Watershed

February 2020

Lower Minnesota River Watershed Total Maximum Daily Load

Part II—Northern Watersheds: Riley-Purgatory-Bluff Creek and Nine Mile Creek Watersheds

MINNESOTA POLLUTION CONTROL AGENCY

wq-iw7-50e

CLEAN WATER LAND & LEGACY AMENDMENT

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Acronyms

AGREETT	Agriculture Research, Education and Extension Technology Transfer Program
AUID	Assessment Unit ID
BMP	best management practice
Chl-*a*	Chlorophyll-*a*
DNR	Minnesota Department of Natural Resources
EPA	United States Environmental Protection Agency
EQuIS	Environmental Quality Information System
LA	load allocation
lb	pound
lb/day	pounds per day
lb/yr	pounds per year
m	meter
mg/L	milligrams per liter
mL	milliliter
MnDOT	Minnesota Department of Transportation
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
NCHF	North Central Hardwood Forest
NMCWD	Nine Mile Creek Watershed District
NPDES	National Pollutant Discharge Elimination System
RPBCWD	Riley-Purgatory-Bluff Creek Watershed District
SSTS	Subsurface Sewage Treatment Systems
SWPPP	Stormwater Pollution Prevention Plan
TMDL	Total Maximum Daily Load
TP	Total phosphorus
UAA	Use Attainability Analysis
WLA	wasteload allocation
WOMP	Watershed Outlet Monitoring Program
WRAPS	Watershed Restoration and Protection Strategy

Executive Summary

This Total Maximum Daily Load (TMDL) report is a part of a larger effort addressing impaired waters in the Lower Minnesota River Watershed. The focus of this report is on waters in the northern urban portion of the watershed in the Twin Cities Metropolitan Area covering portions of Carver and Hennepin Counties, specifically the Riley-Purgatory-Bluff Creek Watershed District (RPBCWD) and Nine Mile Creek Watershed District (NMCWD). Overall, this report provides TMDLs for 13 lakes impaired by excess nutrients (phosphorus), two streams impaired by bacteria (*Escherichia coli* (*E. coli)*) and one stream impaired by both total suspended solids (TSS) and having impaired biota (fish and macroinvertebrates). Nutrients and *E. coli* are parameters related to aquatic recreational use, and TSS is related to aquatic life use.

RPBCWD Waterbodies

There are seven phosphorus-impaired lakes in the RPBCWD: Rice Marsh, Susan, Riley, Hyland, Silver, Lotus, and Staring. The lower portion of Riley Creek is impaired by *E. coli* and TSS, and the lower portion of Purgatory Creek is impaired by *E. coli*. The lakes and streams are popular for various recreational uses and are the focus of considerable efforts by RPBCWD, cities and others for monitoring, evaluation and restoration. In addition to the impaired waterbodies, two waterbodies that are not impaired but that are close to water quality standards (Lake Lucy for phosphorus and Purgatory Creek for TSS are included in this report for the purpose of data analysis for protection purposes).

For the lakes, the relative abundance of sources of phosphorus vary by lake, but they are predominantly urban stormwater runoff and internal loading from lake sediments. For some lakes, erosion from streambanks from inlet channels also is a source. The primary source of TSS in Riley Creek is likely streambank and near-channel erosion of sediment. Loading from urban stormwater is believed to be a much smaller source. A separate biological stressor identification process identified TSS as the primary stressor for the fish and macroinvertebrates impairments in Riley Creek. Thus, the TSS TMDL will address those biota impairments as well. The primary sources of *E. coli* are likely improperly managed pet waste and wildlife inputs (e.g., waterfowl, geese, etc.) directly to impervious surfaces and water features. As with runoff-derived phosphorus and TSS, bacteria are transported via overland flow paths or storm sewer systems to the impaired waterbodies.

The overall phosphorus loading reduction needed for the lakes range from 17% to 50%. For TSS and *E. coli* in Riley Creek estimated reductions of 88% and 81%, respectively, are needed. For *E. coli* in Purgatory Creek an estimated reduction of 68% is needed. The primary implementation strategies that will be needed to restore these waters will be improved stormwater management to both capture/treat pollutants and reduce runoff volume. This reduced runoff volume will decrease peak flow levels in Riley Creek and thereby reduce streambank erosion. Also, for lakes, management of internal loading will be needed through continued invasive species management, as well as alum treatment to bind phosphorus.

NMCWD Waterbodies

There are six phosphorus-impaired lakes in the NMCWD: Wing, Rose, North Cornelia, South Cornelia, Edina, and Penn. In addition, the lower portion of Nine Mile Creek is impaired by *E. coli*. The lakes and creek are popular for various recreational uses and are the focus of considerable efforts by NMCWD, cities, and others for monitoring, evaluation and restoration.

For the lakes, the relative abundance of sources of phosphorus vary by lake, but they are predominantly urban stormwater runoff and internal loading from lake sediments. The primary sources of *E. coli* are likely improperly managed pet waste and wildlife inputs (e.g., waterfowl, geese, etc.) directly to impervious surfaces and water features. As with runoff-derived phosphorus, bacteria are transported via overland flow paths or storm sewer systems to the impaired waterbodies.

The overall phosphorus loading reduction needed for the lakes range from 31% to 59%. For *E. coli* in Nine Mile Creek an estimated reduction of 41% is needed. The primary implementation strategies that will be needed to restore these waters will be improved stormwater management to capture/treat pollutants, plus control of internal loading through invasive species management as well as alum treatment to bind phosphorus.

1. Project Overview

1.1 Purpose

The Clean Water Act Section 303(d) requires that states publish a list of surface waters that do not meet water quality standards and therefore, do not support their designated use(s). These waters are then classified as impaired, which dictates that a TMDL report be completed for them. The goal of this TMDL report is to calculate the maximum amount of a pollutant that certain impaired waterbodies can receive and still meet the state water quality standards.

The passage of Minnesota's Clean Water Legacy Act (CWLA) in 2006 provided a policy framework and resources to state and local governments to accelerate efforts to monitor, assess and restore impaired waters, and to protect unimpaired waters. The result has been a comprehensive "watershed approach" that integrates water resource management efforts by the state, local governments, and stakeholders to develop watershed-scale TMDLs, restoration and protection strategies, and plans for each of Minnesota's 80 major watersheds. The waterbodies in the RPBCWD and NMCWD have been monitored for many years and studies locally referred to as "Use Attainability Analysis (UAA) reports" have been prepared for many of them to address known water quality issues, and present possible restoration and protection strategies. (Note: these are not intended as UAAs as defined in federal law.) The historical water quality data was also used to assess the whether any of these waterbodies were considered impaired for one or more water quality parameters and should be assigned TMDLs.

Completed studies in these two watershed districts that were referenced and used during this TMDL analysis include:

- Lake Ann and Lake Lucy UAA Update (Barr 2013a)
- Lake Susan Use Attainability Assessment Update (Wenck 2013)
- Rice Marsh Lake and Lake Riley UAA Update (Barr 2016)
- Lotus, Silver, Duck, Round Mitchell, Red Rock UAA Update; Lake Idlewild, and Staring Lake UAA; and Lower Purgatory Creek Stabilization Study (Barr 2017c)
- Creek Restoration Action Strategy (Barr 2015)
- RPBCWD Watershed Management Plan-Draft (Barr 2017b)
- Lake Cornelia UAA Revised Draft (Barr 2010)
- NMCWD Water Management Plan (Barr 2017a)

This document address RPBCWD and NMCWD waterbodies that have been identified as impaired by the Minnesota Pollution Control Agency (MPCA) that have not been addressed in prior TMDLs, have an approved water quality standard and have sufficient data for assessment. The findings of this study can be used in combination with the UAA reports, water management plans and other studies to develop watershed-wide restoration and protection strategies to aid in the planning of water quality improvement projects.

While not directly connected to any of the waterbodies discussed in this report, the previously completed TMDL implementation plan for Bluff Creek (Barr 2013b) should also be considered as part of the comprehensive plan to address water quality impairments in the RPBCWD.

1.2 Identification of Waterbodies

This TMDL report applies to 10 separate impairment listings for 2 stream reaches and 7 lakes in the RPBCWD (Table 1.1). Locations of Riley and Purgatory Creeks are shown in Figure 1.1. Figure 1.1 also shows watersheds for the eight lakes (Lucy, Rice Marsh, Susan, Riley, Hyland, Silver, Lotus, and Staring) within the RPBCWD included in this TMDL report.

Table 1.1 List of 303(d) impaired lakes and streams in the RPBCWD

AUID	Stream or Lake Name	Affected Designated Use	Impairment (Pollutant)	Designated Use Class	Listing Year	Target Completion
07020012-511	Riley Creek, Lake Riley to the Minnesota River	Aquatic Life	Turbidity (TSS)	2B, 3C	2002	2019
			Aquatic macroinvertebrate bioassessments [a]		2018	2019
			Fishes bioassessments [a]		2018	2019
		Aquatic Recreation	Bacteria (*E. coli*)		2018	2019
07020012-828	Purgatory Creek, Staring Lake to the Minnesota River	Aquatic Life	Turbidity (TSS)[b]		NA	NA
			Aquatic macroinvertebrate bioassessments [c]		2018	2019
		Aquatic Recreation	Bacteria (*E. coli*)		2018	2019
10-0007-00	Lake Lucy[d]	NA	NA		NA	NA
10-0013-00	Lake Susan	Aquatic Recreation	Nutrient/ Eutrophication Biological Indicators (Phosphorus)		2010	2019
10-0001-00	Rice Marsh Lake				2018	2019
10-0002-00	Riley Lake				2002	2019
		Aquatic Life	Fishes bioassessments [e]		2018	2029
27-0136-00	Silver Lake	Aquatic Recreation	Nutrient/ Eutrophication Biological Indicators (Phosphorus)		2016	2019
10-0006-00	Lotus Lake				2002	2019
		Aquatic Life	Fishes bioassessments [e]		2018	2029
27-0078-00	Staring Lake	Aquatic Recreation	Nutrient/ Eutrophication		2002	2019
27-0048-00	Hyland Lake				2008	2019

AUID	Stream or Lake Name	Affected Designated Use	Impairment (Pollutant)	Designated Use Class	Listing Year	Target Completion
			Biological Indicators (Phosphorus)			

a: This impairment is addressed via completion of the TSS impairment. See Section 4.3.

b: Analysis of the recent Purgatory Creek TSS data does not show impairment and it will be assigned protection status rather than a TMDL. See Section 3.7.2.1.

c: This impairment is not due to a pollutant and is expected to be recategorized to EPA category 4C in the 2020 303(d) list.

d: Lake Lucy was assigned protection status rather than inclusion on the impaired waters list.

e: This listing is not addressed in this TMDL report. Any TMDL, if needed, will be deferred until a later date.

This TMDL report also applies to seven separate impairment listings for one stream reach and six lakes in the NMCWD (Table 1.2). The location of Nine Mile Creek is shown in Figure 1.2. Figure 1.2 also highlights the watersheds for the six lakes (Wing, Rose, North Cornelia, South Cornelia, Edina, and Penn) within the NMCWD included in this TMDL Report.

Table 1.2 List of 303(d) impaired lakes and streams in the NMCWD

AUID	Stream or Lake Name	Affected Designated Use	Impairment (Pollutant)	Designated Use Class	Listing Year	Target Completion
07020012-807	Nine Mile Creek, Headwaters to Metro Blvd	Aquatic Life	Fishes bioassessments [a]	2B, 3C	2004	2029
07020012-808	Nine Mile Creek, Metro Blvd to end of unnamed wetland (Marsh Lake)	Aquatic Life	Aquatic macroinvertebrate bioassessments [b]		2018	2029
			Fishes bioassessments [b]		2018	2029
07020012-809	Nine Mile Creek, Unnamed wetland (Marsh Lake) to the Minnesota River	Aquatic Life	Aquatic macroinvertebrate bioassessments [b]		2018	2029
			Fishes bioassessments [b]		2018	2029
		Aquatic Recreation	Bacteria (*E. coli*)		2018	2019
07020012-723	South Fork Nine Mile Creek, Smetana Lk to Ninemile Cr	Aquatic Life	Aquatic macroinvertebrate bioassessments [b]		2018	2029
			Fishes bioassessments [b]		2018	2029
27-0091-00	Wing Lake	Aquatic Recreation	Nutrient/ Eutrophication Biological Indicators (Phosphorus)		2010	2019
27-0092-00	Lake Rose				2010	2019
27-0028-01	North Cornelia Lake				2008	2019

AUID	Stream or Lake Name	Affected Designated Use	Impairment (Pollutant)	Designated Use Class	Listing Year	Target Completion
27-0028-02	South Cornelia Lake				2018	2019
27-0029-00	Lake Edina				2008	2019
27-0004-00	Penn Lake				2018	2019
27-0067-00	Bryant Lake	Aquatic Life	Fishes bioassessments [b]		2018	2029

a: This impairment is not due to a pollutant and is expected to be recategorized to EPA category 4C in the 2020 303(d) list.

b: This listing is not addressed in this TMDL report. Any TMDL, if needed, will be deferred until a later date.

1.3 Priority Ranking

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

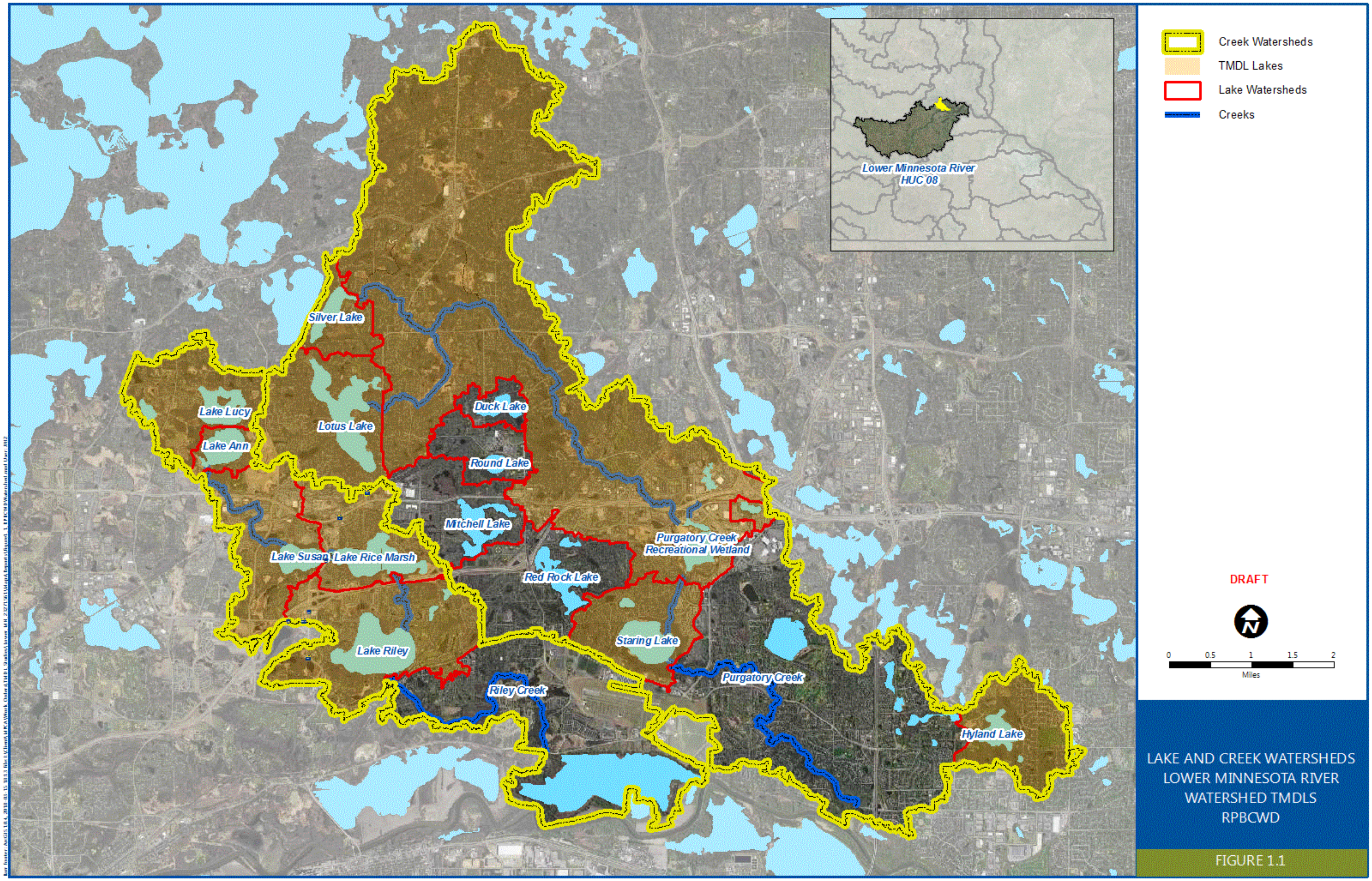


Figure 1.1 Location of Riley Creek, Purgatory Creek, and RPBCWD Lake Watersheds

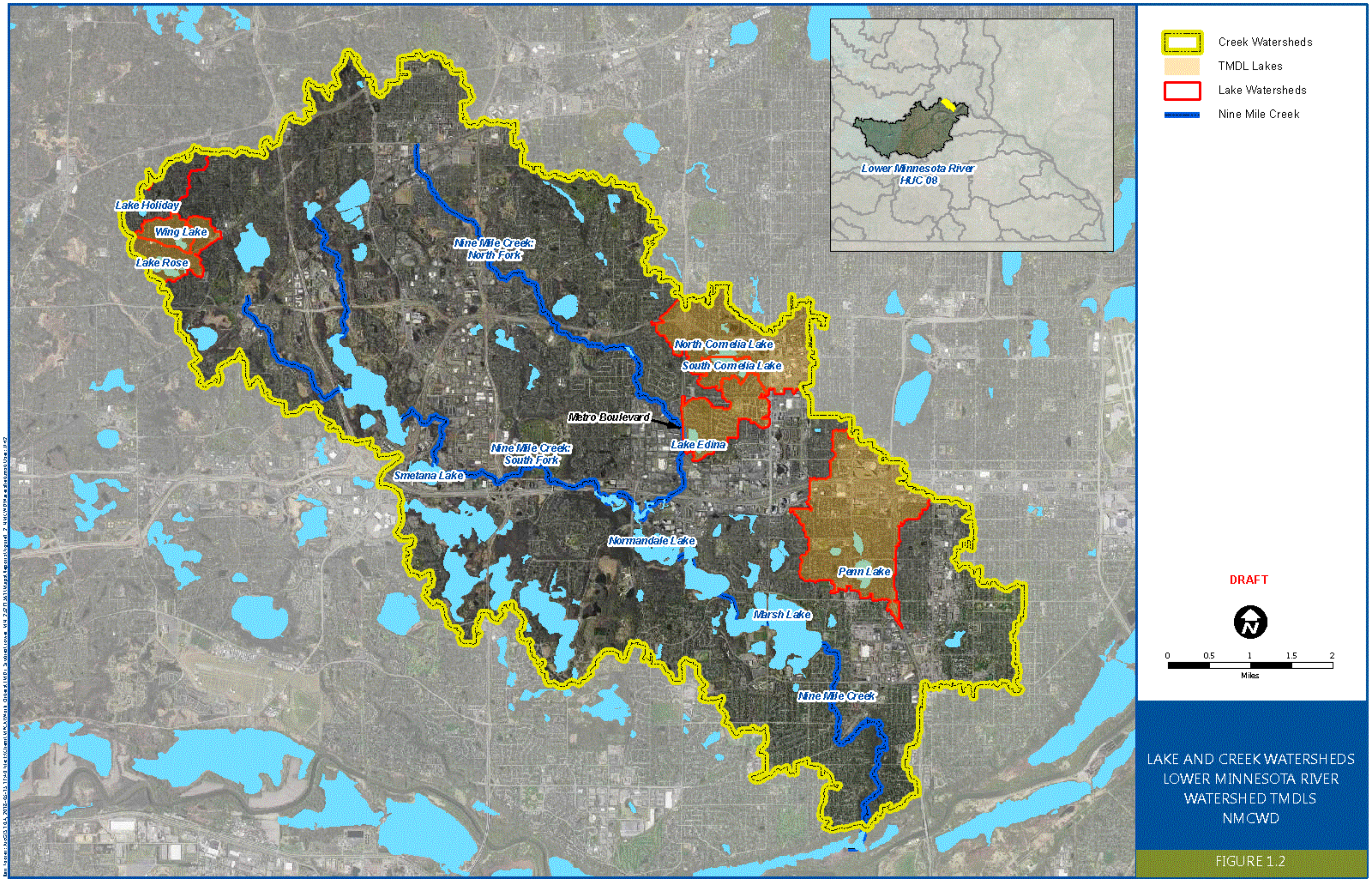


Figure 1.2 Location of Nine Mile Creek and NMCWD Lake Watersheds

2. Applicable Water Quality Standards and Numeric Water Quality Targets

For aquatic recreation uses, water quality in Minnesota lakes is evaluated using three parameters: total phosphorus (TP), chlorophyll-a (Chl-*a*,) and Secchi depth. Phosphorus is typically the limiting nutrient in Minnesota lakes, meaning that algal growth will increase with increased phosphorus. Chl-*a* is the primary pigment in aquatic algae and has been shown to have a direct correlation with algal biomass. Secchi depth is a physical measurement of water clarity taken by lowering a white or black-and-white disk until it can no longer be seen from the surface, then noting the depth where this occurs. Greater Secchi depths indicate less light-refracting particulates in the water column and better water quality; conversely, high TP, and Chl-*a* concentrations point to poor water quality.

The protected beneficial use for all lakes is aquatic recreation, including body-contact activities such as swimming. Minnesota's lake water quality standards vary primarily by ecoregion, and secondarily by lake depth. The lakes of this report are entirely within the North Central Hardwood Forest (NCHF) ecoregion. The standards define a "shallow" lake as one that has either a maximum depth less than 15 feet or a littoral area greater than 80% of the lake's total area. The "littoral" area is defined in practice as the portion of the lake that is shallower than 15 feet.

In addition to meeting phosphorus limits, Chl-*a* and Secchi transparency standards must be met. In developing the lake nutrient standards for Minnesota lakes (Minn. R. ch. 7050), the MPCA evaluated data from a large cross-section of lakes within each of the state's ecoregions (MPCA 2005). Clear relationships were established between the causal factor TP and the response variables Chl-*a* and Secchi transparency. Based on these relationships it is expected that by meeting the phosphorus target in each lake, the Chl-*a* and Secchi standards will likewise be met.

Table 2.1 MPCA lake water quality standards for NCHF Ecoregion

Lake depth category	TP concentration (µg/L)	Chlorophyll-a conc. (µg/L)	Minimum Secchi depth (meters)
Deep	40	14	1.4
Shallow	60	20	1.0

Note: Values are summer averages (June 1 through September 30).

For aquatic recreation uses of streams in Minnesota, *E. coli* is used as an indicator species of potential waterborne pathogens. The aquatic life use water quality standards for streams include TSS. These standards are described in Table 2.2.

Table 2.2 MPCA water quality standards for TMDL parameters in streams for RPBCWD and NMCWD watersheds

Parameter	Water quality standard	Applicable period
E. coli	Not to exceed 126 organisms per 100 milliliters (org/100 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 org/100 mL.	April 1 to October 31
TSS	South region: 65 mg/L (milligrams per liter); TSS standards for class 2B may be exceeded for no more than 10% of the time.	April 1 to September 30

3. Watershed and Waterbody Characterization

3.1 RPBCWD Watershed and Waterbody Characterization

The Riley Creek Watershed encompasses an 11 square mile area. The headwaters of Riley Creek originate in Lake Lucy, then flow through a chain of lakes including Lake Ann, Lake Susan, Rice Marsh Lake, and finally Lake Riley. This portion of the watershed is characterized by mild topography. Upon exiting Lake Riley, Riley Creek flows down the steep north valley wall of the Minnesota River Valley Bluffs before entering the Minnesota River. Riley Creek is located entirely within the boundaries of two municipalities, the City of Chanhassen and the City of Eden Prairie.

The Purgatory Creek Watershed encompasses a 30 square mile area. The headwaters of Purgatory Creek originate in Lotus and Silver Lakes. Purgatory Creek then flows through a series of wetland complexes before entering the Purgatory Creek Recreational Area, which was constructed in 2003. From the Recreational Area, Purgatory Creek continues into Staring Lake and then through the bluffs of the Minnesota River Valley on its way to its confluence with the Minnesota River. The Purgatory Creek watershed ranges in character from marshy with a number of wetlands that have poor drainage north of Highway 7, to a mix of marsh and forested upland areas in the middle of the watershed, to finally the steep valley walls of the Minnesota River Valley. In addition to the direct watershed of Purgatory Creek, a chain of lakes known as the Eden Prairie Chain of Lakes discharges into Staring Lake during high flow periods. This chain of lakes includes Duck Lake, Round Lake, Mitchell Lake, and Red Rock Lake. The four lakes were connected to each other, and then Staring Lake, through a series of pipes installed in 1998 to control lake water levels. Hyland Lake is located in the far eastern portion of the Purgatory Creek watershed. Under high water conditions, Hyland Lake will outflow to the west through the storm sewer systems of the cities of Bloomington and Eden Prairie before ultimately discharging into Purgatory Creek just upstream of River View Road.

3.2 NMCWD Watershed and Waterbody Characterization

The Nine Mile Creek Watershed encompasses a 46.5 square mile area. The headwaters of Nine Mile Creek originate in Minnetoga Lake (South Fork) and the city of Hopkins (North Fork). The South Fork also flows through Bryant Lake before merging with the North Fork just upstream of Normandale Lake. From Normandale Lake, Nine Mile Creek flows into Marsh Lake and then through the bluffs of the Minnesota River Valley on its way to its confluence with the Minnesota River. The Nine Mile Creek Watershed is generally highly developed, with many small lakes and ponds. The watershed topography is generally mild except for the steep ravine between County Road 1 and the Minnesota River.

3.3 Lakes

Lake morphology of the impaired RPBCWD lakes is listed in Table 3.1 and the impaired NMCWD lakes are listed in Table 3.2.

Table 3.1 RPBCWD Lake morphology

AUID	Lake	Surface Area (acres)	Average Depth (ft)	Maximum Depth (ft)	Lake Volume (acre-ft)	Littoral Area (acre)	Lake Depth Class	Direct Watershed Area[a] (acre)
10-0007-00	Lake Lucy	88[b]	6.5	20	560	86	shallow	900
10-0013-00	Lake Susan	88[b]	10	17	890	83	shallow	1,137
10-0001-00	Rice Marsh Lake	83[d]	5	11	375	81	shallow	877[e]
10-0002-00	Lake Riley	297[b]	23	49	6,230	113	deep	1,491
27-0136-00	Silver Lake	71	5	14	190	71	shallow	350
10-0006-00	Lotus Lake	240	16	31	2,500	177	deep	1,168
27-0078-00	Staring Lake	164	7	16	1,200	155	shallow	10,038[c]
27-0048-00	Hyland Lake	84[f]	8[f]	12[f]	780[f]	84[f]	shallow	838[g]

a: Direct watershed area excludes lake surface area

b: Surface area from DNR NWI lake data

c: Excludes watershed areas from Red Rock, Mitchell, Round, Duck, Lotus, and Silver Lakes

d: Open water area varies seasonally due to lake's aquatic vegetative fringe area

e: Excludes watershed areas from lakes Susan, Ann and Lucy. Includes approximately 101 acres of wetland surrounding the lake.

f: According to data from the DNR LakeFinder website and 2011 LiDAR. Surface area, depth and volume can vary widely depending on climatic conditions.

g: Includes the Colorado Pond watershed area.

