

Green Lake (30-0136-00) is located in Wyanett Township of west-central Isanti County, approximately 6.8 miles east of Princeton in the south-central portion of the Rum River Hydraulic Unit Code (HUC) 8. Select lake and watershed characteristics are listed in Table F-2. Green Lake covers approximately 833 acres and, with a mean depth of about 16 feet, is classified as a deep lake. The lake is configured with a general elliptical shape from the northwest to southeast, which provides a long wind fetch, and is located in the NCHF ecoregion. The lake's watershed is large and covers an area of about 15,887 acres, which provide a watershed to lake-surface area ratio of about 19:1. Green Lake has one public access maintained by the DNR. Lake-level fluctuations can be large and range from about one foot to four feet. As assessed by the Lake GR of 5.0, Green Lake is a medium-depth lake. However, with an Osgood Index Value of 2.7, Green Lake suggests periodic mixing potential because of its surface area, fetch, and depth structure. Green Lake bathymetry is shown in Figure F-1, and water level data are shown in Figure F-2.

Water Quality

Green Lake's monitoring data for the TMDL period included paired TP, Chl-*a*, Secchi transparency (Secchi) data (17 samples) and Secchi measurements (96 measurements). Corresponding growing-season averages for TP, Chl-*a*, and Secchi transparency with corresponding lake standards are summarized in Table F-3, which illustrates that lake averages exceed the P and Chl-*a* standards. Average Secchi values do not exceed the standard threshold. Lake P and Chl-*a* averages remain stubbornly above standards in recent years, which suggests persistent watershed sources. In a somewhat contradictory fashion, Secchi transparency has tended to show an opposite effect (somewhat increasing) and may reflect aquatic vegetation shifts. Annual average growing-season data are shown in Figures F-3 through F-5. The number of samples annually are shown in Table F-4.

Available data were converted into growing-season mean monthly water quality observations, as depicted in Figures F-6 through F-8. P monthly means showed a progressive increase over the growing season from about 35 micrograms per liter (µg/L) to about 75 µg/L. The corresponding Chl-*a* monthly mean values increase sequentially during the summer months to a peak of about 43 µg/L. Correspondingly, June to September average monthly Secchi transparencies vary from approximately 1.75 meters (m) to about 1.5 m.

Table F-2. Green Lake Select Morphometric and Watershed Characteristics

Characteristic	Green Lake	Source
Lake-Surface Area (acres)	833	DNR LakeFinder
Number of Islands	0	
Percent Lake Littoral Surface Area	43%	DNR LakeFinder
Drainage Area, Including Lake acres (ac)/square kilometers (km^2)	15,887 ac/64.3 km^2	Model Subwatersheds
Watershed Area to Lake Area Ratio	19.1:1	Calculated
Wetland Area (% of watershed)	21.7	University of Minnesota [2016]
Number of Upland Lakes	Numerous small	US Geological Survey topographic maps
Number of Perennial Inlet Streams	2	US Geological Survey topographic maps
Lake Volume (acre-feet (ac-ft)/cubic hectometers (hm^3))	13,499 ac-ft/16.7 hm^3	DNR LakeFinder
Mean Depth (ft/m)	16.2 ft/4.9 m	DNR LakeFinder
Annual Lake-Level Fluctuations (ft):typical, maximum	1–4+ ft	DNR Lake Levels
Maximum Depth (ft/m)	28 ft/8.5 m	DNR LakeFinder
Maximum Fetch Length (miles (mi)/kilometers (km))	1.57 mi/2.53 km	Measured in Google Earth
Lake Geometry Ratio	5.0	Calculated
Osgood Index	2.7	Calculated
Estimated Water Residence Time (years/days)	1.4 years	Calculated
Public Access	1	DNR
Shore Land Properties	164	Isanti County
DNR Fisheries Class	27	DNR

Dissolved Oxygen and Temperature Data Summary

The DO and temperature data monitored by depth were examined to better define lake-mixing patterns that affect biological responses and lake P dynamics. Available data from 1988 to 1991 are plotted in Figures F-9 and F-10 for temperature and DO, respectively.

Figure F-1. Green Lake Bathymetry Aerial Imagery.

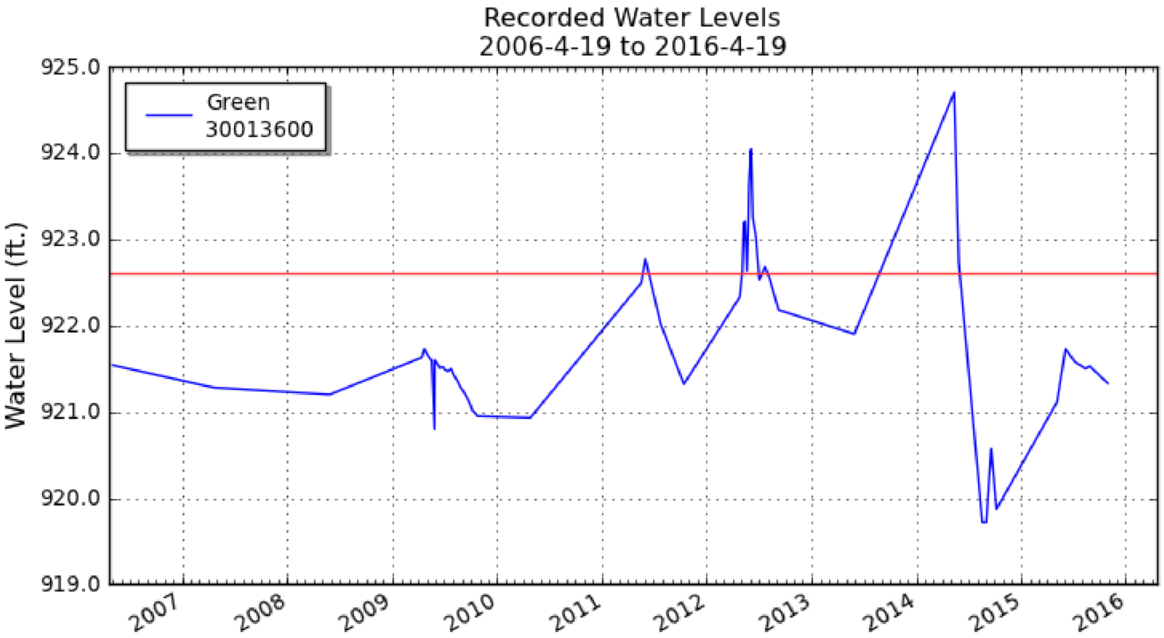
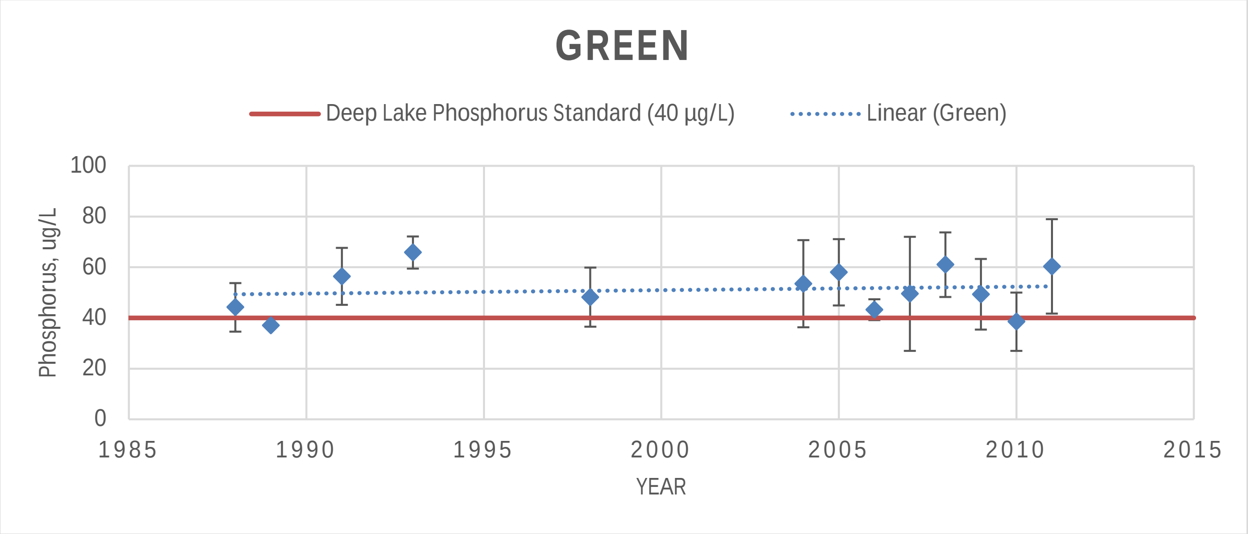


Figure F-2. Green Lake Lake-Level Fluctuations (DNR Lake-Level Program, 2016).

Table F-3. Total Maximum Daily Load Period Total Phosphorus, Chlorophyll-a, and Secchi Transparency Growing-Season Means for Green Lake

Paramenter	Minimum	Mean	Maximum	Standard Deviation	Sample Number	Lake Standards
TP (µg/L)	26.0	50.6	90.0	20.6	17	≤ 40
Chlorophyll-*a* (µg/L)	7.0	27.5	69.0	21.0	17	≤ 14
Secchi disk depth (m)	0.5	1.6	4.6	0.8	96	≥ 1.4

Figure F-3. Annual Growing-Season Mean of Total Phosphorus Concentrations for Green Lake.



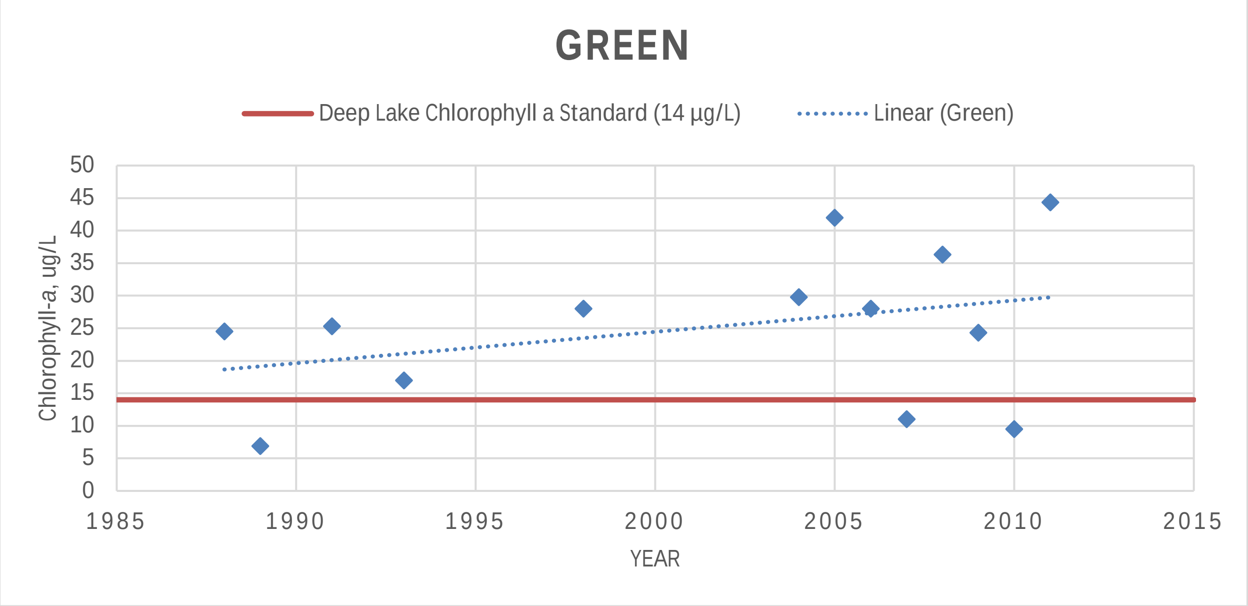


Figure F-4. Annual Growing-Season Mean of Chlorophyll-*a* Concentrations for Green Lake.

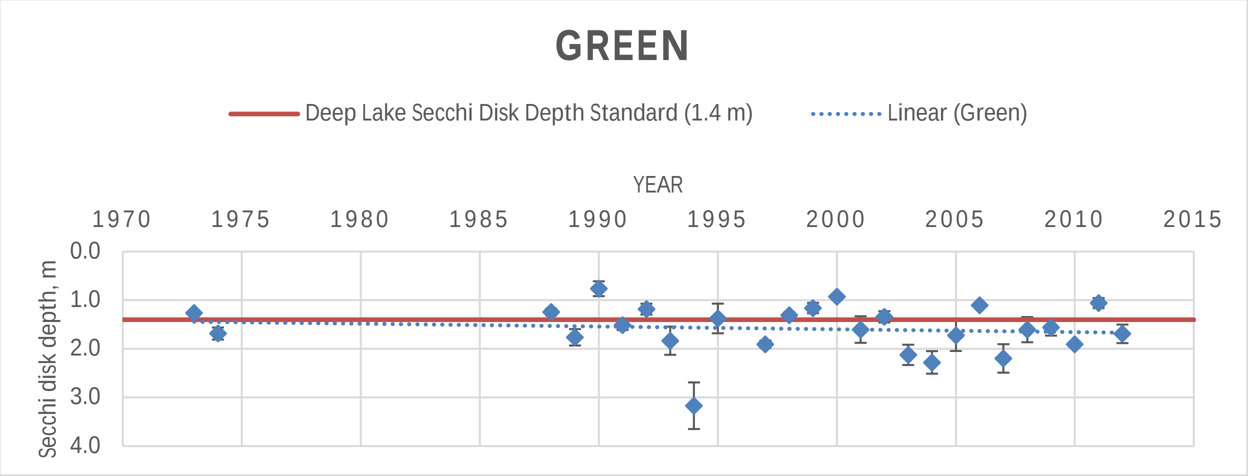


Figure F-5. Annual Growing-Season Mean of Secchi Transparency for Green Lake.

Table F-4. Total Phosphorus, Chlorophyll-*a*, and Secchi Transparency Number of Samples Annually for Green Lake

Lake	Constituent	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
Green	TP	4	2	3	3	2	3					17
	Chl-*a*	4	2	3	3	2	3					17
	Secchi	17	17	17	9	12	12	12				96

Water-temperature variation by depth profiles are shown in Figure F-9 with data indicating relatively well-mixed conditions with similar temperatures from the surface to about 5 to 6 m of depth, followed by the formation of a stable thermocline. Peak monitored summer bottom water temperatures (July through September) ranged from approximately 12° to 23°C.

The growing-season DO profile data typically exhibited similar concentrations to a depth of about 4 m and then showed a considerable depletion of oxygen concentrations below 4 to 5 meters, as shown in Figure F-10.

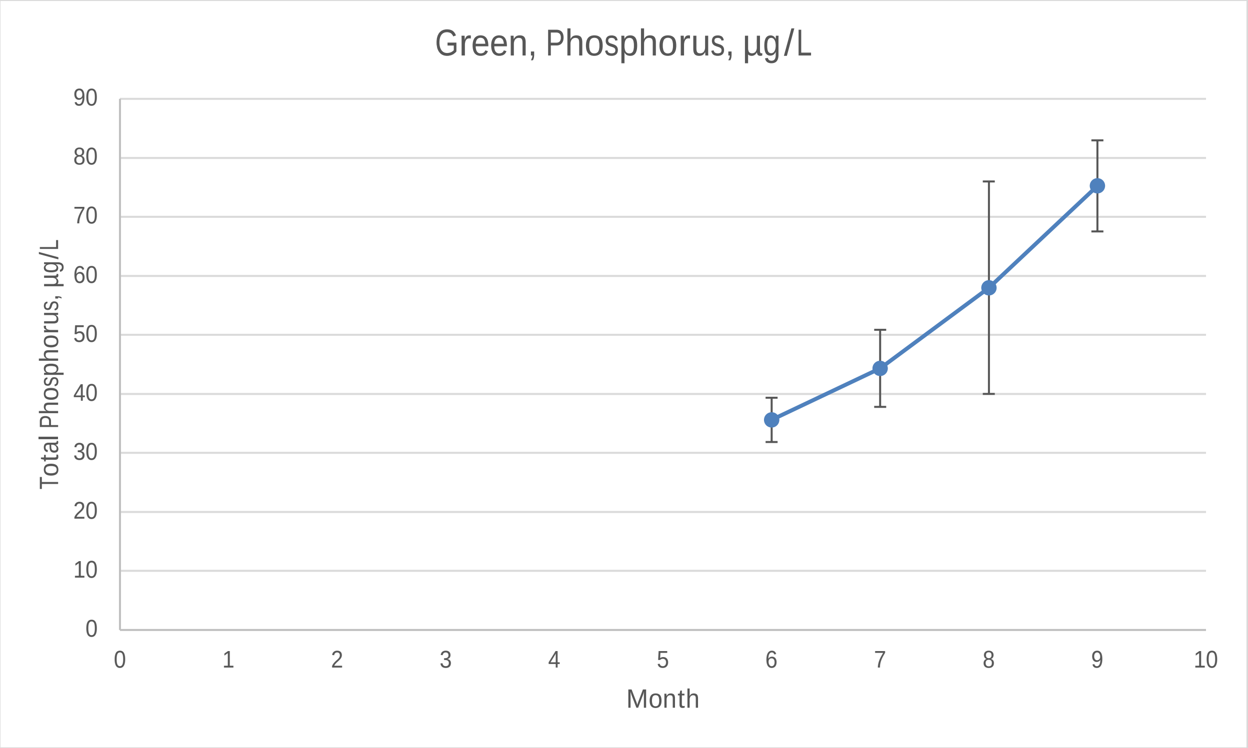


Figure F-6. Growing-Season Monthly Mean of Total Phosphorus for Green Lake (All Available Data Between 2006–2015).

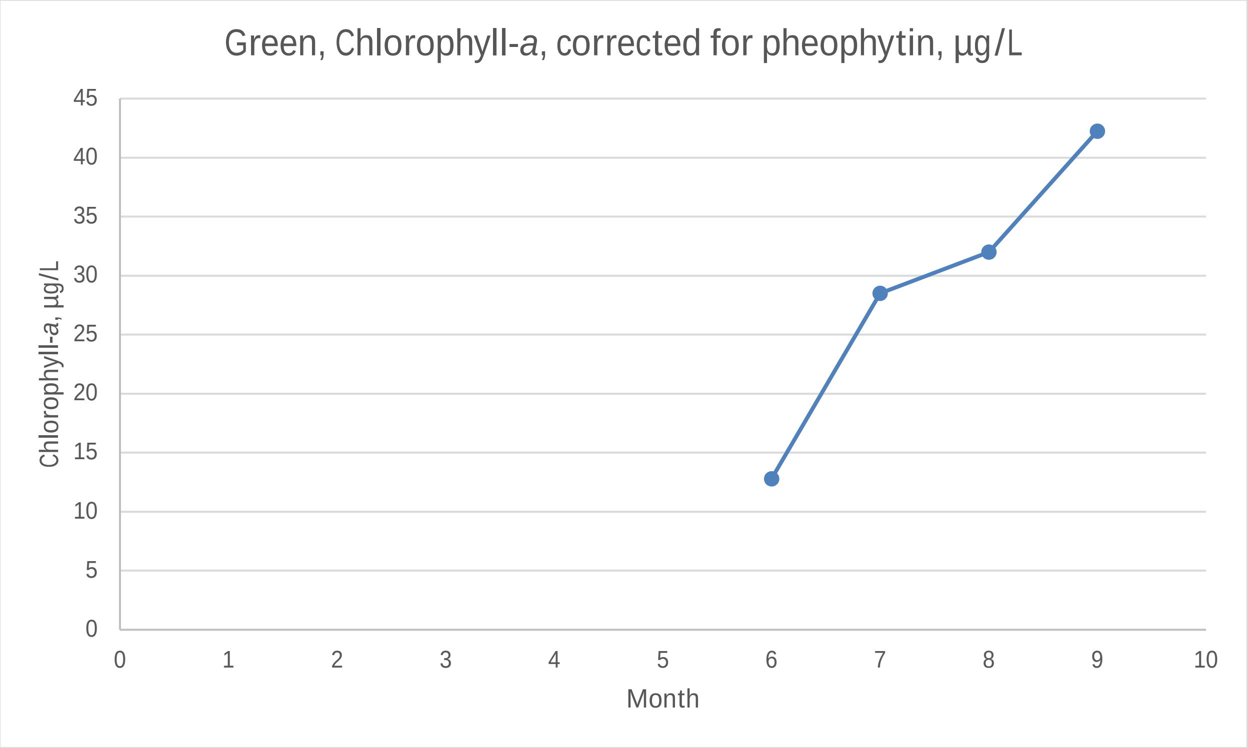


Figure F-7. Growing-Season Monthly Mean of Chlorophyll-*a* for Green Lake (All Available Data Between 2006–2015).

Aquatic Plants

Aquatic plants survey data were not available for Green Lake.

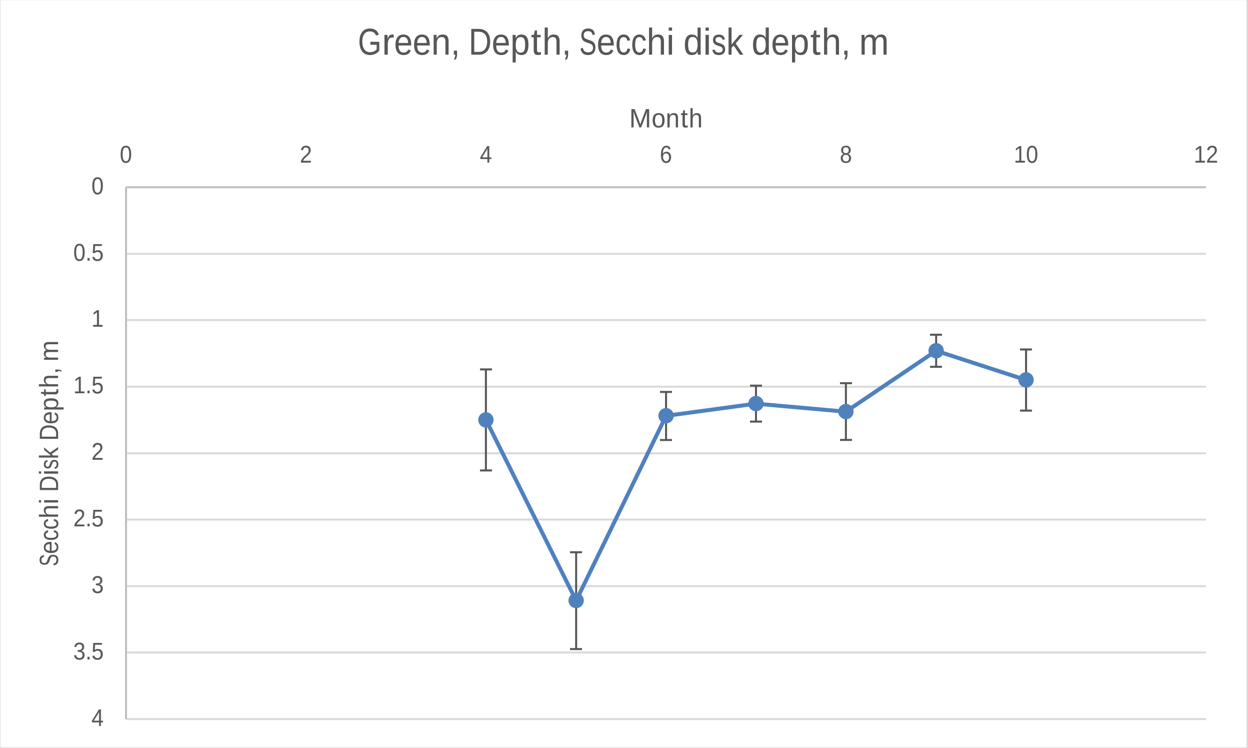


Figure F-8. Growing-Season Monthly Mean of Secchi Transparency for Green Lake (All Available Data Between 2006–2015).