Table 3.2 NMCWD Lake morphology

AUID	Lake	Surface Area (acres)[b]	Average Depth (ft)[b]	Maximum Depth (ft)[b]	Lake Volume (acre-ft)[b]	Littoral Area (acre)[c]	Lake Depth Class	Direct Watershed Area[a] (acre)
27-0091-00	Wing Lake	14	4	8	49	14	shallow	113
27-0092-00	Rose Lake	30	4	14	120	30	shallow	227
27-0028-01	North Cornelia Lake	19	4	7	73	19	shallow	855
27-0028-02	South Cornelia Lake	33	5	8	163	33	shallow	80
27-0029-00	Lake Edina	25	3	5	68	25	shallow	368
27-0004-00	Penn Lake	32	4	6	105	32	shallow	1,284

a: Direct watershed area excludes lake surface area and the watershed area of any upstream lakes.

b: Surface area, depth and volume at lake outlet control elevation, can change depending on climatic conditions.

c: Littoral area assumed to be the same as surface area in these shallow lakes

3.4 Streams

The total length of Riley Creek is eight miles, with the impaired reach of Riley Creek stretching from Riley Lake to the Minnesota River. The total length of Purgatory Creek starting at Silver Lake is 12 miles, with the impaired reach stretching from Staring Lake to the Minnesota River. The North Fork of Nine Mile Creek is 7.6 miles long, the South Fork is 8.6 miles long, and the lower portion of Nine Mile Creek is 7.4 miles long. The impaired reach of Nine Mile Creek stretches from Marsh Lake to the Minnesota River. The approximate impaired reach lengths and total watershed areas of the three impaired creeks are listed in Table 3.3.

Table 3.3 Impaired RPBCWD and NMCWD streams, areas and impaired reach lengths.

Impaired Reach AUID	HUC08 Subwatershed	Impaired Reach Location	Impaired Reach Length (miles)	Total Watershed Area (acres)
07020012-511	Riley Creek	Lake Riley to the Minnesota River	4.98	8,180
07020012-828	Purgatory Creek	Staring Lake to the Minnesota River	5.64	19,400
07020012-809	Nine Mile Creek	Marsh Lake to the Minnesota River	4.82	29,740

3.5 Subwatersheds

The RPBCWD Subwatershed delineations and conveyance networks are based on the subwatershed divides updated from topographic data (DNR 2011), storm sewer data, and other information from the Minnesota Department of Transportation (MnDOT) and cities, as well as development plans submitted as part of the RPBCWD permit review process. Subwatersheds for all eight RPBCWD lakes are shown in Figure 3.1 to Figure 3.8.

The NMCWD Subwatershed delineations and conveyance networks are based on the subwatershed divides updated from topographic data (DNR 2011), storm sewer data, and other information from MnDOT and cities. Subwatersheds for all six NMCWD lakes are shown in Figure 3.9 to Figure 3.14.

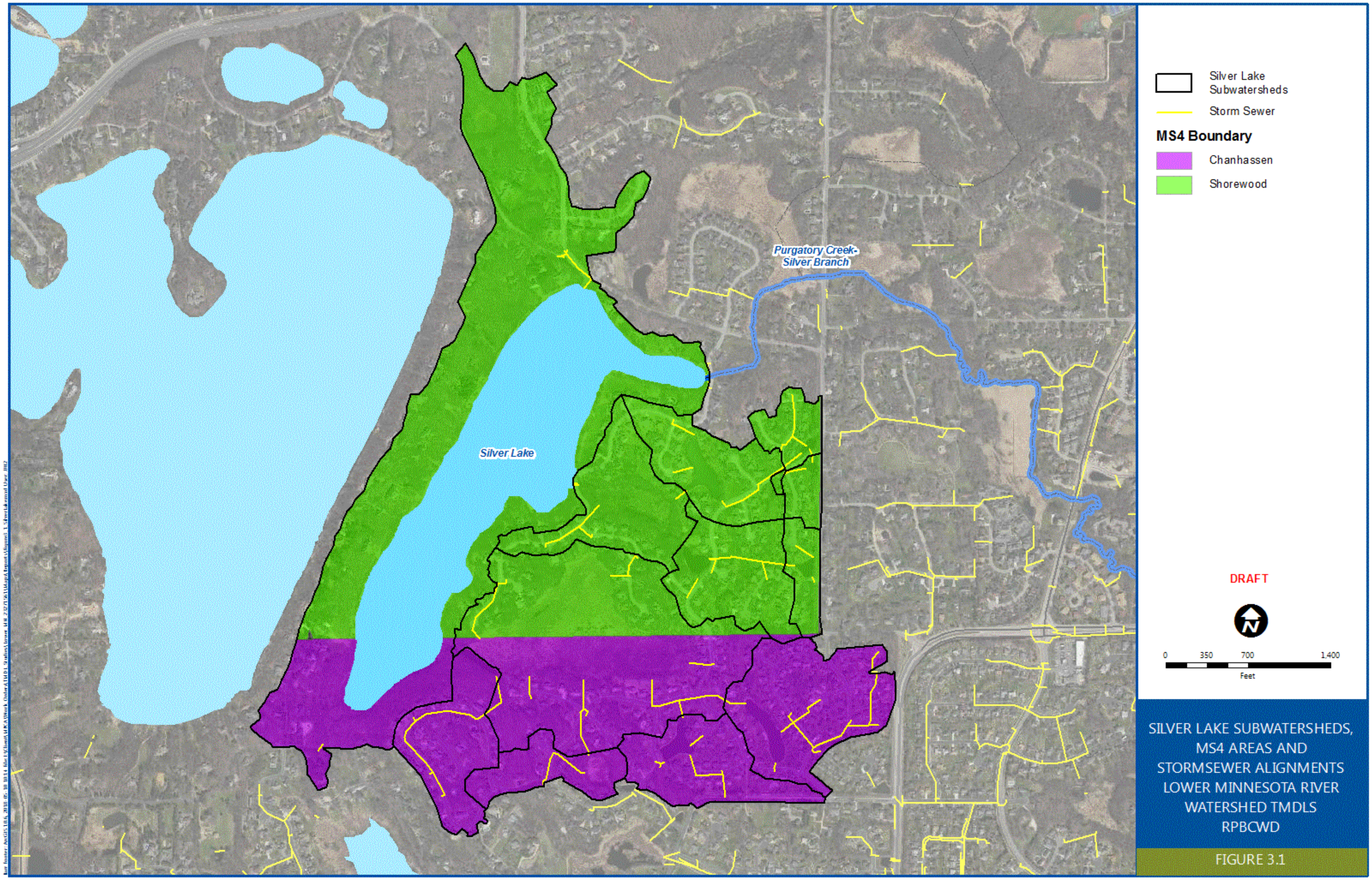


Figure 3.1 Silver Lake Subwatersheds

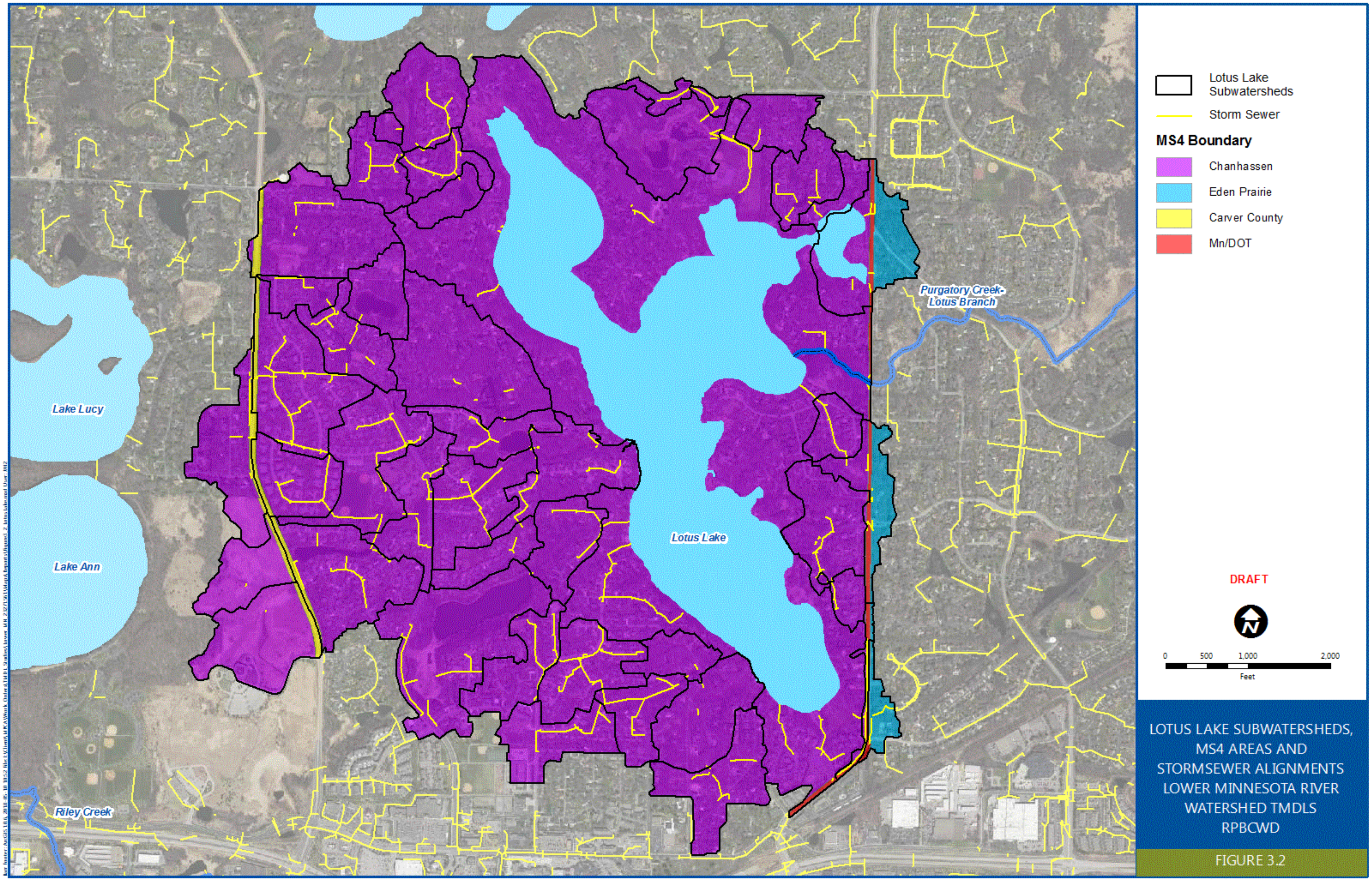


Figure 3.2 Lotus Lake Subwatersheds

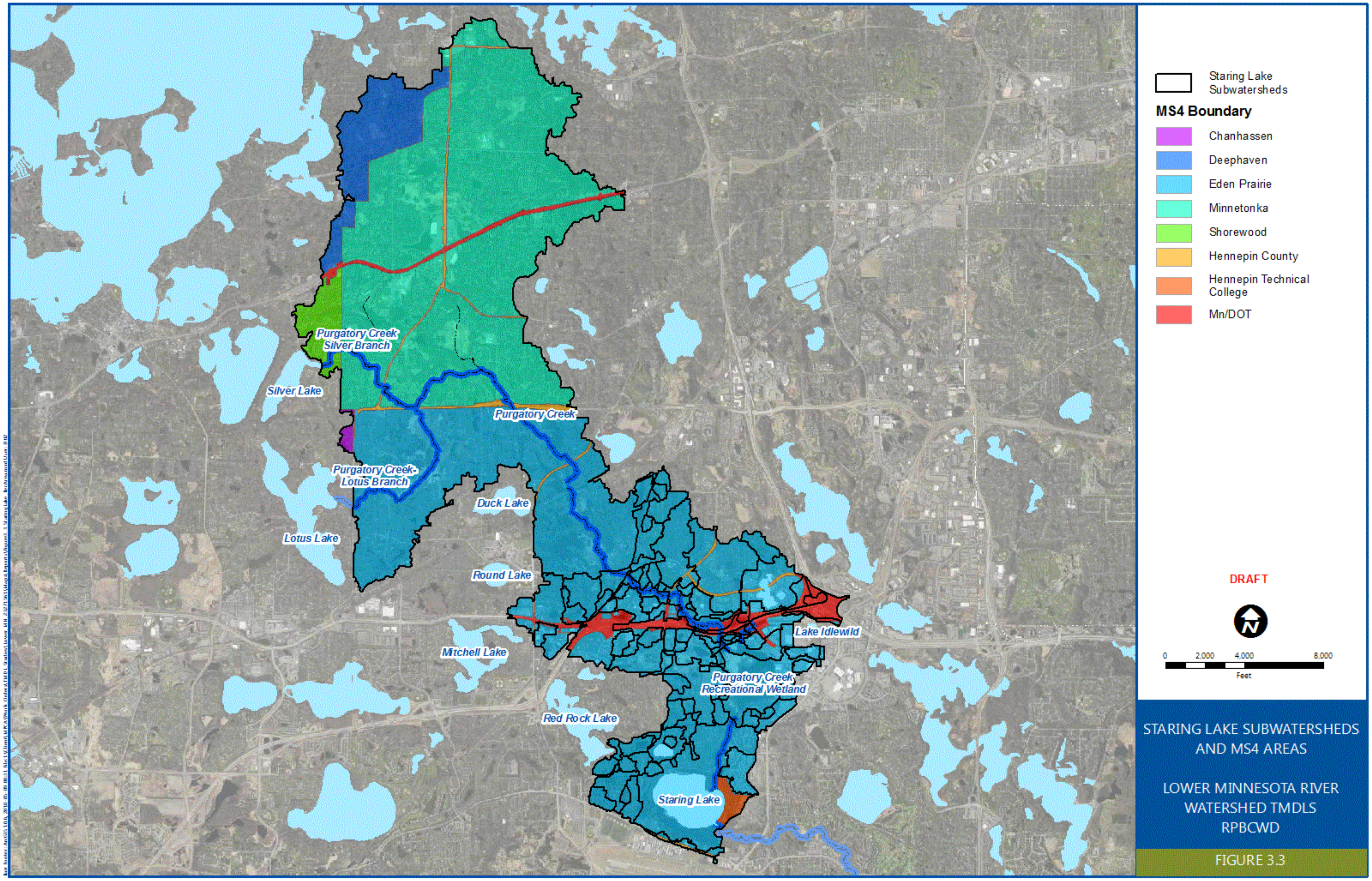


Figure 3.3 Staring Lake Subwatersheds

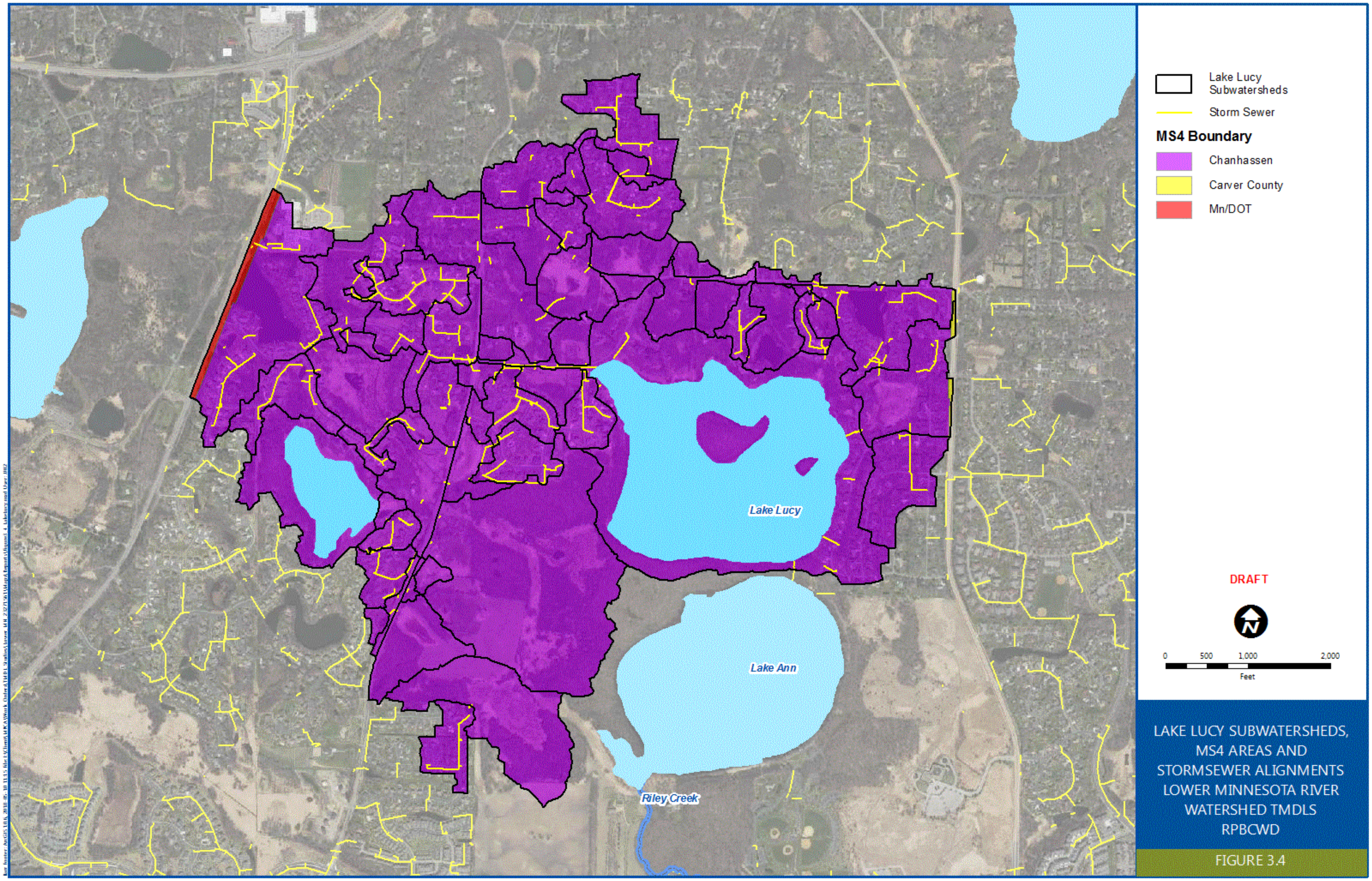


Figure 3.4 Lake Lucy Subwatersheds

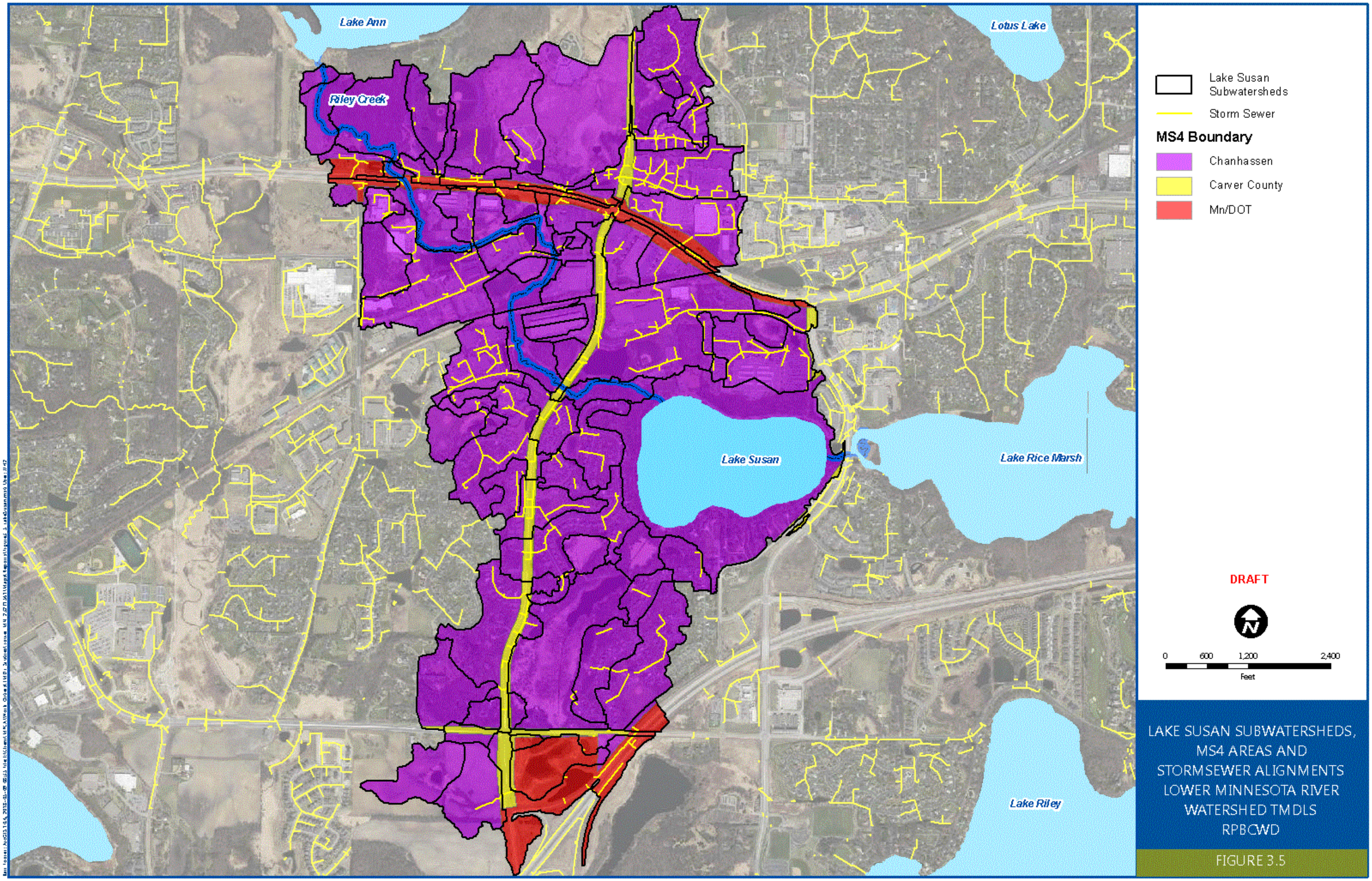


Figure 3.5 Lake Susan Subwatersheds

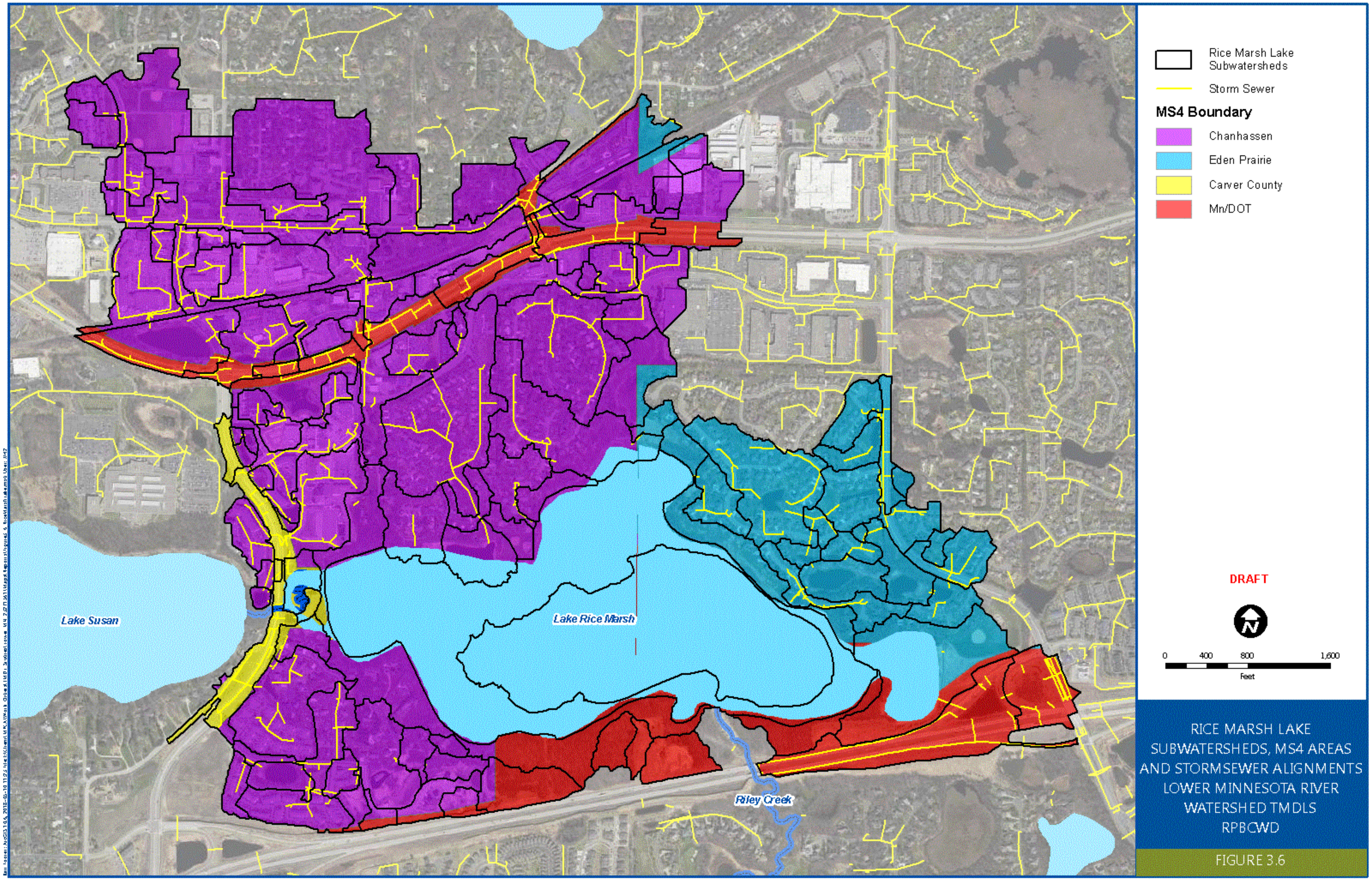


Figure 3.6 Rice March Lake Subwatersheds

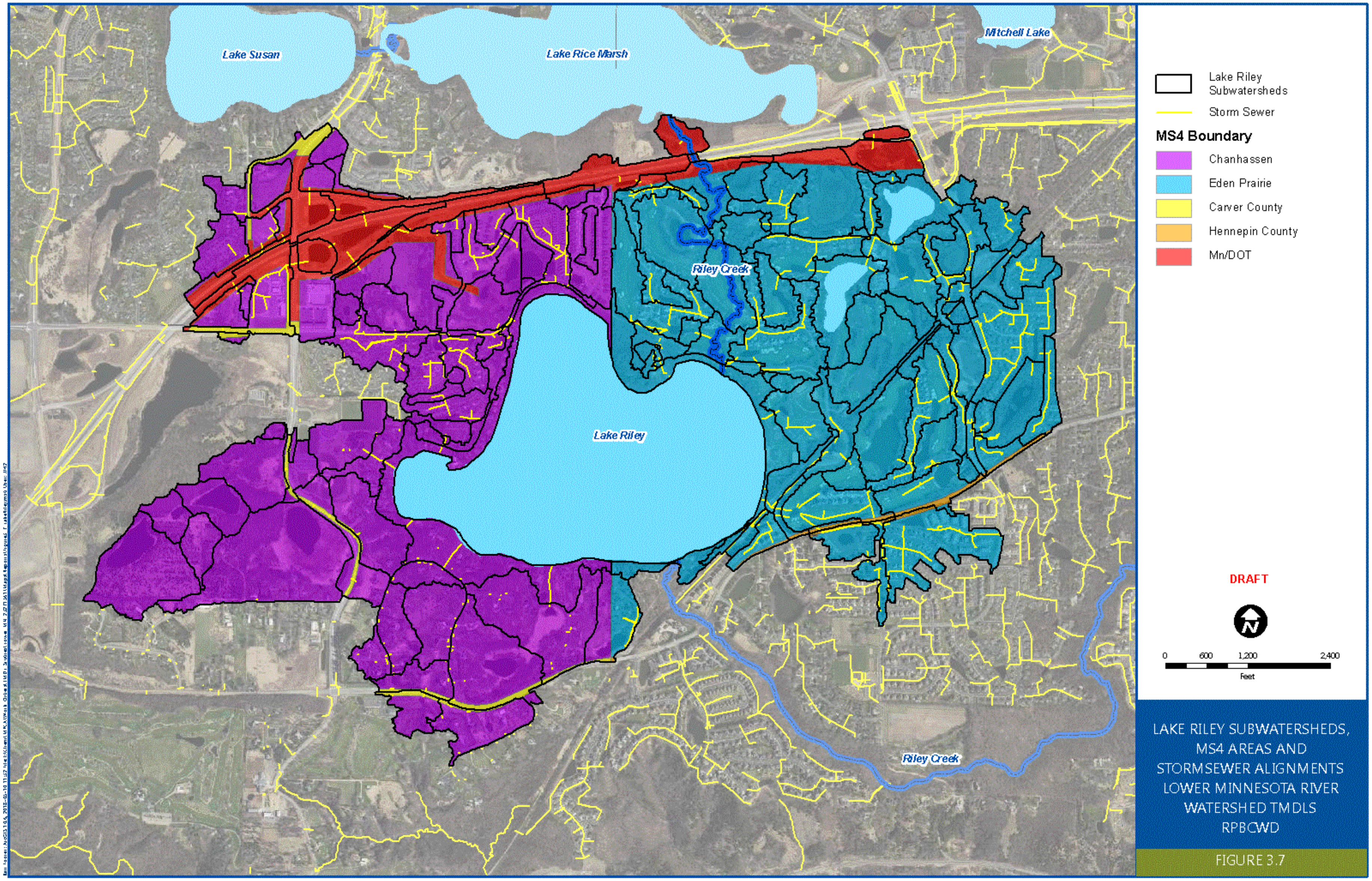


Figure 3.7 Lake Riley Subwatersheds

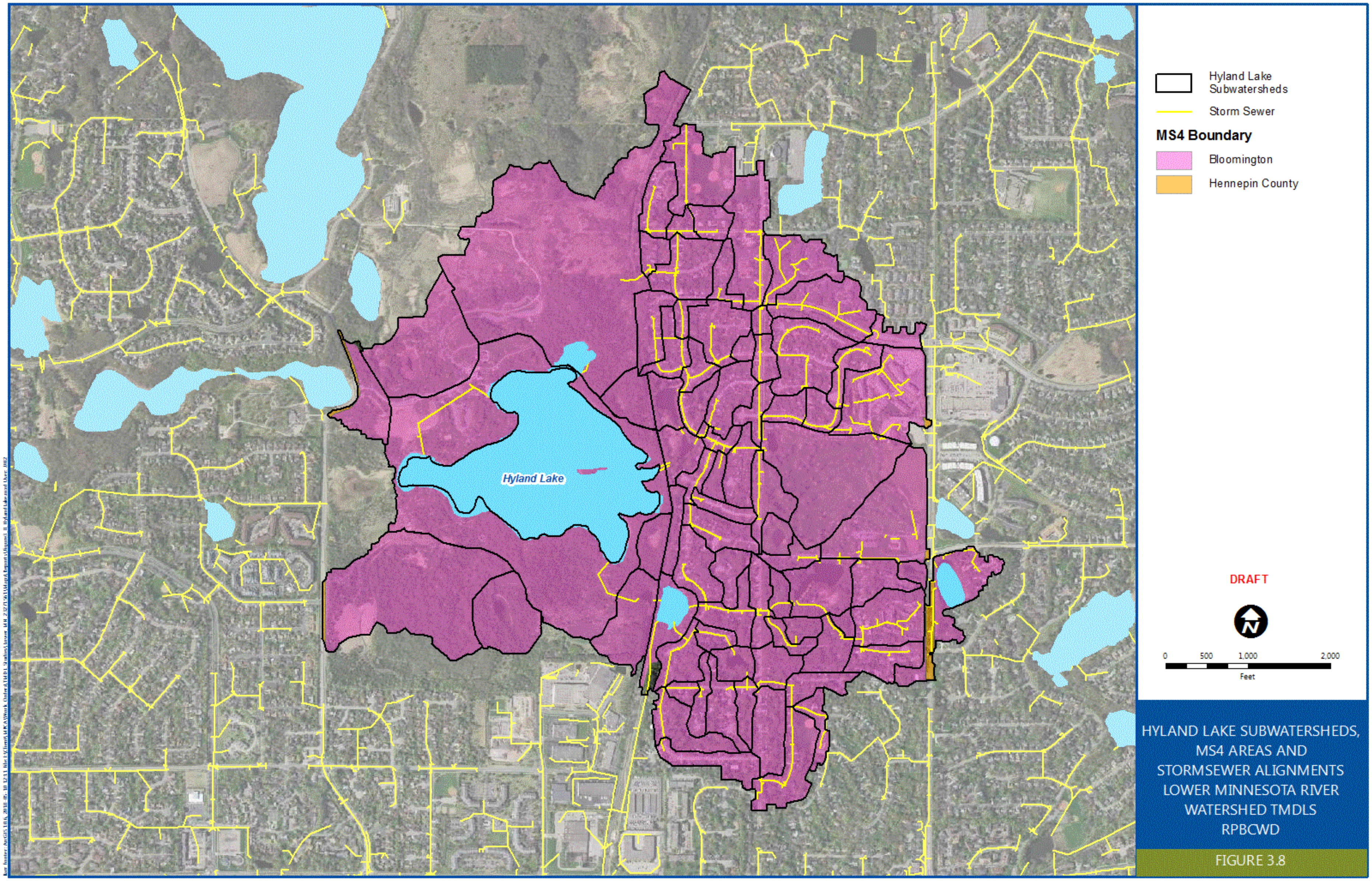


Figure 3.8 Hyland Lake Subwatersheds

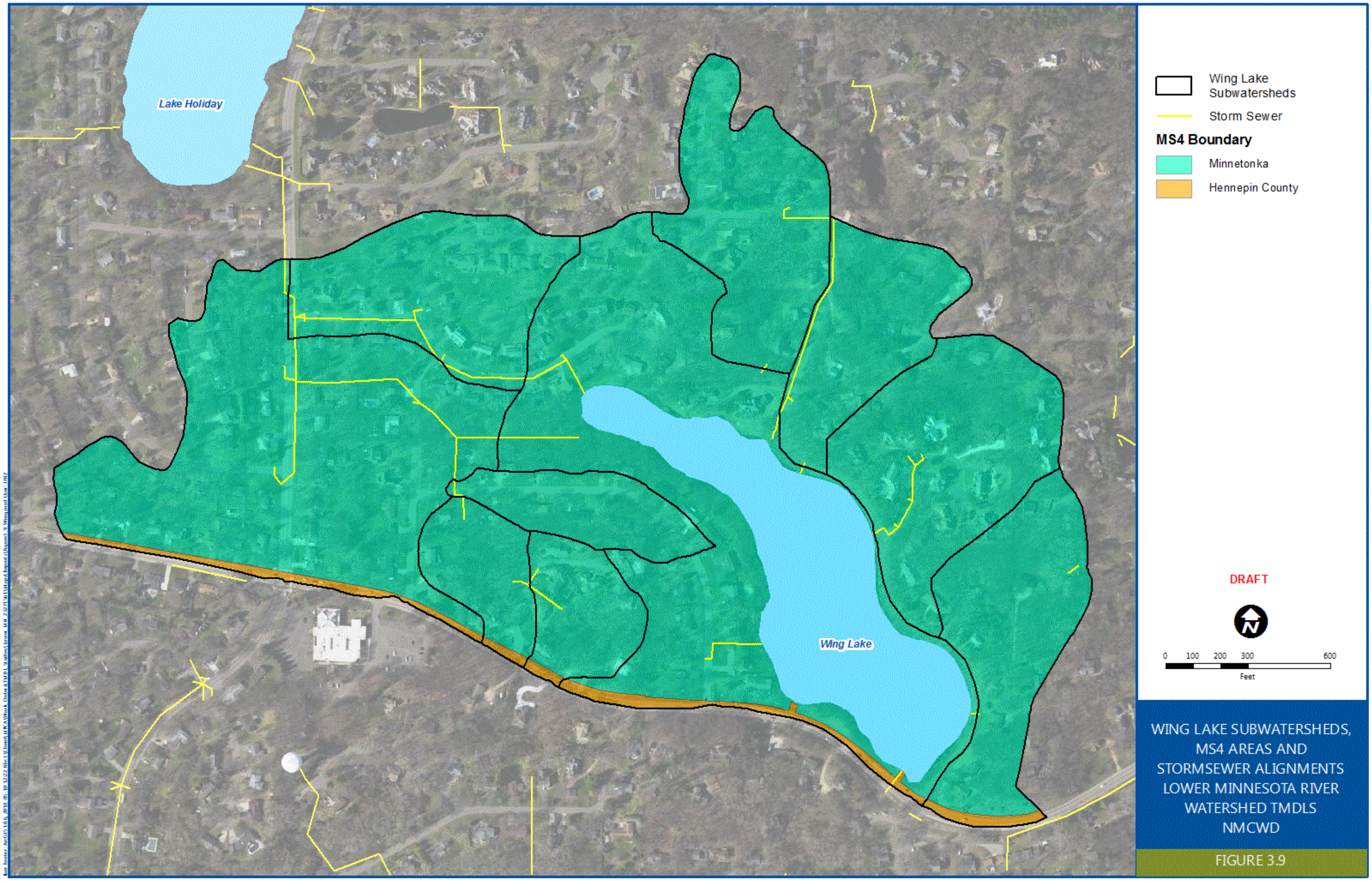


Figure 3.9 Wing Lake Subwatersheds

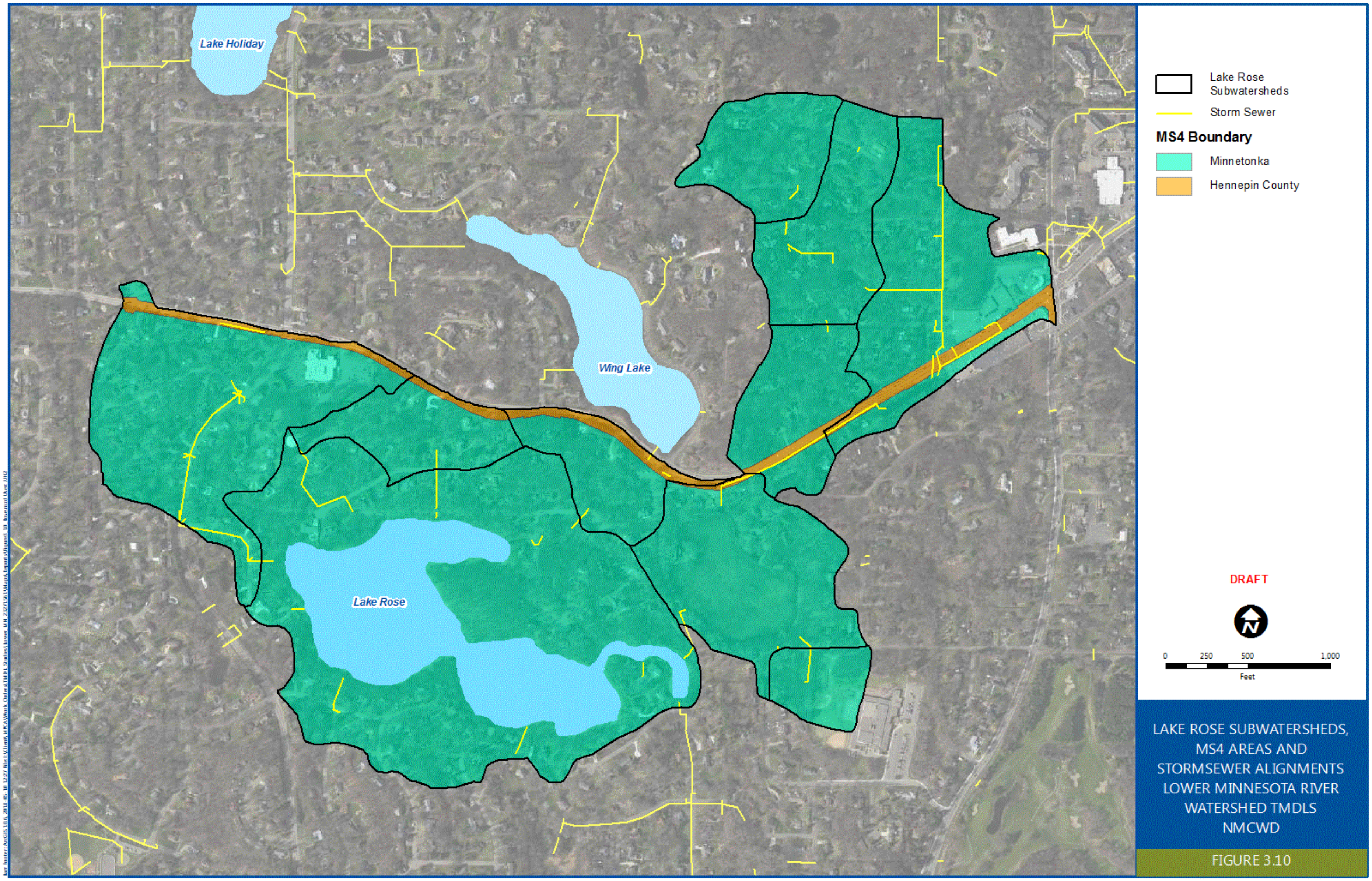


Figure 3.10 Lake Rose Subwatersheds

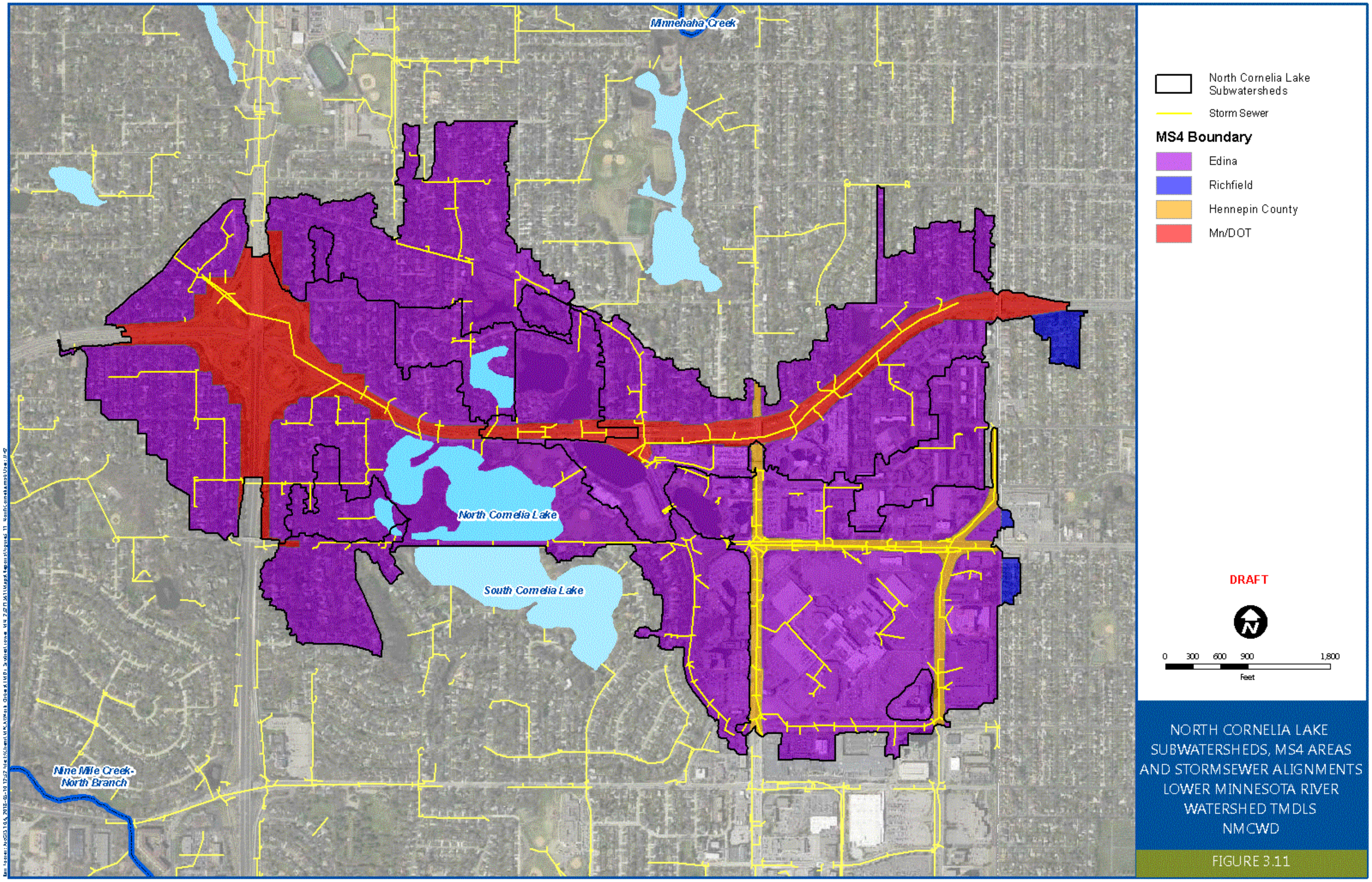


Figure 3.11 North Cornelia Lake Subwatersheds

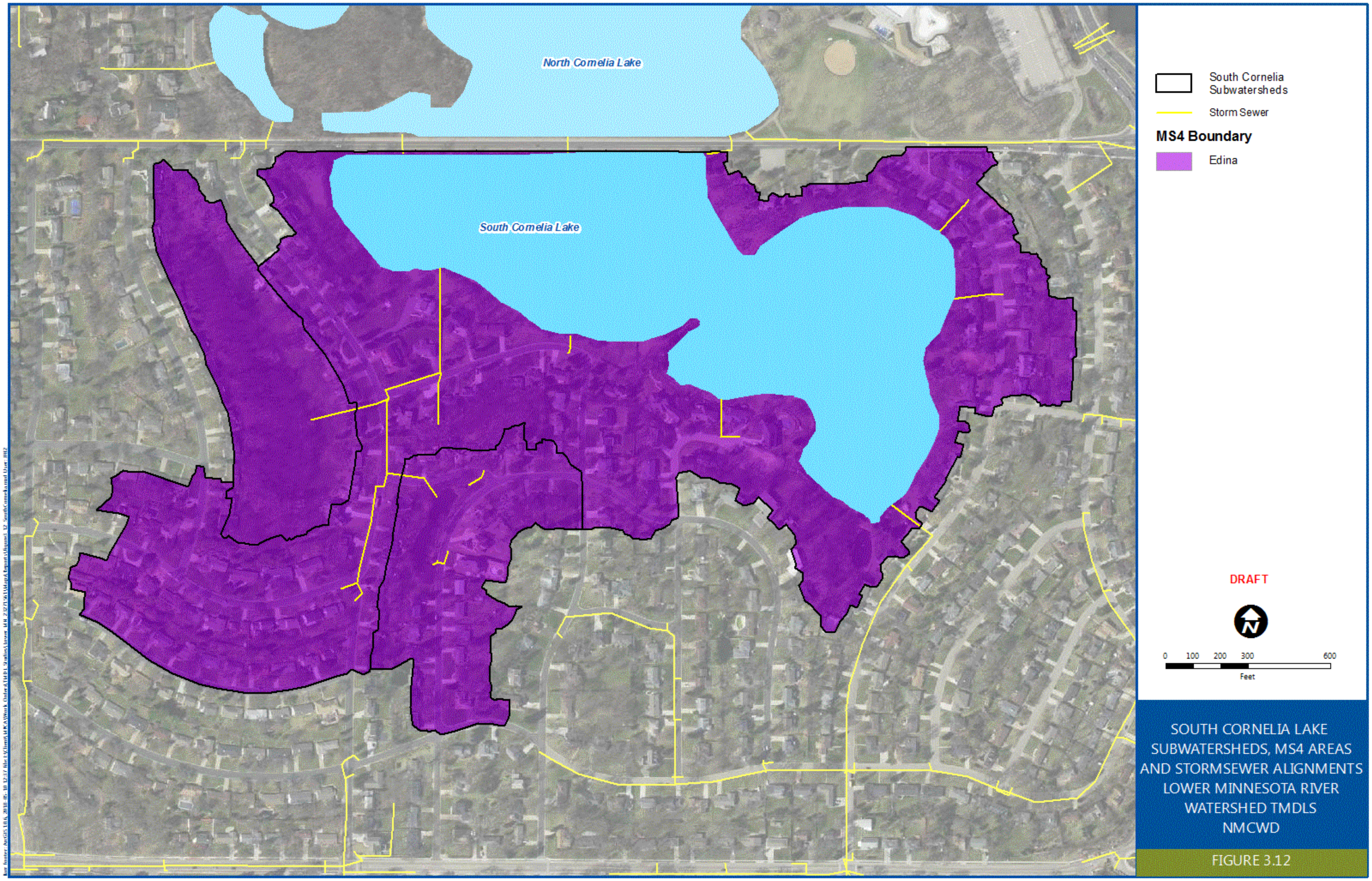


Figure 3.12 South Cornelia Lake Subwatersheds

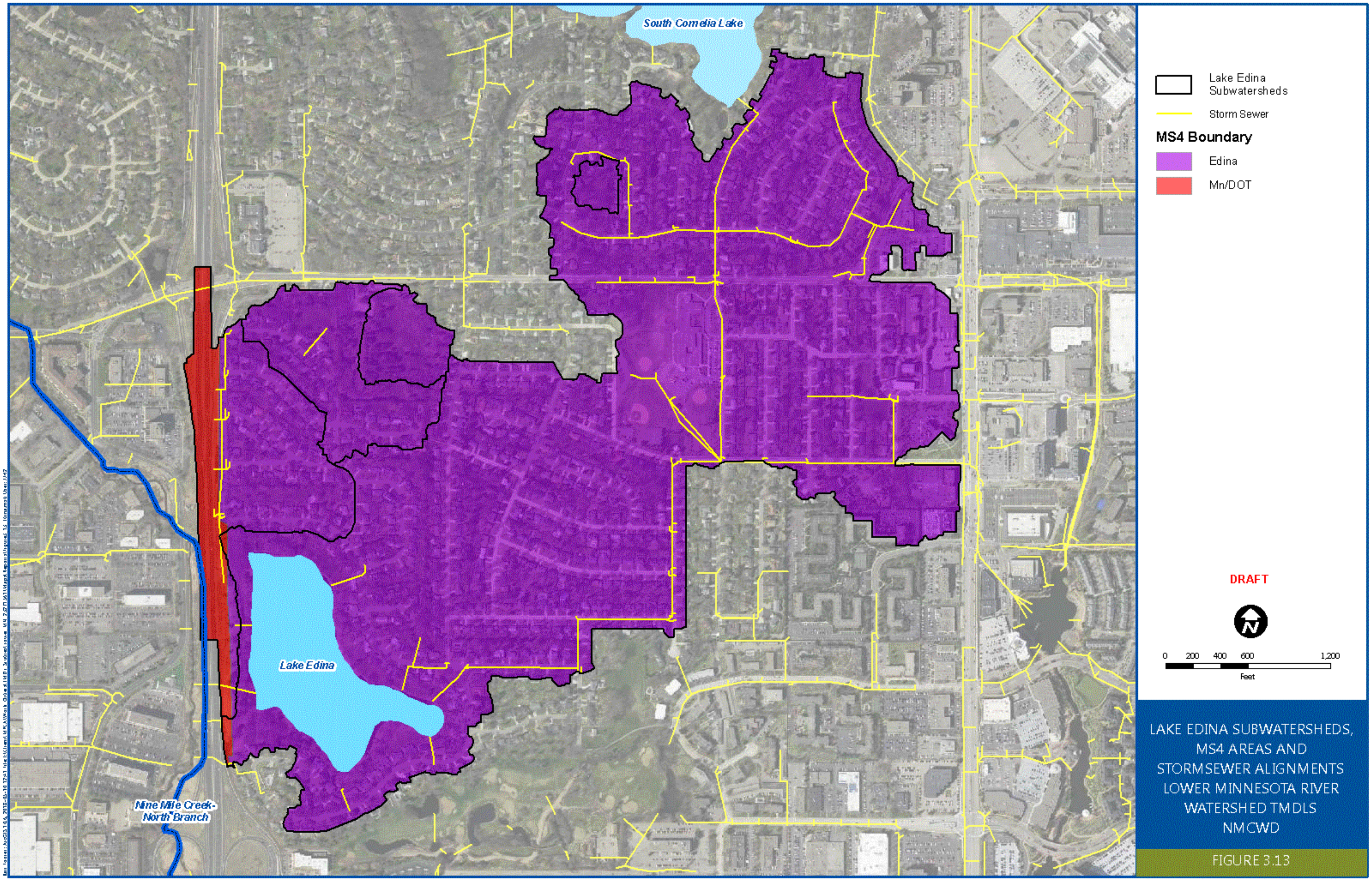


Figure 3.13 Lake Edina Subwatersheds

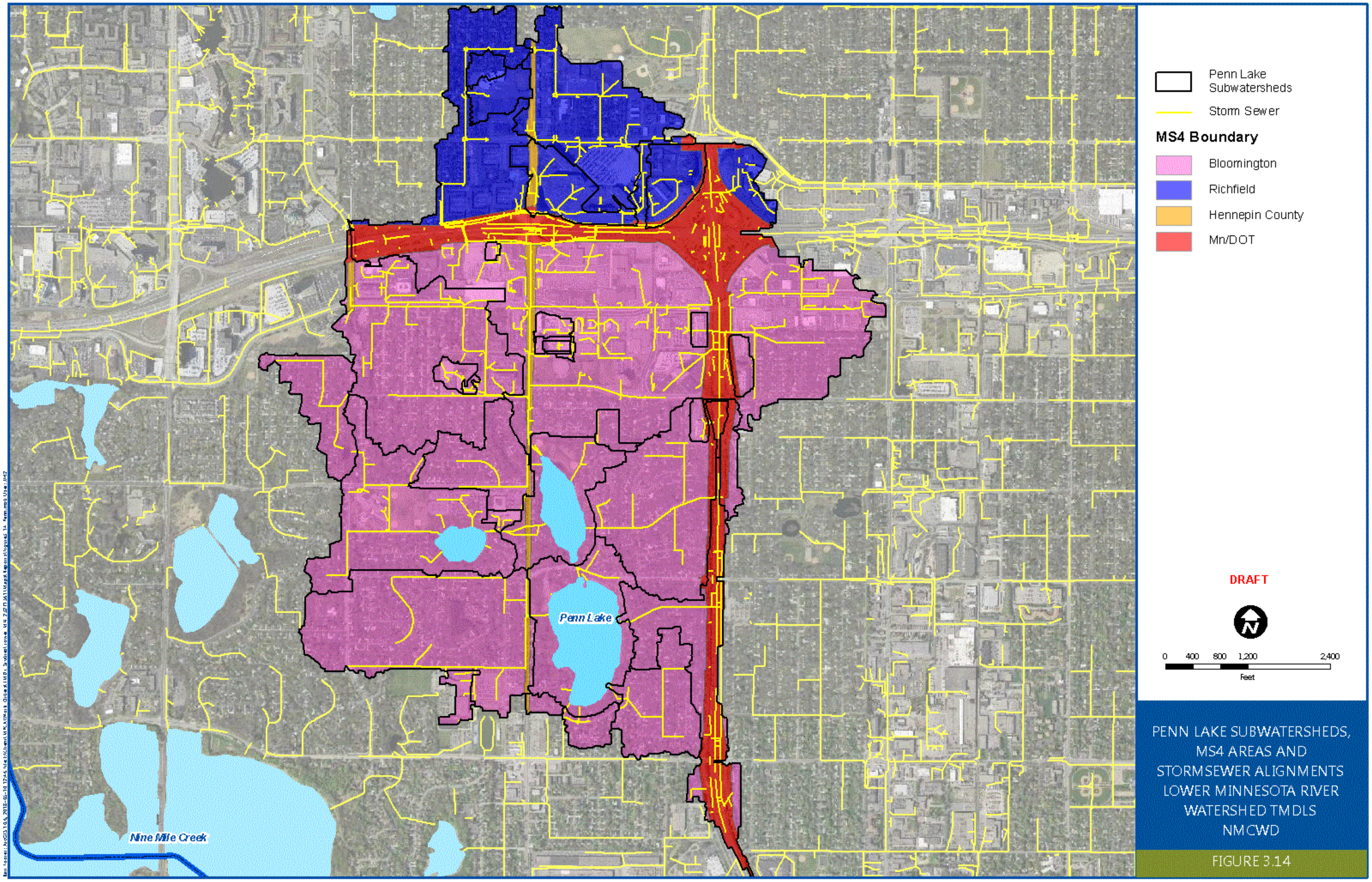


Figure 3.14 Penn Lake Subwatersheds

3.6 Land Use

This TMDL analysis used the Metropolitan Council's 2010 historical land use spatial data set (Metropolitan Council 2010) for the Twin Cities Metropolitan Area. Land use data for all eight RPBCWD lakes, as well as Purgatory and Riley Creek, are displayed in Table 3.4. Land use data for all six NMCWD lakes, as well as Nine Mile Creek, are displayed in Table 3.5.