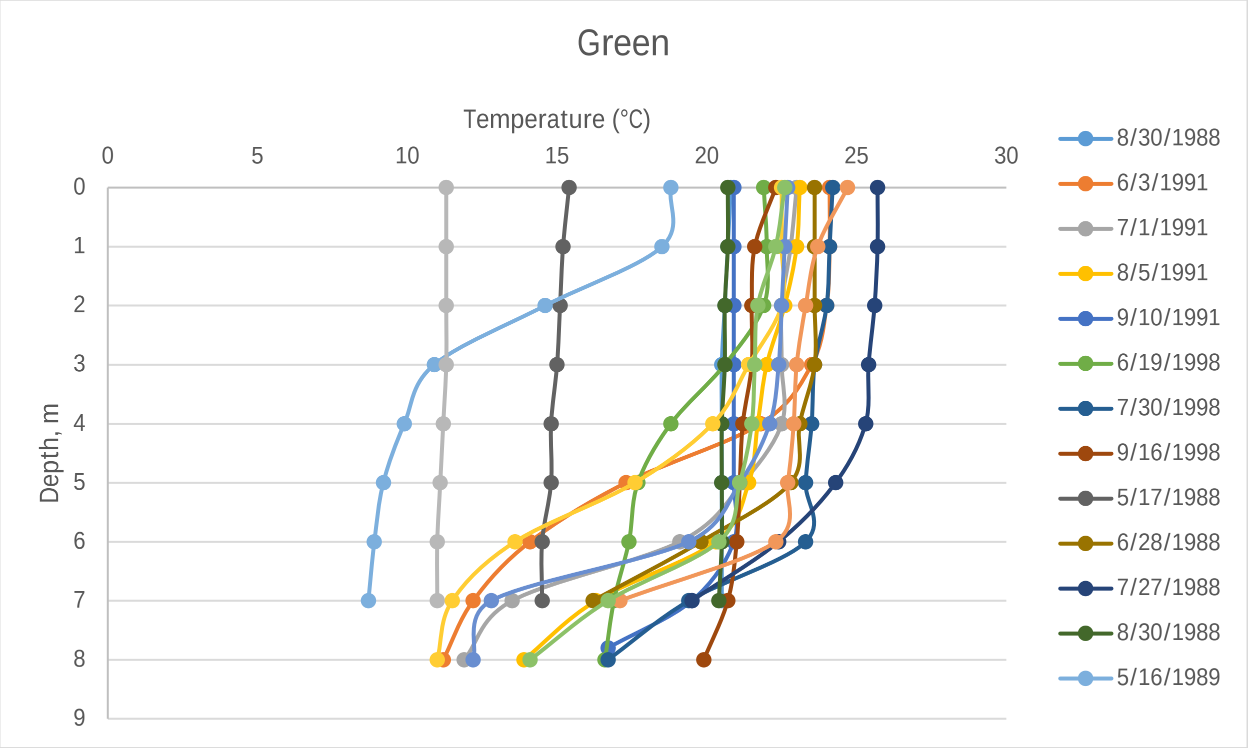


Figure F-9. Lake Temperature Profiles for Green Lake.

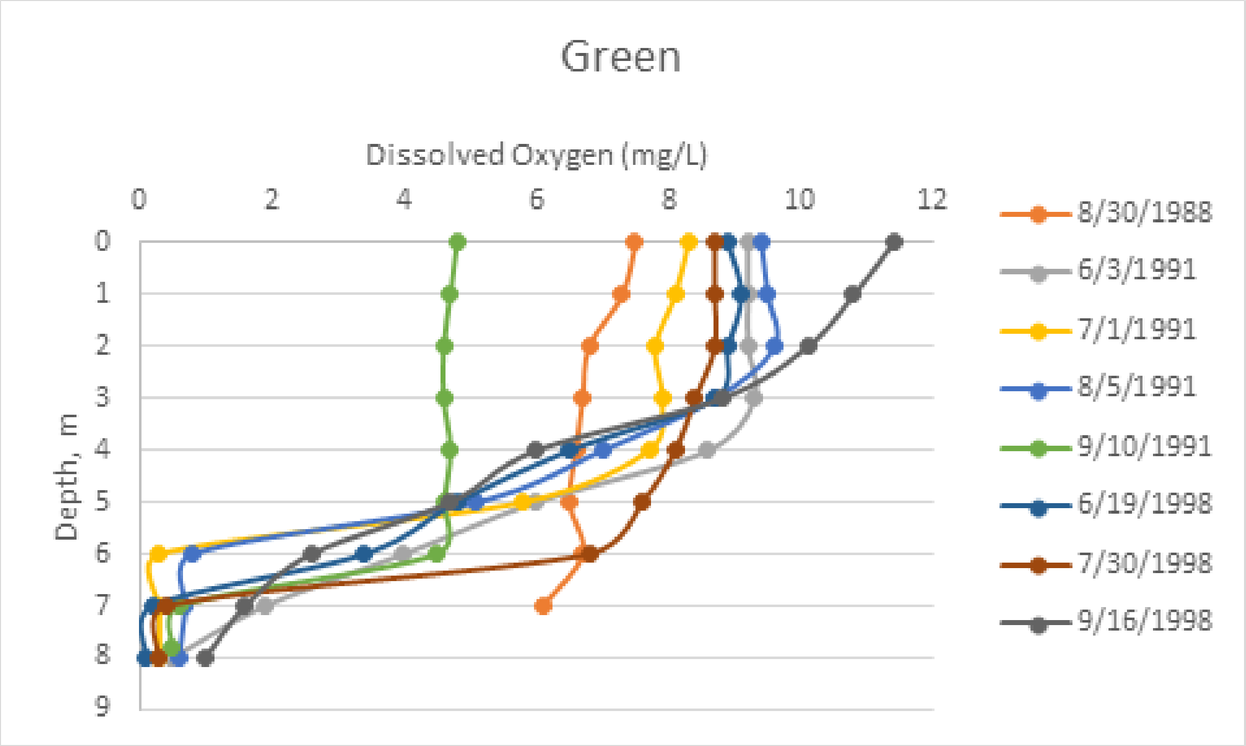


Figure F-10. Dissolved Oxygen Profiles for Green Lake.

Fisheries

DNR Fisheries surveyed Green Lake in August 2012. Green Lake is primarily managed for walleye and northern pike, and the DNR's 2012 assessment found walleye size and abundance at historic highs. The walleye population is maintained through annual fingerling stocking. Green Lake is in a DNR Lake Class 27, which includes moderately large, deep lakes with very hard water. Common carp and black bullheads were found at the low end of the normal range for this type of lake. The Rum River does back up into Green Lake during periods of high water, as noted by DNR Area Fisheries staff.

References

University of Minnesota, 2016. "Metadata, Minnesota Land Cover Classification and Impervious Surface Area by Landsat and LiDAR: 2013 Update - Version 1," *umn.edu*, retrieved June 1, 2016, from *http://portal.gis.umn.edu/map_data_metadata/LandCover_MN2013.html*

Appendix G: Long Lake (30-0072-00)

Land Cover

Land cover defined by the University of Minnesota [2016] for the Long Lake Watershed is summarized in Table G-1. Land cover is dominated by the more water quality protective land covers, including upland forests (30.7%), wetlands (17.2%), and open water (11.4%). The more intense land uses from a water quality perspective include row crops (18.4%) and urban (8.4 %). Grasslands/pasture covered about 13.9% of the watershed. Approximately 216 shoreline dwellings were noted, including one resort.

Table G-1. Long Lake Watershed Land Cover

Impairment	Open Water (%)	Wetlands (%)	Forest (%)	Grassland/ Managed Grass (%)	Hay/ Pastures (%)	Row Crops (%)	Urban (%)
Long	11.4	17.2	30.7	13.9	0.0	18.4	8.4

Physical Characteristics

Long Lake is located in Isanti County approximately 4½ miles west of the city of Isanti in Isanti County of the south-central portion of the Rum River Hydraulic Unit Code (HUC) 8. The lake has an elongated basin covering about 382 acres, with a general north-south orientation and a mean depth of 4.4 feet. Lake bathymetry is depicted in Figure G-1 along with an aerial imagery of the immediate lakeshed. Lake volume and mean depth were calculated from the DNR bathymetry maps.

Long Lake is located in the NCHF ecoregion and, from a regulatory standpoint, is categorized as a shallow lake. Table G-2 lists select morphometric and watershed characteristics. Long Lake has two public accesses with the north access maintained by the DNR.

The watershed for this lake covers 7,416 acres with a resulting watershed to lake ratio of 19.4:1. Modeled water volumes indicate that the lake has a short average water residence time of approximately 0.16 year or 58 days. The lake is classified as shallow (Lake GR) and with high wind mixing potential (Osgood Index Value). Lake-level data for Long Lake are shown in Figure G-2.

Water Quality

A robust monitoring dataset was available from 2007 to 2014. The average growing-season values for TP, Chl-*a*, and Secchi transparency (Secchi) are listed in Table G-3 with the corresponding Minnesota lake water quality standards. The recent data indicates that the lake exceeds the lake standards by about a factor of 2. However, the most recent years may also indicate P level reductions (improving pattern) relative to historical patterns.

Growing-season averages plotted by year for TP, Chl-*a*, and Secchi are depicted in Figures G-3 to G-5, respectively. The long-term data plots of TP indicate a mixed pattern with the most recent years having somewhat lower values. However, subtle improving patterns were noted for Chl-*a* and Secchi in recent years, as indicated by the dashed lines in each of the plots. The number of samples annually are shown in Table G-4.

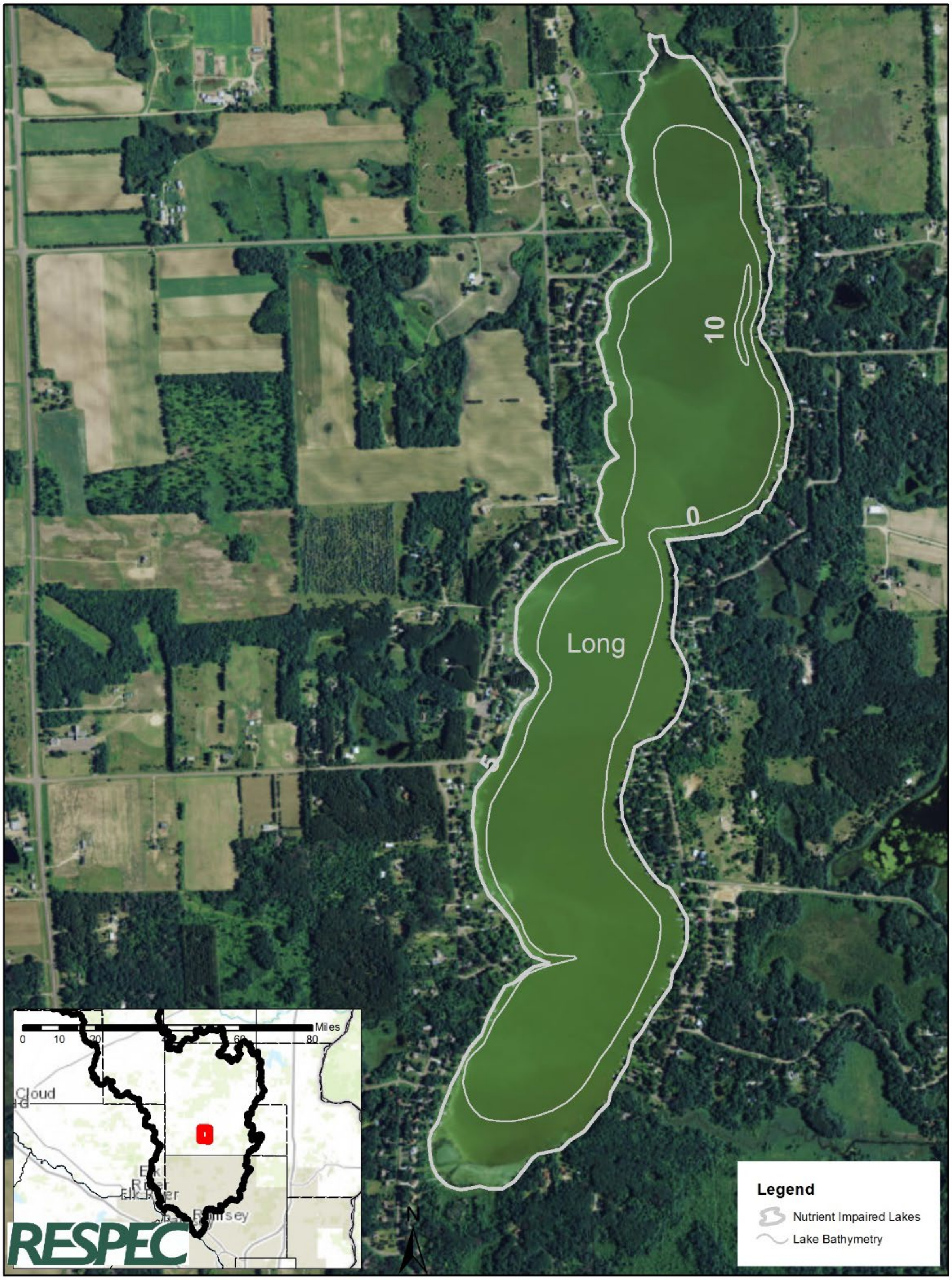


Figure G-1. Long Lake Bathymetry and Aerial Imagery.

The multiyear growing-season monthly means from 2007 through 2014 are depicted in Figures G-6 to G-8, which indicate substantial increases in-lake P and Chl-*a* concentrations from June to August and a slight decline in September. Correspondingly, Secchi was noted to decline through September. These increases are the net result of external loading from the watershed and internal loading from the lake's sediments. Based on the increases in monthly mean P concentrations, internal loading of P from the lake's sediments was incorporated into the lake modeling.

Table G-2. Long Lake Select Lake Morphometric and Watershed Characteristics

Characteristic	Long Lake	Source
Lake-Surface Area (acres)	382	DNR LakeFinder
Number of Islands	0	
Percent Lake Littoral Surface Area	100	DNR LakeFinder
Drainage Area, Including Lake acres (ac)/square kilometers (km^2)	7,416 ac/30.0 km^2	Model Subwatersheds
Watershed Area to Lake Area Ratio	19.4:1	Calculated
Wetland Area (% of watershed)	17.2	University of Minnesota [2016]
Number of Upland Lakes	Small ponds, wetlands	US Geological Survey topographic maps
Number of Perennial Inlet Streams	1	US Geological Survey topographic maps
Lake Volume (acre-feet (ac-ft)/cubic hectometers (hm^3))	1,681 ac-ft/2.1 hm^3	Calculated
Mean Depth (ft/m)	4.4 ft/1.7 m	Calculated
Annual Lake-Level Fluctuations (ft):typical, maximum	0.2–0.4 feet	DNR Lake Levels
Maximum Depth (ft/m)	11 ft/3.4 m	DNR Lake Map
Maximum Fetch Length (miles (mi)/kilometers (km))	1.1 mi/3.55 km 0.25 mi/ 0.4 km	Measured in Google Earth
Lake Geometry Ratio	10.5	Calculated
Osgood Index	1.1	Calculated
Estimated Water Residence Time (years/days)	0.16 year	Calculated
Public Access	2	DNR (NE lake access), Stanford, Township
Shore Land Properties	216: 139 year round, 77 seasonal 1 resort	Counted from topographic maps
DNR Lake Class (shallow turbid lake)	39	DNR

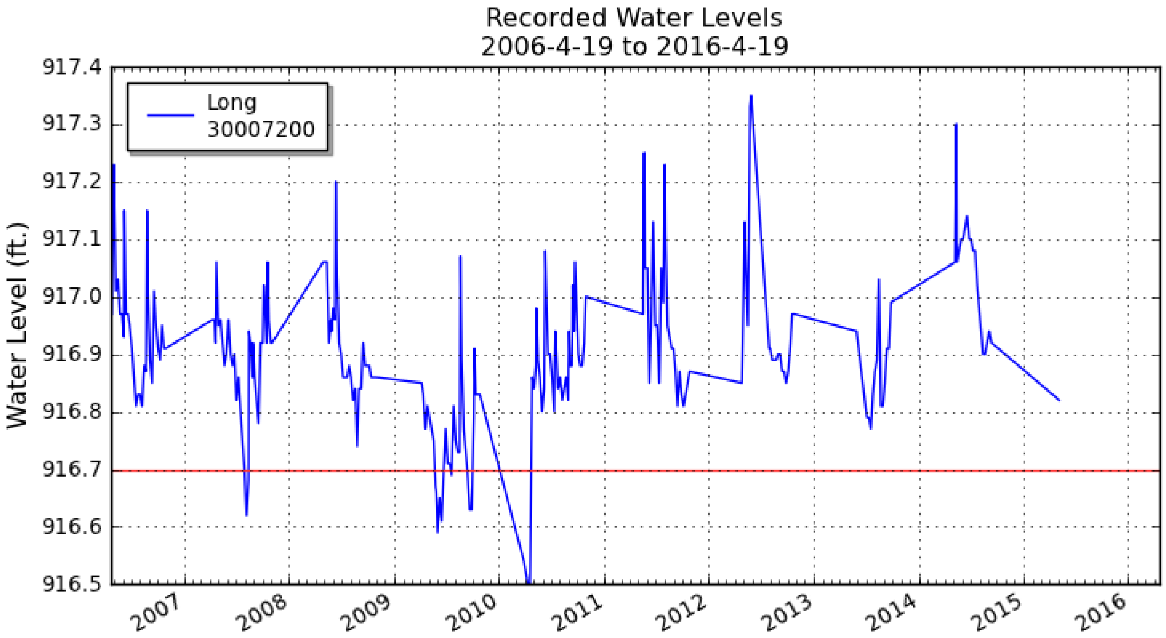


Figure G-2. Long Lake Levels (DNR Lake-Level Program Graphic).

Table G-3. Total Daily Maximum Load Period Total Phosphorus, Chlorophyll-*a*, and Secchi Transparency Growing-Season Means for Long Lake

Parameter	Minimum	Mean	Maximum	Standard Deviation	Sample Number	Lake Standards
TP (µg/L)	44	119.0	528	64.1	80	≤ 60
Chlorophyll-*a* (µg/L)	4.8	50.0	131	29.0	80	≤ 20
Secchi disc depth (m)	0.3	0.49	1.22	0.18	88	≥ 1.0

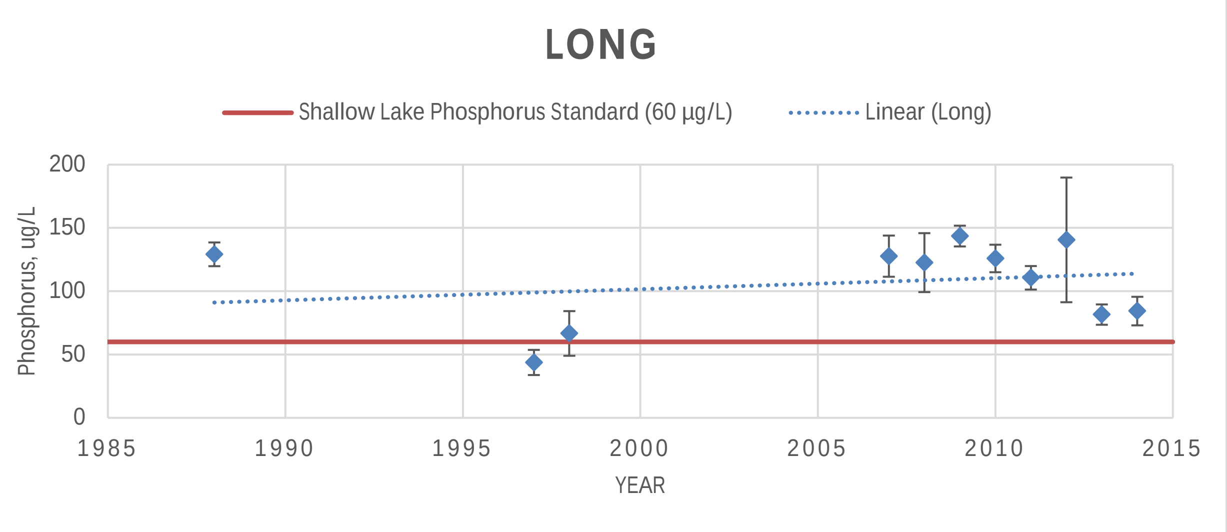


Figure G-3. Annual Growing-Season Mean of Total Phosphorus Concentrations for Long Lake.

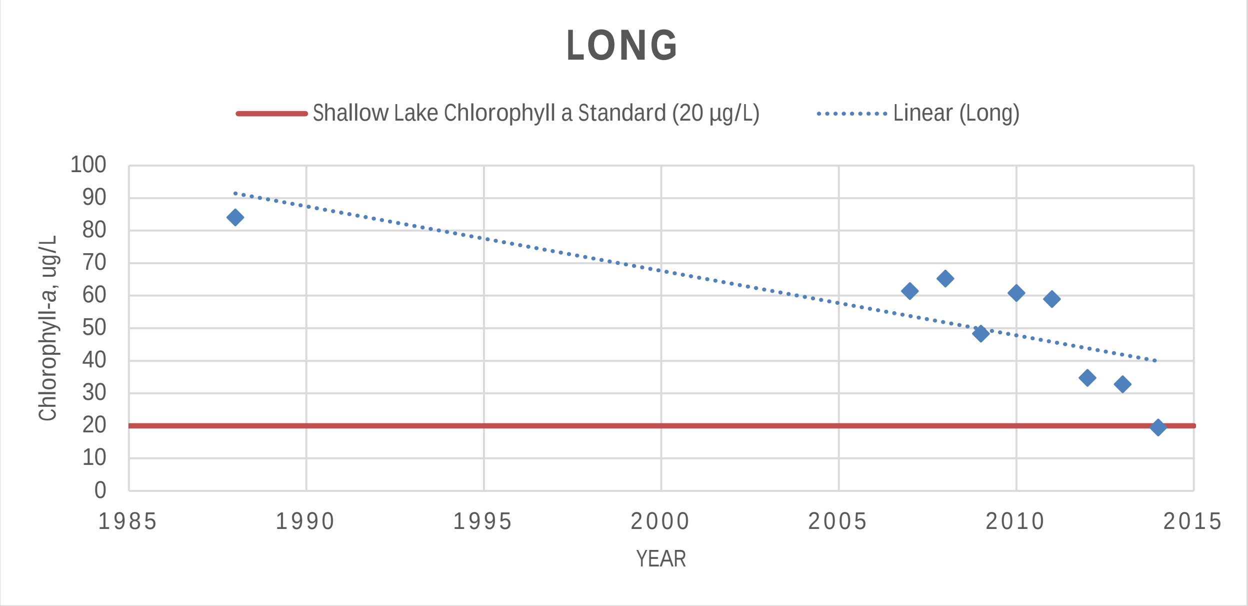


Figure G-4. Annual Growing-Season Mean of Chlorophyll-*a* Concentrations for Long Lake.

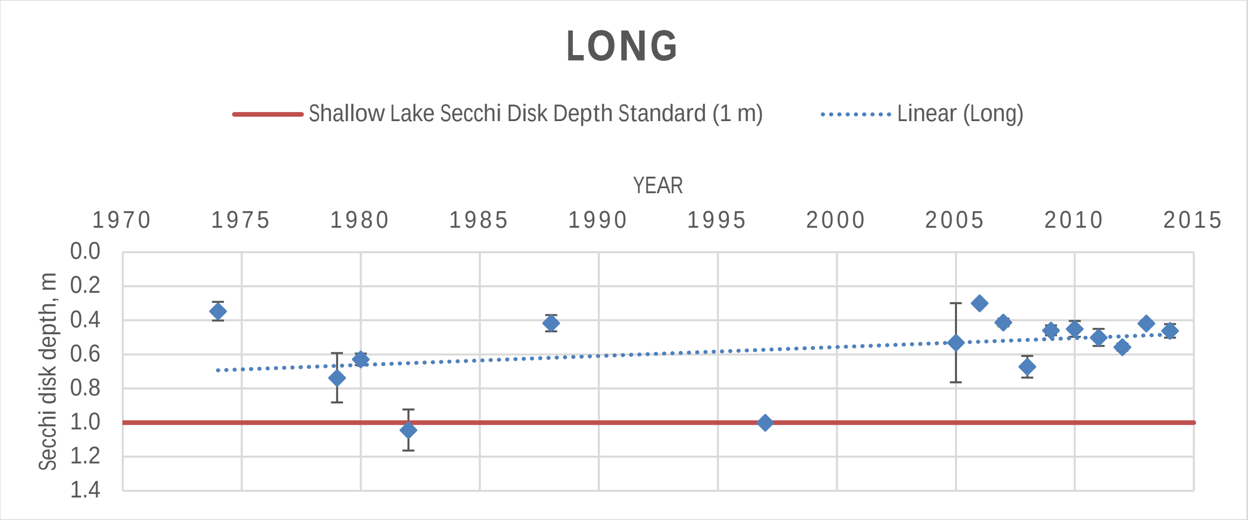


Figure G-5. Annual Growing-Season Mean of Secchi Transparency for Long Lake.