There are no tribal lands within the project area.

Table 3.4 Land use areas within the RPBCWD lake and stream watersheds including percent of total watershed area

Land Use	Land Use Area [Acres (Percent of Watershed)]									
	Silver Lake	Lotus Lake	Staring Lake[a]	Lake Lucy	Lake Susan[b]	Rice Marsh Lake	Lake Riley	Hyland Lake[c]	Riley Creek	Purgatory Creek
Agricultural/ Farmstead			5.2, (0%)	2.1, (0.2%)	60.3, (4.1%)	0.6, (0.1%)	28.9, (1.6%)		218.8, (2.7%)	17.9, (0.1%)
Airport			44.8, (0.3%)						383, (4.7%)	103.7, (0.5%)
Retail and Other Commercial			447.3, (3.3%)		52.1, (3.5%)	117.7, (12.3%)	4.8, (0.3%)	2, (0.2%)	177.9, (2.2%)	683.1, (3.5%)
Golf course			109.1, (0.8%)				189.6, (10.6%)	66.2, (7.2%)	189.7, (2.3%)	288.3, (1.5%)
Major Highway			465.3, (3.5%)		75.2, (5.1%)	71, (7.4%)	78.8, (4.4%)		231.4, (2.8%)	612.8, (3.2%)
Office			107.8, (0.8%)		12.8, (0.9%)	7.5, (0.8%)		7, (0.8%)	44.6, (0.5%)	162.4, (0.8%)
Industrial and Utility		0.8, (0.1%)	436, (3.2%)	1.6, (0.2%)	171.6, (11.6%)	21.3, (2.2%)	4.8, (0.3%)	0.1, (0%)	206.2, (2.5%)	467.2, (2.4%)
Mixed Use			10.9, (0.1%)		5.4, (0.4%)				5.4, (0.1%)	17.4, (0.1%)
Institutional	8.2, (1.9%)	16.7, (1.2%)	530.7, (3.9%)	13.2, (1.3%)	21.7, (1.5%)	48.1, (5%)	1.8, (0.1%)	14.1, (1.5%)	127.6, (1.6%)	712.8, (3.7%)
Single Family Detached	303.1, (71.9%)	852, (60.5%)	6,454.7, (48%)	443.9, (44.9%)	259.5, (17.5%)	262.5, (27.4%)	585.1, (32.7%)	314.0, (34.0%)	2,064.6, (25.2%)	9,298.7, (47.9%)
Multifamily		4.2, (0.3%)	325.1, (2.4%)	2, (0.2%)	13.5, (0.9%)	27.3, (2.8%)	7, (0.4%)	16.4, (1.8%)	49.8, (0.6%)	506.6, (2.6%)
Single Family Attached		64.9, (4.6%)	702, (5.2%)		41, (2.8%)	34, (3.5%)	64.8, (3.6%)	49.5, (5.4%)	254, (3.1%)	1,189.7, (6.1%)
Seasonal/ Vacation	0.1, (0.1%)		0.1, (0%)	0.2, (0%)			1.7, (0.1%)		1.9, (0%)	0.1, (0%)
Park/Preserve /Recreational	10 (2.4%)	112.2, (8%)	1,911.4, (14.2%)	59.7, (6%)	246.6, (16.6%)	139.5, (14.5%)	112.3, (6.3%)	352.9, (38.3%)	1,484.7, (18.2%)	2,632.7, (13.5%)
Undeveloped	5.1 (1.2%)	97.5, (6.9%)	1,130.2, (8.4%)	327.9, (33.2%)	313, (21.1%)	121.2, (12.6%)	335.7, (18.8%)	1.7, (0.2%)	1,619, (19.8%)	1,623.6, (8.4%)
Open Water	94.8 (22.5%)	259.3, (18.4%)	765.8, (5.7%)	137.5, (13.9%)	208.6, (14.1%)	109.5, (11.4%)	373, (20.8%)	97.8, (10.6%)	1,119.5, (13.7%)	1,109.4, (5.7%)

a: Watershed area includes all areas upstream of Staring Lake except Lotus Lake watershed

b: Watershed area includes Lake Ann watershed

c: Only 483 acres of the 839 acre Hyland Lake watershed actually contributed loading to the lake during the 2015 water year.

Table 3.5 Land use areas within the NMCWD lake and stream watersheds including percent of total watershed area

Land Use	Land Use Area [Acres (Percent of Watershed)]						
	Wing Lake	Lake Rose	North Cornelia Lake	South Cornelia Lake	Lake Edina	Penn Lake	Nine Mile Creek
Agricultural/ Farmstead							57.9, (0.2%)
Airport							
Retail and Other Commercial		6.1, (2.4%)	126.4, (14.5%)		5.2, (1.3%)	157.7, (12%)	1,075.3, (3.6%)
Golf course							547.5, (1.8%)
Manufactured Housing Parks							3.1, (0%)
Major Highway			102.2, (11.7%)		13.8, (3.5%)	129.3, (9.8%)	1,466.4, (4.9%)
Railway							31.3, (0.1%)
Office			78.7, (9%)		7.5, (1.9%)	108.9, (8.3%)	1,342, (4.5%)
Industrial and Utility		0.5, (0.2%)	0.3, (0%)		0.2, (0%)	31.5, (2.4%)	1,738.1, (5.8%)
Mixed Use			8.5, (1%)				732.9, (2.5%)
Institutional		11.3, (4.4%)	23.9, (2.7%)		22.2, (5.6%)	105.2, (8%)	1,210, (4.1%)
Single Family Detached	107.9, (85.2%)	183.7, (71.4%)	342.9, (39.2%)	76.5, (67.9%)	280.3, (71.3%)	582.4, (44.3%)	11,594.4, (39%)
Multifamily		0.8, (0.3%)	52.2, (6%)		7.6, (1.9%)	85.7, (6.5%)	1,247.9, (4.2%)
Single Family Attached	0.9, (0.7%)	3.9, (1.5%)	23.5, (2.7%)		4.7, (1.2%)	9.8, (0.7%)	861.4, (2.9%)
Seasonal/ Vacation							
Park/Preserve/ Recreational		9.2, (3.6%)	64.4, (7.4%)	2.9, (2.6%)	20.4, (5.2%)	30.5, (2.3%)	4,663.2, (15.7%)
Undeveloped	3.1, (2.5%)	7, (2.7%)	6, (0.7%)		7.5, (1.9%)	22.4, (1.7%)	1,447.4, (4.9%)
Open Water	14.7, (11.6%)	34.8, (13.5%)	44.5, (5.1%)	33.2, (29.5%)	23.9, (6.1%)	52.3, (4%)	1,718.1, (5.8%)

3.7 Current/Historical Water Quality

Water quality data was compiled for each of the waterbodies from various sources, including the RPBCWD Environmental Quality Information System (EQuIS) database, the NMCWD EQuIS database, the MPCA environmental data access web site, the Metropolitan Council environmental database, electronic data obtained from CH2MHill, and data that was not available electronically but highlighted in various water quality reports.

3.7.1 Lake Water Quality Data

Average summer (June through September) TP and Chl-*a* concentrations, as well as Secchi depths, were calculated for years available since 2006 for the RPBCWD lakes (Table 3.6). With the exception of Lake Lucy, all of the RPBCWD lakes had TP and Chl-*a* concentrations above the water quality standards. Average Secchi depths met the standards in all RPBCWD lakes except for Staring and Silver Lakes. Since Lake Lucy met the standards for average TP and Secchi depth, it is being considered in this study for lake water quality protection and will not be subject to TMDL development.

Average summer (June through September) TP and Chl-*a* concentrations, as well as Secchi depths, were calculated for years available since 2007 for the NMCWD lakes included in this study (Table 3.7). All of the NMCWD lakes had TP and Chl-*a* concentrations above the water quality standards. All of the NMCWD lakes also had Secchi depths less than the standard, except for Lake Rose, which just met the standard of 1.0 meter.

The sources of phosphorus entering the lakes—watershed runoff, internal loading, erosion sources, upstream lakes, and atmospheric deposition—are described in detail in Section 4.2.2, with specific breakdowns of loads to each lake by source shown in Figure 3.17 through Figure 3.30 in Section 3.8.1.

Table 3.6 Average Summer (June through September) water quality data comparison with applicable standards for analyzed lakes in the RPBCWD

AUID	Lake	TP (µg/L)	Chlorophyll-a (µg/L)	Secchi Depth (meters)	Years Monitored
Deep Lake Standards		< 40	< 14	> 1.4	
10-0006-00	Lotus Lake	55	39	1.5	2010-2015
10-0002-00	Lake Riley	48	26	1.5	2010, 2013-2015
Shallow Lake Standards		< 60	< 20	> 1.0	
27-0078-00	Staring Lake	94	41	0.8	2010-2015
10-0007-00	Lake Lucy	60	30	1.0	2006-2015
10-0013-00	Lake Susan	78	43	1.2	2010, 2013-2015
10-0001-00	Rice Marsh Lake	110	24	1.7	2010-2015
27-0048-00	Hyland Lake	95	72	1.3	2011-2015
27-0136-00	Silver Lake	93	48	0.7	2011-2015

Table 3.7 Average Summer (June through September) water quality data comparison with applicable standards for analyzed lakes in the NMCWD

AUID	Lake	TP (µg/L)	Chlorophyll-a (µg/L)	Secchi Depth (meters)	Years Monitored
Shallow Lake Standards		< 60	< 20	> 1.0	
27-0091-00	Wing Lake	97	36	0.8	2007-2016
27-0092-00	Lake Rose	105	48	1.0	2007-2008, 2011,2016
27-0028-01	North Cornelia Lake	148	57	0.4	2008,2013, 2015-2016
27-0028-02	South Cornelia Lake	132	48	0.4	2007-2009, 2013-2016
27-0029-00	Lake Edina	117	39	0.4	2008,2012, 2015
27-0004-00	Penn Lake	148	66	0.4	2009-2016

3.7.2 Stream Water Quality Data

3.7.2.1 Total Suspended Solids

According to the TSS standard for Class 2B waters, a stream reach is considered impaired if more than 10% of TSS samples collected April through September exceed 65 mg/L, based on the last 10 years of monitoring data. Figure 3.15 and Figure 3.16 show the magnitude and frequency with which the TSS sample results have exceeded 65 mg/L for Riley and Purgatory Creeks, respectively. Figure 3.15 shows that 59% of the samples results exceeded the 65 mg/L TSS standard for Riley Creek and 10% or more of the samples exceeded a TSS concentration of 530 mg/L since 2006.

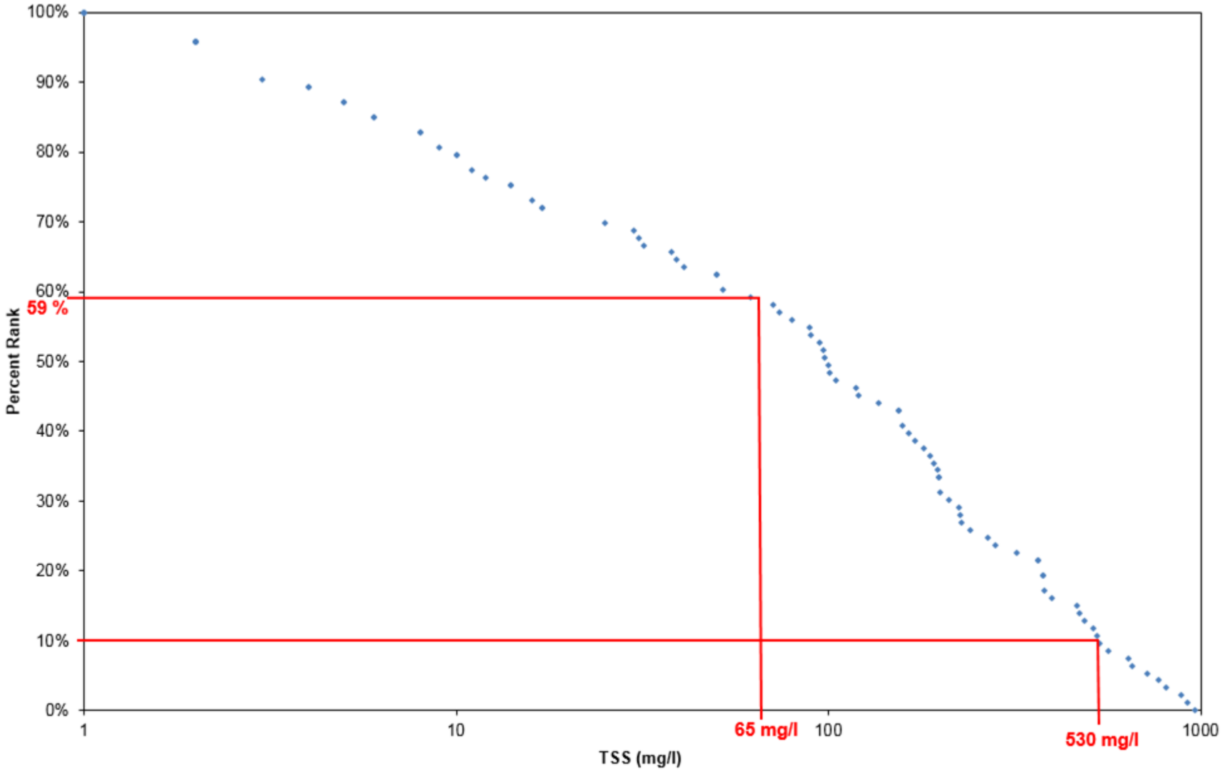


Figure 3.15 Riley Creek TSS concentration cumulative frequency curve, 2006-2015

Figure 3.16 shows that the Purgatory Creek TSS sample results only exceeded a concentration of 51 mg/L 10% of the time. Since just 4% of the Purgatory Creek TSS samples exceeded the 65 mg/L, the standard is being met and Purgatory Creek will be considered for water quality protection in this study and will not be subject to TMDL development. While the available TSS data for Purgatory Creek meets the standard, the results are limited in that most of the historic sampling has occurred upstream of significant near-channel sources of erosion and mass wasting, including landslides.

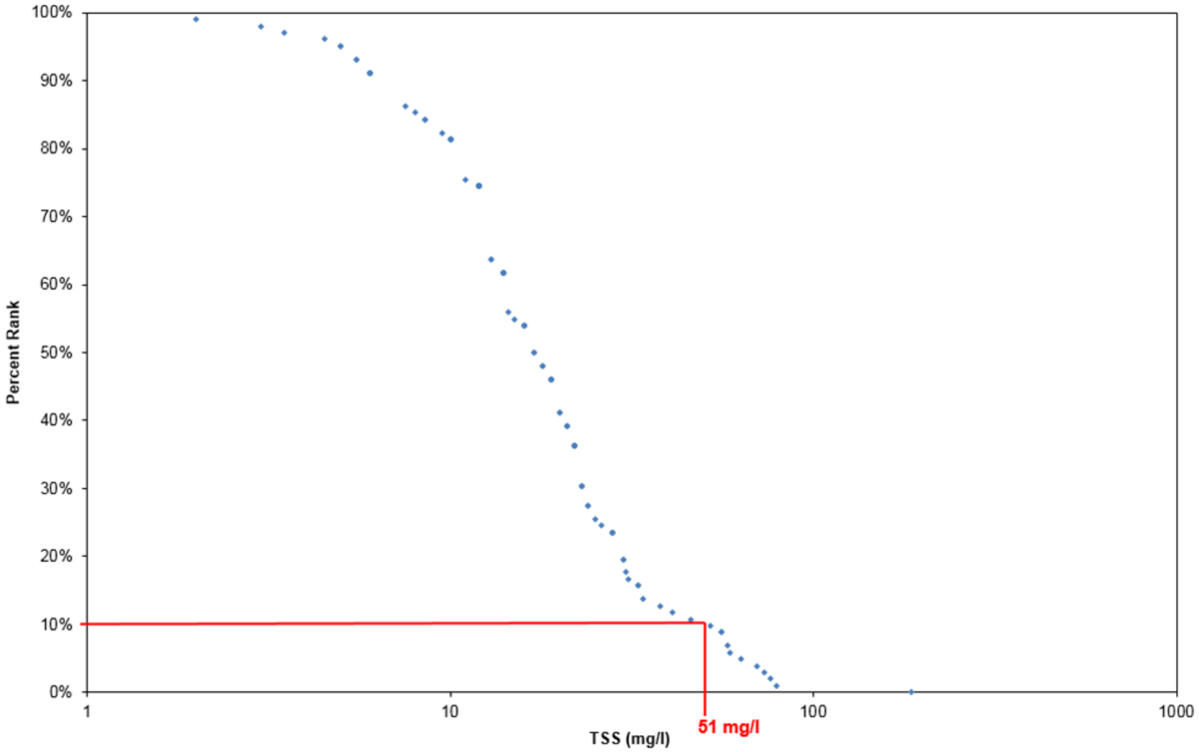


Figure 3.16 Purgatory Creek TSS concentration cumulative frequency curve, 2006-2015

3.7.2.2 Bacteria (*E. coli*)

The *E. coli* standard for Class 2B waters states that a stream reach is impaired if the geometric mean of no less than five samples within a calendar month exceeds 126 organisms per 100 milliliters ([mL] chronic impairment standard), or 10% of samples taken within any calendar month individually exceed 1,260 organisms per 100 mLs (acute impairment standard). Based on data collected by the NMCWD, Metropolitan Council Watershed Outlet Monitoring Program (WOMP), Scott County Stream and Lake Monitoring program, and the National Park Service (summarized in Table 3.8), the reach of Nine Mile Creek downstream of Marsh Lake, the reach of Purgatory Creek downstream of Staring Lake, and the reach of Riley Creek downstream of Riley Lake are impaired based on the Class 2B chronic impairment standard (Table 3.9) None of the stream reaches evaluated are impaired based on the Class 2B acute impairment standard (Table 3.10).

Table 3.8 Stream bacteria (*E. coli*) monitoring summary

Stream	Station ID	Years Collected
Nine Mile Creek	S007-901	2006-2017
	ECU7A/N1	2010-2014
Purgatory Creek	P1.6	2006
	S007-907	2014-2017
Riley Creek	S005-380	2006-2017

Table 3.9 Chronic *E. coli* impairment summary

		Month						
Stream		**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**
Nine Mile Creek	Samples Per Month (#)	7	7	14	12	14	5	5
	E. coli Geometric Mean (org/100 mL)[a]	67	151	149	127	181	212	164
Purgatory Creek	Samples Per Month (#)	3	7	11	12	14	3	3
	E. coli Geometric Mean (org/100 mL)[a]	73	26	126	104	166	392	32
Riley Creek	Samples Per Month (#)	8	8	8	9	9	10	8
	E. coli Geometric Mean (org/100 mL)[a]	51	62	308	654	351	296	113

a: Values highlighted in red indicate the geometric mean of samples collected exceeded the monthly geometric mean criterion (126 org/100 mL).

Table 3.10 Acute *E. coli* impairment summary

Stream	Total Number of Samples	Percent > 1,260 org/100 mL
Nine Mile Creek	64	1.6%
Purgatory Creek	53	1.9%
Riley Creek	60	6.7%

3.8 Pollutant Source Summary

3.8.1 Total Phosphorus

Loading of TP to the lakes is estimated for multiple sources, including watershed load from surface runoff into the lake, internal loading from the lake sediments, loading from upstream lakes, atmospheric deposition directly onto the lake's water surface, groundwater seepage into the lake, and erosion of channel banks. Each of these sources were assessed for all lake studies in the calibration of the in-lake model. The detailed breakdown of loads to the lake by source is shown in Figure 3.17 through Figure 3.30, and detailed in Section 4.2.

3.8.1.1 Permitted

The regulated sources of TP within the RPBCWD impaired waterbodies include National Pollutant Discharge Elimination System (NPDES) permitted wastewater treatment facility (WWTF) effluent, Municipal Separate Storm Sewer Systems (MS4) stormwater, construction site stormwater and industrial stormwater. The regulated sources of TP within the NMCWD impaired waterbodies include MS4 stormwater, construction sites and industrial sites. Runoff from urban areas contains phosphorus in the form of organic remains (primarily leaves, seeds, grass clippings, and other organic debris), lawn and garden fertilizer (where not phosphorus-restricted), and soil particles.

3.8.1.2 Non-permitted

Non-permitted sources of TP loading within the RPBCWD and NMCWD include atmospheric deposition, streambank and hillside erosion, internal loading, groundwater inflows and upstream lake outflows.

Atmospheric Deposition

Atmospheric deposition of phosphorus represents the amount of phosphorus bound to particulates in the atmosphere that deposits directly onto the lake water surface.

Erosion

TP loads from streambank erosion were calculated for tributaries to Lake Susan, Staring Lake, and Lotus Lake based on estimates resulting from the CRAS report (Barr 2015) and associated documentation for the surveys of the stream reaches within the respective watersheds. Erosion TP loads from the steep slopes west of Silver Lake were also estimated based on slope instabilities detected through site surveys and aerial imagery. These TP loads associated with erosion are transported to downstream lakes via the creeks and overland flow paths.

Internal Loading

Internal loading represents the release of phosphorus in the water column from sources within the lake sediments or through decay of macrophytes. The internal release of phosphorus into the water column can occur through three methods: chemical release from the sediments, physical release from the sediments, and release through decaying plant matter.

Chemical release of phosphorus from the bottom sediments occurs when anoxic conditions are present due to thermal stratification. When lakes are stratified oxygen is prevented from mixing into the lake hypolimnion. Anoxic conditions in the hypolimnion then occur resulting in the release of phosphorus bound to the sediment. Elevated sediment phosphorus release rates from in-situ sediment core experiments, and/or concentrations of mobile and organic bound fractions of sediment phosphorus, can be used as a surrogate or indicator of how much chemical release can potentially account for internal loading in each lake.

Physical release of phosphorus can occur through the disturbance of sediment by bottom feeding fish such as carp or other rough fish (e.g., bullheads) causing sediment bound phosphorus to suspend in the water column. Wind can also suspend phosphorus by causing internal waves that mix the sediments into suspension releasing phosphorus back into the water column.

Decaying plant matter, especially the invasive curly-leaf pondweed, is another potential source of internal phosphorus loading. Curly-leaf pondweed grows over the winter and tenaciously during early spring, crowding out native species. It releases a small reproductive pod (turion) that resembles a small pinecone during late June. After curly-leaf pondweed dies out, often in late-June and early-July, it may sink to the lake bottom and decay, releasing phosphorus and causing oxygen depletion and exacerbating internal sediment release of phosphorus. This potential increase in phosphorus concentration during early July can result in algal blooms during the peak of the recreational season. Hyland Lake in particular has had nuisance growth conditions of curly-leaf pondweed in the past that has inhibited recreational use and likely contributed to the lake's impaired water quality. Three Rivers Park District conducted lake-wide endothall herbicide treatments in Hyland Lake to control curly-leaf pondweed from 2013 through 2016, followed by a spot treatment in 2017. These treatments have significantly reduced curly-leaf pondweed densities and Three Rivers Park District plans to continue spot treatments to maintain control of curly-leaf pondweed.

The presence of an internal loading phosphorus release can be observed by examining the hypolimnetic phosphorus concentrations during the summer months when thermal stratification is strong. The presence of elevated concentrations in the hypolimnion compared to the epilimnion indicates internal loading is present.

Groundwater

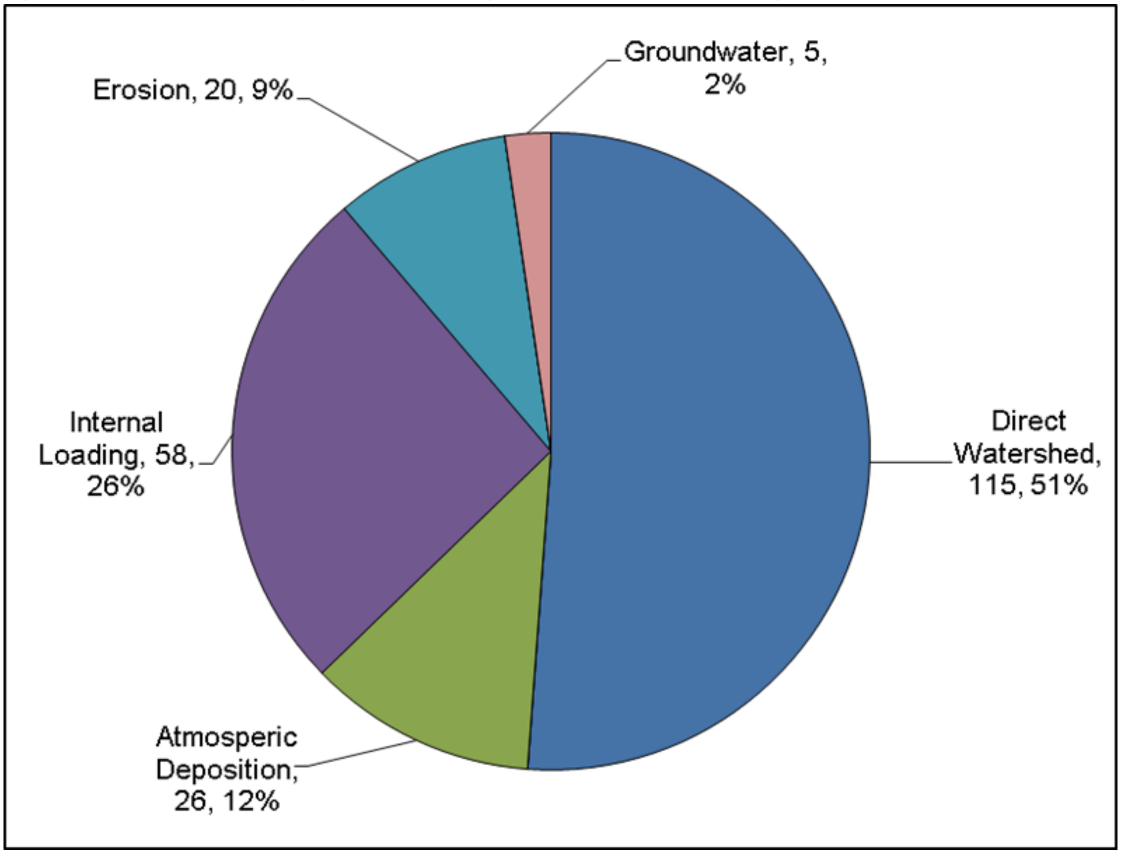
Groundwater intrusions into the lakes can be a source of phosphorus. Groundwater flow into and out of each lake was determined through the lake water balance in the daily in-lake model.

Upstream Lakes

Upstream lakes contribute TP loading to Staring Lake, Lake Riley, Rice Marsh Lake, and Lake Susan in the RPBCWD. Staring Lake has multiple upstream lakes contributing to the overall TP load. The outfalls of Lotus Lake, Duck Lake, and Silver Lake flow into Purgatory Creek, which flows through the Purgatory Creek Recreational Area and into Staring Lake. The Eden Prairie Chain of Lakes (Round, Mitchell, and Red Rock Lake) flow from Red Rock Lake through a series of ponds into Lake McCoy, and finally into Staring Lake. Lake Riley, Rice Marsh Lake, and Lake Susan are located in series along Riley Creek, which carries flows from Lake Ann to Lake Susan, then Rice Marsh Lake, and finally Lake Riley.

In the NMCWD, upstream lakes also contribute TP loading to Wing Lake (from Lake Holiday), Lake Rose (from Wing Lake), South Cornelia Lake (from North Cornelia Lake) and Lake Edina (from South Cornelia Lake).

Figure 3.17 Silver Lake existing conditions loading breakdown for 2015 water year



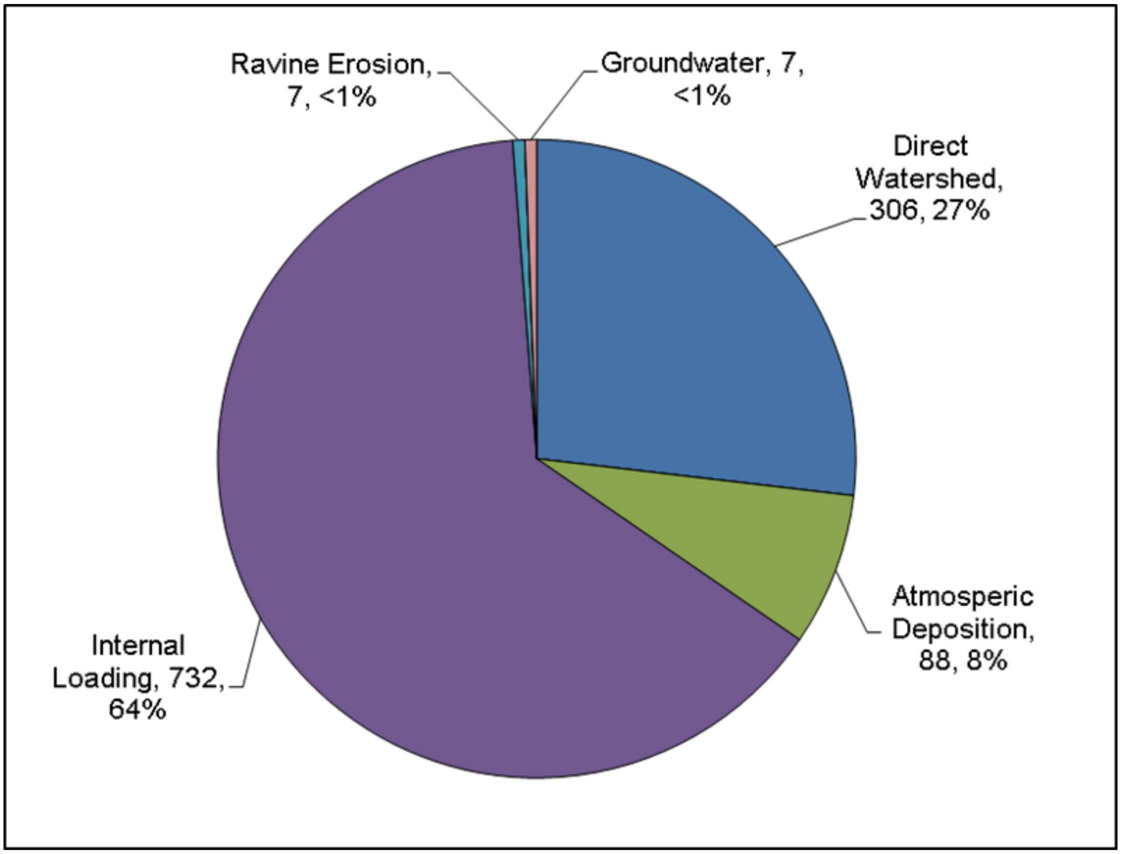


Figure 3.18 Lotus Lake existing conditions loading breakdown for 2015 water year

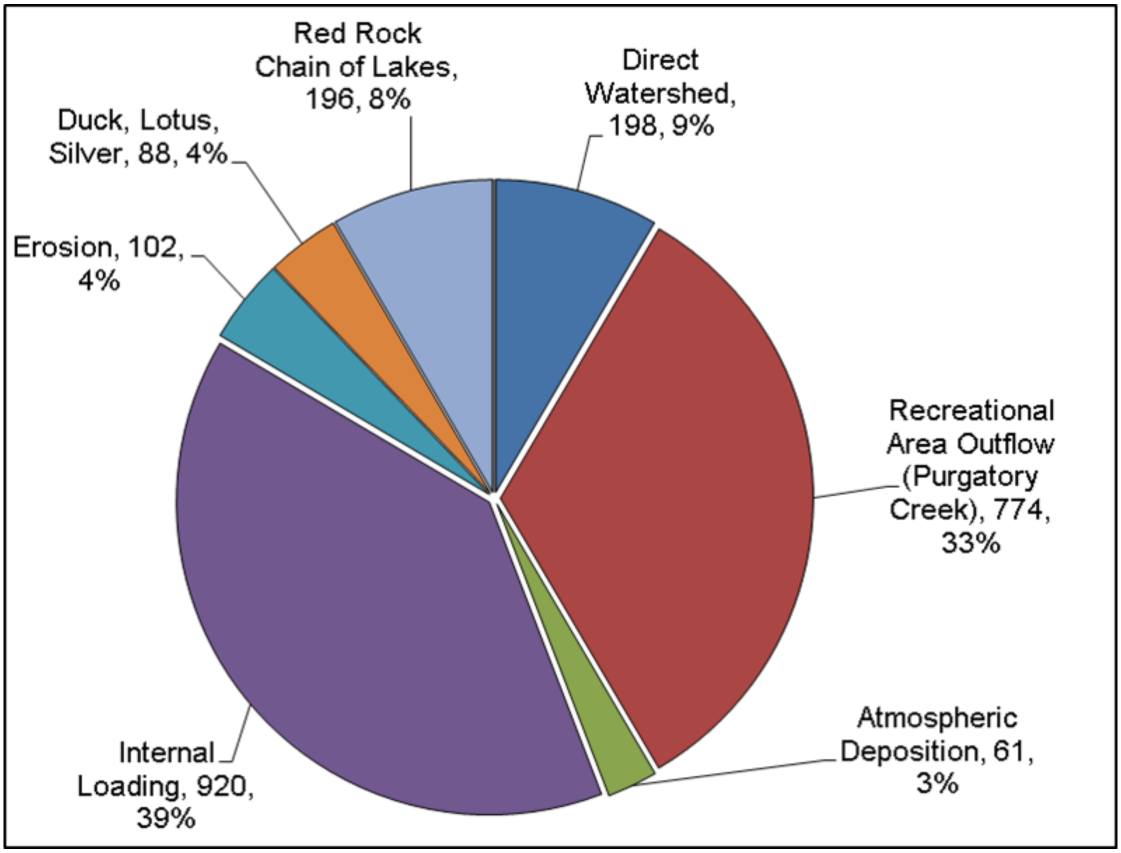


Figure 3.19 Staring Lake existing condition loading breakdown for 2015 water year

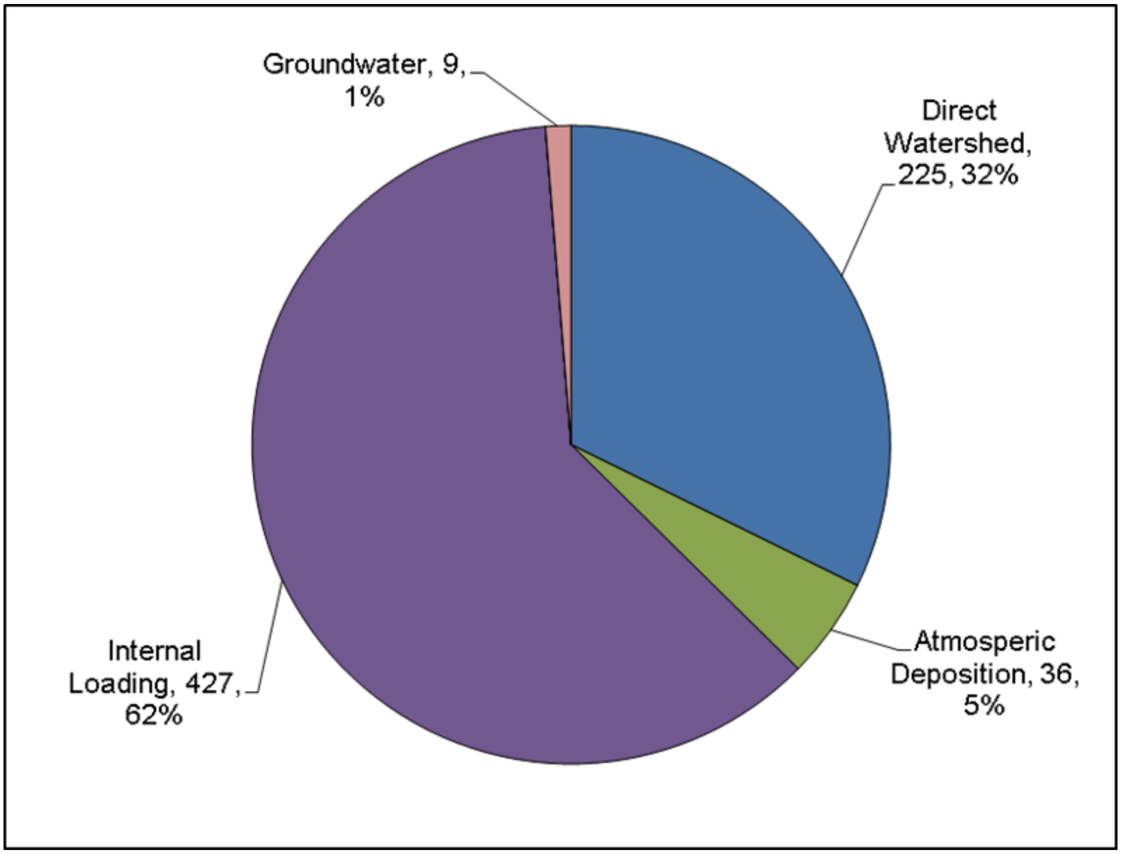


Figure 3.20 Lake Lucy existing condition loading breakdown for 2015 water year

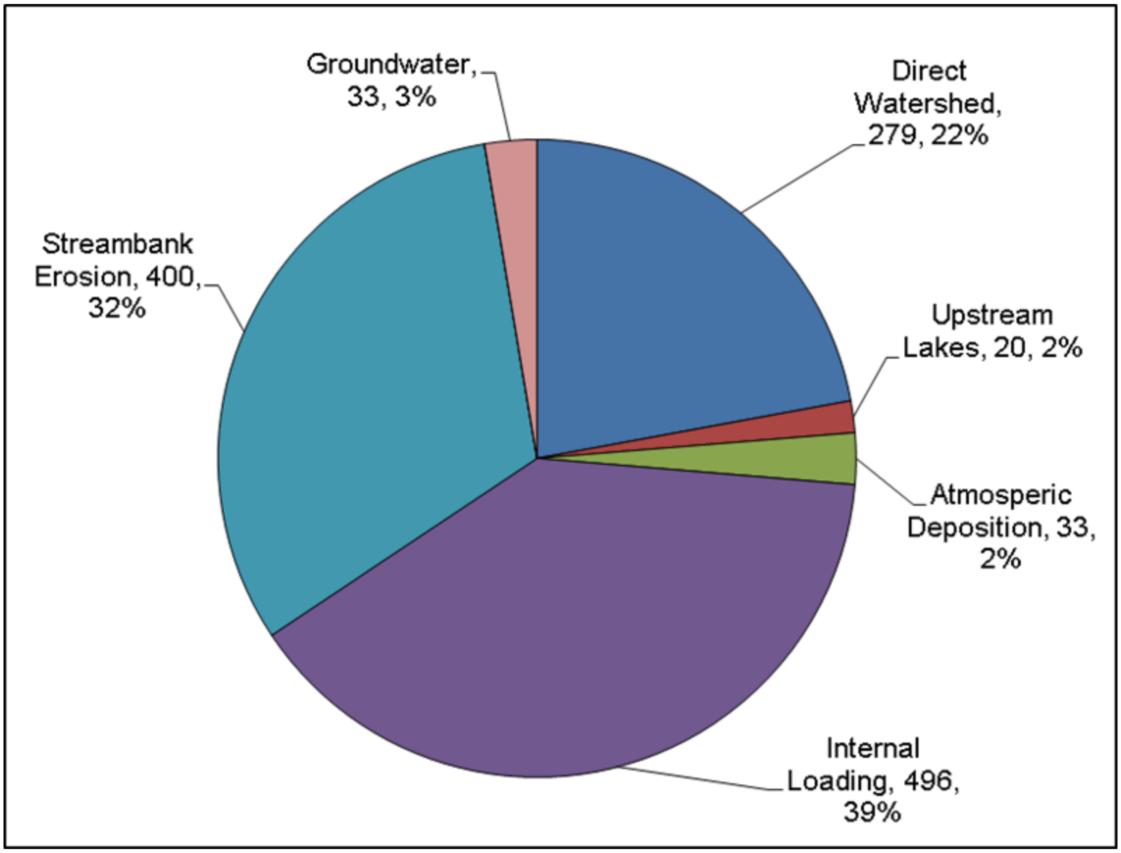


Figure 3.21 Lake Susan existing condition loading breakdown for 2015 water year

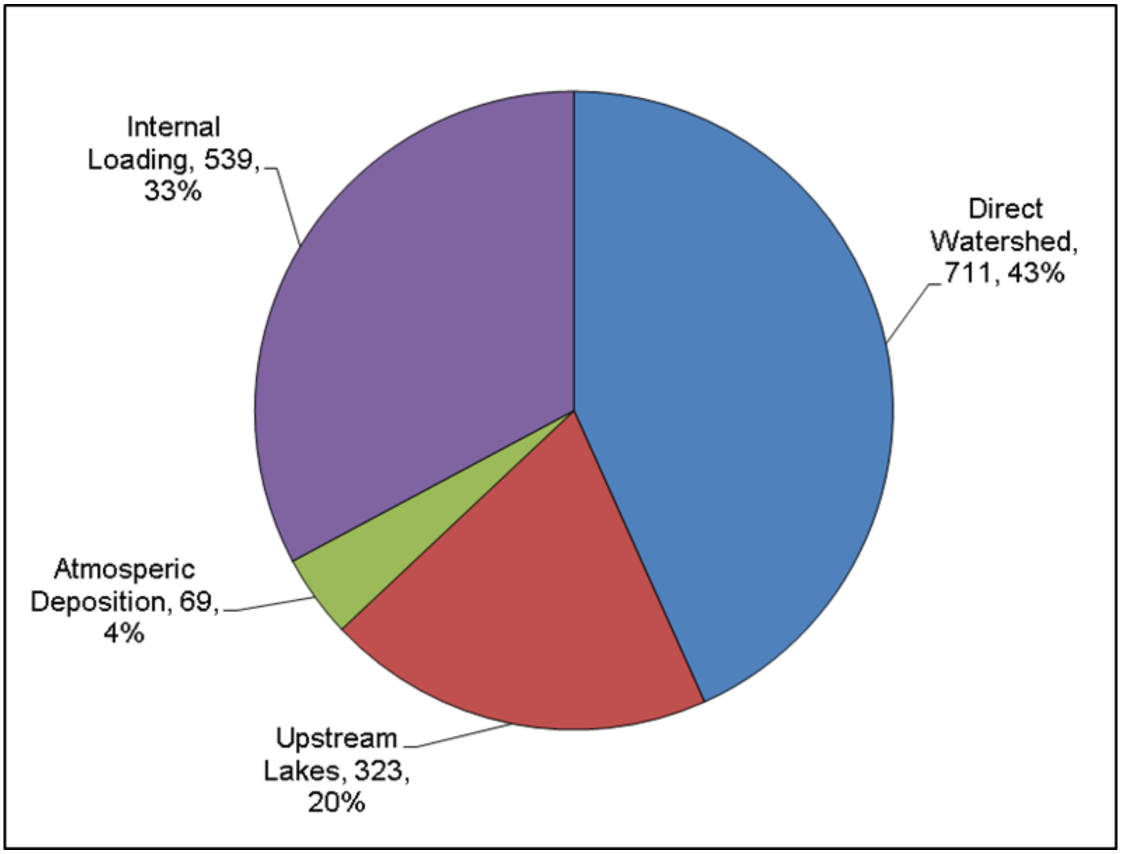


Figure 3.22 Rice Marsh Lake existing condition loading breakdown for 2014 water year

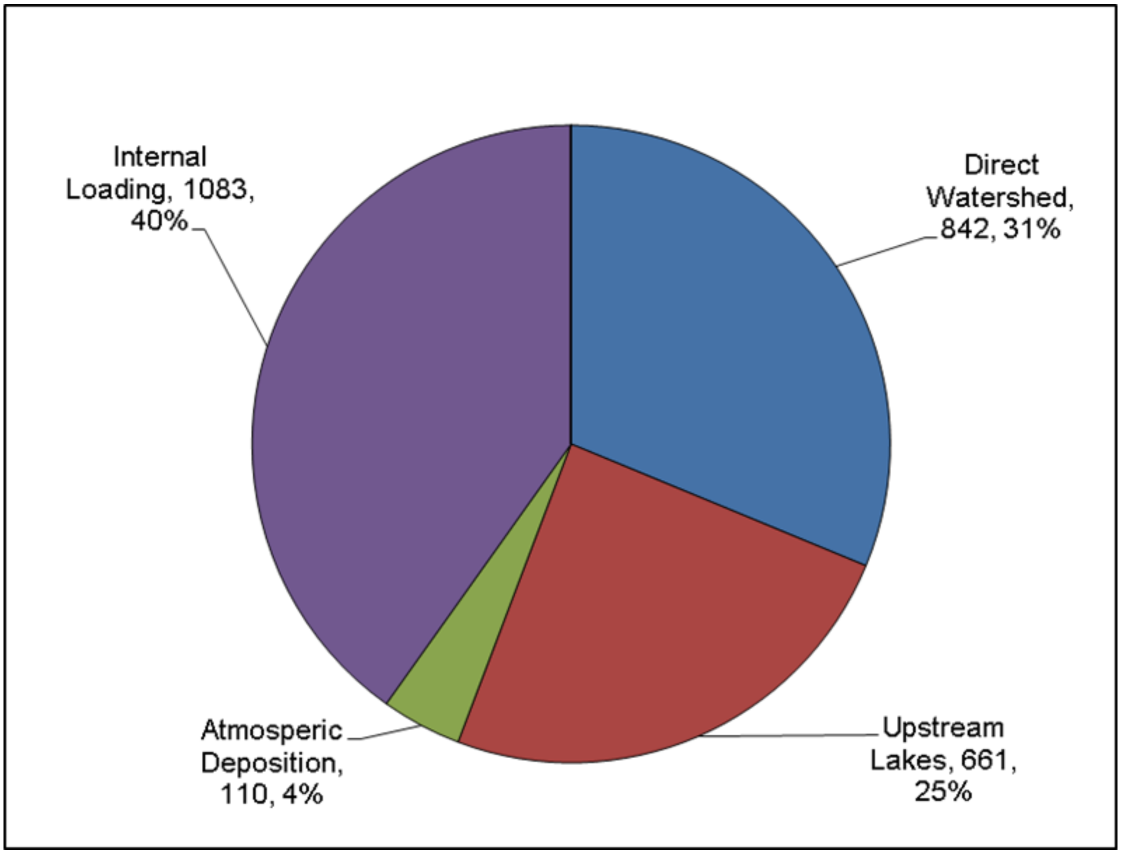


Figure 3.23 Lake Riley existing condition loading breakdown for 2014 water year

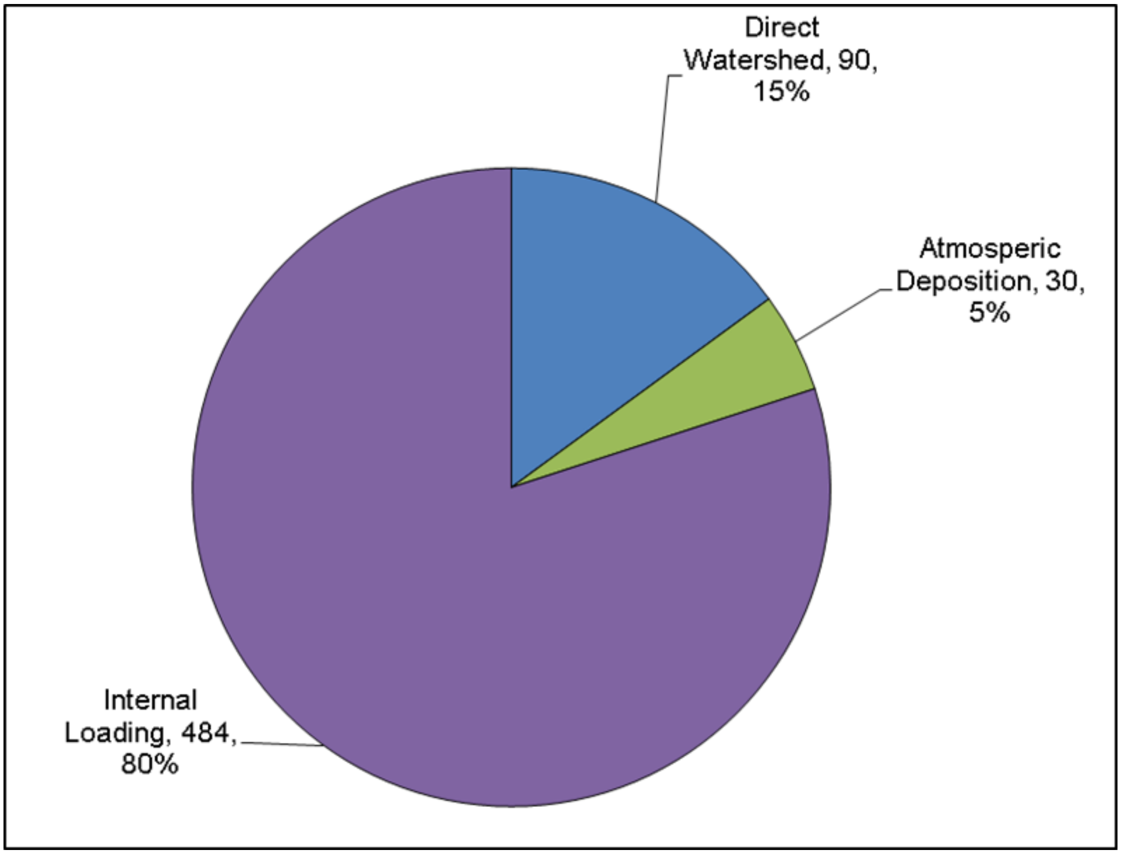


Figure 3.24 Hyland Lake existing condition loading breakdown for 2015 water year

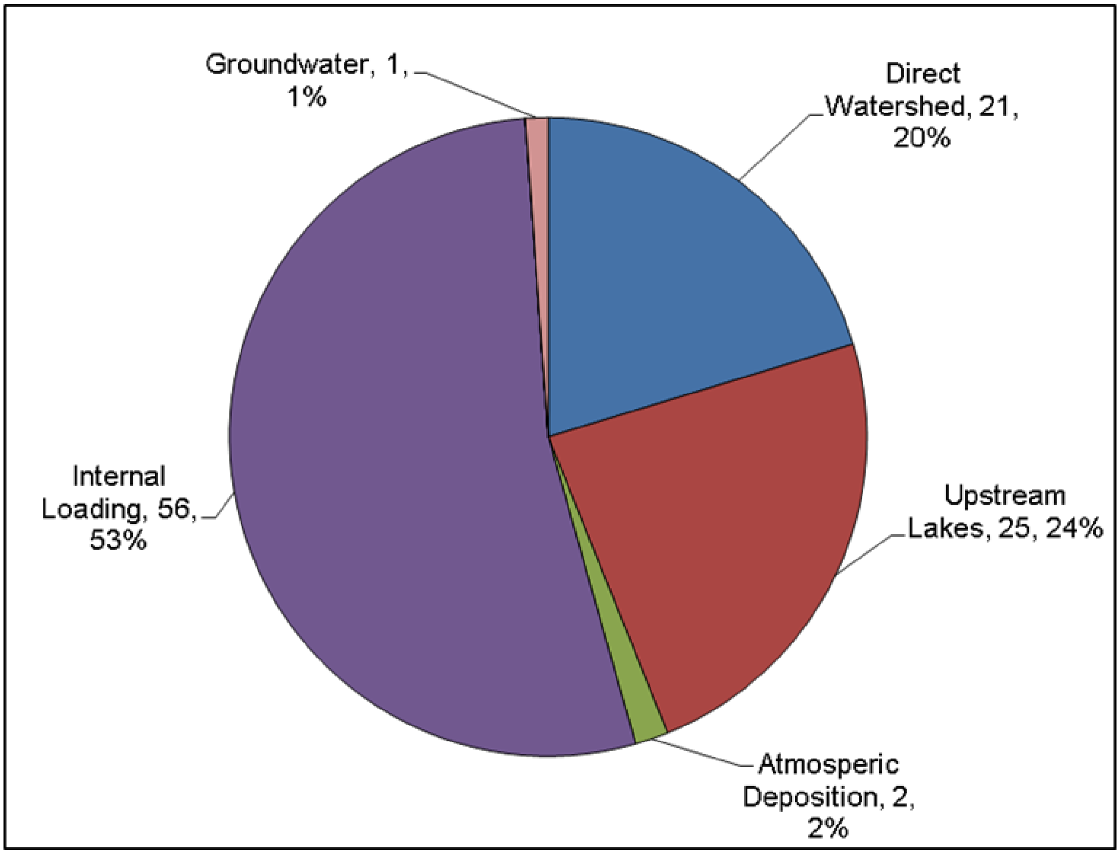


Figure 3.25 Wing Lake existing condition loading breakdown for 2016 growing season