Table G-4. Total Phosphorus, Chlorophyll-*a*, and Secchi Transparency Number of Samples Annually for Long Lake

Lake	Constituent	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
Long	TP		10	10	12	9	15	9	9	6		80
	Chl-*a*		10	10	12	9	15	9	9	6		80
	Secchi	6	17	18	8	8	9	6	9	7		88

Dissolved Oxygen and Temperature Data Summary

Available historical DO and temperature data monitored by depth were examined to better define lake-mixing patterns that affect biological responses and lake P dynamics. Available data from 1987 through 2012 are plotted in Figures G-9 and G-10 for temperature and DO data, respectively.

Water-temperature variation by depth from historical data is shown in Figure G-9 with data indicating well-mixed conditions with little change in temperature with depth. Peak monitored summer bottom water temperatures (July through September) ranged from approximately 20° to 27°C. Growing-season DO concentrations were generally noted to decline below 1 meter (m) of depth with steep declines noted to about 4.0 milligrams per liter (mg/L), as depicted in Figure G-10.

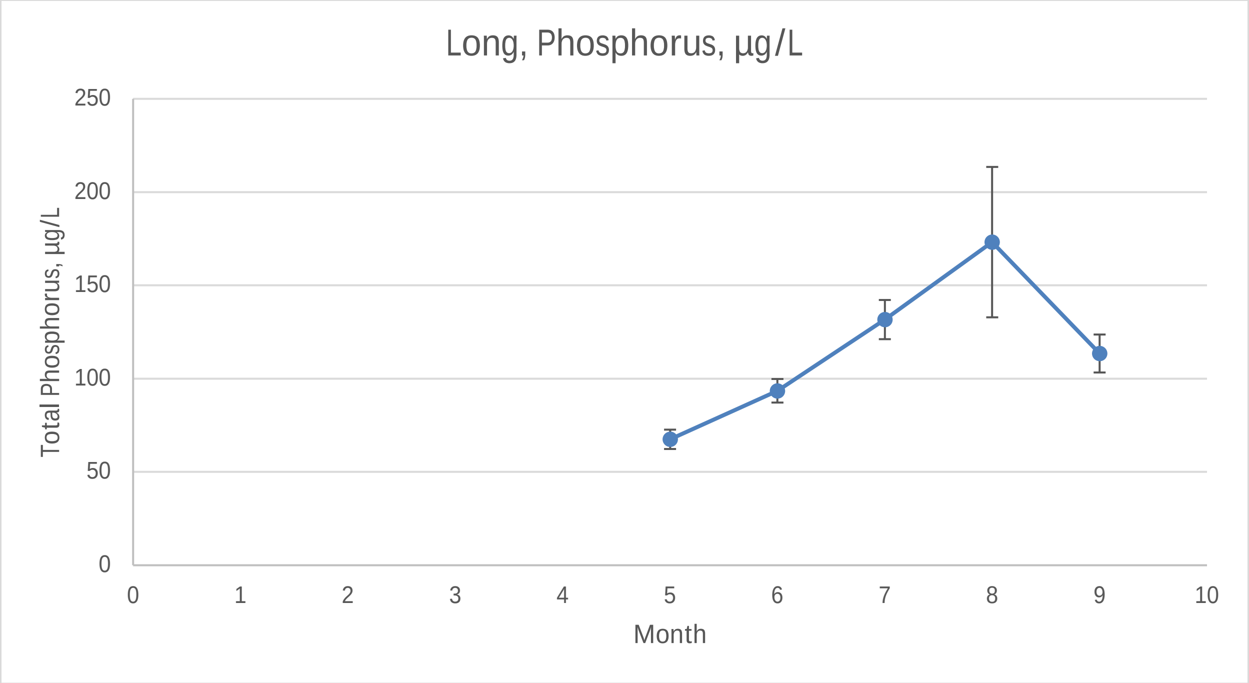


Figure G-6. Growing-Season Monthly Mean of Total Phosphorus for Long Lake (All Available Data Between 2006–2015).

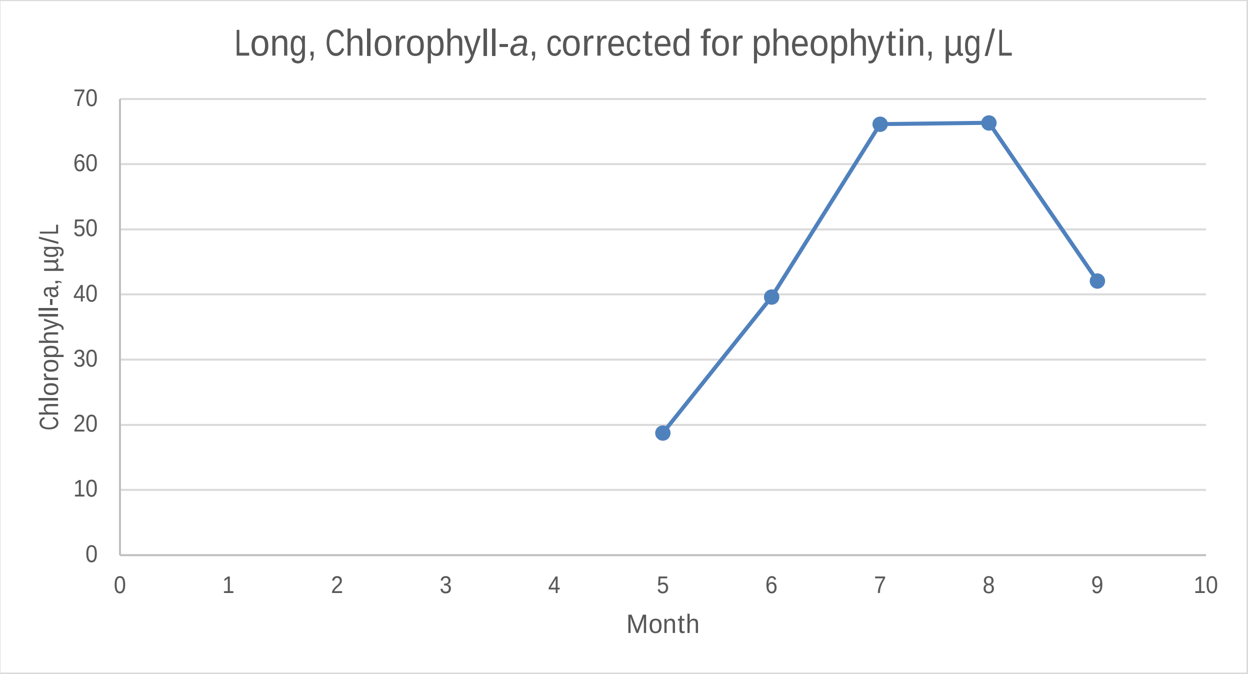


Figure G-7. Growing-Season Monthly Mean of Chlorophyll-*a* for Long Lake (All Available Data Between 2006–2015).

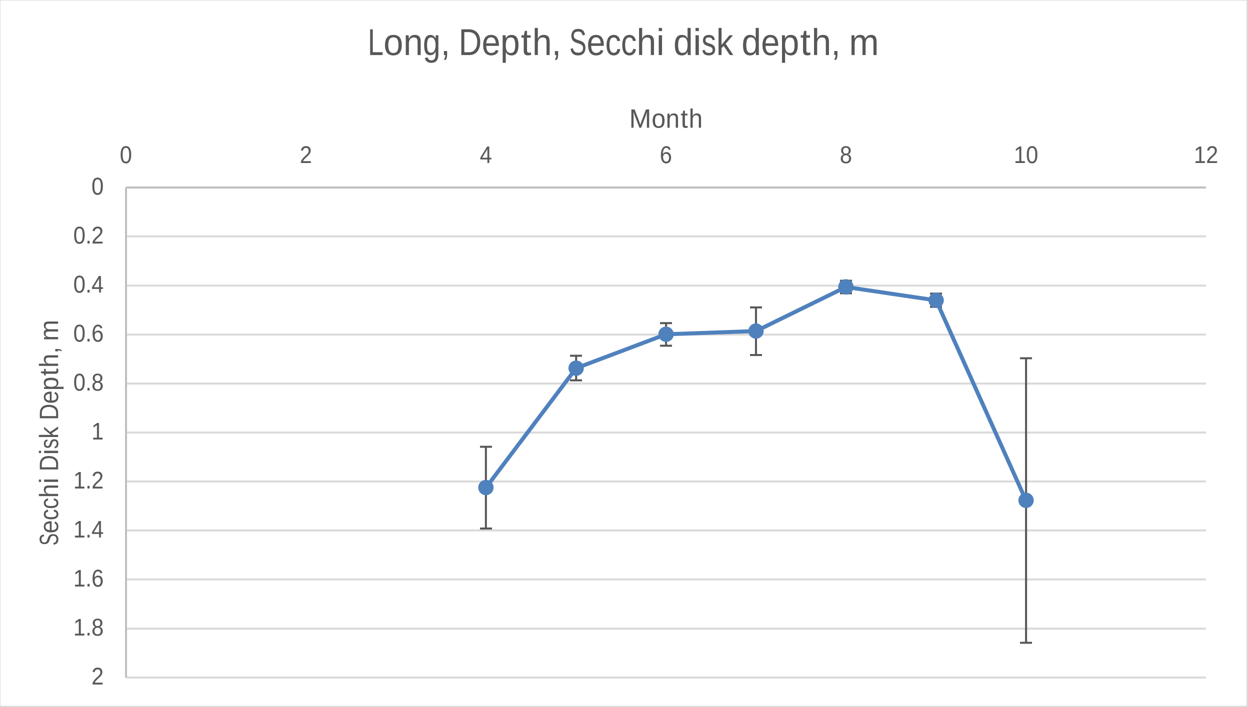


Figure G-8. Growing-Season Monthly Mean of Secchi Transparency for Long Lake (All Available Data Between 2006–2015).

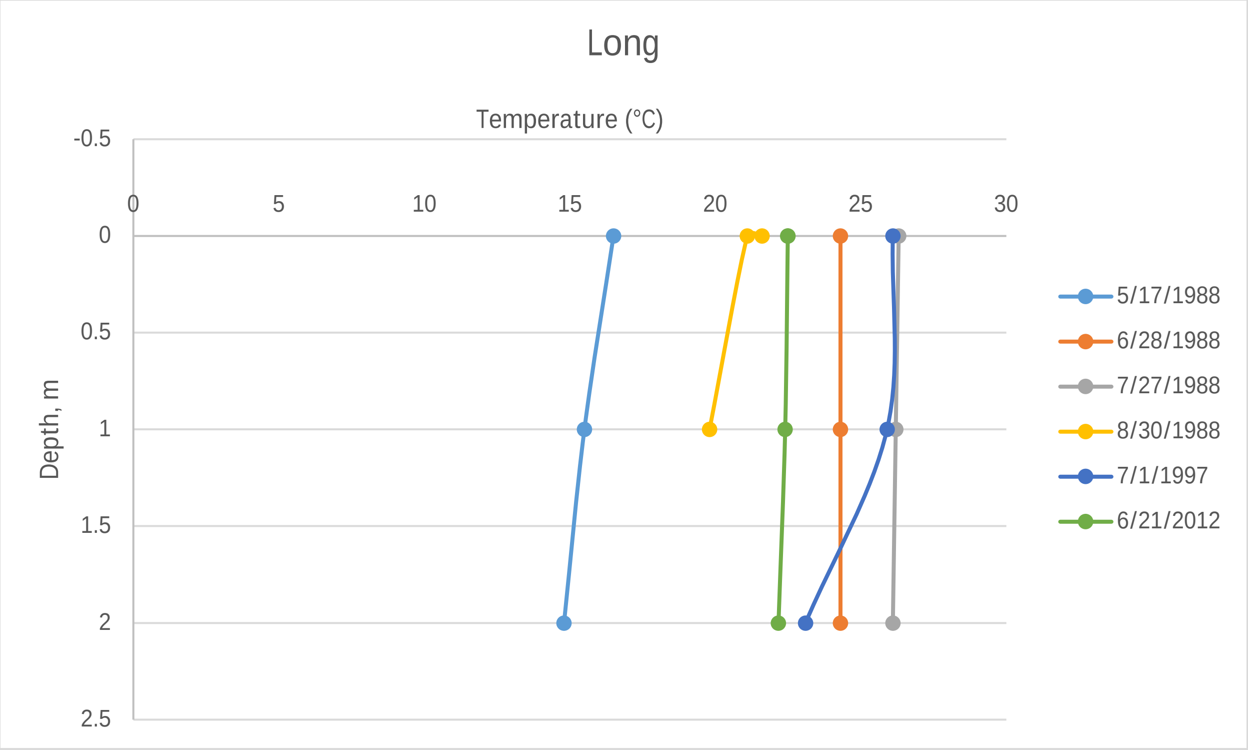


Figure G-9. Lake Temperature Profiles for Long Lake.

Aquatic Plants

A Minnesota biological survey of aquatic plant species was conducted on the north end of Long Lake on June 25, 2013, that detailed submersed, free-floating, floating-leaf, emergent, and shoreline plants. While 14 species of aquatic plants were identified, aquatic vegetation is quite limited in this turbid lake.

The exotic invasive species curly-leaf pondweed (*Potamogetagon Crispus*) was noted in this survey and has been found to densely colonize Long Lake. Excessive areal coverage of this species can cause nuisance conditions for recreationists until the typical late-June to early-July die-back period. Senescence of curly-leaf pondweed has been associated with an increases in lake P concentrations. Twenty-three species of shoreline plants were also identified.

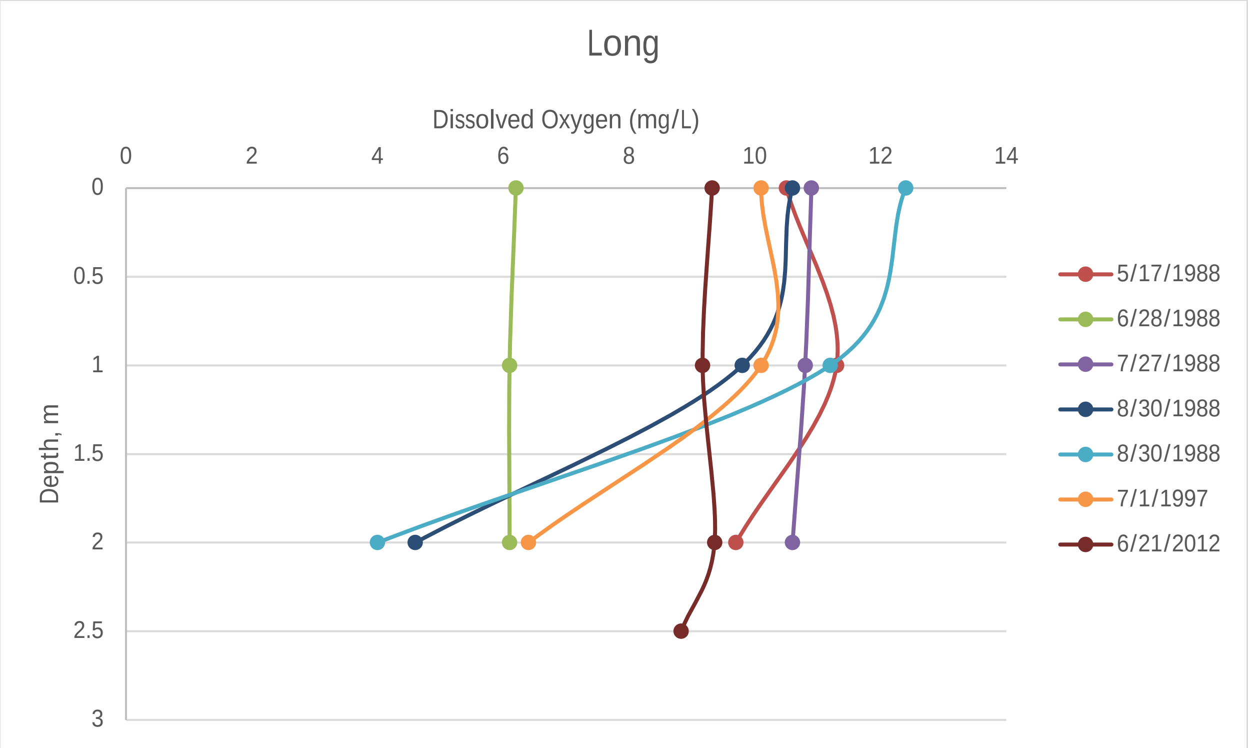


Figure G-10. Dissolved Oxygen Profiles for Long Lake.

Fisheries

Long Lake is a very productive lake that is subject to periodic winterkills, after which gamefish is restocked. In the most recent DNR Fisheries survey of July 29, 2013, largemouth bass catch rates were found to have increased with northern pike at average catch rates relative to similar lakes. Walleye are present in the lake but at lower levels and require stocking to replace lost natural reproduction. Common carp were also captured during the survey.

References

University of Minnesota, 2016. "Metadata, Minnesota Land Cover Classification and Impervious Surface Area by Landsat and LiDAR: 2013 Update - Version 1," *umn.edu*, retrieved June 1, 2016, from *http://portal.gis.umn.edu/map_data_metadata/LandCover_MN2013.html*

Appendix H: South Stanchfield Lake (30-0138-00)

Land Cover

Land cover defined by the University of Minnesota [2016] for the South Stanchfield Lake Watershed is summarized in Table I-1. Row crops and grassland/managed grass comprise 31.6% and 10.0% of the watershed, respectively, while urban lands cover about 6.4% of the watershed. Wetlands and forests comprise 24.3% and 17.7% of the watershed, respectively, with open water covering about 9.1%.

Table H-1. South Stanchfield Lake Watershed Land Cover

Impairment	Open Water (%)	Wetlands (%)	Forest (%)	Grassland/ Managed Grass (%)	Hay/ Pastures (%)	Row Crops (%)	Urban (%)
South Stanchfield	9.1	24.3	17.7	10.0	0.8	31.6	6.4

Physical Characteristics

South Stanchfield Lake (30-0138-00) is located approximately 6.5 miles northeast of Princeton in Isanti County, Minnesota, with its discharge via stream traveling about 0.2 mile before entering North Stanchfield Lake. Dispersive mixing between the lake basins is limited to backwatering effects as a result. The lake has an elliptical shape configured in a general north-south orientation that covers a surface area of approximately 398 acres with a mean depth of approximately 7.8 feet. Lake bathymetry is depicted in Figure I-1 along with an aerial imagery of the immediate lakeshed. Lake volume and mean depth were calculated from the DNR bathymetry map.

South Stanchfield Lake is located in the NCHF ecoregion and, from a regulatory standpoint, is categorized as a shallow lake. Select lake morphometric and watershed characteristics are listed in Table I-2. South Stanchfield Lake has one public access maintained by the Dalbo Township. Recent lake-level fluctuations of about 0.2 foot were noted from DNR lake-level data. Lake levels are shown in Figure I-2.

The watershed for this lake covers 6,675 acres with a resulting watershed to lake ratio of 16.8:1. Modeled water volumes indicate that the lake has a TMDL period average water residence time of approximately 0.7 year.

Water Quality

South Stanchfield Lake's available water quality data in the TMDL period from 2006 to 2015 were limited to data collected in 2014 for paired TP, Chl-*a*, and Secchi transparency (Secchi). Annual growing-season data are shown in Figures I-3 through I-5. The TMDL-period growing-season averages for TP, Chl-*a*, and Secchi with corresponding lake standards are summarized in Table I-3. Average TP and Chl-*a* values exceed state lake standards substantially, while average Secchi just meets the state standards. The lake's Chl-*a* concentrations substantially exceed values suggested by average TP concentrations. The number of samples annually are shown in Table I-4.

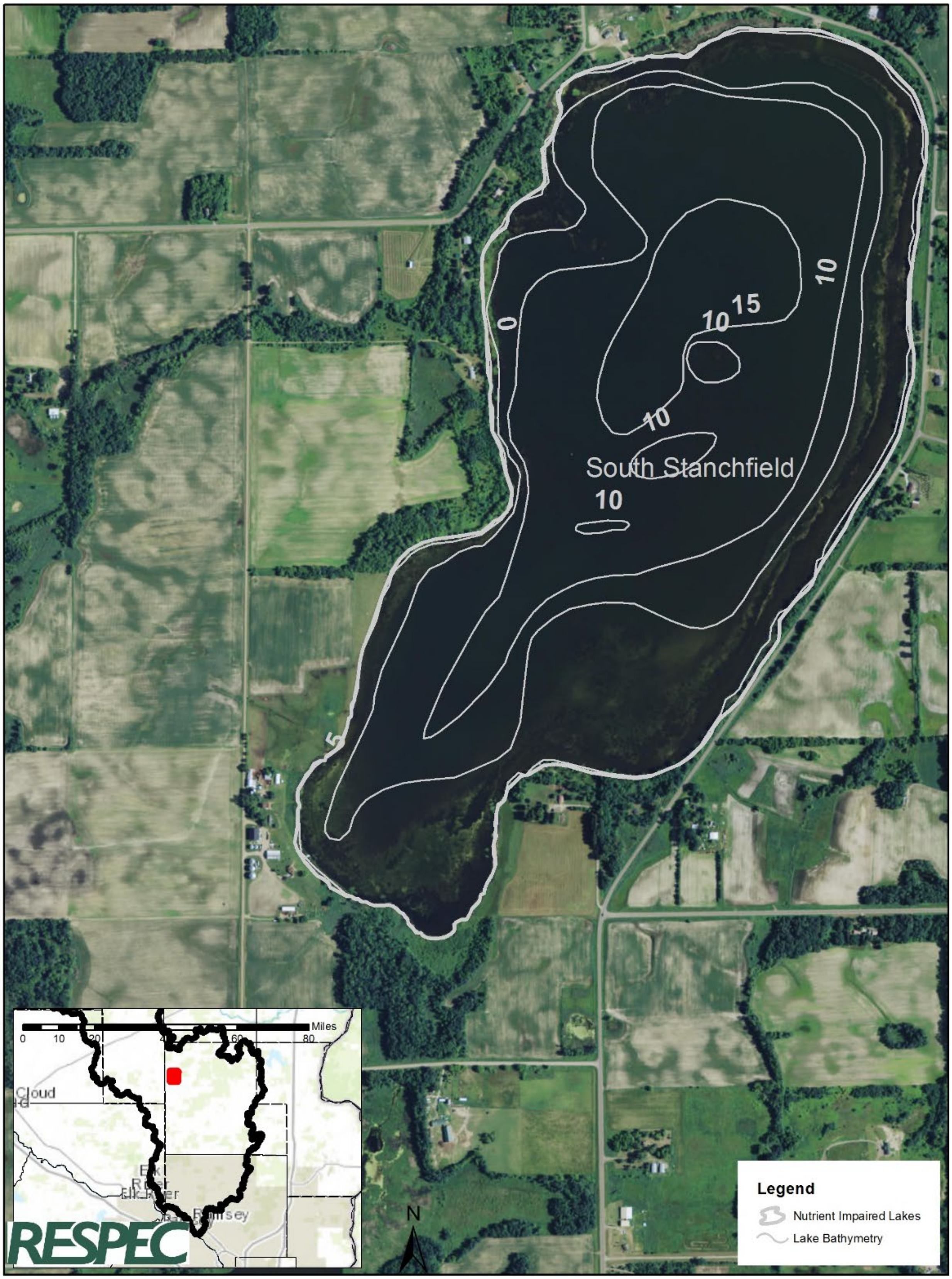


Figure H-1. South Stanchfield Lake Bathymetry and Aerial Imagery.

Table H-2. South Stanchfield Lake Select Lake Morphometric and Watershed Characteristics

Characteristic	South Stanchfield 30-0138	Source
Lake-Surface Area (acres)	398	DNR LakeFinder
Number of Islands	0	
Percent Lake Littoral Surface Area	100	DNR LakeFinder
Drainage Area, Including Lake acres (ac)/square kilometers (km^2)	6,675 a/27.0 km^2	Model Subwatersheds
Watershed Area to Lake Area Ratio	16.8:1	Calculated
Wetland Area (% of watershed)	24.3	University of Minnesota [2016]
Number of Upland Lakes	Several small waterbodies	US Geological Survey topographic maps
Number of Perennial Inlet Streams	6,276 acres/ 25.4 km^2	ArcGIS, 2015 TMDL Lakes Layer
Lake Volume (acre-feet (ac-ft)/cubic hectometers (hm^3))	3,088 ac-ft/3.8 hm^3	Calculated
Mean Depth (ft/m)	7.8 ft/2.4 m	Calculated
Annual Lake-Level Fluctuations (ft):typical, maximum	0.2 feet	DNR Lake Levels
Maximum Depth (ft/m)	17 ft/5.2 m	DNR Lake Map
Maximum Fetch Length (miles (mi)/kilometers (km))	1.5 mi/2.38 km	Measured in Google Earth
Lake Geometry Ratio	6.9	Calculated
Osgood Index	1.9	Calculated
Estimated Water Residence Time (years/days)	0.7 years	Calculated
Public Access	1	Dalbo Township
Shore Land Properties	10	Counted from topographic maps
DNR Lake Class	NA	DNR
Stream distance to North Stanchfield Lake	0.2 mi/0.3 km	Measured in Google Earth

Growing-season monthly average water quality data for the TMDL period are summarized in Figures I-6 through I-8. Plots of growing-season mean monthly TP (2014 data only) show a general increase in TP concentrations, with a decline in August followed by an increase in September. Chl-*a* data from 2013 and 2014 show a sharp increase from May to a peak of 140 micrograms per liter (µg/L) in September. Correspondingly, average monthly Secchi transparencies decline from approximately 3.25 meters (m) in May to 0.5 m in September.