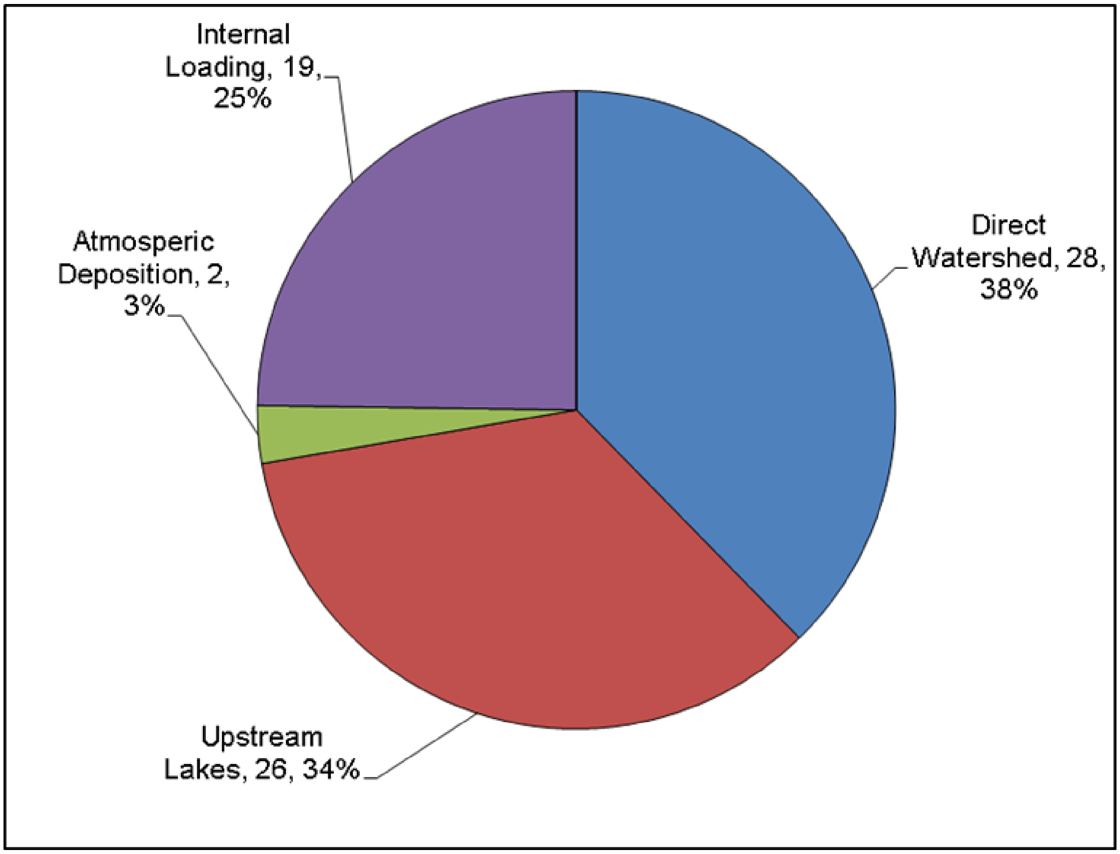


Figure 3.26 Lake Rose existing condition loading breakdown for 2016 growing season

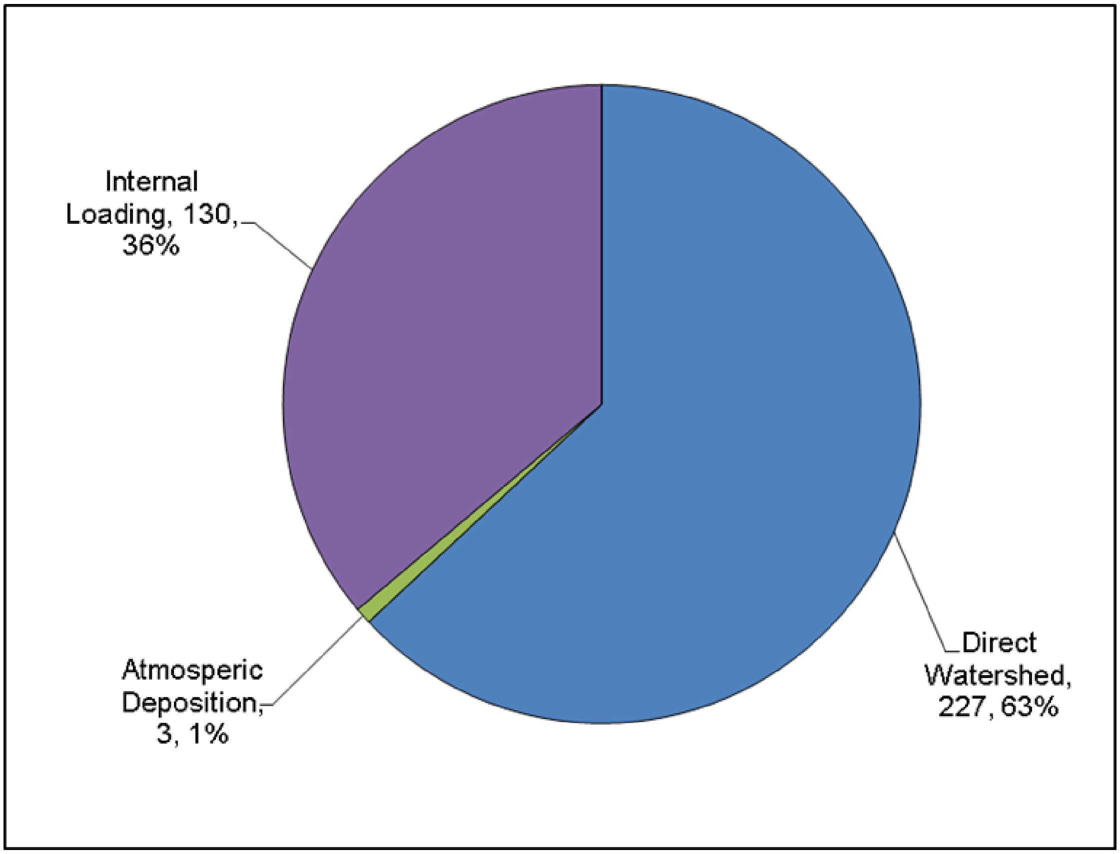


Figure 3.27 North Cornelia Lake existing condition loading breakdown for 2015 growing season

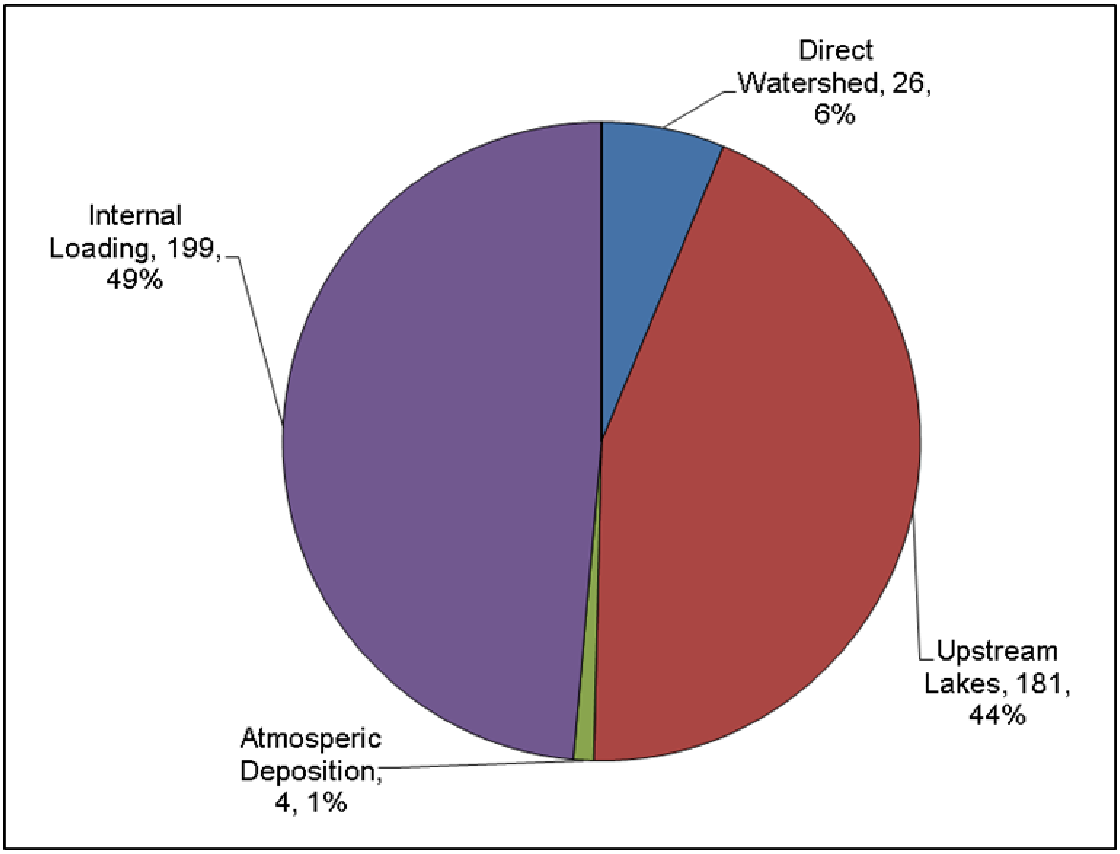


Figure 3.28 South Cornelia Lake existing condition loading breakdown for 2016 growing season

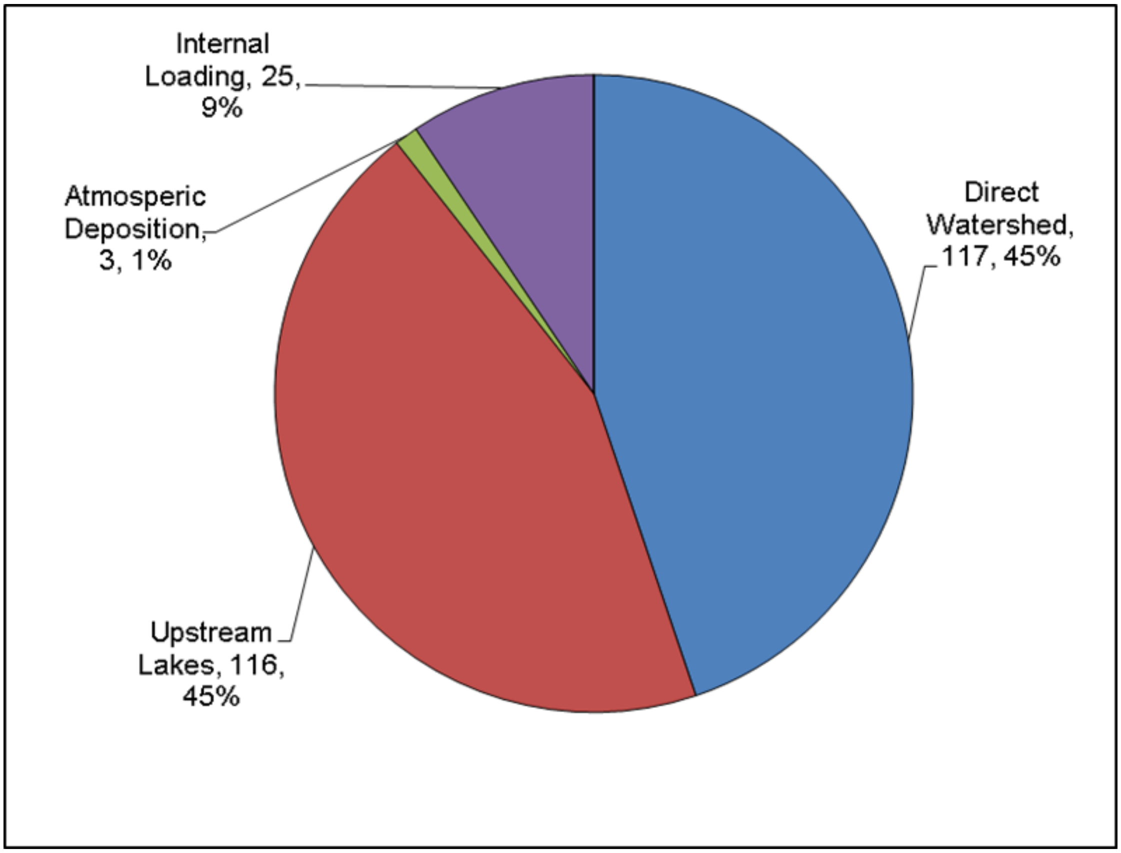


Figure 3.29 Edina Lake existing condition loading breakdown for 2015 growing season

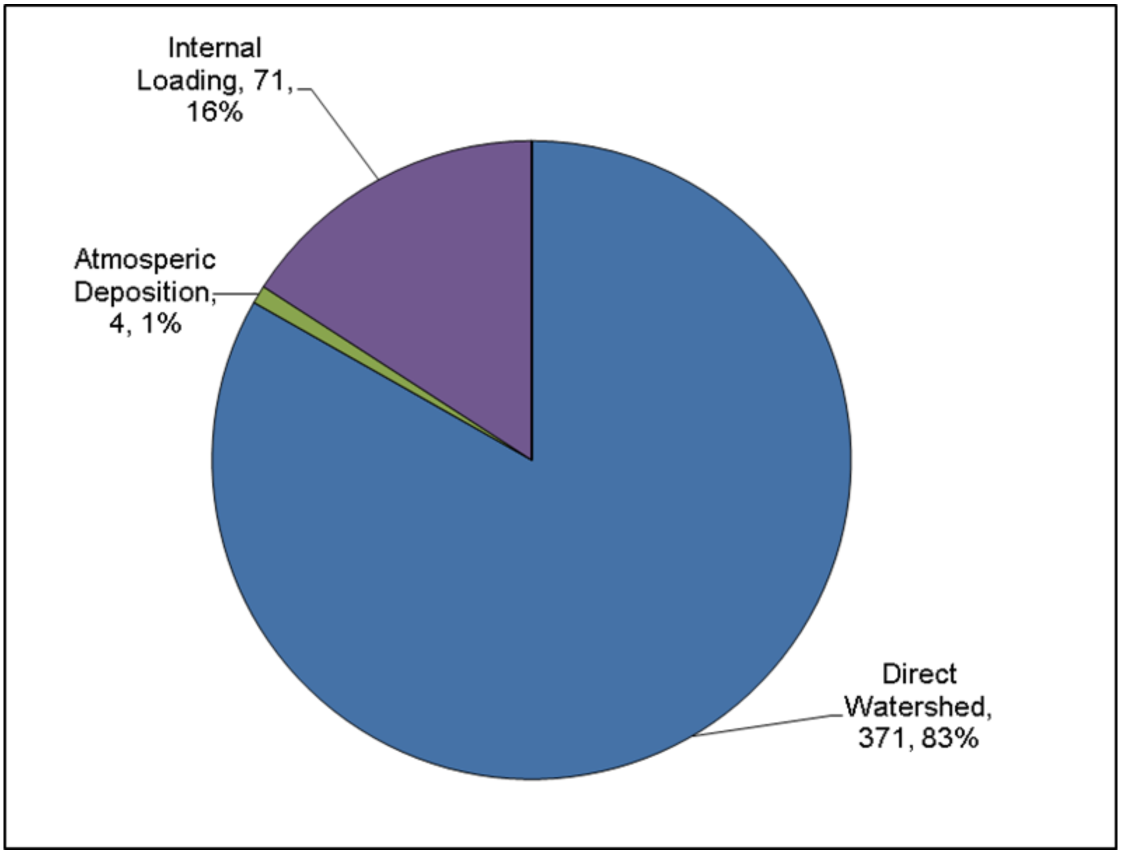


Figure 3.30 Penn Lake existing condition loading breakdown for 2016 growing season

3.8.2 Total Suspended Solids Source Summary

The following sections pertain to the TSS sources within the Riley Creek Watershed. The Purgatory and Nine Mile creeks are not currently impaired by TSS based on the analysis done for this TMDL.

3.8.2.1 Permitted

The regulated sources of TSS within the Riley Creek Watershed include MS4 stormwater, construction sites, and industrial sites. There are no permitted WWTFs within the Riley Creek Watershed.

3.8.2.2 Non-permitted

The non-permitted TSS sources are sources that are not subject to NPDES permit requirements, as well as “natural background” loads. “Natural background” includes the unknown portion of runoff/erosion that would occur in the absence of human influence (such as runoff from forested land). For Riley Creek these include erosional and background sources of TSS, as well as outflow from Lake Riley. Other non-permitted sources include runoff from agricultural land and non-regulated MS4 residential areas (such as direct runoff from parkland and backyard areas). Since the TSS concentration of flow discharging from Riley Lake is not normally expected to exceed 4 mg/L (as discussed in Section 4.3.2), it follows that the primary sources of TSS are likely entrained in the main flow of Riley Creek from streambank and near-channel sources of sediment. In addition, the RPBCWD Creek Restoration Action Strategy (CRAS) Report (Barr 2015), and associated documentation for the surveys of Riley Creek, indicated that seven of the nine reaches downstream of Lake Riley were rated as having high to severe levels of erosion and channel instability.

3.8.3 Bacteria (*E. coli*) Source Summary

The following paragraphs discuss sources of *E. coli* bacteria. Also, research in the last 15 years has found the persistence of *E. coli* in soil, beach sand, and sediments throughout the year in the north central United States, without the continuous presence of sewage or mammalian sources. An Alaskan study [Adhikari et al. 2007] found that total coliform bacteria in soil were able to survive for six months in subfreezing conditions. A study of cold water streams in southeastern Minnesota completed by the MPCA staff found the resuspension of *E. coli* in the stream water column due to stream sediment disturbance. A study near Duluth, Minnesota [Ishii et al. 2010] found that *E. coli* were able to grow in agricultural field soil. A study by Chandrasekaran et al. [2015] of ditch sediment in the Seven Mile Creek Watershed in southern Minnesota found that strains of *E. coli* had become naturalized to the water−sediment ecosystem. Survival and growth of fecal coliform has been documented in stormsewer sediment in Michigan [Marino and Gannon 1991].

3.8.3.1 Permitted

The primary source of bacteria loading within MS4s likely derives from typical urban sources - improperly managed pet waste and wildlife inputs (e.g., waterfowl, geese, etc.) directly to land and transported via stormwater conveyances to the impaired waterbodies. Construction and industrial stormwater sources of *E. coli* were not evaluated for the RPBCWD and NMCWD impaired waterbodies. *E. coli* is not a typical pollutant from construction sites, and there are no bacteria or *E. coli* benchmarks associated with any of the industrial stormwater permits in these watersheds. There are no permitted wastewater sources of *E. coli* in the Nine Mile Creek, Purgatory Creek, or Riley Creek watersheds.

3.8.3.2 Non-permitted

Non-permitted sources of bacteria within the watersheds of Nine Mile Creek, Purgatory Creek, and Riley Creek downstream of Marsh Lake, Staring Lake, and Riley Lake, respectively include runoff from shoreland or near-shoreland areas that are not tied into an MS4 conveyance. Loading from the upstream lakes (Marsh Lake, Staring Lake, and Riley Lake) is considered a boundary condition for the purposes of the TMDL, and is placed (as an aggregated value) into the load allocation (LA) or non-permitted portion (see Section 4.4.2.1 for further explanation). There are no known subsurface sewage treatment systems (SSTSs) and no known livestock feedlots within the impaired reach watershed of the three streams.

4. TMDL Development

The TMDL process determines that maximum allowable amount of a pollutant a waterbody can receive and still meet the required water quality standards and designated uses. It is the sum of all the contributing point and nonpoint sources of a single pollutant to a waterbody. The TMDL process can be described by the following equation.

$$\mathbf{TMDL = LC = \sum WLA + \sum LA + MOS + RC}$$

Where:

LC = loading capacity: maximum pollutant loading amount a waterbody can receive and still meet the required water quality standards.

WLA = wasteload allocations: portion of the TMDL loading capacity allocated to existing or future point (permitted) sources of the analyzed pollutant

LA = load allocation: portion of the TMDL loading capacity allocated to existing or future nonpoint (non-permitted) and/or "natural background" sources of the analyzed pollutant.

MOS = margin of safety: accounting of uncertainty in the relationship between pollutant loading and the water quality of the receiving waterbody.

RC = reserve capacity: an allocation of future growth. This is an MPCA-required element if applicable. Not applicable in this TMDL.

4.1 Loading Allocation Methodology/Natural Background

4.1.1 Natural Background Consideration

Natural background conditions refer to inputs that would be expected under natural, undisturbed conditions. Natural background sources can include inputs from natural geologic processes such as soil loss from upland erosion and stream development, atmospheric deposition, and loading from forested land, wildlife, etc. For each impairment, natural background levels are implicitly incorporated in the water quality standards used by the MPCA to determine/assess impairment, and therefore natural background is accounted for and addressed through the MPCA's waterbody assessment process. Natural background conditions were also evaluated, where possible, within the modeling and source assessment portion of this study. These source assessment exercises indicate natural background inputs are generally low compared to the primary source in these watersheds, namely urban stormwater runoff.

Based on the MPCA's waterbody assessment process and the TMDL source assessment exercises, there is no evidence at this time to suggest that natural background sources are a major driver of any of the impairments and/or affect the waterbodies' ability to meet state water quality standards. For all impairments addressed in this TMDL study, natural background sources are implicitly included in the LA portion of the TMDL allocation tables. Recent Minnesota Court of Appeals decisions have affirmed the MPCA is within its rights to not provide a separate allocation for natural background sources when not feasible (*In re Little Rock Creek TMDL*, No. A16-0123 (Minn. App. Nov. 28, 2016), *review denied* (Minn.

Feb. 14, 2017; *In re Crystal Lake TMDL*, No. A18-0581 (Minn. App. April. 24, 2019)), *review denied*. TMDL reductions should focus on the major human sources identified in the source assessment.

4.2 Lakes, Total Phosphorus

4.2.1 TP Loading Capacity

A daily time step, in-lake, TP mass balance model was developed for each lake, to quantify the existing load and the loading capacity of phosphorus to the lakes. The in-lake model tracks both water volume and phosphorus concentrations in the lake on a daily time step. The model was calibrated to both lake level data (to balance the water budget) and in-lake average TP concentrations for the TP budget. Methods used in the development of the in-lake model are found in Appendix A.

The in-lake models were calibrated to the most recent year with observed lake level and water quality data that best represented the conditions that contributed to their impairment. Rice Marsh Lake and Lake Riley were calibrated to the 2014 water year (October 2013 through September 2014). Lakes Lucy, Susan, Lotus, Silver, and Staring were calibrated to the 2015 water year (October 2014 through September 2015). Lakes South Cornelia, Penn, Wing, and Rose were calibrated to the 2016 growing season (June 2016 through September 2016). Lake Edina and North Cornelia Lake were calibrated to the 2015 growing season (June 2015 through September 2015). The NMCWD lakes have short residence times (one to four months) and are located off the main creek channels (which could provide a significant phosphorus load year-round). For these reasons, the NMCWD lake allocations were evaluated based on the growing season time period when most of the loading (both internal and external) occurs.

The loading capacities of the lakes, as well as the lake protection phosphorus loading goal for Lake Lucy, were determined using the existing conditions in-lake models. Phosphorus loads to the lake were adjusted until the average TP concentrations in the lake during the growing season (June through September) were equivalent to the water quality goal. The resulting total load received by the lake during the modeled year (2014, 2015, or 2016 depending on the lake) and time period (either water year or growing season) was defined as the lake's loading capacity. Table 4.1 compares the modeled load to the lake under existing conditions to the modeled phosphorus loading required to meet the water quality goals for the RPBCWD lakes, while Table 4.2 does the same for the NMCWD lakes. Each of the lake models for this analysis simulated elevated loads above the required loading capacity (in the case of the impaired lakes) and the lake protection phosphorus loading goal (in the case of Lake Lucy). Reductions are needed to meet the water quality goals for all 14 lakes, based on the lakes baseline condition/year. These baseline years mean that, unless noted in this report, only wasteload reductions that occur during or after these years are creditable toward the overall needed reductions.

Once the loading capacity was determined, the general approach for assigning reductions (and thereby arriving at the allocations for reducible sources) was to first reduce any upstream lakes to equal the loading of those lakes discharging at their respective water quality standard. Then streambank erosion sources, which are a high priority in the watershed and contribute to existing or potential TSS impairments, were reduced as described in Section 3.8.1.2. Next, the P8-modeled phosphorus removal efficiencies by MS4s were considered. In general, a moderate to high level of stormwater management is needed in order to prevent additional lake sediment enrichment, and otherwise achieve and maintain long-term lake water quality. Internal load, generally considered high for many of the watershed's lakes, is also evaluated in this final step for appropriate reductions. In some cases, it is apparent that reductions in external sources alone will not meet the TMDL, requiring reduction in internal loading. In these instances, where alum treatment is the most feasible internal load reduction method, it makes sense to apply an expected alum reduction percentage of 80% (Welch & Cooke 1999) first, and then determine the needed external source decrease for the remaining load reduction. The 80% load reduction assumes that the proper alum dosing has been calculated.

Table 4.1 Total phosphorus load under existing condition and proposed condition to meet water quality goals in the RPBCWD lakes

Lakes	Baseline year	Existing growing season average TP concentration (µg/L)	TP loading rate under existing conditions (lbs/yr)	Water quality goal TP concentration (µg/L)	Loading Capacity to meet WQ goals/ standards (lbs/yr)	Percent reduction need to meet goal (%)
Silver Lake	2015	97	224	60	185	17%
Lotus Lake	2015	69[b]	1,140	40	631	45%
Staring Lake	2015	86[a]	2,339	60	1,624	31%
Lake Lucy	2015	84[b]	697	60	488	30%
Lake Susan	2015	82[b]	1,261	60	995	21%
Rice Marsh Lake	2014	107[a]	1,642	60	961	41%
Lake Riley	2014	52[b]	2,701	40	1,986	26%
Hyland Lake	2015	115[a,c]	604	60	299	50%

a. Volumetric average concentration for entire water column

b. Volumetric average concentration for epilimnion only

c. RPBCWD believes TP measurement on 9/9/15 of 304 µg/L to be an outlier, but lacking definitive evidence that it is inaccurate it is included in the summer average for now.