Figure H-2. South Stanchfield Lake Lake-Level Fluctuations (DNR Lake-Level Program Graphic).

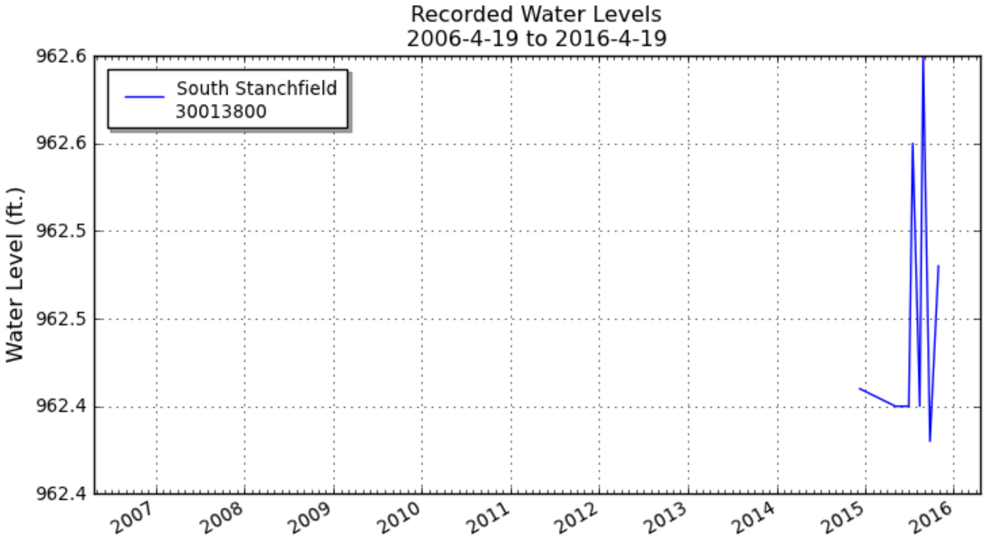


Figure H-3. Annual Growing-Season Mean of Total Phosphorus Concentrations for South Stanchfield Lake.

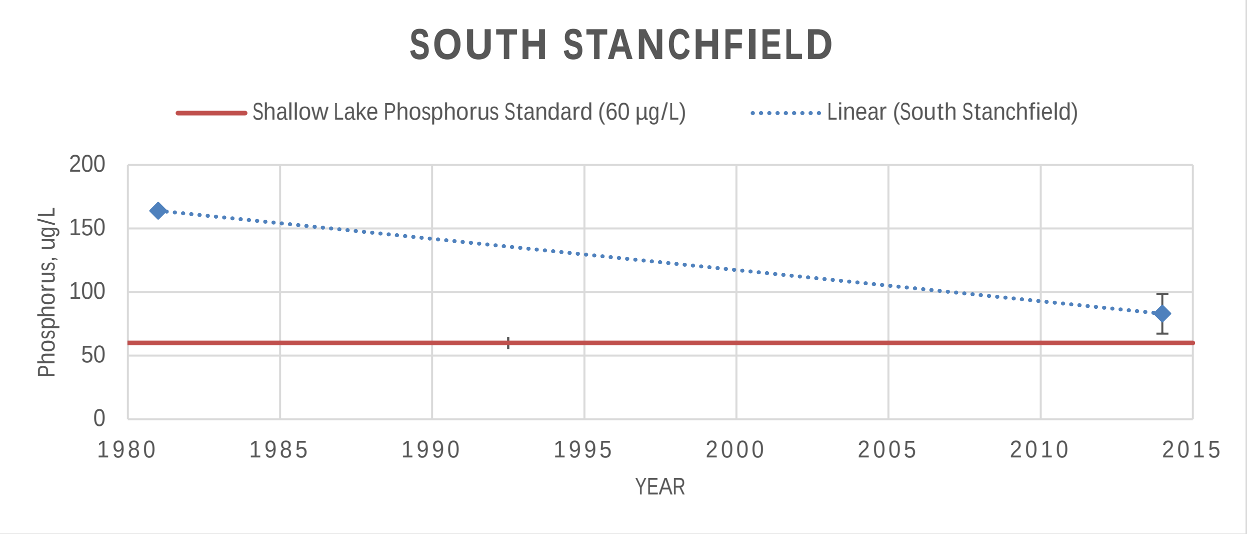
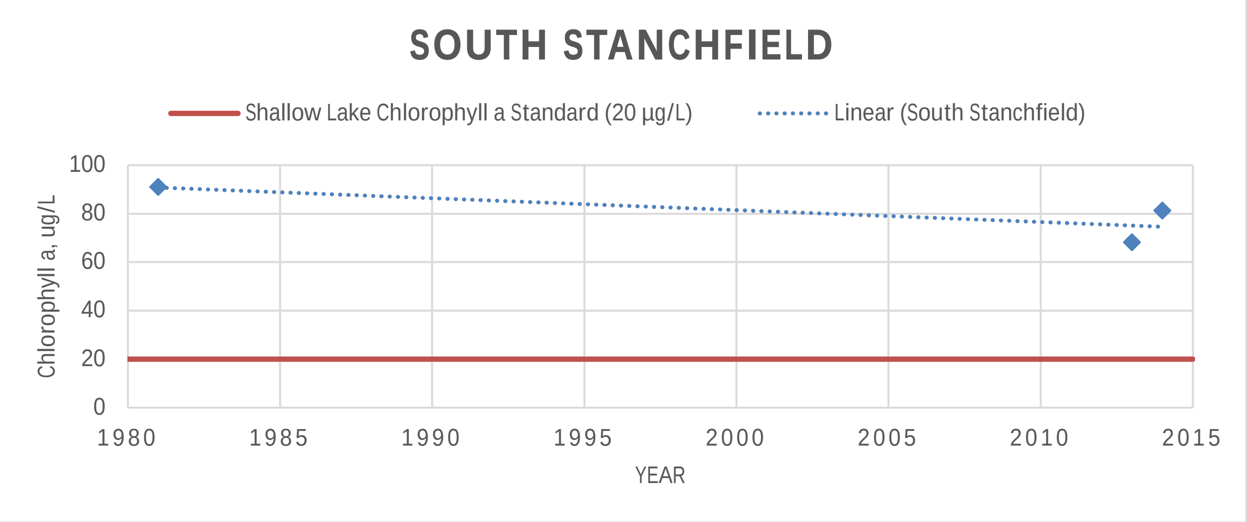


Figure H-4. Annual Growing-Season Mean of Chlorophyll-*a* Concentrations for South Stanchfield Lake.



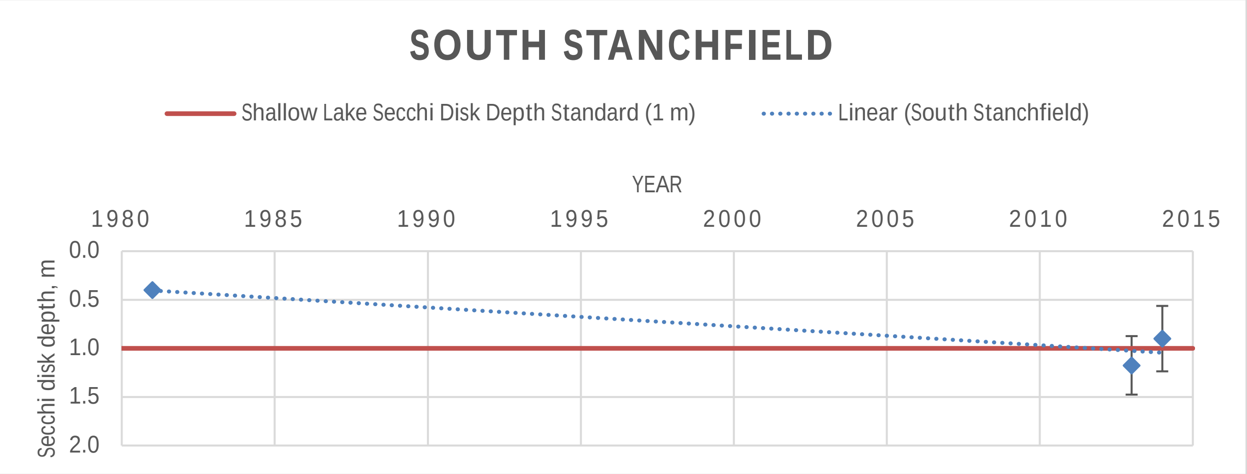


Figure H-5. Annual Growing-Season Mean of Secchi Transparency for South Stanchfield Lake.

Table H-3. Total Maximum Dailt Load Period Total Phosphorus, Chlorophyll-a, and Secchi Transparency Growing-Season Means for South Stanchfield Lake

Parameter	Minimum	Mean	Maximum	Standard Deviation	Sample Number	Lake Standards
TP (µg/L)	46	83.0	117.0	31.4	4	≤ 60
Chlorophyll-*a* (µg/L)	5.5	74.7	193.0	60.3	8	≤ 20
Secchi disk depth (m)	0.5	1.0	2.0	0.61	8	≥ 1.0

Table H-4. Total Phosphorus, Chlorophyll-a, and Secchi Transparency Number of Samples Annually for South Stanchfield Lake

Lake	Constituent	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
South Stanchfield	TP									4		4
	Chl-*a*								4	4		8
	Secchi								4	4		8

Dissolved Oxygen and Temperature Data Summary

The DO and temperature data monitored by depth were examined to better define lake-mixing patterns that affect biological responses and lake P dynamics. Available data from 1981 and 2013 are plotted in Figures I-9 and I-10 for temperature and DO, respectively.

Water-temperature profiles as depicted in Figure I-9 indicate relatively well-mixed conditions with similar temperatures going from the surface to depth. The June 20, 2013, profiled temperatures varied the most with the surface and 3-meter values within about 5°C. Peak monitored summer bottom water temperatures (July through September) ranged from approximately 18° to 25°C.

The DO profile data typically exhibited substantial concentration losses with depth, which indicates large oxygen depletion rates (Figure I-10) with values decreasing to values less than 2 mg/L observed on three dates. Frequent winterkills have been noted as a result. Peak growing-season DO profiles generally show a difference of approximately 5 to 10 mg/L between maximum and minimum measured DO concentrations.

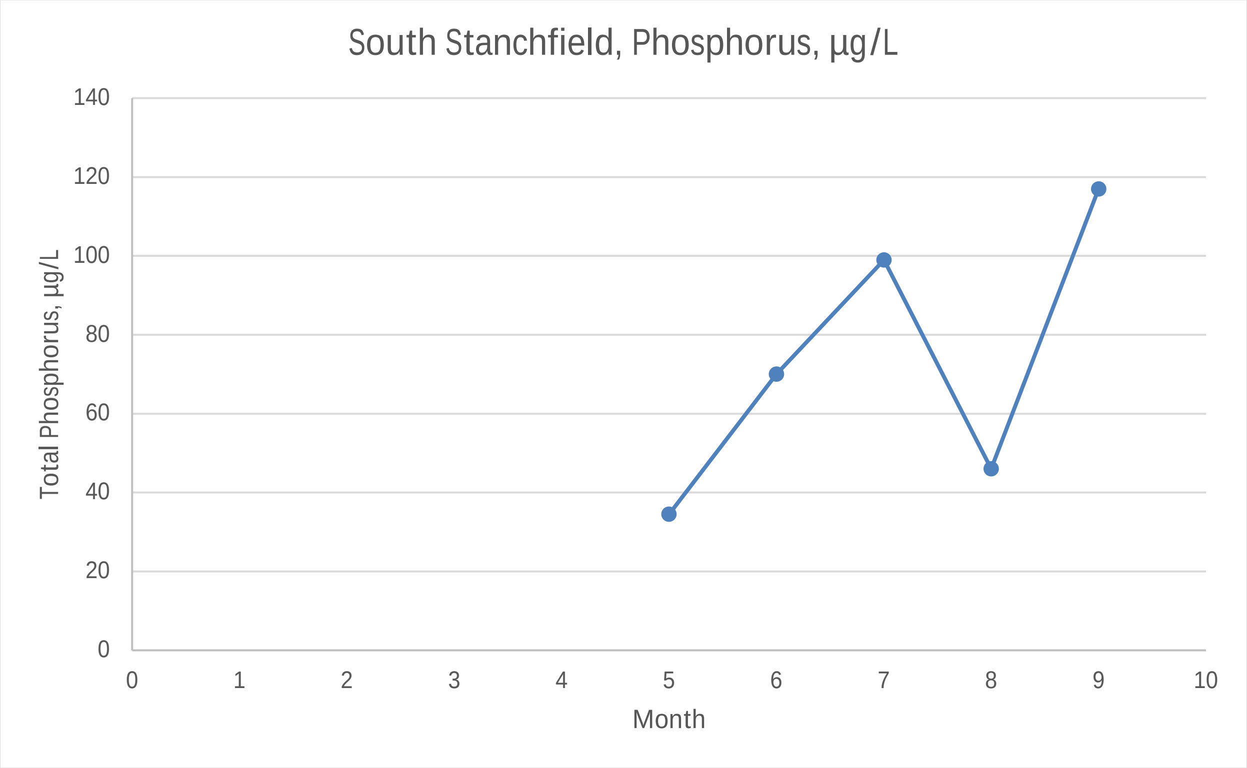


Figure H-6. Growing-Season Monthly Mean of Total Phosphorus for South Stanchfield Lake (All Available Data Between 2006–2015).

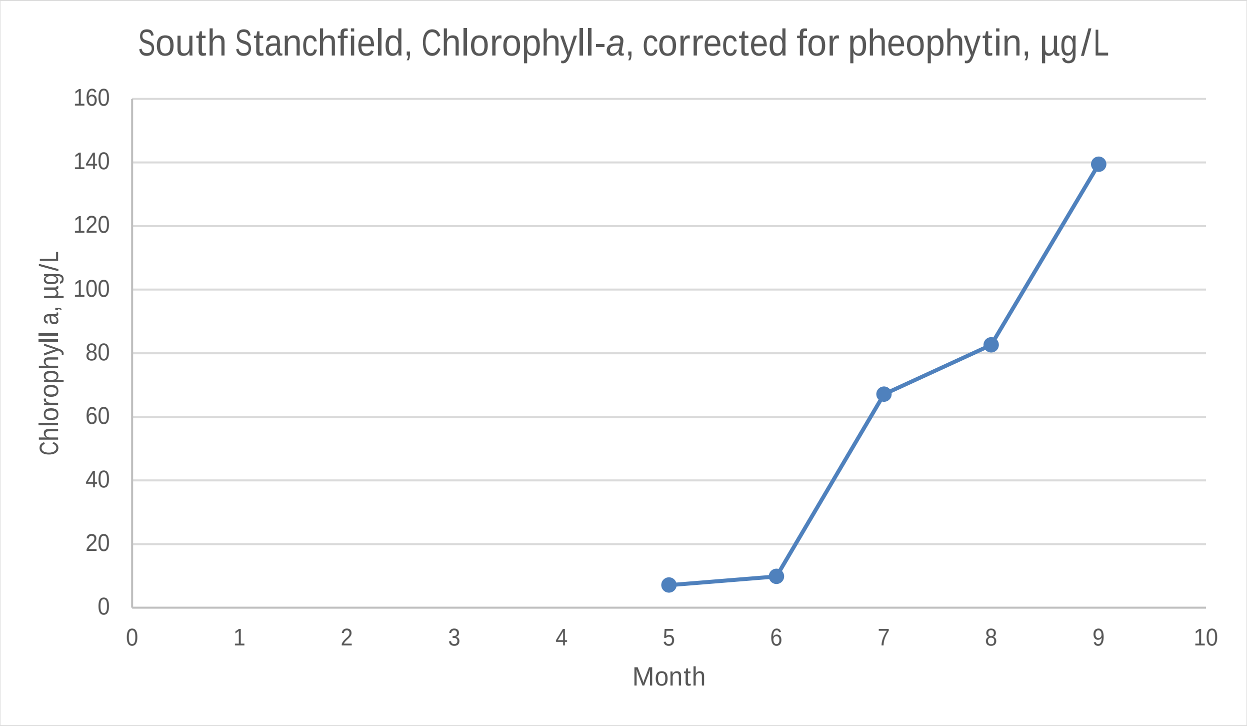
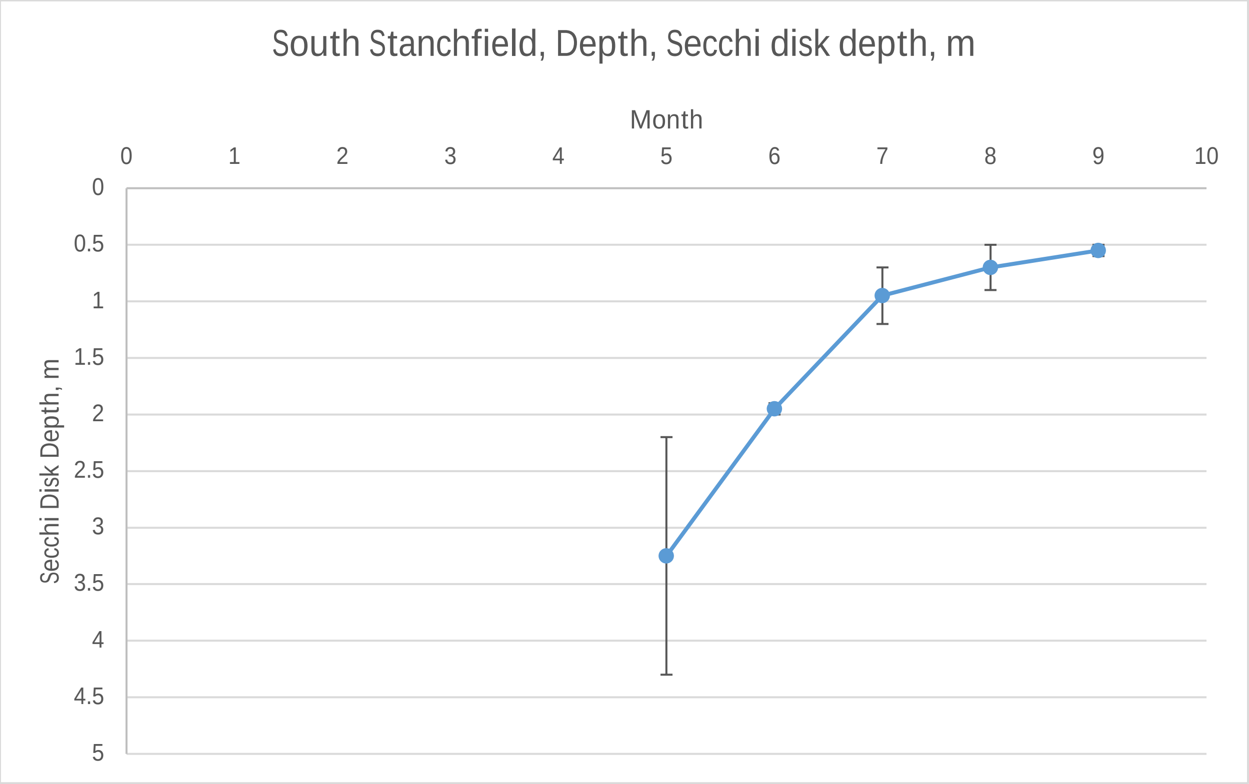


Figure H-7. Growing-Season Monthly Mean of Chlorophyll-*a* for South Stanchfield Lake (All Available Data Between 2006–2015).

Figure H-8. Growing-Season Monthly Mean of Secchi Transparency for South Stanchfield Lake (All Available Data Between 2006–2015).



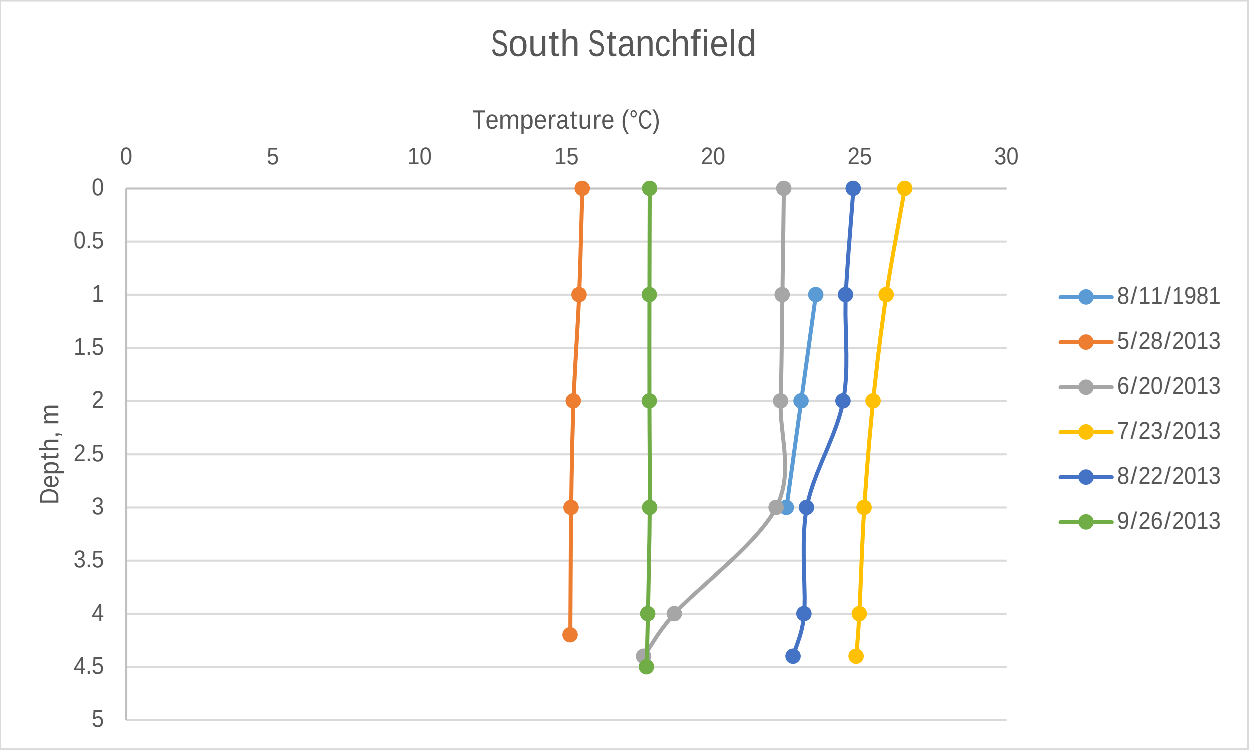


Figure H-9. Lake Temperature Profiles for South Stanchfield Lake.

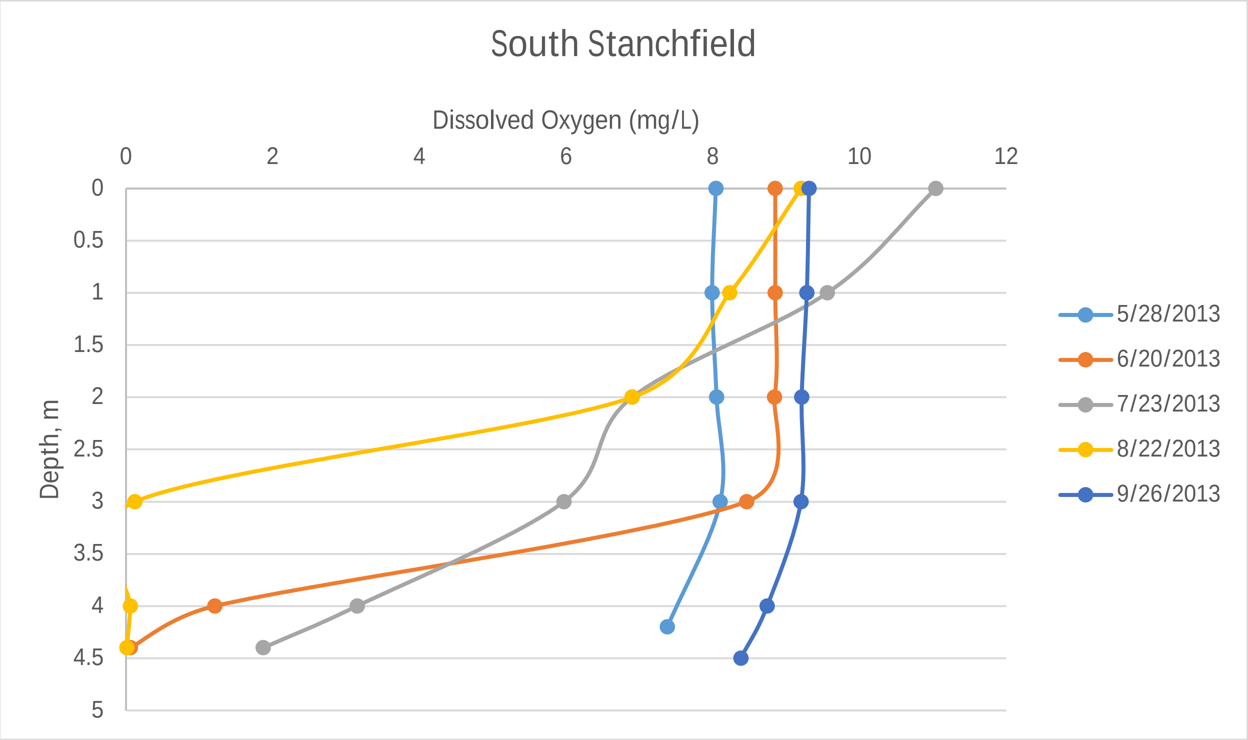


Figure H-10. Dissolved Oxygen Profiles for South Stanchfield Lake.

Aquatic Plants

A Minnesota biological survey of aquatic plant species was conducted on the northeast shore of South Stanchfield Lake on June 17, 2013. This report tabulated only nine species of submersed, free-floating, floating-leaf, emergent plants and is an indication of the effects of excessive algal concentrations in this turbid lake. The exotic invasive species curly-leaf pondweed (*Potamogetagon Crispus*) was noted in this survey.

Fisheries

South Stanchfield Lake is a very productive lake and is subject to frequent winterkills, after which gamefish is restocked. In the most recent DNR Fisheries survey of July 30, 1991, large populations of black bullheads and common carp were present.

References

University of Minnesota, 2016. "Metadata, Minnesota Land Cover Classification and Impervious Surface Area by Landsat and LiDAR: 2013 Update - Version 1," *umn.edu*, retrieved June 1, 2016, from *http://portal.gis.umn.edu/map_data_metadata/LandCover_MN2013.html*

Appendix I: North Stanchfield Lake (30-0143-00)

Land Cover

Land cover defined by the University of Minnesota [2016] for the North Stanchfield Lake Watershed is summarized in Table J-1. Row crops and grassland/managed grass comprise 28.3% and 10.0%, respectively, while urban lands cover about 4.9% of the watershed. Wetlands and forests comprise 35.2% and 15.4%, respectively, with open water covering the remaining 5.8% of the watershed.

Table I-1. North Stanchfield Lake Watershed Land Cover

Impairment	Open Water (%)	Wetlands (%)	Forest (%)	Grassland/ Managed Grass (%)	Hay/ Pastures (%)	Row Crops (%)	Urban (%)
North Stanchfield	5.8	35.2	15.4	10.0	0.4	28.3	4.9

Physical Characteristics

North Stanchfield Lake (30-0143-00) is a small lake that is located approximately 7 miles northeast of Princeton in Isanti County, Minnesota. The lake receives flows from South Stanchfield Lake along with flows from a large contributing watershed draining from the northeast. The lake has a general southwest-to-northeast configuration that covers a surface area of approximately 143 acres with a mean depth of approximately 4 feet. Lake bathymetry is depicted in Figure J-1 along with an aerial imagery of the immediate lakeshed.

North Stanchfield Lake is located in the NCHF ecoregion and, from a regulatory standpoint, is categorized as a shallow lake. Table J-2 lists select lake morphometric and watershed characteristics. North Stanchfield Lake does not have a listed public access. Recent lake-level fluctuations up to 2.0 feet were noted from recent DNR lake-level data depicted in Figure J-2.

The watershed for this lake covers 15,907 acres with a resulting very large watershed area to lake-surface area ratio of 111.2:1. Modeled water runoff indicate that the lake has a very short average water residence time of about 0.04 year (approximately 18 days) that translates into the lake's volume being flushed about 21 times a year. While the water residence times suggest that the lake's algae may be influenced by this flushing rate, North Stanchfield receives South Stanchfield Lake's flows, including algal export.

Water Quality

North Stanchfield Lake water quality data for the TMDL period (2006 through 2015) was monitored in 2013 and 2014 for TP, Chl-*a*, and Secchi transparency (Secchi) measurements. The TMDL-period growing-season averages for TP, Chl-*a*, and Secchi transparency with corresponding lake standards are summarized in Table J-3 for the paired lakes of South Stanchfield and North Stanchfield. Average TP, Chl-*a*, and Secchi values for North Stanchfield Lake exceeded state lake standards. North Stanchfield Lake's TP is over double the average value noted for South Stanchfield while its Chl-*a* concentrations were about one-half of the corresponding South Stanchfield Lake average value. Runoff volumes from the large watershed area cause rapid flushing of North Stanchfield Lake; hence, water residence times likely influence this lake's algal responses over the growing season. Average annual growing-season data are shown in Figures J-3 through J-5. The number of samples annually are shown in Table J-4.

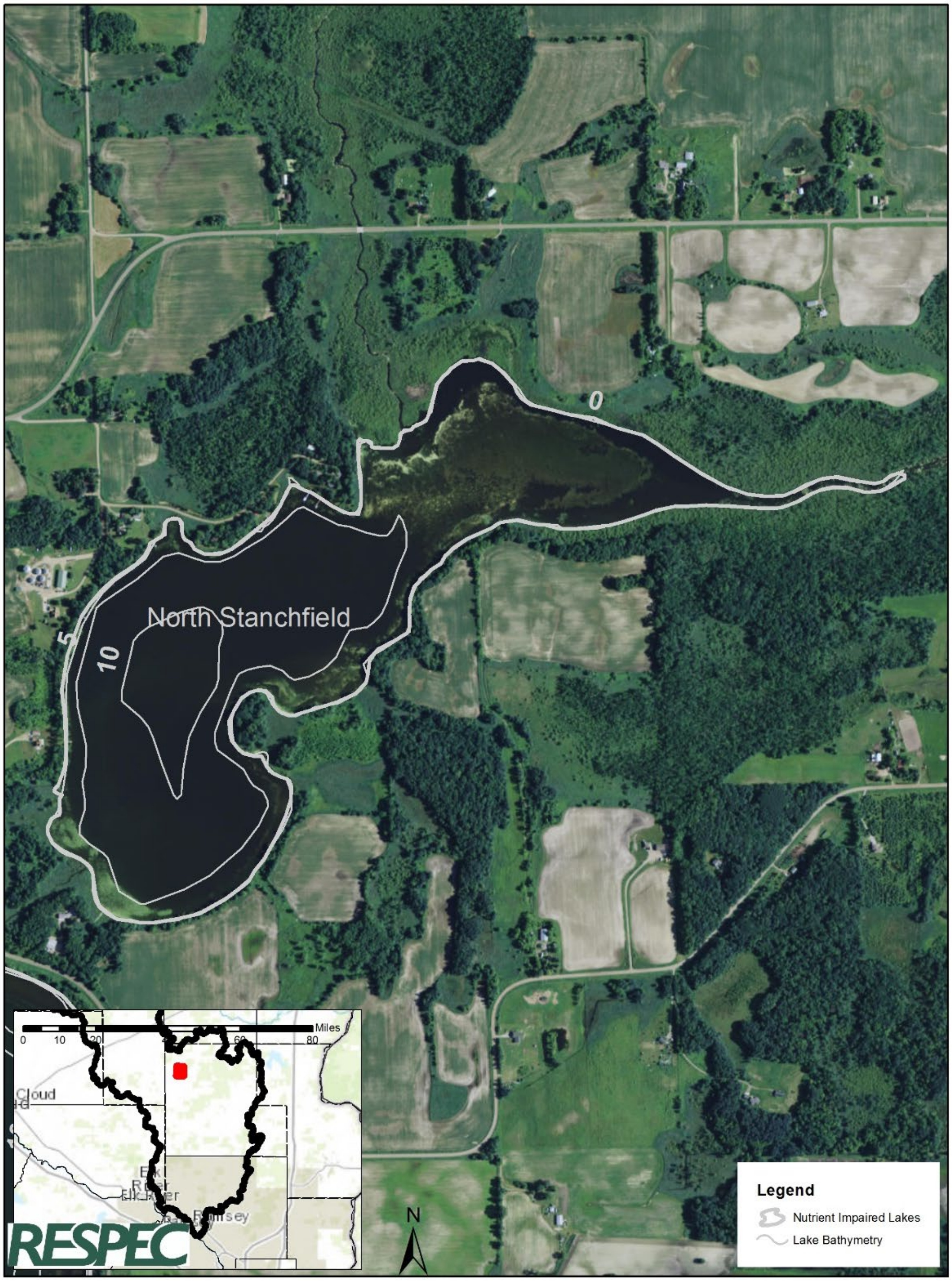


Figure I- 1. North Stanchfield Lake Bathymetry and Aerial Imagery.

Growing-season water quality data averaged by month from 2013 and 2014 are summarized in Figures J-6 to J-8. Plots of growing-season mean monthly TP show a general overall increase in TP concentrations and a decline in August followed by an increase in September. Chl-*a* data show a sharp peak of 67 micrograms per liter (µg/L) in August. Correspondingly, average monthly Secchi declines from approximately 1.2 meters (m) in June to about 0.7 m in September.

Table I-2. North Stanchfield Lake Select Lake Morphometric and Watershed Characteristics

Characteristic	North Stanchfield 30-0143	Source
Lake-Surface Area (acres)	143	DNR LakeFinder
Number of Islands	0	
Percent Lake Littoral Surface Area	100	DNR LakeFinder
Drainage Area, Including Lake acres (ac)/square kilometers (km^2)	15,907 ac/64.4 km^2	Model Subwatersheds
Watershed Area to Lake Area Ratio	111.2:1	Calculated
Wetland Area (% of watershed)	35.2	University of Minnesota [2016]
Number of Upland Lakes	Numerous small waterbodies and wetlands	US Geological Survey topographic maps
Lake Volume (acre-feet (ac-ft)/cubic hectometers (hm^3))	634 ac-ft/0.8 hm^3	Calculated
Mean Depth (ft/(m)	4.4 ft/1.3 mi	Calculated
Annual Lake-Level Fluctuations (ft):typical, maximum	1.9 ft	DNR Lake Levels
Maximum Depth (ft/mi)	11 ft/3.3 mi	DNR Lake Map
Maximum Fetch Length (miles (mi)/kilometers (km))	0.9 mi/0.3 km	Measured in Google Earth
Lake Geometry Ratio	8.0	Calculated
Osgood Index	2.6	Calculated
Estimated Water Residence Time (years/days)	0.05 year	Calculated
Public Access	NA	Dalbo Township
Shore Land Properties	10	Tabulated from US Geological Survey topographic maps
DNR Lake Class	NA	DNR

Dissolved Oxygen and Temperature Data Summary

The DO and temperature data monitored by depth were examined to better define lake-mixing patterns that affect biological responses and lake P dynamics. Available data from 2013 and 2014 are plotted in Figures J-9 and J-10 for temperature and DO, respectively.

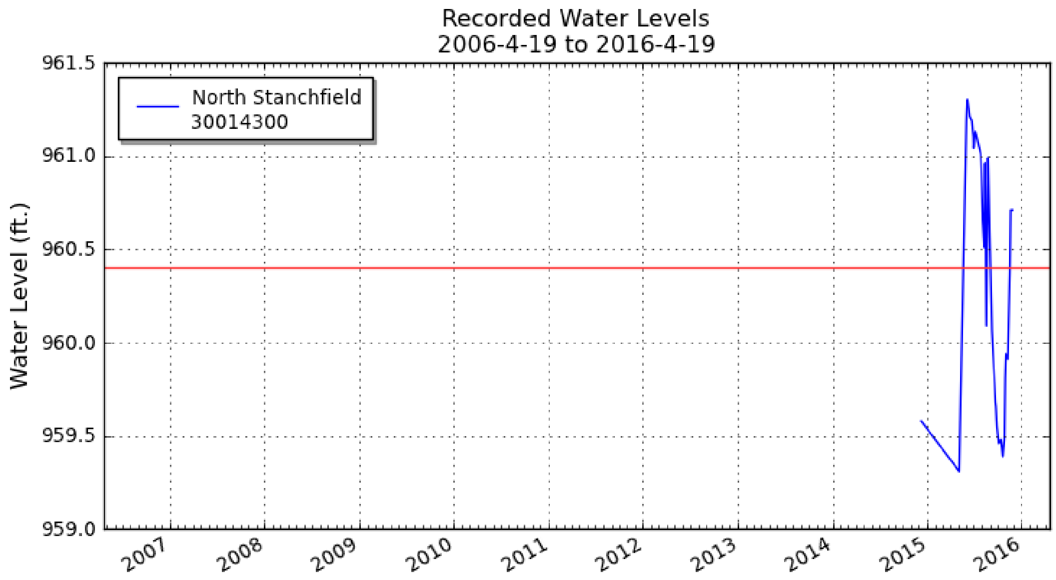


Figure I-2. North Stanchfield Lake Levels (DNR Lake-Level Program Graphic)

Table I-3. Total Maximum Daily Load Period Total Phosphorus, Chlorophyll-a, and Secchi Transparency Growing-Season Means for North and South Stanchfield Lakes

	Minimum	Mean	Maximum	Standard Deviation	Sample Number	Lake Standards
South Stanchfield Lake						
TP (µg/L)	46	83.0	117.0	31.4	4	≤ 60
Chlorophyll-*a* (µg/L)	5.5	74.7	193.0	60.3	8	≤ 20
Secchi disk depth (m)	0.5	1.0	2.0	0.61	8	≥ 1.0
North Stanchfield Lake						
TP (µg/L)	122.0	194.5	338.0	62.2	10	≤ 60
Chlorophyll-*a* (µg/L)	9.6	35.5	84.2	22.7	10	≤ 20
Secchi disk depth (m)	0.5	0.8	1.7	0.39	9	≥ 1.0

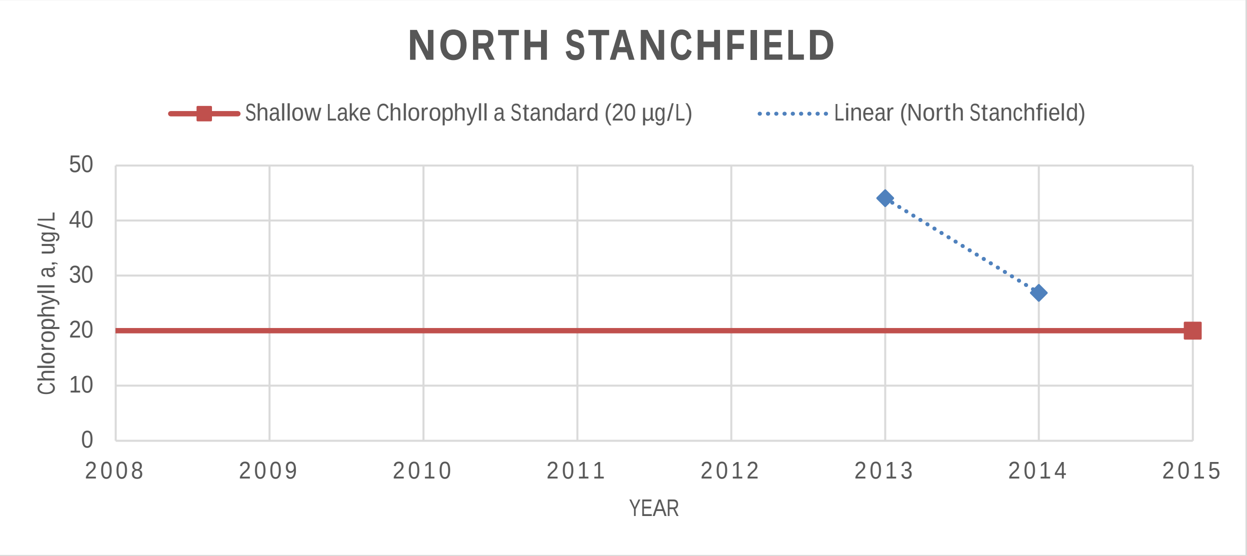


Figure I-3. Annual Growing-Season Mean of Total Phosphorus Concentrations for North Stanchfield Lake.

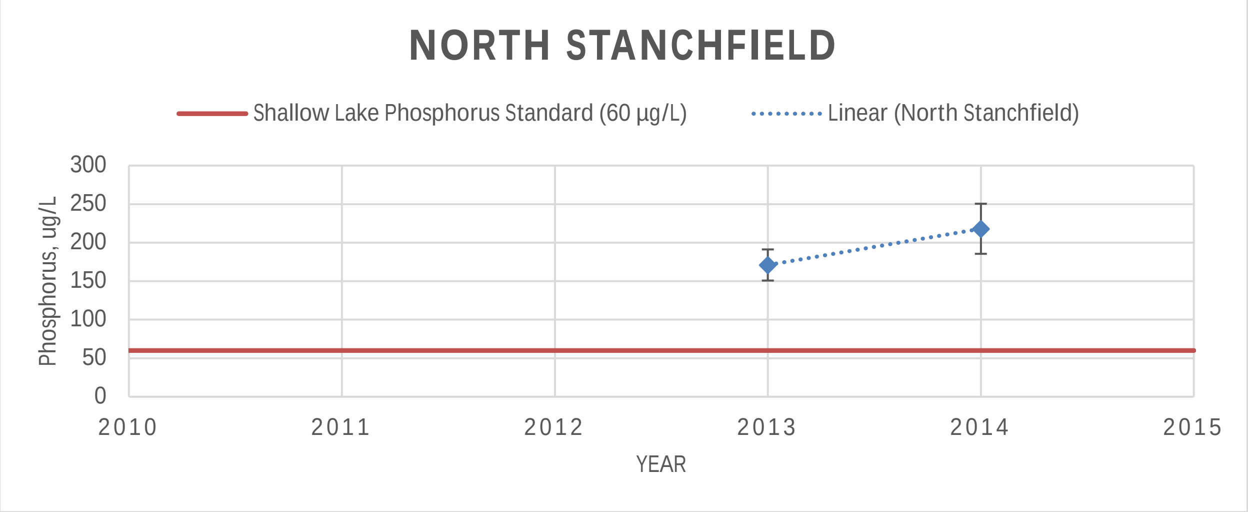


Figure I-4. Annual Growing-Season Mean of Chlorophyll-*a* Concentrations for North Stanchfield Lake.

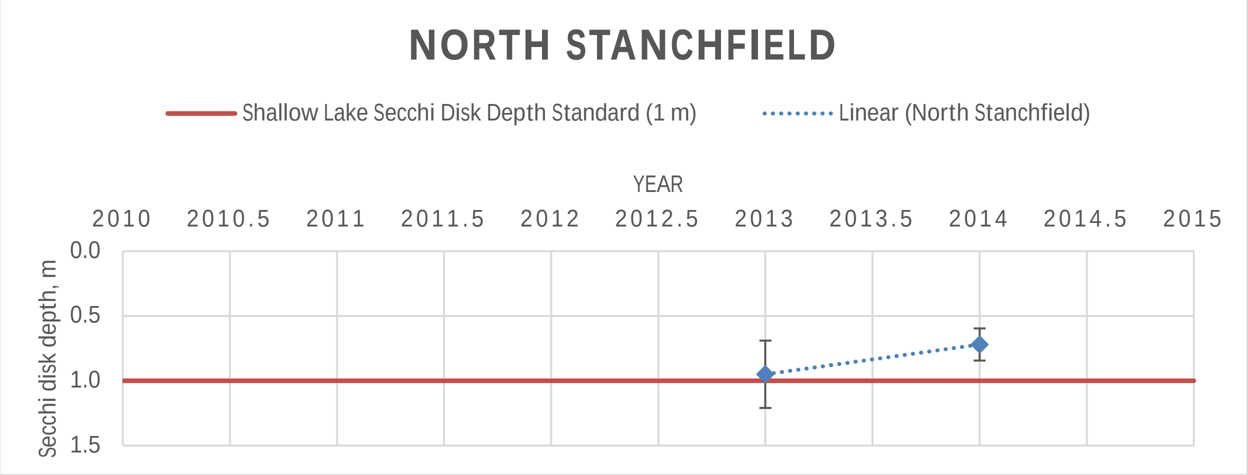


Figure I-5. Annual Growing-Season Mean of Secchi Transparency for North Stanchfield Lake.

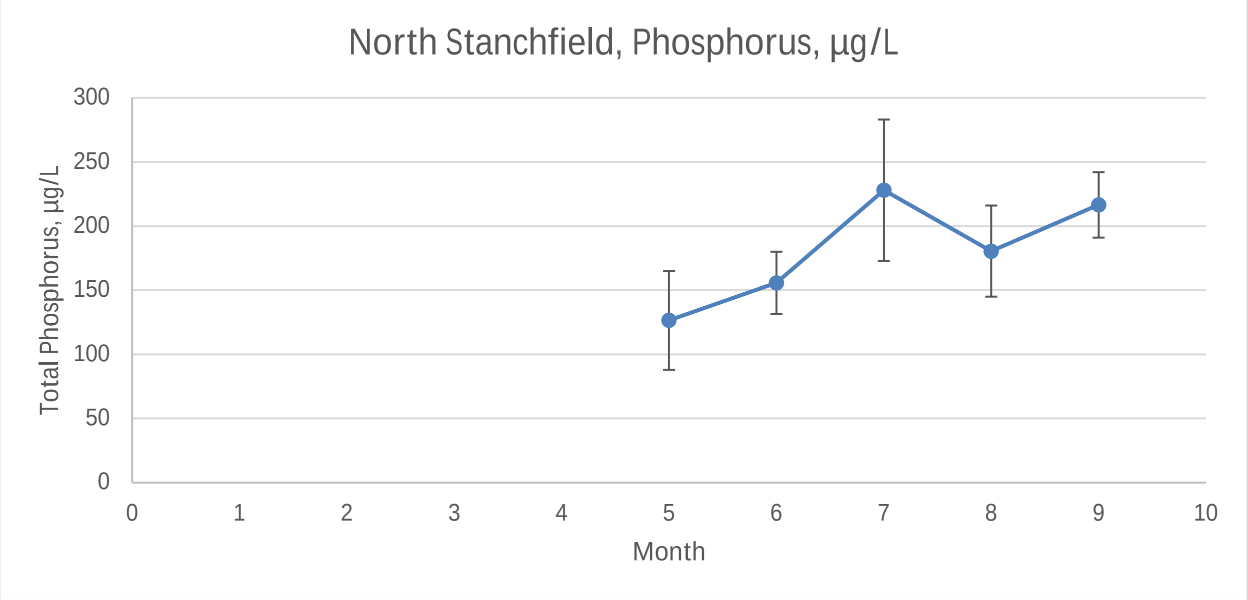


Figure I-6. Growing-Season Monthly Mean of Total Phosphorus for North Stanchfield Lake (All Available Data Between 2006–2015).