Table 4.2 Total phosphorus load under existing condition and proposed condition to meet water quality goals in the NMCWD lakes

Lakes	Baseline year	Existing growing season average TP concentration (µg/L)	TP loading rate under existing conditions (lbs/gs)	Water quality goal TP concentration (µg/L)	Loading Capacity to meet WQ goals/ standards (lbs/gs)	Percent reduction need to meet goal (%)
Wing Lake	2016	92[a]	105	60	68	35
Lake Rose	2016	105[a]	75	60	46	39
North Cornelia Lake	2015	146[a]	360	60	154	57
South Cornelia Lake	2016	153[a]	410	60	169	59
Lake Edina	2015	87[a]	261	60	180	31
Penn Lake	2016	109[a]	446	60	247	45

a: Volumetric average concentration for entire water column

4.2.2 TP Load Allocation Methodology

The LA includes nonpoint pollution sources that are not subject to NPDES permit requirements, as well as "natural background" loads. For the lake studies, LAs include atmospheric deposition, internal loading, tributary streambank and lakeshore erosion, upstream lakes and groundwater intrusions.

4.2.2.1 Atmospheric Deposition

Atmospheric deposition of phosphorus onto the lakes water surface was calculated by using the estimated statewide phosphorus atmospheric deposition rate of 0.42 kg/ha/year (Barr 2007) multiplied by the lakes surface area. Atmospheric deposition TP sources are minimal (less than 6% of existing load) in all lakes.

4.2.2.2 Erosion

TP loads from streambank erosion were calculated for tributaries to Lake Susan, Staring Lake and Lotus Lake based on estimates resulting from the CRAS report (Barr 2015) and associated documentation for the surveys of the stream reaches within the respective watersheds. Since the CRAS methodology quantifies a range in the amount of material that is at-risk of eroding during a 20-year period, the streambank erosion estimates used for the TMDL analysis were based on the average of the highest and lowest annual sediment and phosphorus loading rate estimates, which were further reduced to account for a 20% delivery ratio to the respective lakes. Where applicable, the potential TP load reduction was estimated for the TMDL LAs by assuming that the respective stream reaches could be restored to the 'slight' CRAS erosion category, which is a condition in which little active erosion is apparent. Erosion TP loads from the steep slopes west of Silver Lake were also estimated based on slope instabilities detected through site surveys and aerial imagery.

4.2.2.3 Internal Loading

The release of phosphorus was estimated using the daily time step phosphorus balance model. Internal loading rates were calibrated with measured water quality data for the entire lake water column, as well as concentration measured in the hypolimnion only. Sediment phosphorus had previously been evaluated for most of the study lakes. As a result, published estimates of sediment phosphorus release rates were compared to the values used in the lake water quality modeling to ensure that the calibrated values did not exceed the potential for chemical release, after accounting for the potential load from physical release and plant senescence. In addition, sediment phosphorus release rates were also compared with representative literature values (Pilgrim et al. 2007 and Huser et al. 2011) to evaluate how much the internal load would differ from other areas lakes before and after a chemical treatment (such as alum) to immobilize sediment phosphorus.

4.2.2.4 Groundwater

Groundwater flow into and out of each lake was determined through the lake water balance in the daily in-lake model. A TP concentration of 0.035 was applied to any groundwater that entered the lake to determine the TP load. Groundwater sources of TP were minimal (less than 3% of existing load) and were applicable in Lakes Lucy, Susan, Silver, Lotus, Wing, South Cornelia, and Penn.

4.2.2.5 Upstream Lakes

Upstream lakes contribute TP loading to Staring Lake, Lake Riley, Rice Marsh Lake, and Lake Susan in the RPBCWD. Staring Lake has multiple upstream lakes contributing to the overall TP load. The outfalls of Lotus Lake, Duck Lake, and Silver Lake flow into Purgatory Creek, which flows through the Recreational Area and into Staring Lake. The Eden Prairie Chain of Lakes (Round, Mitchell, and Red Rock Lake) flow from Red Rock Lake through a series of ponds into Lake McCoy and finally into Staring Lake. Lake Riley, Rice Marsh Lake, and Lake Susan are located in series along Riley Creek, which carries flows from Lake Ann to Lake Susan, then Rice Marsh Lake and finally Lake Riley. The in-lake TP model accounts for the water and phosphorus loads from upstream waterbodies (that have not been modeled as part of the watershed model). For Staring Lake, all upstream lakes have a daily time step in-lake TP model that was created for year 2015. Flows and TP concentration from those lakes were added to Staring Lake model to determine the load. Rice Marsh Lake also has an existing daily time step lake water quality model that was used to determine the upstream lake loads into Lake Riley. For Rice Marsh Lake, lake level data, an outflow rating curve, and grab sample TP concentrations from Lake Susan were used to estimate loads. Likewise, Lake Ann lake level data, outflow rating curve, and grab sample TP concentrations were used to estimate the upstream lake loads to Lake Susan. The results of the Lake Susan in-lake model were not used as inputs to the Rice Marsh in-lake model because they were not modeled for the same water year.

Upstream lakes also contribute TP loading to Wing Lake, Lake Rose, South Cornelia Lake, and Lake Edina in the NMCWD. A daily time step lake water quality model was created for Lake Holiday (a seven acre lake which falls below MPCA guidance criteria for assessment) and used to determine the upstream lake loads into Wing Lake. The modeled output from Wing Lake was then used as the upstream lake loads to Lake Rose. The output from the North Cornelia Lake in-lake model was used as the upstream lake inputs to South Cornelia Lake, which in turn was used as the upstream lake inputs to Lake Edina.

TMDL allocations were determined based on the assumption that upstream lake concentrations meet the respective water quality goals. TP load reductions highlight the required load reduction from the upstream lakes that is needed to meet this assumption.

4.2.3 TP Wasteload Allocation Methodology

WLA represent the portion of the TP load associated with permitted sources. WLAs include three sub-categories: permitted wastewater facilities, the MS4s permitted stormwater source category, and a construction plus industrial permitted stormwater category.

4.2.3.1 Permitted Industrial and Municipal Wastewater Facilities

Staring Lake is the only lake with industrial or municipal WWTFs within the watershed. The discharge comes from two well houses (Eden Prairie Well houses 6 and 7; MNG250084) located along Purgatory Creek. This is an emergency back-up system that has never actually been used for its intended purpose. If it were needed, the city estimates that it would be used once per year and would run for one day before the primary system is back on line. The well houses are pumped into Purgatory Creek on a monthly basis to test equipment functionality. TP loads were estimated by summing the estimated daily maximum flow and the annual flow due to monthly testing (i.e., monthly average flow multiplied by 12 months). This total flow value was then multiplied by the average TP concentration from the well houses to determine annual load to the creek, which then enters Staring Lake. The resulting load was calculated as 0.7 lbs per year rounded to 1 lb/yr.

4.2.3.2 Municipal Separate Storm Sewer Systems: Individual WLAs

MS4 boundaries were defined for each lake watershed. Overall, 10 MS4s cover the watershed area for the eight RPBCWD lakes analyzed, and six MS4s cover the watershed area for the six NMCWD lakes analyzed. These MS4s include the cities of Bloomington, Chanhassen, Deephaven, Eden Prairie, Edina, Minnetonka, Richfield, and Shorewood, Hennepin and Carver Counties, MnDOT, and in the Staring Lake watershed, it included the Hennepin Technical College as an additional MS4. MS4 boundaries were also determined for the Riley, Purgatory, and Nine Mile Creek watersheds. Right of way boundaries were obtained from MnDOT. County MS4 boundaries were determined using parcel data and county road locations. The parcel road boundaries were used as the cross section for the Hennepin and Carver County roads in the watershed. After MnDOT and county MS4 boundaries were accounted for, the remaining areas were assigned to cities based on municipal boundaries. Finally, in the Staring Lake Watershed the areas assigned to the Hennepin Technical College were separated from the city of Eden Prairie as an individual MS4. Figure 4.1 shows the RPBCWD MS4 boundaries and Figure 4.2 shows the NMCWD MS4 boundaries.

The modeling results (Appendix A) were used to determine TP loads to the lakes for each MS4 for the TMDL time periods. First, the lake subwatersheds were further subdivided by MS4 boundaries. The total watershed TP loads from each MS4 subwatershed were extracted from the P8 modeling. From those loads, the mass of TP to reach the lake was calculated by applying the annual average removal efficiencies from each BMP in succession along the watershed flow path until the cumulative flow reached the lake. This calculation resulted in the amount of TP load from each MS4 that reached the lake without being removed by an existing BMP. Typically, P8 modeling indicates that watersheds with extensive implementation of structural BMPs with good pollutant settling will attain about 60% TP removal. Depending on when past development and BMP implementation has occurred and other constraints (such as the effect of natural wetlands, shoreland development and development density), moderate to high levels of stormwater management within a watershed would be expected to remove approximately 50% to 60% of the untreated TP in runoff on an annual basis.

4.2.3.3 Construction/Industrial Stormwater: Categorical WLAs

Construction stormwater is regulated by NPDES permits for construction activity disturbing one acre or more of soil, less than one acre of soil if the activity is part of a “larger common plan of development or sale” that is greater than one acre, or less than one acre of soil where the MPCA has determined that the activity poses a risk to water resources. If industrial activity has the potential to be exposed to stormwater discharges, it is required to be regulated by NPDES permits. The WLA for each lake includes an allocation for construction and industrial stormwater that is equal to 1% of the total WLA. This is a conservative value, as estimates of areas under construction at any one time in the metro area are typically less than half this value. This value includes room for any future industrial stormwater sources.

There are no permitted industrial stormwater facilities currently within the Nine Mile Creek, Purgatory Creek, or Riley Creek watersheds that require a WLA.

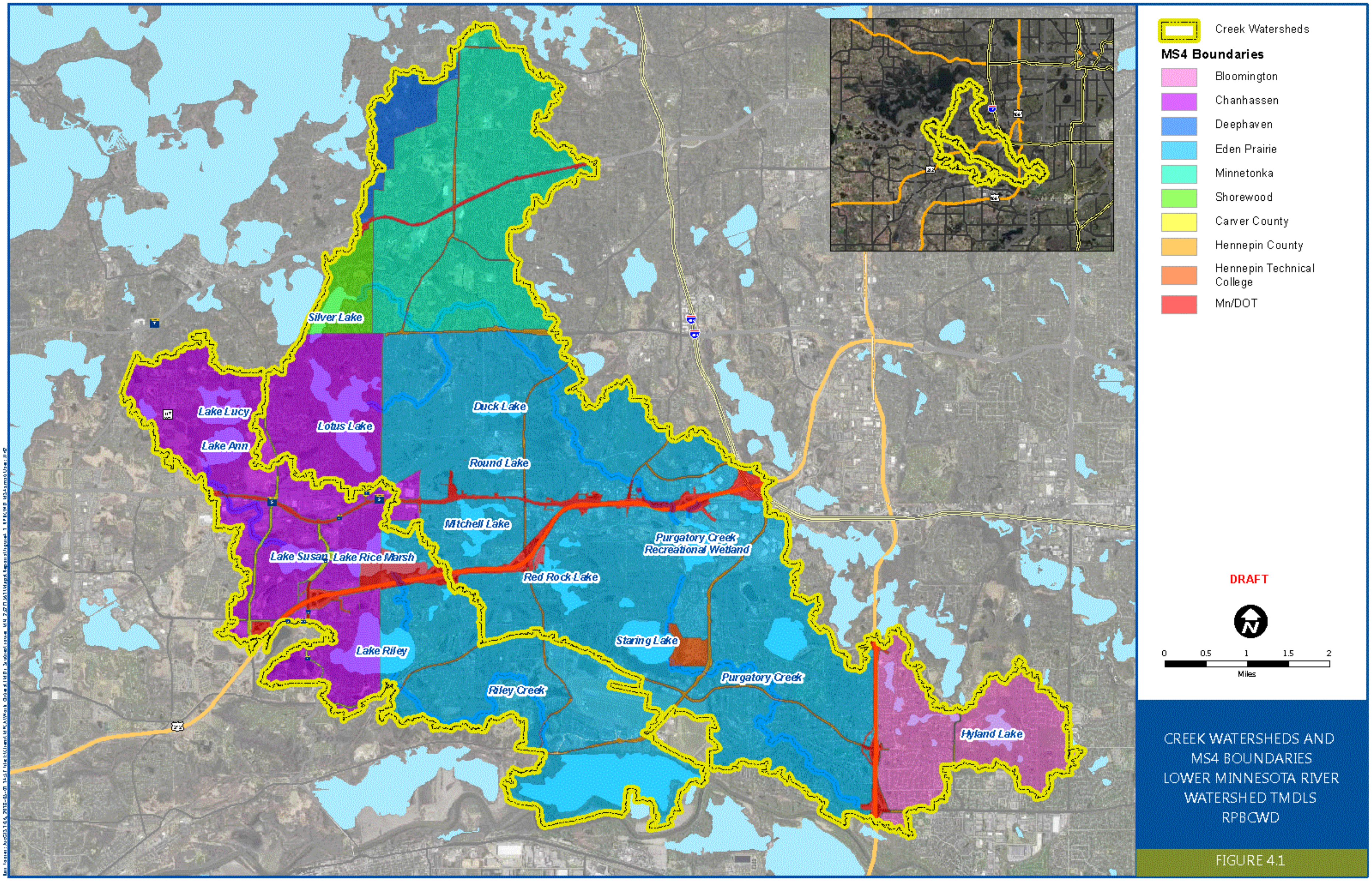


Figure 4.1 RPBCWD MS4 Boundaries

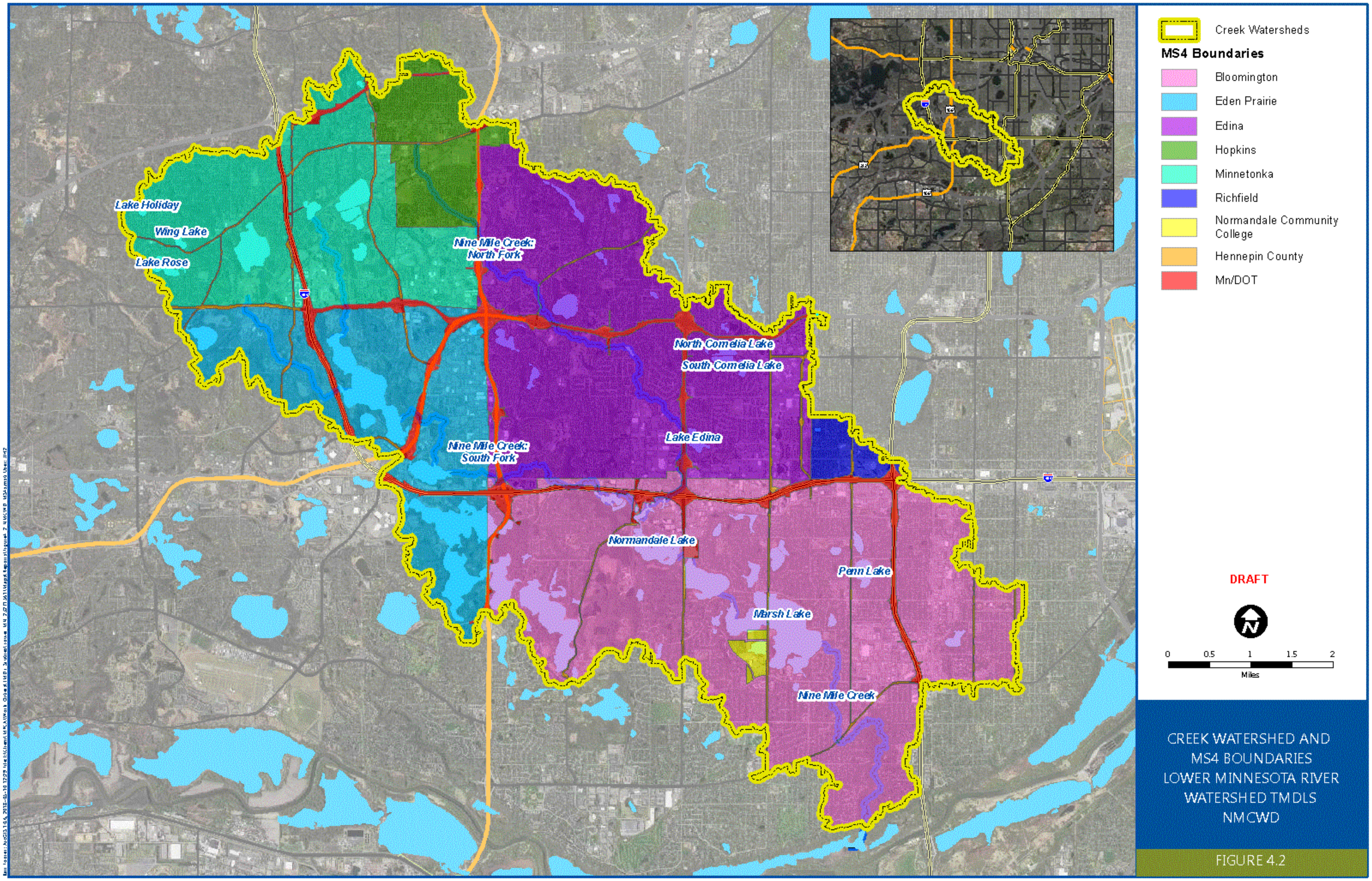


Figure 4.2 NMCWD MS4 Boundaries

4.2.4 Margin of Safety

The purpose of the MOS in the TMDL is to provide capacity to allow for uncertainty. The federal guidance for TMDLs states that the MOS may be implicit, that is incorporated into the calculations by using conservative assumptions, or explicit by being expressed as loadings set aside for the MOS in the TMDL (MPCA 2007b). The MOS for all lakes was an explicit 5% of the total TP loading capacity. This MOS is considered sufficient, given each lake's reasonably robust data set and the generally very solid lake response model performance. (Appendix A includes results of statistical comparisons between the modeled and measured volumetric averaged epilimnetic TP concentrations, as well as comparisons between the modeled and monitored epilimnetic volumetric averaged TP concentrations over the course of the subject water years.)

4.2.5 Seasonal Variation

The EPA states that the critical condition *"…can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence"* (EPA 1999). Algal growth in lakes peaks during the summer months. By applying the water quality standard to the average TP concentration during the algae growing season (June through September), this analysis becomes protective for the entire year.

4.2.6 TP TMDL Summary

TP loads were allocated for each lake among the WLA, LA, and the MOS, or the lake protection reduction goals, as described in the previous sections and summarized in Table 4.3 through Table 4.10 for the RPBCWD lakes and Table 4.11 through Table 4.16 for the NMCWD lakes. Loads have been rounded to the nearest whole number. TMDL allocation tables include existing annual loading rate, the allocated annual and daily loading rates, as well as the percent reductions required to meet the allocations for the impaired lakes. For Lake Lucy, Table 4.6 shows existing and target TP loadings, as well as the load reduction goals for each phosphorus source.

4.2.6.1 Silver Lake

Phosphorus load reductions in Silver Lake were divided among watershed and erosion sources. MS4 allocations were divided proportionally between the cities of Chanhassen and Shorewood. Erosion reduction estimates were based on stabilizing the steep slopes along the west bank of Silver Lake. A number of the erosion locations are on private property, therefore it is assumed that minimal erosion mitigation will be possible. Internal loading was applied to cover the final required reductions to meet the TMDL requirement.

Table 4.3 Total Phosphorus Wasteload Allocations, Load Allocations, and Existing Conditions for Silver Lake (27-0136-00) during 2015 water year.

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
TOTAL LOAD		**224**	**0.614**	**185**	**0.507**	**48**	**21**
Wasteload	**Total WLA**	**115**	**0.315**	**92**	**0.252**	**23**	**20**
	Chanhassen (MS400079)	*27*	*0.074*	*21*	*0.058*	*6*	*22*
	Shorewood (MS400122)	*87*	*0.238*	*70*	*0.192*	*17*	*20*
	Construction/Industrial SW	*1*	*0.003*	*1*	*0.003*	*0*	*0*
Load	**Total LA**	**109**	**0.299**	**84**	**0.230**	**25**	**23**
	Atmospheric deposition	*26*	*0.071*	*26*	*0.071*	*0*	*0*
	Internal load	*58*	*0.159*	*37*	*0.101*	*21*	*36*
	Erosion sources	*20*	*0.055*	*16*	*0.044*	*4*	*20*
	Groundwater	*5*	*0.014*	*5*	*0.014*	*0*	*0*
MOS (5%)				**9**	**0.025**		

4.2.6.2 Lotus Lake

The Lotus Lake load reductions were divided among watershed, internal load, and erosion. Reduction percentages were based on balancing the removal between outside sources of phosphorus to the lake (erosion and watershed loads) and internal loading. Internal loading warrants a more substantial reduction given that it is a significant source in this lake. MS4 load reductions were allocated to Chanhassen as the only major contributor to the existing TP load. For this watershed, existing loads from the other MS4s are very small (each are about 1% or less of the overall existing loading) with limited opportunity for load reduction and are not assigned a reduction.

Table 4.4 Total Phosphorus Wasteload Allocations, Load Allocations, and Existing Conditions for Lotus Lake (10-0006-00) during 2015 water year.

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
TOTAL LOAD		**1,140**	**3.123**	**631**	**1.729**	**541**	**47**
Wasteload	**Total WLA**	**306**	**0.838**	**256**	**0.701**	**50**	**16**
	MnDOT (MS400170)	*3*	*0.008*	*3*	*0.008*	*0*	*0*
	Carver County (MS400070)	*2*	*0.005*	*2*	*0.005*	*0*	*0*
	Chanhassen (MS400079)	*291*	*0.797*	*241*	*0.660*	*50*	*17*
	Eden Prairie (MS400015)	*7*	*0.019*	*7*	*0.019*	*0*	*0*
	Construction/Industrial SW	*3*	*0.008*	*3*	*0.008*	*0*	*0*
Load	**Total LA**	**834**	**2.285**	**343**	**0.940**	**491**	**59**
	Atmospheric deposition	*88*	*0.241*	*88*	*0.241*	*0*	*0*
	Internal load	*732*	*2.005*	*247*	*0.677*	*485*	*66*
	Erosion sources	*7*	*0.019*	*1*	*0.003*	*6*	*86*
	Groundwater	*7*	*0.019*	*7*	*0.019*	*0*	*0*
MOS (5%)				**32**	**0.088**		

4.2.6.3 Staring Lake

The Staring Lake load reductions were divided between watershed, internal load, upstream lakes and erosion. Reduction percentages were based on balancing the removal between outside sources of phosphorus to the lake (erosion and watershed loads) and internal loading. TP reduction percentages applied to upstream lakes are the reductions achieved if those lakes were to meet the water quality standards. As previously discussed, moderate to high levels of stormwater management within a watershed would be expected to remove approximately 50% to 60% of the untreated TP in runoff on an annual basis. As a result, MS4 allocations were applied based on current BMP removal efficiencies as an equitable method for distributing allocated TP load to the major contributors. For this watershed, existing loads from Hennepin County, Chanhassen, and Hennepin Technical College are very small (each are less than 1% of the overall existing loading) with limited opportunity for load reduction and are not assigned a reduction. MnDOT and Eden Prairie were found to have a current combined 41% and 44% removal efficiency, respectively, based on the P8 watershed modeling. BMPs in Minnetonka, Deephaven and Shorewood were found to have a combined removal efficiency of 57%. Therefore, WLAs applied to MnDOT and Eden Prairie were based on achieving TP load reductions that would increase overall BMP treatment efficiency above 50% for both MS4s. Finally, the allocations also included an internal load reduction, as the monitoring/modeling data indicated that carp and sediment phosphorus release/resuspension play a significant role in the observed summer water quality.

Table 4.5 Total Phosphorus Wasteload Allocations, Load Allocations, and Existing Conditions for Staring Lake (27-0078-00) during 2015 water year.

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
TOTAL LOAD		**2,339**	**6.408**	**1,624**	**4.449**	**796**	**34**
Wasteload	**Total WLA**	**972**	**2.663**	**769**	**2.107**	**203**	**21**
	MnDOT (MS400170)	*88*	*0.241*	*63*	*0.173*	*25*	*28*
	Hennepin County (MS400138)	*19*	*0.052*	*19*	*0.052*	*0*	*0*
	Chanhassen (MS400079)	*1*	*0.003*	*1*	*0.003*	*0*	*0*
	Eden Prairie (MS400015)	*627*	*1.718*	*449*	*1.230*	*178*	*28*
	Deephaven (MS400013)	*21*	*0.058*	*21*	*0.058*	*0*	*0*
	Minnetonka (MS400035)	*185*	*0.507*	*185*	*0.507*	*0*	*0*
	Shorewood (MS400122)	*8*	*0.022*	*8*	*0.022*	*0*	*0*
	Hennepin Technical College (MS400199)	*14*	*0.038*	*14*	*0.038*	*0*	*0*
	Eden Prairie well houses (MNG250084)	*1*	*0.003*	*1*	*0.003*	*0*	*0*
	Construction/Industrial SW	*8*	*0.022*	*8*	*0.022*	*0*	*0*
Load	**Total LA**	**1,367**	**3.745**	**774**	**2.121**	**593**	**43**
	Atmospheric deposition	*61*	*0.167*	*61*	*0.167*	*0*	*0*
	Internal load	*920*	*2.521*	*447*	*1.225*	*473*	*51*
	Upstream lakes	*284*	*0.778*	*253*	*0.693*	*31*	*11*[a]
	Erosion sources	*102*	*0.279*	*13*	*0.036*	*89*	*87*
MOS (5%)				**81**	**0.222**		

a: percent reduction for upstream lakes represent reducing upstream lake concentrations to meet water quality standards.

4.2.6.4 Lake Lucy

Due to Lake Lucy's good water quality in the past 10 years (both TP and Secchi depth just meet state water quality standards), the lake was assigned protection status rather than including it on the impaired waters list. Understanding Lake Lucy's nutrient budget is still critical to developing a protection plan for the lake. The recommended reductions shown below were developed to help maintain or improve water quality in Lake Lucy. The TP load reduction goals were developed based on lake water quality monitoring and modeling of the 2015 water year, a year in which the average summer TP concentration exceeded the standard (as indicated in Table 2.1). Because this is not a TMDL, the reductions in this table are considered voluntary.

The Lake Lucy total watershed load reduction was based on the estimated watershed load reductions from recommended BMPs identified in the Lake Lucy/Lake Ann UAA update (Barr 2013). The remainder of the load reduction was assigned to the internal load reduction.

Table 4.6 Nutrient Budgets and Recommended Reductions for Lake Lucy (10-0007-00) during 2015 water year.