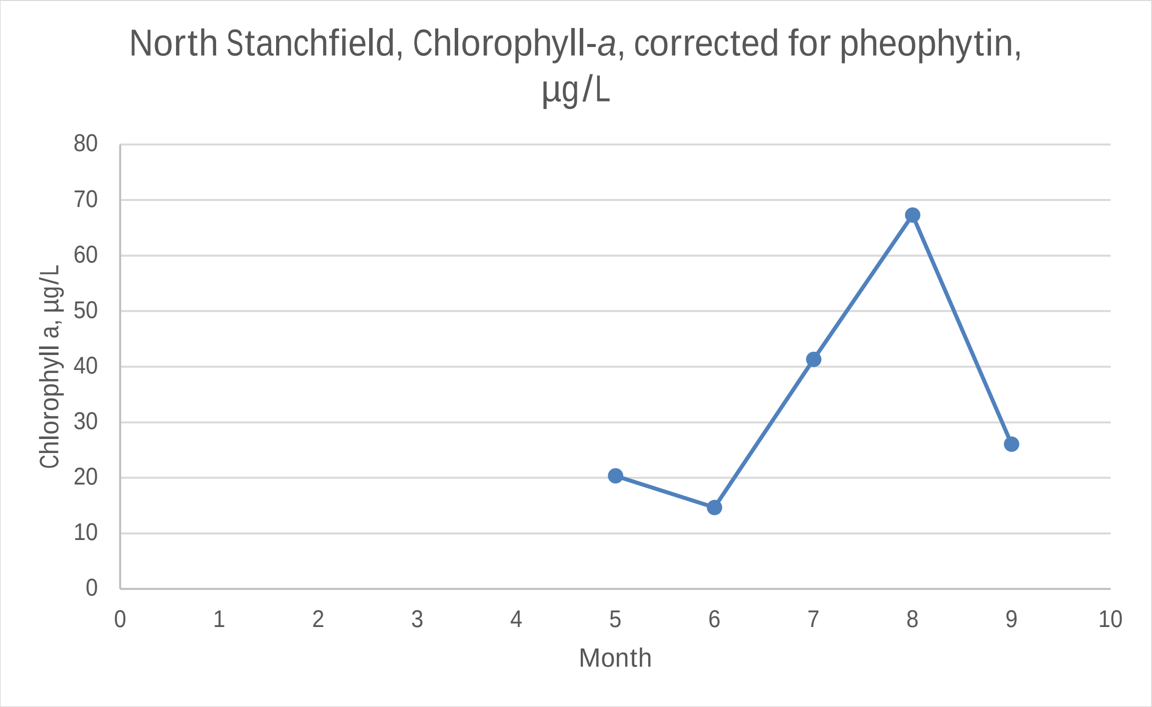


Figure I-7. Growing-Season Monthly Mean of Chlorophyll-*a* for North Stanchfield Lake (All Available Data Between 2006–2015).

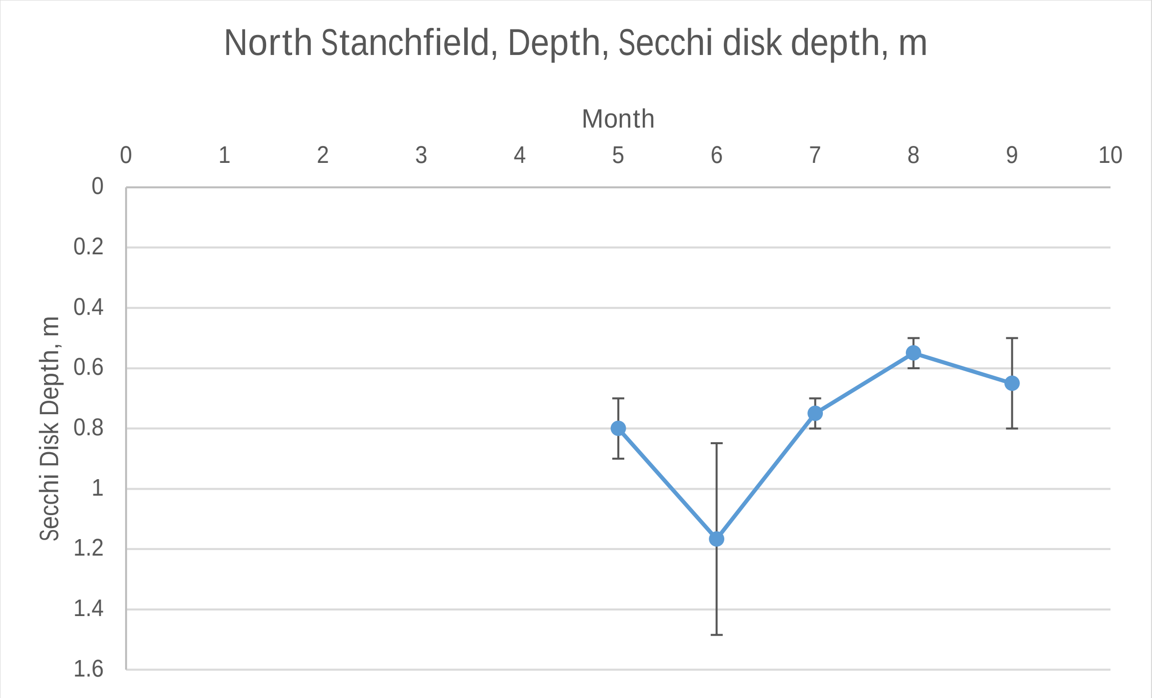


Figure I-8. Growing-Season Monthly Mean of Secchi Transparency for North Stanchfield Lake (All Available Data Between 2006–2015).

Table I-4. Total Phosphorus, Chlorophyll-a, and Secchi Transparency Number of Samples Annually for North Stanchfield Lake

Lake	Constituent	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
North Stanchfield	TP								5	5		10
	Chl-*a*								5	5		10
	Secchi								4	5		9

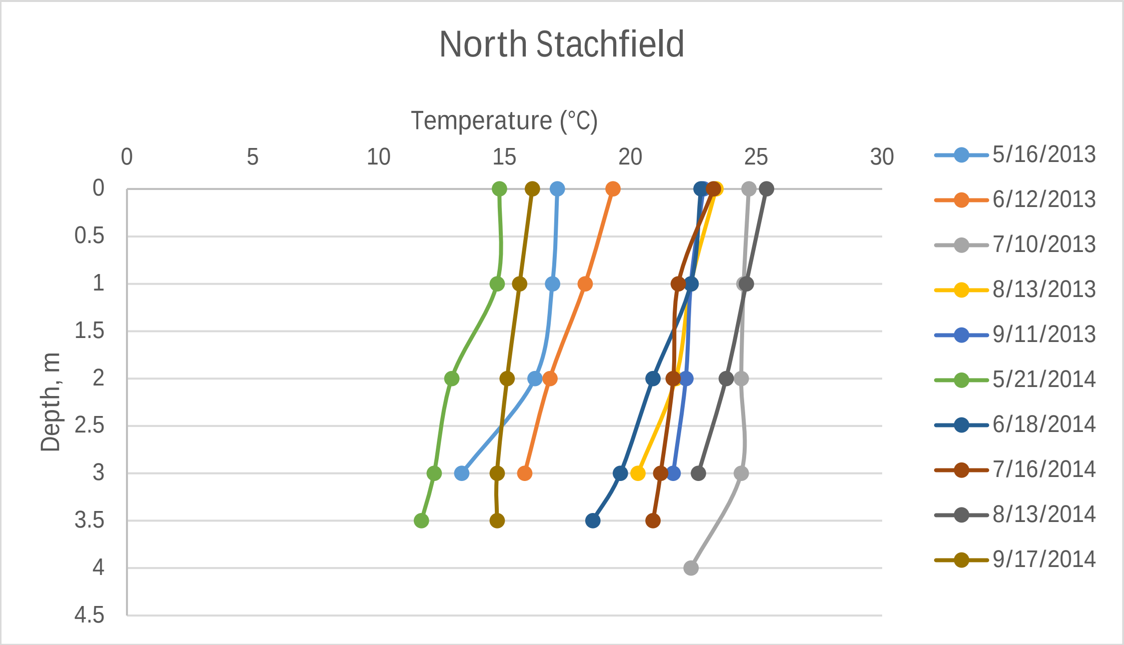


Figure I-9. Lake Temperature Profiles for North Stanchfield Lake.

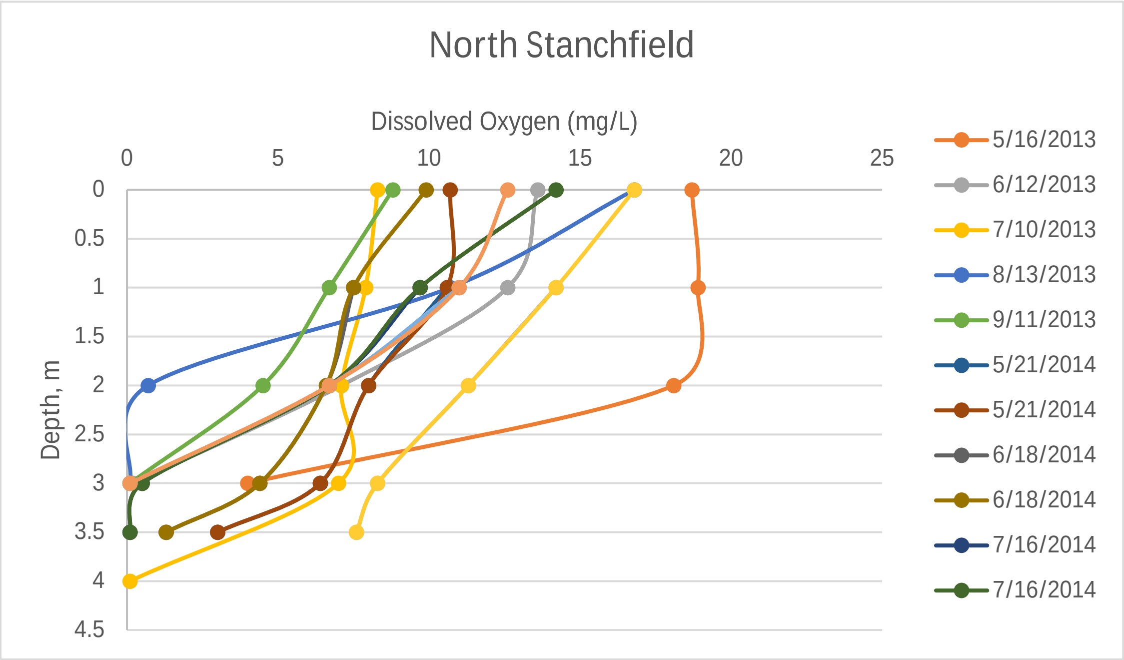


Figure I-10. Dissolved Oxygen Profiles for North Stanchfield Lake.

Water-temperature profiles as shown in Figure J-9 indicate relatively well-mixed conditions with temperatures relatively similar from the surface to depth. Peak monitored summer bottom water temperatures (July through September) ranged from approximately 18° to 24°C.

The DO profile data typically exhibited substantial concentration losses with depth, which indicates that excessive oxygen depletion rates are occurring, as shown in Figure J-10. North Stanchfield Lake exhibited substantial growing-season oxygen depletion rates with DO values typically decreasing to values less than 2 milligrams per liter (mg/L) at the deepest depths. This lake has been noted to frequently experience winterkill. Accordingly, an internal loading component was included in the BATHTUB P budget for North Stanchfield Lake.

Aquatic Plants

A Minnesota biological survey of aquatic plant species was conducted on the northwestern shore of North Stanchfield Lake on June 17, 2013. This report found 13 species of submersed, free-floating, floating-leaf, and emergent plants. The exotic invasive species curly-leaf pondweed (*Potamogetagon Crispus*) was noted in this survey. Seven species of shoreline plants were identified.

Fisheries

North Stanchfield Lake is managed as a warm-water gamefish lake that frequently experiences winterkills. In the most recent DNR Fisheries survey of July 29, 1991, large populations of black bullheads and common carp were detailed.

References

University of Minnesota, 2016. "Metadata, Minnesota Land Cover Classification and Impervious Surface Area by Landsat and LiDAR: 2013 Update - Version 1," *umn.edu*, retrieved June 1, 2016, from *http://portal.gis.umn.edu/map_data_metadata/LandCover_MN2013.html*

Appendix J: Lake Data Summary

Table J-1. Lake Data Summary

Lake	BATHTUB Models Employed		
	Phosphorus	Chlorophyll-*a*	Secchi
Baxter	8	4	1
East Hunter	8	4	1
West Hunter	8	4	1
Francis	8	2	1
Long	8	2	1
South Stanchfield	8	2	1
North Stanchfield	8	2	1
Green	8	2	1
Skogman	8	2	1
Fannie	8	2	1
Rogers	4	4	1

Phosphorus Model 8: Canfield and Bachmann Lakes
Phosphorus Model 4: Canfield and Bachmann, Reservoir
Chlorophyll-a Model 4: P, Linear
Chlorophyll-a Model 2: P, light, turbidity
Secchi Model 1: Chlorophyll-a and turbidity

Appendix K: Lake Sediment Sample Results

Table K-1. 2014 Lake Sediment Sample Analytical Results by Lake

Lake	Lake Area (sq km)	Mean Depth (m)	TP Mean (µg/l)	Sediment Data–Laboratory Results		
				P Iron Adsorbed (BD-P) mg/g dry	P Total as P mg/g dry	Organic Matter (% Wt)
Baxter	0.36	1.52	97	0.094	1.1	0.37
Francis	1.07	1.6	421	0.096	1	0.38
Long-1	1.54	1.3	118	0.075	1.3	0.33
Long-2	1.54	1.3	118	0.084	1.1	0.34
Little Stanchfield	0.59	1.7	154	0.27	1.2	0.28
South Stanchfield	1.66	2.4	164	0.024	1	0.24
Fannie-1	1.43	2.5	46	0.26	3.9	0.4
Fannie-2	1.43	2.5	46	0.026	2	0.43
Skogman-1	0.9	3.9	43	0.1	5.9	0.45
Skogman-2	0.9	3.9	43	0.43	2.6	0.39
Green	3.37	4.9	52	0.02	1.1	0.31
Lory	0.87	1.4	18.6	0.039	0.95	0.49
Blue-1	1.06	2.68	35	0.3	3.1	0.3
Blue-2	1.06	2.68	35	0.09	0.96	0.26
George	1.97	2.37	27	0.27	2.1	0.36

Appendix L: BATHTUB Input and Model Summary

Baxter Cal Final.btb

Vers 6.14 (09/26/2011)

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Vers 6.14 (09/26/2011)

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4,"Global Parmameters"
1,"AVERAGING PERIOD
(YRS)",1,0
2,"PRECIPITATION
(METERS)",.78,0
3,"EVAPORATION
(METERS)",.75,0
4,"INCREASE IN STORAGE
(METERS)",0,0
12,"Model Options"
1,"CONSERVATIVE
SUBSTANCE",0
2,"PHOSPHORUS BALANCE",8
3,"NITROGEN BALANCE",0
4,"CHLOROPHYLL-A",4
5,"SECCHI DEPTH",1
6,"DISPERSION",1
7,"PHOSPHORUS
CALIBRATION",2
8,"NITROGEN CALIBRATION",2
9,"ERROR ANALYSIS",1
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",1,.45
3,"N DECAY RATE",1,.55
4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA  M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",.33,0
15,"Avail Factor - Ortho
P",1.93,0
16,"Avail Factor - TN",.59,0
17,"Avail Factor - Inorganic
N",.79,0
5,"Atmospheric Loads"
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2,"TOTAL P",26.8,.5
3,"TOTAL N",1000,.5
4,"ORTHO P",13,.5
5,"INORGANIC N",500,.5
1,"Segments"
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0,0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",.55,0
1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,1,0
1,"TOTAL P
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1,"TOTAL N    MG/M3",0,0,1,0
1,"CHL-A
MG/M3",31.47,.45,1.539628,0
1,"SECCHI         M",1.6,.06,1.4,0
1,"ORGANIC N  MG/M3",0,0,1,0
1,"TP-ORTHO-P MG/M3",0,0,1,0
1,"HOD-V  MG/M3-DAY",0,0,1,0
1,"MOD-V  MG/M3-DAY",0,0,1,0
4,"Tributaries"
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1,"TOTAL P",99.4,.03
1,"TOTAL N",0,0
1,"ORTHO P",46.3,.06
1,"INORGANIC N",0,0
1,"LandUses",0,0,0,0,0,0,0,0
2,"West Hunter
Discharge",1,1,2.3,.506,0,0
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2,"TOTAL P",72,.06
2,"TOTAL N",0,0
2,"ORTHO P",19.6,.11
2,"INORGANIC N",0,0
2,"LandUses",0,0,0,0,0,0,0,0
3,"East Hunter
SSTS",1,1,.001,.0003,0,0
3,"CONSERVATIVE SUBST.",0,0
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3,"TOTAL N",0,0
3,"ORTHO P",0,0
3,"INORGANIC N",0,0
3,"LandUses",0,0,0,0,0,0,0,0
4,"Outlet",1,4,2.8,.6,.15,0
4,"CONSERVATIVE SUBST.",0,0
4,"TOTAL P",49,.06
4,"TOTAL N",0,0
4,"ORTHO P",12.5,.08
4,"INORGANIC N",0,0
4,"LandUses",0,0,0,0,0,0,0,0
0,"Channels"
8,"Land Use Export Categories"
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1,"CONSERVATIVE SUBST.",0,0
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1,"TOTAL N",0,0
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1,"INORGANIC N",0,0
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2,"Runoff",0,0
2,"CONSERVATIVE SUBST.",0,0
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2,"TOTAL N",0,0
2,"ORTHO P",0,0
2,"INORGANIC N",0,0
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3,"Runoff",0,0
3,"CONSERVATIVE SUBST.",0,0
3,"TOTAL P",0,0
3,"TOTAL N",0,0
3,"ORTHO P",0,0
3,"INORGANIC N",0,0
4,"landuse4"
4,"Runoff",0,0
4,"CONSERVATIVE SUBST.",0,0
4,"TOTAL P",0,0
4,"TOTAL N",0,0
4,"ORTHO P",0,0
4,"INORGANIC N",0,0
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5,"Runoff",0,0
5,"CONSERVATIVE SUBST.",0,0
5,"TOTAL P",0,0
5,"TOTAL N",0,0
5,"ORTHO P",0,0
5,"INORGANIC N",0,0
6,""
6,"Runoff",0,0
6,"CONSERVATIVE SUBST.",0,0
6,"TOTAL P",0,0
6,"TOTAL N",0,0
6,"ORTHO P",0,0
6,"INORGANIC N",0,0
7,""
7,"Runoff",0,0
7,"CONSERVATIVE SUBST.",0,0
7,"TOTAL P",0,0
7,"TOTAL N",0,0
7,"ORTHO P",0,0
7,"INORGANIC N",0,0
8,""
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8,"CONSERVATIVE SUBST.",0,0
8,"TOTAL P",0,0
8,"TOTAL N",0,0
8,"ORTHO P",0,0
8,"INORGANIC N",0,0
"Notes"
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East Hunter Reduced Cal Final.btb

Vers 6.14 (09/26/2011)

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4,"Global Parmameters"
1,"AVERAGING PERIOD (YRS)",1,0
2,"PRECIPITATION (METERS)",.78,0
3,"EVAPORATION (METERS)",.75,0
4,"INCREASE IN STORAGE (METERS)",0,0
12,"Model Options"
1,"CONSERVATIVE SUBSTANCE",0
2,"PHOSPHORUS BALANCE",8
3,"NITROGEN BALANCE",0
4,"CHLOROPHYLL-A",4
5,"SECCHI DEPTH",1
6,"DISPERSION",1
7,"PHOSPHORUS CALIBRATION",2
8,"NITROGEN CALIBRATION",2
9,"ERROR ANALYSIS",1
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",1,.45
3,"N DECAY RATE",1,.55
4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA  M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",.33,0
15,"Avail Factor - Ortho P",1.93,0
16,"Avail Factor - TN",.59,0
17,"Avail Factor - Inorganic N",.79,0
5,"Atmospheric Loads"
1,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",26.8,.5
3,"TOTAL N",1000,.5
4,"ORTHO P",13,.5
5,"INORGANIC N",500,.5
1,"Segments"
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1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,1,0
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1,"SECCHI         M",1.6,.06,1.4,0
1,"ORGANIC N  MG/M3",0,0,1,0
1,"TP-ORTHO-P MG/M3",0,0,1,0
1,"HOD-V  MG/M3-DAY",0,0,1,0
1,"MOD-V  MG/M3-DAY",0,0,1,0
4,"Tributaries"
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1,"TOTAL N",0,0
1,"ORTHO P",46.3,.06
1,"INORGANIC N",0,0
1,"LandUses",0,0,0,0,0,0,0,0,0
2,"West Hunter Discharge",1,1,2.3,.506,0,0
2,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",65,.06
2,"TOTAL N",0,0
2,"ORTHO P",19.6,.11
2,"INORGANIC N",0,0
2,"LandUses",0,0,0,0,0,0,0,0,0
3,"East Hunter SSTS",1,1,.001,.00001,0,0
3,"CONSERVATIVE SUBST.",0,0
3,"TOTAL P",10000,.3
3,"TOTAL N",0,0
3,"ORTHO P",0,0
3,"INORGANIC N",0,0
3,"LandUses",0,0,0,0,0,0,0,0,0
4,"Outlet",1,4,2.8,.6,.15,0
4,"CONSERVATIVE SUBST.",0,0
4,"TOTAL P",49,.06
4,"TOTAL N",0,0
4,"ORTHO P",12.5,.08
4,"INORGANIC N",0,0
4,"LandUses",0,0,0,0,0,0,0,0,0
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8,"Land Use Export Categories"
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1,"TOTAL N",0,0
1,"ORTHO P",0,0
1,"INORGANIC N",0,0
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2,"Runoff",0,0
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2,"TOTAL P",0,0
2,"TOTAL N",0,0
2,"ORTHO P",0,0
2,"INORGANIC N",0,0
3,"landuse3"
3,"Runoff",0,0
3,"CONSERVATIVE SUBST.",0,0
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3,"TOTAL N",0,0
3,"ORTHO P",0,0
3,"INORGANIC N",0,0
4,"landuse4"
4,"Runoff",0,0
4,"CONSERVATIVE SUBST.",0,0
4,"TOTAL P",0,0
4,"TOTAL N",0,0
4,"ORTHO P",0,0
4,"INORGANIC N",0,0
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5,"Runoff",0,0
5,"CONSERVATIVE SUBST.",0,0
5,"TOTAL P",0,0
5,"TOTAL N",0,0
5,"ORTHO P",0,0
5,"INORGANIC N",0,0
6,""
6,"Runoff",0,0
6,"CONSERVATIVE SUBST.",0,0
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6,"ORTHO P",0,0
6,"INORGANIC N",0,0
7,""
7,"Runoff",0,0
7,"CONSERVATIVE SUBST.",0,0
7,"TOTAL P",0,0
7,"TOTAL N",0,0
7,"ORTHO P",0,0
7,"INORGANIC N",0,0
8,""
8,"Runoff",0,0
8,"CONSERVATIVE SUBST.",0,0
8,"TOTAL P",0,0
8,"TOTAL N",0,0
8,"ORTHO P",0,0
8,"INORGANIC N",0,0
"Notes"
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Fannie Cal Final.btb

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Vers 6.14 (09/26/2011)
Fannie Lake Model
4,"Global Parmameters"
1,"AVERAGING PERIOD (YRS)",1,0
2,"PRECIPITATION (METERS)",.77,.06
3,"EVAPORATION (METERS)",.75,.3
4,"INCREASE IN STORAGE (METERS)",0,0
12,"Model Options"
1,"CONSERVATIVE SUBSTANCE",0
2,"PHOSPHORUS BALANCE",8
3,"NITROGEN BALANCE",0
4,"CHLOROPHYLL-A",2
5,"SECCHI DEPTH",1
6,"DISPERSION",1
7,"PHOSPHORUS CALIBRATION",2
8,"NITROGEN CALIBRATION",2
9,"ERROR ANALYSIS",1
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",.9734567,.45
3,"N DECAY RATE",1,.55
4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA  M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",.33,0
15,"Avail Factor - Ortho P",1.93,0
16,"Avail Factor - TN",.59,0
17,"Avail Factor - Inorganic N",.79,0
5,"Atmospheric Loads"
1,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",26.8,.5
3,"TOTAL N",1000,.5
4,"ORTHO P",14,.5
5,"INORGANIC N",500,.5
1,"Segments"
1,"Fannie",0,1,1.28,2.61,2.92,2.6,.12,4,.2,.08,1.47,0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",0,0
1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,1,0
1,"TOTAL P MG/M3",44.11,.07,.7639023,0
1,"TOTAL N    MG/M3",0,0,1,0
1,"CHL-A MG/M3",25.56,.16,1.066135,0
1,"SECCHI M",1.69,.05,1.2,0
1,"ORGANIC N  MG/M3",0,0,1,0
1,"TP-ORTHO-P MG/M3",0,0,1,0
1,"HOD-V  MG/M3-DAY",0,0,1,0
1,"MOD-V  MG/M3-DAY",0,0,1,0
5,"Tributaries"
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1,"TOTAL P",50,.06
1,"TOTAL N",0,0
1,"ORTHO P",30.1,.31
1,"INORGANIC N",0,0
1,"LandUses",0,0,0,0,0,0,0,0
2,"MS4",1,1,1.74,.4,.04,0
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2,"TOTAL N",0,0
2,"ORTHO P",101.5,.1
2,"INORGANIC N",0,0
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3,"INORGANIC N",0,0
3,"LandUses",0,0,0,0,0,0,0,0
4,"Outflow",1,4,31.2,5.44,.16,0
4,"CONSERVATIVE SUBST.",0,0
4,"TOTAL P",82.85,.04
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4,"ORTHO P",12.94,.04
4,"INORGANIC N",0,0
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5,"TOTAL N",0,0
5,"ORTHO P",10000,.3
5,"INORGANIC N",0,0
5,"LandUses",0,0,0,0,0,0,0,0
0,"Channels"
8,"Land Use Export Categories"
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1,"TOTAL N",0,0
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2,"TOTAL N",0,0
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2,"INORGANIC N",0,0
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3,"Runoff",0,0
3,"CONSERVATIVE SUBST.",0,0
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3,"TOTAL N",0,0
3,"ORTHO P",0,0
3,"INORGANIC N",0,0
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4,"TOTAL N",0,0
4,"ORTHO P",0,0
4,"INORGANIC N",0,0
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5,"TOTAL N",0,0
5,"ORTHO P",0,0
5,"INORGANIC N",0,0
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6,"TOTAL N",0,0
6,"ORTHO P",0,0
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8,"ORTHO P",0,0
8,"INORGANIC N",0,0
"Notes"
Atmospheric from MPCA 2007 and includes dry and wet deposition for Upper Miss. Basin
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Fannie Reduced v2 Final.btb

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Vers 6.14 (09/26/2011)
Fannie Lake Model
4,"Global Parmameters"
1,"AVERAGING PERIOD
(YRS)",1,0
2,"PRECIPITATION
(METERS)",.77,.06
3,"EVAPORATION
(METERS)",.75,.3
4,"INCREASE IN STORAGE
(METERS)",0,0
12,"Model Options"
1,"CONSERVATIVE
SUBSTANCE",0
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3,"NITROGEN BALANCE",0
4,"CHLOROPHYLL-A",2
5,"SECCHI DEPTH",1
6,"DISPERSION",1
7,"PHOSPHORUS
CALIBRATION",2
8,"NITROGEN CALIBRATION",2
9,"ERROR ANALYSIS",1
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",.9734567,.45
3,"N DECAY RATE",1,.55
4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA  M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",.33,0
15,"Avail Factor - Ortho
P",1.93,0
16,"Avail Factor - TN",.59,0
17,"Avail Factor - Inorganic
N",.79,0
5,"Atmospheric Loads"
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2,"TOTAL P",26.8,.5
3,"TOTAL N",1000,.5
4,"ORTHO P",14,.5
5,"INORGANIC N",500,.5
1,"Segments"
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1,"TOTAL P",0,0
1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,1,0
1,"TOTAL P
MG/M3",44.11,.07,.7639023,0
1,"TOTAL N     MG/M3",0,0,1,0
1,"CHL-A
MG/M3",25.56,.16,1.066135,0
1,"SECCHI
M",1.69,.05,1.2,0
1,"ORGANIC N  MG/M3",0,0,1,0
1,"TP-ORTHO-P MG/M3",0,0,1,0
1,"HOD-V  MG/M3-DAY",0,0,1,0
1,"MOD-V  MG/M3-DAY",0,0,1,0
5,"Tributaries"
1,"Fannie Tributary
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1,"INORGANIC N",0,0
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3,"INORGANIC N",0,0
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4,"Outflow",1,4,31.2,5.44,.16,0
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4,"TOTAL N",0,0
4,"ORTHO P",12.94,.04
4,"INORGANIC N",0,0
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5,"INORGANIC N",0,0
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8,"Land Use Export Categories"
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1,"ORTHO P",0,0
1,"INORGANIC N",0,0
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2,"Runoff",0,0
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2,"TOTAL P",0,0
2,"TOTAL N",0,0
2,"ORTHO P",0,0
2,"INORGANIC N",0,0
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3,"Runoff",0,0
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3,"TOTAL N",0,0
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6,"Runoff",0,0
6,"CONSERVATIVE SUBST.",0,0
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6,"TOTAL N",0,0
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6,"INORGANIC N",0,0
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7,"Runoff",0,0
7,"CONSERVATIVE SUBST.",0,0
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7,"TOTAL N",0,0
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7,"INORGANIC N",0,0
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8,"Runoff",0,0
8,"CONSERVATIVE SUBST.",0,0
8,"TOTAL P",0,0
8,"TOTAL N",0,0
8,"ORTHO P",0,0
8,"INORGANIC N",0,0
"Notes"
Atmospheric from MPCA 2007
and includes dry and wet
deposition for Upper Miss. Basin
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Francis Cal Final.btb

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Vers 6.14 (09/26/2011)
Francis Lake Model
4,"Global Parmameters"
1,"AVERAGING PERIOD (YRS)",1,0
2,"PRECIPITATION (METERS)",.77,.06
3,"EVAPORATION (METERS)",.75,.3
4,"INCREASE IN STORAGE (METERS)",0,0
12,"Model Options"
1,"CONSERVATIVE SUBSTANCE",0
2,"PHOSPHORUS BALANCE",8
3,"NITROGEN BALANCE",0
4,"CHLOROPHYLL-A",2
5,"SECCHI DEPTH",1
6,"DISPERSION",1
7,"PHOSPHORUS CALIBRATION",2
8,"NITROGEN CALIBRATION",2
9,"ERROR ANALYSIS",1
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",1,.45
3,"N DECAY RATE",1,.55
4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA  M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",.33,0
15,"Avail Factor - Ortho P",1.93,0
16,"Avail Factor - TN",.59,0
17,"Avail Factor - Inorganic N",.79,0
5,"Atmospheric Loads"
1,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",26.8,.2
3,"TOTAL N",1000,.5
4,"ORTHO P",13,.3
5,"INORGANIC N",500,.5
1,"Segments"
1,"Francis",0,1,1.07,1.52,1.46,1.5,.12,0,0,.08,11.63,0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",5.5,0
1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,1,0
1,"TOTAL P MG/M3",235,.3,.9979488,0
1,"TOTAL N    MG/M3",0,0,1,0
1,"CHL-A MG/M3",108.63,.32,1.140388,0
1,"SECCHI         M",.5,.06,1.5,0
1,"ORGANIC N  MG/M3",0,0,1,0
1,"TP-ORTHO-P MG/M3",0,0,1,0
1,"HOD-V  MG/M3-DAY",0,0,1,0
1,"MOD-V  MG/M3-DAY",0,0,1,0
4,"Tributaries"
1,"Francis Tributary 359",1,1,18.8,3.43,.15,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",149.13,.05
1,"TOTAL N",0,0
1,"ORTHO P",90.7,.07
1,"INORGANIC N",0,0
1,"LandUses",0,0,0,0,0,0,0,0
2,"Lakeshed",1,1,1.97,.39,.14,0
2,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",143.1,.04
2,"TOTAL N",0,0
2,"ORTHO P",84.97,.06
2,"INORGANIC N",0,0
2,"LandUses",0,0,0,0,0,0,0,0
3,"Francis SSTS",1,1,.01,.003724,.3,0
3,"CONSERVATIVE SUBST.",0,0
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3,"TOTAL N",0,0
3,"ORTHO P",10000,.3
3,"INORGANIC N",0,0
3,"LandUses",0,0,0,0,0,0,0,0
4,"Outlet",1,4,21.9,3.96,.16,0
4,"CONSERVATIVE SUBST.",0,0
4,"TOTAL P",143.1,.04
4,"TOTAL N",0,0
4,"ORTHO P",84.6,.06
4,"INORGANIC N",0,0
4,"LandUses",0,0,0,0,0,0,0,0
0,"Channels"
8,"Land Use Export Categories"
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1,"Runoff",0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",0,0
1,"TOTAL N",0,0
1,"ORTHO P",0,0
1,"INORGANIC N",0,0
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2,"ORTHO P",0,0
2,"INORGANIC N",0,0
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3,"Runoff",0,0
3,"CONSERVATIVE SUBST.",0,0
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3,"TOTAL N",0,0
3,"ORTHO P",0,0
3,"INORGANIC N",0,0
4,"landuse4"
4,"Runoff",0,0
4,"CONSERVATIVE SUBST.",0,0
4,"TOTAL P",0,0
4,"TOTAL N",0,0
4,"ORTHO P",0,0
4,"INORGANIC N",0,0
5,""
5,"Runoff",0,0
5,"CONSERVATIVE SUBST.",0,0
5,"TOTAL P",0,0
5,"TOTAL N",0,0
5,"ORTHO P",0,0
5,"INORGANIC N",0,0
6,""
6,"Runoff",0,0
6,"CONSERVATIVE SUBST.",0,0
6,"TOTAL P",0,0
6,"TOTAL N",0,0
6,"ORTHO P",0,0
6,"INORGANIC N",0,0
7,""
7,"Runoff",0,0
7,"CONSERVATIVE SUBST.",0,0
7,"TOTAL P",0,0
7,"TOTAL N",0,0
7,"ORTHO P",0,0
7,"INORGANIC N",0,0
8,""
8,"Runoff",0,0
8,"CONSERVATIVE SUBST.",0,0
8,"TOTAL P",0,0
8,"TOTAL N",0,0
8,"ORTHO P",0,0
8,"INORGANIC N",0,0
"Notes"
MPCA average year total deposition for Upper Miss. Basin used and assumed 50% for Ortho P
```

Francis Reduced Cal Final.btb

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Vers 6.14 (09/26/2011)
Francis Lake Model
4,"Global Parmameters"
1,"AVERAGING PERIOD (YRS)",1,0
2,"PRECIPITATION (METERS)",.77,.06
3,"EVAPORATION (METERS)",.75,.3
4,"INCREASE IN STORAGE (METERS)",0,0
12,"Model Options"
1,"CONSERVATIVE SUBSTANCE",0
2,"PHOSPHORUS BALANCE",8
3,"NITROGEN BALANCE",0
4,"CHLOROPHYLL-A",2
5,"SECCHI DEPTH",1
6,"DISPERSION",1
7,"PHOSPHORUS CALIBRATION",2
8,"NITROGEN CALIBRATION",2
9,"ERROR ANALYSIS",1
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",1,.45
3,"N DECAY RATE",1,.55
4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA  M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",.33,0
15,"Avail Factor - Ortho P",1.93,0
16,"Avail Factor - TN",.59,0
17,"Avail Factor - Inorganic N",.79,0
5,"Atmospheric Loads"
1,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",26.8,.2
3,"TOTAL N",1000,.5
4,"ORTHO P",13,.3
5,"INORGANIC N",500,.5
1,"Segments"
1,"Francis",0,1,1.07,1.52,1.46,1.5,.12,0,0,.08,11.63,0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",0,0
1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,1,0
1,"TOTAL P MG/M3",235,.3,.9979488,0
1,"TOTAL N    MG/M3",0,0,1,0
1,"CHL-A MG/M3",108.63,.32,1.140388,0
1,"SECCHI         M",.5,.06,1.5,0
1,"ORGANIC N  MG/M3",0,0,1,0
1,"TP-ORTHO-P MG/M3",0,0,1,0
1,"HOD-V  MG/M3-DAY",0,0,1,0
1,"MOD-V  MG/M3-DAY",0,0,1,0
4,"Tributaries"
1,"Francis Tributary 359",1,1,18.8,3.43,.15,0
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1,"TOTAL N",0,0
1,"ORTHO P",45,.07
1,"INORGANIC N",0,0
1,"LandUses",0,0,0,0,0,0,0,0
2,"Lakeshed",1,1,1.97,.39,.14,0
2,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",105,.04
2,"TOTAL N",0,0
2,"ORTHO P",42,.06
2,"INORGANIC N",0,0
2,"LandUses",0,0,0,0,0,0,0,0
3,"Francis SSTS",1,1,.01,.003724,.3,0
3,"CONSERVATIVE SUBST.",0,0
3,"TOTAL P",1,.3
3,"TOTAL N",0,0
3,"ORTHO P",10000,.3
3,"INORGANIC N",0,0
3,"LandUses",0,0,0,0,0,0,0,0
4,"Outlet",1,4,21.9,3.96,.16,0
4,"CONSERVATIVE SUBST.",0,0
4,"TOTAL P",143.1,.04
4,"TOTAL N",0,0
4,"ORTHO P",84.6,.06
4,"INORGANIC N",0,0
4,"LandUses",0,0,0,0,0,0,0,0
0,"Channels"
8,"Land Use Export Categories"
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1,"TOTAL N",0,0
1,"ORTHO P",0,0
1,"INORGANIC N",0,0
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2,"Runoff",0,0
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2,"TOTAL P",0,0
2,"TOTAL N",0,0
2,"ORTHO P",0,0
2,"INORGANIC N",0,0
3,"landuse3"
3,"Runoff",0,0
3,"CONSERVATIVE SUBST.",0,0
3,"TOTAL P",0,0
3,"TOTAL N",0,0
3,"ORTHO P",0,0
3,"INORGANIC N",0,0
4,"landuse4"
4,"Runoff",0,0
4,"CONSERVATIVE SUBST.",0,0
4,"TOTAL P",0,0
4,"TOTAL N",0,0
4,"ORTHO P",0,0
4,"INORGANIC N",0,0
5,""
5,"Runoff",0,0
5,"CONSERVATIVE SUBST.",0,0
5,"TOTAL P",0,0
5,"TOTAL N",0,0
5,"ORTHO P",0,0
5,"INORGANIC N",0,0
6,""
6,"Runoff",0,0
6,"CONSERVATIVE SUBST.",0,0
6,"TOTAL P",0,0
6,"TOTAL N",0,0
6,"ORTHO P",0,0
6,"INORGANIC N",0,0
7,""
7,"Runoff",0,0
7,"CONSERVATIVE SUBST.",0,0
7,"TOTAL P",0,0
7,"TOTAL N",0,0
7,"ORTHO P",0,0
7,"INORGANIC N",0,0
8,""
8,"Runoff",0,0
8,"CONSERVATIVE SUBST.",0,0
8,"TOTAL P",0,0
8,"TOTAL N",0,0
8,"ORTHO P",0,0
8,"INORGANIC N",0,0
"Notes"
MPCA average year total deposition for Upper Miss. Basin used and assumed 50% for Ortho P
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Green Cal Final.btb

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Vers 6.14 (09/26/2011)
Green Lake Model
4,"Global Parmameters"
1,"AVERAGING PERIOD (YRS)",1,0
2,"PRECIPITATION (METERS)",.77,.06
3,"EVAPORATION (METERS)",.75,.3
4,"INCREASE IN STORAGE (METERS)",0,0
12,"Model Options"
1,"CONSERVATIVE SUBSTANCE",0
2,"PHOSPHORUS BALANCE",8
3,"NITROGEN BALANCE",0
4,"CHLOROPHYLL-A",2
5,"SECCHI DEPTH",1
6,"DISPERSION",1
7,"PHOSPHORUS CALIBRATION",2
8,"NITROGEN CALIBRATION",2
9,"ERROR ANALYSIS",1
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",1,.45
3,"N DECAY RATE",1,.55
4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA  M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",.33,0
15,"Avail Factor - Ortho P",1.93,0
16,"Avail Factor - TN",.59,0
17,"Avail Factor - Inorganic N",.79,0
5,"Atmospheric Loads"
1,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",26.8,.5
3,"TOTAL N",1000,.5
4,"ORTHO P",13.4,.5
5,"INORGANIC N",500,.5
1,"Segments"
1,"Green",0,1,3.37,4.94,2.53,4.5,.12,2,.3,.08,1.67,0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",0,0
1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,1,0
1,"TOTAL P   MG/M3",50.65,.1,.8769192,0
1,"TOTAL N    MG/M3",0,0,1,0
1,"CHL-A   MG/M3",27.53,.18,1.303391,0
1,"SECCHI         M",1.6,.05,1.2,0
1,"ORGANIC N  MG/M3",0,0,1,0
1,"TP-ORTHO-P MG/M3",0,0,1,0
1,"HOD-V  MG/M3-DAY",0,0,1,0
1,"MOD-V  MG/M3-DAY",0,0,1,0
5,"Tributaries"
1,"Green Tributary 281",1,1,22.28,4.88,.11,0
1,"CONSERVATIVE SUBST.",0,0
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1,"ORTHO P",109.4,.1
1,"INORGANIC N",0,0
1,"LandUses",0,0,0,0,0,0,0,0,0
2,"Green Tributary 283",1,1,19.34,3.65,.15,0
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2,"TOTAL N",0,0
2,"ORTHO P",100.3,.07
2,"INORGANIC N",0,0
2,"LandUses",0,0,0,0,0,0,0,0,0
3,"Lakeshed",1,1,19.3,3.48,.15,0
3,"CONSERVATIVE SUBST.",0,0
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3,"TOTAL N",0,0
3,"ORTHO P",104.1,.07
3,"INORGANIC N",0,0
3,"LandUses",0,0,0,0,0,0,0,0,0
4,"Green SSTS",1,1,.01,.005,.3,0
4,"CONSERVATIVE SUBST.",0,0
4,"TOTAL P",10000,.3
4,"TOTAL N",0,0
4,"ORTHO P",10000,.3
4,"INORGANIC N",0,0
4,"LandUses",0,0,0,0,0,0,0,0,0
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5,"INORGANIC N",0,0
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0,"Channels"
8,"Land Use Export Categories"
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1,"Runoff",0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",0,0
1,"TOTAL N",0,0
1,"ORTHO P",0,0
1,"INORGANIC N",0,0
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2,"Runoff",0,0
2,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",0,0
2,"TOTAL N",0,0
2,"ORTHO P",0,0
2,"INORGANIC N",0,0
3,"landuse3"
3,"Runoff",0,0
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3,"INORGANIC N",0,0
4,"landuse4"
4,"Runoff",0,0
4,"CONSERVATIVE SUBST.",0,0
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4,"TOTAL N",0,0
4,"ORTHO P",0,0
4,"INORGANIC N",0,0
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5,"TOTAL N",0,0
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5,"INORGANIC N",0,0
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6,"Runoff",0,0
6,"CONSERVATIVE SUBST.",0,0
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7,"TOTAL N",0,0
7,"ORTHO P",0,0
7,"INORGANIC N",0,0
8,""
8,"Runoff",0,0
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8,"TOTAL P",0,0
8,"TOTAL N",0,0
8,"ORTHO P",0,0
8,"INORGANIC N",0,0
"Notes"
Atmospheric deposition is average total (wet and dry) based on MPCA 2007 for Upper Miss. Basin
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Green Reduced Final.btb

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Vers 6.14 (09/26/2011)
Green Lake Model
4,"Global Parmameters"
1,"AVERAGING PERIOD (YRS)",1,0
2,"PRECIPITATION (METERS)",.77,.06
3,"EVAPORATION (METERS)",.75,.3
4,"INCREASE IN STORAGE (METERS)",0,0
12,"Model Options"
1,"CONSERVATIVE SUBSTANCE",0
2,"PHOSPHORUS BALANCE",8
3,"NITROGEN BALANCE",0
4,"CHLOROPHYLL-A",2
5,"SECCHI DEPTH",1
6,"DISPERSION",1
7,"PHOSPHORUS CALIBRATION",2
8,"NITROGEN CALIBRATION",2
9,"ERROR ANALYSIS",1
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",1,.45
3,"N DECAY RATE",1,.55
4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA  M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",.33,0
15,"Avail Factor - Ortho P",1.93,0
16,"Avail Factor - TN",.59,0
17,"Avail Factor - Inorganic N",.79,0
5,"Atmospheric Loads"
1,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",26.8,.5
3,"TOTAL N",1000,.5
4,"ORTHO P",13.4,.5
5,"INORGANIC N",500,.5
1,"Segments"
1,"Green",0,1,3.37,4.94,2.53,4.5,.12,2,.3,.08,1.67,0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",0,0
1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,1,0
1,"TOTAL P MG/M3",50.65,.1,.8769192,0
1,"TOTAL N    MG/M3",0,0,1,0
1,"CHL-A MG/M3",27.53,.18,1.303391,0
1,"SECCHI         M",1.6,.05,1.2,0
1,"ORGANIC N  MG/M3",0,0,1,0
1,"TP-ORTHO-P MG/M3",0,0,1,0
1,"HOD-V  MG/M3-DAY",0,0,1,0
1,"MOD-V  MG/M3-DAY",0,0,1,0
5,"Tributaries"
1,"Green Tributary 281",1,1,22.28,4.88,.11,0
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1,"ORTHO P",109.4,.1
1,"INORGANIC N",0,0
1,"LandUses",0,0,0,0,0,0,0,0,0
2,"Green Tributary 283",1,1,19.34,3.65,.15,0
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2,"TOTAL N",0,0
2,"ORTHO P",100.3,.07
2,"INORGANIC N",0,0
2,"LandUses",0,0,0,0,0,0,0,0,0
3,"Lakeshed",1,1,19.3,3.48,.15,0
3,"CONSERVATIVE SUBST.",0,0
3,"TOTAL P",113,.04
3,"TOTAL N",0,0
3,"ORTHO P",104.1,.07
3,"INORGANIC N",0,0
3,"LandUses",0,0,0,0,0,0,0,0,0
4,"Green SSTS",1,1,.01,.005,.3,0
4,"CONSERVATIVE SUBST.",0,0
4,"TOTAL P",10,.3
4,"TOTAL N",0,0
4,"ORTHO P",10000,.3
4,"INORGANIC N",0,0
4,"LandUses",0,0,0,0,0,0,0,0,0
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0,"Channels"
8,"Land Use Export Categories"
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1,"Runoff",0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",0,0
1,"TOTAL N",0,0
1,"ORTHO P",0,0
1,"INORGANIC N",0,0
2,"landuse2"
2,"Runoff",0,0
2,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",0,0
2,"TOTAL N",0,0
2,"ORTHO P",0,0
2,"INORGANIC N",0,0
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8,"INORGANIC N",0,0
"Notes"
Atmospheric deposition is average total (wet and dry) based on MPCA 2007 for Upper Miss. Basin
```

Long cal Final.btb

```
Vers 6.14 (09/26/2011)
Long Lake Model
4,"Global Parmameters"
1,"AVERAGING PERIOD (YRS)",1,0
2,"PRECIPITATION (METERS)",.78,.06
3,"EVAPORATION (METERS)",.75,.3
4,"INCREASE IN STORAGE (METERS)",0,0
12,"Model Options"
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2,"PHOSPHORUS BALANCE",8
3,"NITROGEN BALANCE",0
4,"CHLOROPHYLL-A",2
5,"SECCHI DEPTH",1
6,"DISPERSION",1
7,"PHOSPHORUS CALIBRATION",2
8,"NITROGEN CALIBRATION",2
9,"ERROR ANALYSIS",1
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",1.009392,.45
3,"N DECAY RATE",1,.55
4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA  M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",.33,0
15,"Avail Factor - Ortho P",1.93,0
16,"Avail Factor - TN",.59,0
17,"Avail Factor - Inorganic N",.79,0
5,"Atmospheric Loads"
1,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",26.8,.2
3,"TOTAL N",1000,.5
4,"ORTHO P",13.4,.3
5,"INORGANIC N",500,.5
1,"Segments"
1,"Long",0,1,1.55,1.34,3.55,1.3,.12,0,0,.75,.2,0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",1,0
1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,1,0
1,"TOTAL P    MG/M3",119.04,.06,1.028924,0
1,"TOTAL N    MG/M3",0,0,1,0
1,"CHL-A    MG/M3",50.05,.07,.8109547,0
1,"SECCHI         M",.5,.04,1,0
1,"ORGANIC N  MG/M3",0,0,1,0
1,"TP-ORTHO-P MG/M3",0,0,1,0
1,"HOD-V  MG/M3-DAY",0,0,1,0
1,"MOD-V  MG/M3-DAY",0,0,1,0
4,"Tributaries"
1,"Long Tributary 367",1,1,15.5,3.06,.1,0
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1,"TOTAL P",126.47,.06
1,"TOTAL N",0,0
1,"ORTHO P",69.36,.11
1,"INORGANIC N",0,0
1,"LandUses",0,0,0,0,0,0,0,0
2,"Lakeshed",1,1,12.97,2.57,.11,0
2,"CONSERVATIVE SUBST.",0,0
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2,"ORTHO P",83.7,.09
2,"INORGANIC N",0,0
2,"LandUses",0,0,0,0,0,0,0,0
3,"Long SSTS",1,1,.01,.0049,.3,0
3,"CONSERVATIVE SUBST.",0,0
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3,"INORGANIC N",0,0
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4,"Outlet",1,4,30,5.9,.11,0
4,"CONSERVATIVE SUBST.",0,0
4,"TOTAL P",74.39,.08
4,"TOTAL N",0,0
4,"ORTHO P",26.77,.29
4,"INORGANIC N",0,0
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1,"ORTHO P",0,0
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3,"Runoff",0,0
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3,"TOTAL N",0,0
3,"ORTHO P",0,0
3,"INORGANIC N",0,0
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4,"Runoff",0,0
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4,"TOTAL N",0,0
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4,"INORGANIC N",0,0
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5,"INORGANIC N",0,0
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6,"Runoff",0,0
6,"CONSERVATIVE SUBST.",0,0
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6,"ORTHO P",0,0
6,"INORGANIC N",0,0
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7,"Runoff",0,0
7,"CONSERVATIVE SUBST.",0,0
7,"TOTAL P",0,0
7,"TOTAL N",0,0
7,"ORTHO P",0,0
7,"INORGANIC N",0,0
8,""
8,"Runoff",0,0
8,"CONSERVATIVE SUBST.",0,0
8,"TOTAL P",0,0
8,"TOTAL N",0,0
8,"ORTHO P",0,0
8,"INORGANIC N",0,0
"Notes"
Atmospheric P (wet and dry) from average year for Upper Miss. Basin (MPCA, 2007)
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Long Reduced Cal Final.btb

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Vers 6.14 (09/26/2011)
Long Lake Model
4,"Global Parmameters"
1,"AVERAGING PERIOD (YRS)",1,0
2,"PRECIPITATION (METERS)",.78,.06
3,"EVAPORATION (METERS)",.75,.3
4,"INCREASE IN STORAGE (METERS)",0,0
12,"Model Options"
1,"CONSERVATIVE SUBSTANCE",0
2,"PHOSPHORUS BALANCE",8
3,"NITROGEN BALANCE",0
4,"CHLOROPHYLL-A",2
5,"SECCHI DEPTH",1
6,"DISPERSION",1
7,"PHOSPHORUS CALIBRATION",2
8,"NITROGEN CALIBRATION",2
9,"ERROR ANALYSIS",1
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",1,.45
3,"N DECAY RATE",1,.55
4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA  M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",.33,0
15,"Avail Factor - Ortho P",1.93,0
16,"Avail Factor - TN",.59,0
17,"Avail Factor - Inorganic N",.79,0
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4,"ORTHO P",13.4,.3
5,"INORGANIC N",500,.5
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1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,1,0
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1,"TP-ORTHO-P MG/M3",0,0,1,0
1,"HOD-V  MG/M3-DAY",0,0,1,0
1,"MOD-V  MG/M3-DAY",0,0,1,0
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2,"TOTAL N",0,0
2,"ORTHO P",83.7,.09
2,"INORGANIC N",0,0
2,"LandUses",0,0,0,0,0,0,0,0,0
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4,"Outlet",1,4,30,5.9,.11,0
4,"CONSERVATIVE SUBST.",0,0
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4,"TOTAL N",0,0
4,"ORTHO P",26.77,.29
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4,"Runoff",0,0
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4,"TOTAL N",0,0
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5,"INORGANIC N",0,0
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6,"Runoff",0,0
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6,"TOTAL N",0,0
6,"ORTHO P",0,0
6,"INORGANIC N",0,0
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7,"ORTHO P",0,0
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8,"TOTAL N",0,0
8,"ORTHO P",0,0
8,"INORGANIC N",0,0
"Notes"
Atmospheric P (wet and dry) from average year for Upper Miss. Basin (MPCA, 2007)
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North Stanchfield Cal Final.btb

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Vers 6.14 (09/26/2011)
North Stanchfield Lake Model
4,"Global Parmameters"
1,"AVERAGING PERIOD (YRS)",1,0
2,"PRECIPITATION (METERS)",.77,.06
3,"EVAPORATION (METERS)",.075,.3
4,"INCREASE IN STORAGE (METERS)",0,0
12,"Model Options"
1,"CONSERVATIVE SUBSTANCE",0
2,"PHOSPHORUS BALANCE",8
3,"NITROGEN BALANCE",0
4,"CHLOROPHYLL-A",2
5,"SECCHI DEPTH",1
6,"DISPERSION",1
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8,"NITROGEN CALIBRATION",2
9,"ERROR ANALYSIS",1
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",1,.45
3,"N DECAY RATE",1,.55
4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA  M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",.33,0
15,"Avail Factor - Ortho P",1.93,0
16,"Avail Factor - TN",.59,0
17,"Avail Factor - Inorganic N",.79,0
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3,"TOTAL N",1000,.5
4,"ORTHO P",13.4,.3
5,"INORGANIC N",500,.5
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1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,1,0
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1,"TOTAL N    MG/M3",0,0,1,0
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1,"SECCHI         M",.82,.16,1,0
1,"ORGANIC N  MG/M3",0,0,1,0
1,"TP-ORTHO-P MG/M3",0,0,1,0
1,"HOD-V  MG/M3-DAY",0,0,1,0
1,"MOD-V  MG/M3-DAY",0,0,1,0
5,"Tributaries"
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4,"North Stanchfield SSTS",1,1,.01,.0002,.3,0
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4,"TOTAL N",0,0
4,"ORTHO P",10000,.3
4,"INORGANIC N",0,0
4,"LandUses",0,0,0,0,0,0,0,0
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5,"INORGANIC N",0,0
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8,"ORTHO P",0,0
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"Notes"
Atmospheric deposition (wet and dry) from Upper Miss. Basin average year data (MPCA, 2007)
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North Stanchfield Reduced Cal Final.btb

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Vers 6.14 (09/26/2011)
North Stanchfield Lake Model
4,"Global Parmameters"
1,"AVERAGING PERIOD (YRS)",1,0
2,"PRECIPITATION (METERS)",.77,.06
3,"EVAPORATION (METERS)",.075,.3
4,"INCREASE IN STORAGE (METERS)",0,0
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10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",1,.45
3,"N DECAY RATE",1,.55
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5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA  M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",.33,0
15,"Avail Factor - Ortho P",1.93,0
16,"Avail Factor - TN",.59,0
17,"Avail Factor - Inorganic N",.79,0
5,"Atmospheric Loads"
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2,"TOTAL P",26.8,.2
3,"TOTAL N",1000,.5
4,"ORTHO P",13.4,.3
5,"INORGANIC N",500,.5
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1,"TOTAL P",0,0
1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,1,0
1,"TOTAL P MG/M3",194.5,.1,1.011222,0
1,"TOTAL N    MG/M3",0,0,1,0
1,"CHL-A MG/M3",35.46,.2,.4674992,0
1,"SECCHI         M",.82,.16,1,0
1,"ORGANIC N  MG/M3",0,0,1,0
1,"TP-ORTHO-P MG/M3",0,0,1,0
1,"HOD-V  MG/M3-DAY",0,0,1,0
1,"MOD-V  MG/M3-DAY",0,0,1,0
5,"Tributaries"
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"Notes"
Atmospheric deposition (wet and dry) from Upper Miss. Basin average year data (MPCA, 2007)
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Skogman Cal Final.btb

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Vers 6.14 (09/26/2011)
Skogman Lake Model
4,"Global Parmameters"
1,"AVERAGING PERIOD
(YRS)",1,0
2,"PRECIPITATION
(METERS)",.77,.06
3,"EVAPORATION
(METERS)",.75,.3
4,"INCREASE IN STORAGE
(METERS)",0,0
12,"Model Options"
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SUBSTANCE",0
2,"PHOSPHORUS BALANCE",8
3,"NITROGEN BALANCE",0
4,"CHLOROPHYLL-A",2
5,"SECCHI DEPTH",1
6,"DISPERSION",1
7,"PHOSPHORUS
CALIBRATION",2
8,"NITROGEN CALIBRATION",2
9,"ERROR ANALYSIS",1
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",1,.45
3,"N DECAY RATE",1,.55
4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA  M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",.33,0
15,"Avail Factor - Ortho
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16,"Avail Factor - TN",.59,0
17,"Avail Factor - Inorganic
N",.79,0
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3,"TOTAL N",1000,.5
4,"ORTHO P",13.4,.3
5,"INORGANIC N",500,.5
1,"Segments"
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1,"TOTAL P",0,0
1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,1,0
1,"TOTAL P
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1,"MOD-V  MG/M3-DAY",0,0,1,0
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1,"TOTAL N",0,0
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2,"TOTAL N",0,0
2,"ORTHO P",10000,.3
2,"INORGANIC N",0,0
2,"LandUses",0,0,0,0,0,0,0,0
3,"Outlet",1,4,13.7,2.47,.16,0
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3,"INORGANIC N",0,0
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6,"Runoff",0,0
6,"CONSERVATIVE SUBST.",0,0
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6,"TOTAL N",0,0
6,"ORTHO P",0,0
6,"INORGANIC N",0,0
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7,"Runoff",0,0
7,"CONSERVATIVE SUBST.",0,0
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7,"TOTAL N",0,0
7,"ORTHO P",0,0
7,"INORGANIC N",0,0
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8,"Runoff",0,0
8,"CONSERVATIVE SUBST.",0,0
8,"TOTAL P",0,0
8,"TOTAL N",0,0
8,"ORTHO P",0,0
8,"INORGANIC N",0,0
"Notes"
Atmospheric P deposition (wet +
dry) for average year from MPCA
2007 for Upper Miss. Basin.
Ortho P assumed to be 50% of
TP.

Fetch adjusted to 0.3 due to
orientation
```

Skogman Reduced Final.btb

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Vers 6.14 (09/26/2011)
Skogman Lake Model
4,"Global Parmameters"
1,"AVERAGING PERIOD (YRS)",1,0
2,"PRECIPITATION (METERS)",.77,.06
3,"EVAPORATION (METERS)",.75,.3
4,"INCREASE IN STORAGE (METERS)",0,0
12,"Model Options"
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2,"PHOSPHORUS BALANCE",8
3,"NITROGEN BALANCE",0
4,"CHLOROPHYLL-A",2
5,"SECCHI DEPTH",1
6,"DISPERSION",1
7,"PHOSPHORUS CALIBRATION",2
8,"NITROGEN CALIBRATION",2
9,"ERROR ANALYSIS",1
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",1,.45
3,"N DECAY RATE",1,.55
4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA  M2/MG",.025,0
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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
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3,"TOTAL N",1000,.5
4,"ORTHO P",13.4,.3
5,"INORGANIC N",500,.5
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1,"TOTAL P",0,0
1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,1,0
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1,"TOTAL N     MG/M3",0,0,1,0
1,"CHL-A MG/M3",21.3,.2,1.16772,0
1,"SECCHI M",1.4,.04,1.05,0
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1,"HOD-V  MG/M3-DAY",0,0,1,0
1,"MOD-V  MG/M3-DAY",0,0,1,0
3,"Tributaries"
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1,"INORGANIC N",0,0
1,"LandUses",0,0,0,0,0,0,0,0,0
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2,"TOTAL N",0,0
2,"ORTHO P",10000,.3
2,"INORGANIC N",0,0
2,"LandUses",0,0,0,0,0,0,0,0,0
3,"Outlet",1,4,13.7,2.47,.16,0
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3,"TOTAL N",0,0
3,"ORTHO P",30.8,.3
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4,"TOTAL N",0,0
4,"ORTHO P",0,0
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5,"TOTAL N",0,0
5,"ORTHO P",0,0
5,"INORGANIC N",0,0
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6,"Runoff",0,0
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6,"ORTHO P",0,0
6,"INORGANIC N",0,0
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7,"TOTAL N",0,0
7,"ORTHO P",0,0
7,"INORGANIC N",0,0
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8,"Runoff",0,0
8,"CONSERVATIVE SUBST.",0,0
8,"TOTAL P",0,0
8,"TOTAL N",0,0
8,"ORTHO P",0,0
8,"INORGANIC N",0,0
"Notes"
Atmospheric P deposition (wet + dry) for average year from MPCA 2007 for Upper Miss. Basin. Ortho P assumed to be 50% of TP.

Fetch adjusted to 0.3 due to orientation
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South Stanchfield Cal Final.btb

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Vers 6.14 (09/26/2011)
South Stanchfield Lake Model
4,"Global Parmameters"
1,"AVERAGING PERIOD (YRS)",1,0
2,"PRECIPITATION (METERS)",.77,.06
3,"EVAPORATION (METERS)",.75,.2
4,"INCREASE IN STORAGE (METERS)",0,0
12,"Model Options"
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2,"PHOSPHORUS BALANCE",8
3,"NITROGEN BALANCE",0
4,"CHLOROPHYLL-A",2
5,"SECCHI DEPTH",1
6,"DISPERSION",1
7,"PHOSPHORUS CALIBRATION",2
8,"NITROGEN CALIBRATION",2
9,"ERROR ANALYSIS",1
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",1,.45
3,"N DECAY RATE",1,.55
4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA  M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",.33,0
15,"Avail Factor - Ortho P",1.93,0
16,"Avail Factor - TN",.59,0
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3,"TOTAL N",1000,.5
4,"ORTHO P",13.4,.4
5,"INORGANIC N",500,.5
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1,"TOTAL N",0,0
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1,"TOTAL N    MG/M3",0,0,1,0
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1,"ORGANIC N  MG/M3",0,0,1,0
1,"TP-ORTHO-P MG/M3",0,0,1,0
1,"HOD-V  MG/M3-DAY",0,0,1,0
1,"MOD-V  MG/M3-DAY",0,0,1,0
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2,"TOTAL N",0,0
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2,"INORGANIC N",0,0
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3,"TOTAL N",0,0
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3,"INORGANIC N",0,0
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4,"TOTAL N",0,0
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6,"ORTHO P",0,0
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8,"TOTAL N",0,0
8,"ORTHO P",0,0
8,"INORGANIC N",0,0
"Notes"
Atmospheric deposition (wet + dry) for Upper Miss. Basin (MPCA, 2007) with 50% assumed as Ortho P (not used in this model.
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South Stanchfield Reduced Final.btb

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Vers 6.14 (09/26/2011)
South Stanchfield Lake Model
4,"Global Parmameters"
1,"AVERAGING PERIOD (YRS)",1,0
2,"PRECIPITATION (METERS)",.77,.06
3,"EVAPORATION (METERS)",.75,.2
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5,"SECCHI DEPTH",1
6,"DISPERSION",1
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10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
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6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
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12,"FLUSHING EFFECT",1,0
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15,"Avail Factor - Ortho P",1.93,0
16,"Avail Factor - TN",.59,0
17,"Avail Factor - Inorganic N",.79,0
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3,"TOTAL N",1000,.5
4,"ORTHO P",13.4,.4
5,"INORGANIC N",500,.5
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1,"TOTAL N",0,0
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1,"TOTAL N    MG/M3",0,0,1,0
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1,"SECCHI         M",1.04,.21,2,0
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1,"HOD-V  MG/M3-DAY",0,0,1,0
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8,"TOTAL N",0,0
8,"ORTHO P",0,0
8,"INORGANIC N",0,0
"Notes"
Atmospheric deposition (wet + dry) for Upper Miss. Basin (MPCA, 2007) with 50% assumed as Ortho P (not used in this model.
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West Hunter Cal Final.btb

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Vers 6.14 (09/26/2011)
West Hunter
4,"Global Parmameters"
1,"AVERAGING PERIOD (YRS)",1,0
2,"PRECIPITATION (METERS)",.78,0
3,"EVAPORATION (METERS)",.75,0
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12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
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4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
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14,"Avail Factor - TP",.33,0
15,"Avail Factor - Ortho P",1.93,0
16,"Avail Factor - TN",.59,0
17,"Avail Factor - Inorganic N",.79,0
5,"Atmospheric Loads"
1,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",26.8,.5
3,"TOTAL N",1000,.5
4,"ORTHO P",13,.5
5,"INORGANIC N",500,.5
1,"Segments"
1,"West Hunter",0,1,.242,1.52,1.02,1.5,0,0,0,.2,0,0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",0,0
1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,1,0
1,"TOTAL P MG/M3",65.62,.1,.8609063,0
1,"TOTAL N    MG/M3",0,0,1,0
1,"CHL-A MG/M3",18.83,.18,1.02484,0
1,"SECCHI         M",1.49,.04,1,0
1,"ORGANIC N  MG/M3",0,0,1,0
1,"TP-ORTHO-P MG/M3",0,0,1,0
1,"HOD-V  MG/M3-DAY",0,0,1,0
1,"MOD-V  MG/M3-DAY",0,0,1,0
3,"Tributaries"
1,"Lakeshed",1,1,2.08,.47,.1,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",177.5,.06
1,"TOTAL N",0,0
1,"ORTHO P",115.6,.08
1,"INORGANIC N",0,0
1,"LandUses",0,0,0,0,0,0,0,0
2,"West Hunter SSTS",1,1,.001,.0004,0,0
2,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",10000,0
2,"TOTAL N",0,0
2,"ORTHO P",10000,0
2,"INORGANIC N",0,0
2,"LandUses",0,0,0,0,0,0,0,0
3,"Outlet",1,4,2.3,.506,.11,0
3,"CONSERVATIVE SUBST.",0,0
3,"TOTAL P",72,.06
3,"TOTAL N",0,0
3,"ORTHO P",19.6,.11
3,"INORGANIC N",0,0
3,"LandUses",0,0,0,0,0,0,0,0
0,"Channels"
8,"Land Use Export Categories"
1,"landuse1"
1,"Runoff",0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",0,0
1,"TOTAL N",0,0
1,"ORTHO P",0,0
1,"INORGANIC N",0,0
2,"landuse2"
2,"Runoff",0,0
2,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",0,0
2,"TOTAL N",0,0
2,"ORTHO P",0,0
2,"INORGANIC N",0,0
3,"landuse3"
3,"Runoff",0,0
3,"CONSERVATIVE SUBST.",0,0
3,"TOTAL P",0,0
3,"TOTAL N",0,0
3,"ORTHO P",0,0
3,"INORGANIC N",0,0
4,"landuse4"
4,"Runoff",0,0
4,"CONSERVATIVE SUBST.",0,0
4,"TOTAL P",0,0
4,"TOTAL N",0,0
4,"ORTHO P",0,0
4,"INORGANIC N",0,0
5,""
5,"Runoff",0,0
5,"CONSERVATIVE SUBST.",0,0
5,"TOTAL P",0,0
5,"TOTAL N",0,0
5,"ORTHO P",0,0
5,"INORGANIC N",0,0
6,""
6,"Runoff",0,0
6,"CONSERVATIVE SUBST.",0,0
6,"TOTAL P",0,0
6,"TOTAL N",0,0
6,"ORTHO P",0,0
6,"INORGANIC N",0,0
7,""
7,"Runoff",0,0
7,"CONSERVATIVE SUBST.",0,0
7,"TOTAL P",0,0
7,"TOTAL N",0,0
7,"ORTHO P",0,0
7,"INORGANIC N",0,0
8,""
8,"Runoff",0,0
8,"CONSERVATIVE SUBST.",0,0
8,"TOTAL P",0,0
8,"TOTAL N",0,0
8,"ORTHO P",0,0
8,"INORGANIC N",0,0
"Notes"
Split up West and East Hunter Models
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West Hunter Reduced Cal Final.btb

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Vers 6.14 (09/26/2011)
West Hunter
4,"Global Parmameters"
1,"AVERAGING PERIOD (YRS)",1,0
2,"PRECIPITATION (METERS)",.78,0
3,"EVAPORATION (METERS)",.75,0
4,"INCREASE IN STORAGE (METERS)",0,0
12,"Model Options"
1,"CONSERVATIVE SUBSTANCE",0
2,"PHOSPHORUS BALANCE",8
3,"NITROGEN BALANCE",0
4,"CHLOROPHYLL-A",4
5,"SECCHI DEPTH",1
6,"DISPERSION",1
7,"PHOSPHORUS CALIBRATION",2
8,"NITROGEN CALIBRATION",2
9,"ERROR ANALYSIS",1
10,"AVAILABILITY FACTORS",0
11,"MASS-BALANCE TABLES",1
12,"OUTPUT DESTINATION",2
17,"Model Coefficients"
1,"DISPERSION RATE",1,.7
2,"P DECAY RATE",1,.45
3,"N DECAY RATE",1,.55
4,"CHL-A MODEL",1,.26
5,"SECCHI MODEL",1,.1
6,"ORGANIC N MODEL",1,.12
7,"TP-OP MODEL",1,.15
8,"HODV MODEL",1,.15
9,"MODV MODEL",1,.22
10,"BETA  M2/MG",.025,0
11,"MINIMUM QS",.1,0
12,"FLUSHING EFFECT",1,0
13,"CHLOROPHYLL-A CV",.62,0
14,"Avail Factor - TP",.33,0
15,"Avail Factor - Ortho P",1.93,0
16,"Avail Factor - TN",.59,0
17,"Avail Factor - Inorganic N",.79,0
5,"Atmospheric Loads"
1,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",26.8,.5
3,"TOTAL N",1000,.5
4,"ORTHO P",13,.5
5,"INORGANIC N",500,.5
1,"Segments"
1,"West Hunter",0,1,.242,1.52,1.02,1.5,0,0,0,.2,0,0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",0,0
1,"TOTAL N",0,0
1,"CONSERVATIVE SUB",0,0,1,0
1,"TOTAL P MG/M3",65.62,.1,.8609063,0
1,"TOTAL N    MG/M3",0,0,1,0
1,"CHL-A MG/M3",18.83,.18,1.02484,0
1,"SECCHI         M",1.49,.04,1,0
1,"ORGANIC N  MG/M3",0,0,1,0
1,"TP-ORTHO-P MG/M3",0,0,1,0
1,"HOD-V  MG/M3-DAY",0,0,1,0
1,"MOD-V  MG/M3-DAY",0,0,1,0
3,"Tributaries"
1,"Lakeshed",1,1,2.08,.47,.1,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",158,.06
1,"TOTAL N",0,0
1,"ORTHO P",90,.08
1,"INORGANIC N",0,0
1,"LandUses",0,0,0,0,0,0,0,0
2,"West Hunter SSTS",1,1,.001,.0004,0,0
2,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",10,0
2,"TOTAL N",0,0
2,"ORTHO P",10000,0
2,"INORGANIC N",0,0
2,"LandUses",0,0,0,0,0,0,0,0
3,"Outlet",1,4,2.3,.506,.11,0
3,"CONSERVATIVE SUBST.",0,0
3,"TOTAL P",72,.06
3,"TOTAL N",0,0
3,"ORTHO P",19.6,.11
3,"INORGANIC N",0,0
3,"LandUses",0,0,0,0,0,0,0,0
0,"Channels"
8,"Land Use Export Categories"
1,"landuse1"
1,"Runoff",0,0
1,"CONSERVATIVE SUBST.",0,0
1,"TOTAL P",0,0
1,"TOTAL N",0,0
1,"ORTHO P",0,0
1,"INORGANIC N",0,0
2,"landuse2"
2,"Runoff",0,0
2,"CONSERVATIVE SUBST.",0,0
2,"TOTAL P",0,0
2,"TOTAL N",0,0
2,"ORTHO P",0,0
2,"INORGANIC N",0,0
3,"landuse3"
3,"Runoff",0,0
3,"CONSERVATIVE SUBST.",0,0
3,"TOTAL P",0,0
3,"TOTAL N",0,0
3,"ORTHO P",0,0
3,"INORGANIC N",0,0
4,"landuse4"
4,"Runoff",0,0
4,"CONSERVATIVE SUBST.",0,0
4,"TOTAL P",0,0
4,"TOTAL N",0,0
4,"ORTHO P",0,0
4,"INORGANIC N",0,0
5,""
5,"Runoff",0,0
5,"CONSERVATIVE SUBST.",0,0
5,"TOTAL P",0,0
5,"TOTAL N",0,0
5,"ORTHO P",0,0
5,"INORGANIC N",0,0
6,""
6,"Runoff",0,0
6,"CONSERVATIVE SUBST.",0,0
6,"TOTAL P",0,0
6,"TOTAL N",0,0
6,"ORTHO P",0,0
6,"INORGANIC N",0,0
7,""
7,"Runoff",0,0
7,"CONSERVATIVE SUBST.",0,0
7,"TOTAL P",0,0
7,"TOTAL N",0,0
7,"ORTHO P",0,0
7,"INORGANIC N",0,0
8,""
8,"Runoff",0,0
8,"CONSERVATIVE SUBST.",0,0
8,"TOTAL P",0,0
8,"TOTAL N",0,0
8,"ORTHO P",0,0
8,"INORGANIC N",0,0
"Notes"
Split up West and East Hunter Models
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