LOAD SOURCE[a]	Existing TP Load		Target TP Load		Load Reduction Goal	
	lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
TOTAL LOAD	**697**	**1.910**	**488**	**1.337**	**209**	**30**
Chanhassen (MS400079)	*225*	*0.616*	*191*	*0.523*	*34*	*15*
Carver County (MS400070)	*0.4*	*0.001*	*0.4*	*0.001*	*0*	*0*
Atmospheric deposition	*36*	*0.099*	*36*	*0.099*	*0*	*0*
Internal load	*427*	*1.170*	*252*	*0.690*	*175*	*41*
Groundwater	*9*	*0.025*	*9*	*0.025*	*0*	*0*

a: Runoff from the MnDOT MS4 does not reach the lake under most conditions so it was not assigned a load reduction.

4.2.6.5 Lake Susan

The load to Lake Susan is significantly impacted by phosphorus associated with streambank erosion, and thus needed reductions for this source are large. In addition, a major stormwater treatment system—a spent lime treatment system installed in the southwest portion of the watershed—was installed in 2016 (which is, of course, after the 2015 water year used for calculating the existing load). This treatment system reduces phosphorus loading from runoff by 52 pounds (lbs) per year, according to modeling estimates. Between the needed streambank erosion reduction and the recent stormwater reduction, the TMDL will be met.

Table 4.7 Total Phosphorus Wasteload Allocations, Load Allocations, and Existing Conditions for Lake Susan (10-0013-00) during 2015 water year.

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
TOTAL LOAD		**1,261**	**3.455**	**995**	**2.726**	**316**	**25**
Wasteload	**Total WLA**	**279**	**0.764**	**229**	**0.627**	**50**	**18**
	MnDOT (MS400170)	*27*	*0.074*	*27*	*0.074*	*0*	*0*
	Carver County (MS400070)	*9*	*0.025*	*9*	*0.025*	*0*	*0*
	Chanhassen (MS400079)	*241*	*0.660*	*191*	*0.523*	*50*[a]	*21*
	Construction/Industrial SW	*2*	*0.005*	*2*	*0.005*	*0*	*0*
Load	**Total LA**	**982**	**2.690**	**716**	**1.962**	**266**	**27**
	Atmospheric deposition	*33*	*0.090*	*33*	*0.090*	*0*	*0*
	Internal load	*496*	*1.359*	*496*	*1.359*	*0*	*0*
	Upstream lakes	*20*	*0.055*	*20*	*0.055*	*0*	*0*
	Erosion sources	*400*	*1.096*	*134*	*0.367*	*266*	*67*
	Groundwater	*33*	*0.090*	*33*	*0.090*	*0*	*0*
MOS (5%)				**50**	**0.137**		

a: this load reduction is already being met as a result of project to implement spent lime treatment system in 2016.

4.2.6.6 Rice Marsh Lake

The Rice Marsh Lake MS4 allocations were determined through an analysis of the P8 model results to determine the current, overall TP removal percentages from the MnDOT, Carver County, Chanhassen, and Eden Prairie areas. The Chanhassen, Carver County, and MnDOT areas are very interconnected, with Chanhassen BMPs treating a large portion of the MnDOT and Carver County areas. For this reason, Chanhassen, Carver County, and MnDOT were assigned the same load reduction based on their existing, combined BMP's removal of 45% of the existing conditions watershed load from their combined watershed areas. Eden Prairie was assigned a lower load reduction than Chanhassen and MnDOT based on its existing BMP's removal of 52% of the existing conditions watershed load from its watershed area. The upstream lakes LA was calculated based on the load reduction needed to bring Lake Susan's average growing season TP concentration down to the shallow lake standard. The remainder of the load reduction needed for Rice Marsh Lake to meet the shallow lake water quality standard was assigned to the internal load, which is generally considered high.

Table 4.8 Total Phosphorus Wasteload Allocations, Load Allocations, and Existing Conditions for Rice Marsh Lake (10-0001-00) during 2014 water year.

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
TOTAL LOAD		**1,642**	**4.499**	**961**	**2.633**	**729**	**44**
Wasteload	**Total WLA**	**711**	**1.948**	**506**	**1.386**	**205**	**29**
	MnDOT (MS400170)	*97*	*0.266*	*68*	*0.186*	*29*	*30*
	Carver County (MS400070)	*21*	*0.058*	*15*	*0.041*	*6*	*29*
	Chanhassen (MS400079)	*504*	*1.381*	*353*	*0.967*	*151*	*30*
	Eden Prairie (MS400015)	*83*	*0.227*	*64*	*0.175*	*19*	*23*
	Construction/Industrial SW	*6*	*0.016*	*6*	*0.016*	*0*	*0*
Load	**Total LA**	**931**	**2.551**	**407**	**1.115**	**524**	**56**
	Atmospheric deposition	*69*	*0.189*	*69*	*0.189*	*0*	*0*
	Internal load	*539*	*1.477*	*108*	*0.296*	*431*	*80*
	Upstream lakes	*323*	*0.885*	*230*	*0.630*	*93*	*29*
MOS (5%)				**48**	**0.132**		

4.2.6.7 Lake Riley

As previously discussed, moderate to high levels of stormwater management within this watershed would be expected to remove approximately 50% to 60% of the untreated TP in runoff on an annual basis. MS4 allocations were applied based on current BMP removal efficiencies as an equitable method for distributing allocated TP load to the major contributors. For this watershed, existing loads from Carver and Hennepin Counties are very small (combined they are less than 0.5% of the overall existing loading) with limited opportunity for load reduction, and are not assigned a reduction. As a result, the Lake Riley MS4 allocations were determined through an analysis of the P8 model results to determine the overall TP removal efficiency of the MnDOT, Chanhassen and Eden Prairie BMPs. The MnDOT BMPs had the greatest removal efficiency, approximately 54%. The Chanhassen and Eden Prairie WLAs were calculated based on the TP load reductions they would each need to match MnDOT's treatment efficiency. This resulted in 69 lbs. of TP load reduction from stormwater sources, which is consistent with what was expected from BMP implementation within the direct watershed, as described in the Lake Riley UAA update (Barr 2016). The upstream lakes' LA was calculated based on the load reduction need to bring Rice Marsh Lake's average growing season TP concentration down to the shallow lake standard. The remainder of the load reduction needed for Lake Riley to meet the deep lake water quality standard was assigned to the internal load, which is generally considered high. The necessary load reduction to meet (or exceed) the allocation for internal sources is expected to be achieved through an in-lake alum treatment that was done in 2016; however, the effectiveness of the treatment will need to be evaluated over time.

Table 4.9 Total Phosphorus Wasteload Allocations, Load Allocations, and Existing Conditions for Lake Riley (10-0002-00) during 2014 water year.

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
TOTAL LOAD		**2,701**	**7.400**	**1,986**	**5.441**	**814**	**30**
Wasteload	**Total WLA**	**843**	**2.310**	**774**	**2.121**	**69**	**8**
	MnDOT (MS400170)	*75*	*0.205*	*75*	*0.205*	*0*	*0*
	Chanhassen (MS400079)	*384*	*1.052*	*328*	*0.899*	*56*	*15*
	Eden Prairie (MS400015)	*363*	*0.995*	*350*	*0.959*	*13*	*4*
	Carver County (MS400070)	*8*	*0.022*	*8*	*0.022*	*0*	*0*
	Hennepin County (MS400138)	*5*	*0.014*	*5*	*0.014*	*0*	*0*
	Construction/Industrial SW	*8*	*0.022*	*8*	*0.022*	*0*	*0*
Load	**Total LA**	**1,858**	**5.090**	**1,113**	**3.049**	**745**	**40**
	Atmospheric deposition	*110*	*0.301*	*110*	*0.301*	*0*	*0*
	Internal load	*1,083*	*2.967*	*637*	*1.745*	*446*[a]	*41*[a]
	Upstream lakes	*665*	*1.822*	*366*	*1.003*	*299*	*45*
MOS (5%)				**99**	**0.271**		

a: this load reduction may be met as a result of an in-lake alum treatment in 2016 pending further evaluation.

4.2.6.8 Hyland Lake

The Hyland Lake TMDL allocations considered the disproportionately high level of internal loading and relatively high level of stormwater treatment in the watershed. No watershed reductions were assigned based on the large number of stormwater ponds in the developed portions of the watershed, and the assumption that these ponds are performing as designed (including being maintained). The lake is also surrounded by mostly undeveloped parkland.

Table 4.10 Total Phosphorus Wasteload Allocations, Load Allocations, and Existing Conditions for Hyland Lake (27-0048-00) during 2015 water year.

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
TOTAL LOAD		**604**	**1.655**	**299**	**0.819**	**305**	**50**
Wasteload	**Total WLA**	**90**	**0.247**	**90**	**0.247**	**0**	**0**
	Bloomington (MS400005)	*90*	*0.247*	*90*	*0.247*	*0*	*0*
	Hennepin County (MS400138)	*0.05*	*0.0001*	*0.05*	*0.0001*	*0*	*0*
	Construction/Industrial SW	*0.4*	*0.001*	*0.4*	*0.001*	*0*	*0*
Load	**Total LA**	**514**	**1.408**	**194**	**0.532**	**320**	**62**
	Atmospheric deposition	*30*	*0.082*	*30*	*0.082*	*0*	*0*
	Internal load	*484*	*1.326*	*164*	*0.449*	*320*	*66*
MOS (5%)				**15**	**0.041**		

4.2.6.9 Wing Lake

The Wing Lake load reductions were divided between upstream lake and internal load. The upstream lakes LA was calculated based on the load reduction needed to bring Lake Holiday's average growing season TP concentration down to the shallow lake standard. The remaining needed load reduction was assigned to the internal load reduction. No watershed reductions were assigned based on the large number of stormwater ponds in the developed portions of the watershed and the assumption that these ponds are performing as designed.

Table 4.11 Total Phosphorus Wasteload Allocations, Load Allocations, and Existing Conditions for Wing Lake (27-0091-00) during 2016 growing season.

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/gs	lbs/day[a]	lbs/gs	lbs/day[a]	lbs/gs	%
TOTAL LOAD		**105**	**0.861**	**68**	**0.557**	**40**	**38**
Wasteload	**Total WLA**	**21**	**0.172**	**21**	**0.172**	**0**	**0**
	Minnetonka (MS400035)	*20*	*0.164*	*20*	*0.164*	*0*	*0*
	Hennepin County (MS400138)	*0.4*	*0.004*	*0.5*	*0.004*	*0*	*0*
	Construction/Industrial SW	*0.2*	*0.002*	*0.2*	*0.002*	*0*	*0*
Load	**Total LA**	**84**	**0.689**	**44**	**0.361**	**40**	**48**
	Atmospheric deposition	*2*	*0.016*	*2*	*0.016*	*0*	*0*
	Internal load	*56*	*0.459*	*28*	*0.230*	*28*	*50*
	Upstream lakes	*25*	*0.205*	*13*	*0.107*	*12*	*48*
	Groundwater	*1*	*0.008*	*1*	*0.008*	*0*	*0*
MOS (5%)				**3**	**0.025**		

a: TMDL (lb/day) value calculated based on 122 day growing season.

4.2.6.10 Lake Rose

The Lake Rose load reductions were divided among watershed, upstream lake and internal load. The upstream lakes LA was calculated based on the load reduction needed to bring Wing Lake's average growing season TP concentration down to the shallow lake standard. The maximum internal load reduction of approximately 80% was assigned and the remaining needed load reduction allocated to the Minnetonka MS4. The Hennepin County MS4 was not assigned a reduction since its load contribution is very small and it has limited opportunity for load reduction.

Table 4.12 Total Phosphorus Wasteload Allocations, Load Allocations, and Existing Conditions for Lake Rose (27-0092-00) during 2016 growing season.

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/gs	lbs/day[a]	lbs/gs	lbs/day[a]	lbs/gs	%
TOTAL LOAD		**75**	**0.615**	**46**	**0.377**	**31**	**41**
Wasteload	**Total WLA**	**28**	**0.230**	**21**	**0.172**	**7**	**25**
	Minnetonka (MS400035)	*27*	*0.221*	*20*	*0.164*	*7*	*26*
	Hennepin County (MS400138)	*1*	*0.008*	*1*	*0.008*	*0*	*0*
	Construction/Industrial SW	*0.2*	*0.002*	*0.2*	*0.002*	*0*	*0*
Load	**Total LA**	**47**	**0.385**	**23**	**0.189**	**24**	**51**
	Atmospheric deposition	*2*	*0.016*	*2*	*0.016*	*0*	*0*
	Internal load	*19*	*0.156*	*4*	*0.033*	*15*	*79*
	Upstream lakes	*26*	*0.213*	*17*	*0.139*	*9*	*35*
MOS (5%)				**2**	**0.016**		

a: TMDL (lb/day) value calculated based on 122 day growing season.

4.2.6.11 North Cornelia Lake

The North Cornelia Lake load reductions were divided between watershed and internal load. Reduction percentages were based on balancing the removal between watershed sources of phosphorus to the lake and internal loading. The maximum internal load reduction of 80% was assigned first and the remaining needed reduction allocated evenly between the MS4s with the exception of Richfield, which was not assigned a reduction since its load contribution is very small and it has limited opportunity for load reduction.

Table 4.13 Total Phosphorus Wasteload Allocations, Load Allocations, and Existing Conditions for North Cornelia Lake (27-0028-01) during 2015 growing season.

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/gs	lbs/day[a]	lbs/gs	lbs/day[a]	lbs/gs	%
TOTAL LOAD		**360**	**2.951**	**154**	**1.262**	**214**	**59**
Wasteload	**Total WLA**	**227**	**1.861**	**117**	**0.959**	**110**	**48**
	Edina (MS400016)	*182*	*1.492*	*93*	*0.762*	*89*	*49*
	Richfield (MS400045))	*2*	*0.016*	*2*	*0.016*	*0*	*0*
	MnDOT (MS400170)	*34*	*0.279*	*17*	*0.139*	*17*	*50*
	Hennepin County (MS400138)	*8*	*0.066*	*4*	*0.033*	*4*	*50*
	Construction/Industrial SW	*1*	*0.008*	*1*	*0.008*	*0*	*0*
Load	**Total LA**	**133**	**1.090**	**29**	**0.238**	**104**	**78**
	Atmospheric deposition	*3*	*0.025*	*3*	*0.025*	*0*	*0*
	Internal load	*130*	*1.066*	*26*	*0.213*	*104*	*80*
MOS (5%)				**8**	**0.066**		

a: TMDL (lb/day) value calculated based on 122 day growing season.

4.2.6.12 South Cornelia Lake

The South Cornelia Lake load reductions were divided between upstream lake and internal load. The upstream lakes LA was calculated based on the load reduction needed to bring North Cornelia Lake's average growing season TP concentration down to the shallow lake standard. The remaining needed load reduction was assigned to the internal load reduction. No watershed reductions were assigned based on the relatively small contribution of the watershed loads and the assumption that the existing watershed BMPs are functioning as designed.

Table 4.14 Total Phosphorus Wasteload Allocations, Load Allocations, and Existing Conditions for South Cornelia Lake (27-0028-02) during 2016 growing season.

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/gs	lbs/day[a]	lbs/gs	lbs/day[a]	lbs/gs	%
TOTAL LOAD		**410**	**3.361**	**168**	**1.377**	**250**	**61**
Wasteload	**Total WLA**	**26**	**0.213**	**26**	**0.213**	**0**	**0**
	Edina (MS400016)	*26*	*0.213*	*26*	*0.213*	*0*	*0*
	Construction/Industrial SW	*0.3*	*0.002*	*0.3*	*0.002*	*0*	*0*
Load	**Total LA**	**384**	**3.148**	**134**	**1.098**	**250**	**65**
	Atmospheric deposition	*4*	*0.033*	*4*	*0.033*	*0*	*0*
	Upstream lakes	*181*	*1.484*	*81*	*0.664*	*100*	*55*
	Internal load	*199*	*1.631*	*49*	*0.402*	*150*	*75*
MOS (5%)				**8**	**0.066**		

a: TMDL (lb/day) value calculated based on 122 day growing season.

4.2.6.13 Lake Edina

The Lake Edina load reductions were divided among watershed and upstream lake loads. The upstream lakes LA was calculated based on the load reduction needed to bring South Cornelia Lake's average growing season TP concentration down to the shallow lake standard. The remaining needed load reduction was assigned to the Edina City MS4 watershed reduction. The MnDOT Metro MS4 was not assigned a reduction since its load contribution is very small and it has limited opportunity for load reduction. No internal load reductions were assigned due to its relatively small contribution to the total load.

Table 4.15 Total Phosphorus Wasteload Allocations, Load Allocations, and Existing Conditions for Edina Lake (27-0029-00) during 2015 growing season.

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/gs	lbs/day[a]	lbs/gs	lbs/day[a]	lbs/gs	%
TOTAL LOAD		**261**	**2.139**	**180**	**1.475**	**90**	**34**
Wasteload	**Total WLA**	**117**	**0.959**	**79**	**0.648**	**38**	**32**
	Edina (MS400016)	*112*	*0.918*	*74*	*0.607*	*38*	*34*
	MnDOT (MS400170)	*4*	*0.033*	*4*	*0.033*	*0*	*0*
	Construction/Industrial SW	*1*	*0.008*	*1*	*0.008*	*0*	*0*
Load	**Total LA**	**144**	**1.180**	**92**	**0.754**	**52**	**36**
	Atmospheric deposition	*3*	*0.025*	*3*	*0.025*	*0*	*0*
	Upstream lakes	*116*	*0.951*	*64*	*0.525*	*52*	*45*
	Internal load	*25*	*0.205*	*25*	*0.205*	*0*	*0*
MOS (5%)				**9**	**0.074**		

a: TMDL (lb/day) value calculated based on 122 day growing season.

4.2.6.14 Penn Lake

The Penn Lake load reductions were divided between watershed and internal load. Reduction percentages were based on balancing the removal between watershed sources of phosphorus to the lake and internal loading. The maximum internal load reduction of 80% was assigned first, and the remaining needed reduction allocated as evenly as possible between the MS4s with the exception of Hennepin County, which was not assigned a reduction since its load contribution is very small and it has limited opportunity for load reduction.

Table 4.16 Total Phosphorus Wasteload Allocations, Load Allocations, and Existing Conditions for Penn Lake (27-0004-00) during 2016 growing season.

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/gs	lbs/day[a]	lbs/gs	lbs/day[a]	lbs/gs	%
TOTAL LOAD		**446**	**3.656**	**247**	**2.025**	**211**	**47**
Wasteload	**Total WLA**	**371**	**3.041**	**217**	**1.779**	**154**	**42**
	Bloomington (MS400005)	*260*	*2.131*	*150*	*1.230*	*110*	*42*
	Richfield (MS400045))	*47*	*0.385*	*27*	*0.221*	*20*	*43*
	MnDOT (MS400170)	*56*	*0.459*	*32*	*0.262*	*24*	*43*
	Hennepin County (MS400138)	*6*	*0.049*	*6*	*0.049*	*0*	*0*
	Construction/Industrial SW	*2*	*0.016*	*2*	*0.016*	*0*	*0*
Load	**Total LA**	**75**	**0.615**	**18**	**0.148**	**57**	**76**
	Atmospheric deposition	*4*	*0.033*	*4*	*0.033*	*0*	*0*
	Internal load	*71*	*0.582*	*14*	*0.115*	*57*	*80*
MOS (5%)				**12**	**0.098**		

a: TMDL (lb/day) value calculated based on 122 day growing season.

4.3 Streams, Total Suspended Solids

The data used for the development of the Riley Creek TSS TMDL (Assessment Unit ID [AUID] # 07020012-511) are based on continuous flow monitoring and TSS sample results (both grab and storm composite samples) collected by the Metropolitan Council at the Riley Creek WOMP station site, which is 1.3 miles from the confluence with the Minnesota River. The WOMP station location corresponds with MPCA Station ID S005-380. The monitoring station was out of commission from early 2005 through late 2006 due to equipment failure, but has otherwise operated continuously since 1999.

This TSS TMDL also addresses the fishes and macroinvertebrates impairment listings for this reach. A separate report titled Lower Minnesota Watershed Stressor Identification Report (MPCA 2018) evaluated all of the biota impairments in this major watershed. Stressors evaluated for each reach included dissolved oxygen, eutrophication, nitrate, suspended sediment, chloride, habitat, and flow alteration/connectivity. The only pollutant among these candidate stressors to be conclusively contributing to the biota impairments for Riley Creek was suspended sediment (TSS). This was based on both the TSS levels observed to date and the assemblage of biota species present relative to their tolerance/sensitivity to TSS. The non-pollutant stressor flow alteration/connectivity was also identified as impacting aquatic life, but TMDLs are not done for flow alteration/connectivity.

4.3.1 TSS Loading Capacity Methodology

The TSS loading capacity for the Riley Creek impaired reach was developed using a load duration curve approach (EPA 2007). Load duration curves incorporate flow and the TSS data across five stream flow zones, and provide a means to determine loading capacities and estimated load reductions necessary to meet water quality standards. Average daily flows from the Riley Creek WOMP station during the 2006 to 2015 time period were extrapolated for differences between the total and monitored watershed areas, and used in conjunction with the 65 mg/L TSS standard to develop a load duration curve that shows the daily loading capacity associated with the continuous flow duration data. The 10-year TSS load duration curve for the impaired reach of Riley Creek is shown in Figure 4.3. The curve represents the loading capacity of the stream for each daily flow and is divided into five flow zones including very high (0% to 10%), high (10% to 40%), mid (40% to 60%), low (60% to 90%) and very low (90% to 100%) flow conditions. For simplicity, only the median (or midpoint) load of each flow zone is used to show the TMDL equation components in the TMDL table. However, it should be understood that the entire curve represents the TMDL for Riley Creek. Also plotted in Figure 4.3 are the 90th percentile monitored TSS concentrations for each flow zone (solid green square).

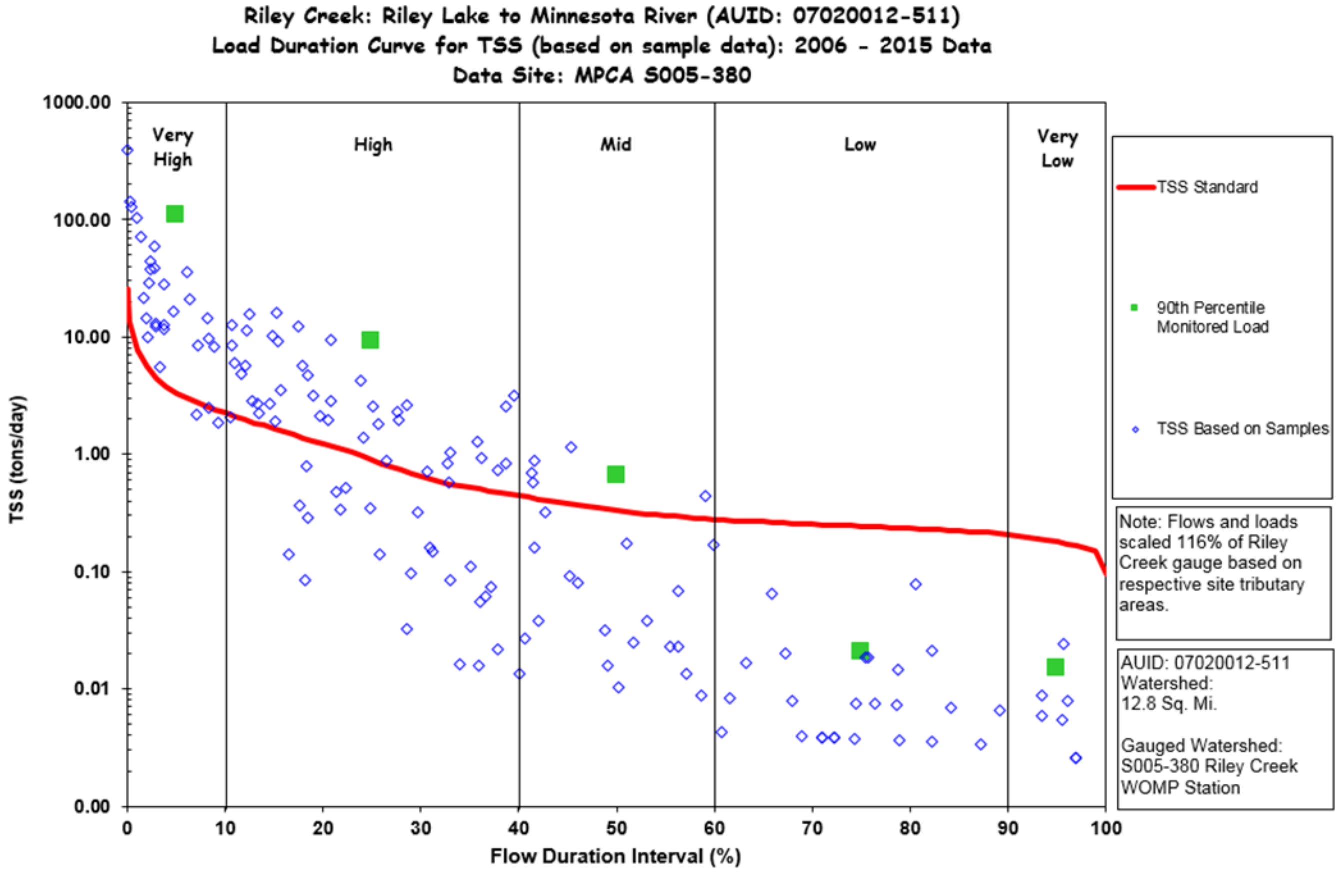


Figure 4.3 Riley Creek TSS concentration cumulative frequency curve, 2006-2015

4.3.2 TSS Load Allocation Methodology

The LAs include nonpoint pollution sources that are not subject to NPDES permit requirements, as well as natural background loads. For Riley Creek, LAs include non-regulated surface runoff, near channel erosion and natural background sources of TSS, as well as outflow from Lake Riley. The LA is the remaining load after the MOS and WLAs are subtracted from the total load capacity of each flow zone.

4.3.2.1 Upstream Lakes

For the purposes of this study, outflow from Lake Riley (referred to as the Lake Riley Boundary Condition) was included as a separate line item in the LA. Lake Riley is a natural sink for the TSS, and therefore contributes minimal TSS levels to Riley Creek. Allocations for the Lake Riley Boundary

Condition were based on an estimated TSS discharge for this lake in an unimpaired state. A discharge concentration of 4 mg/L is used, which is the midpoint of the range of TSS concentrations for lakes of the NCHF ecoregion, as reported by MPCA (https://www.pca.state.mn.us/quick-links/eda-guide-typical-minnesota-water-quality-conditions).

4.3.2.2 Non-regulated surface runoff and near-channel erosion

The watershed LA includes all non-permitted sources such as runoff from agricultural land, forested land, and non-regulated MS4 residential areas (such as direct runoff from backyard areas). There are no available data or studies to partition natural background loads from the rest of the LA.

4.3.2.3 Unallocated load

For some flow zones, the existing pollutant load (as denoted by 90th percentile monitored load) fell below the allowable pollutant load (see Figure 4.3). To adhere to antidegradation requirements, the difference between the existing load and allocated load for these flow zones was classified as "unallocated" load. (The remaining allowable load (i.e., what falls below the 90th percentile is what is divided up among WLA and other LA sources.)

4.3.3 TSS Wasteload Allocation Methodology

WLAs represent the portion of the TSS load associated with permitted sources. WLAs include three sub-categories: permitted wastewater facilities, the MS4s permitted stormwater source category, and a construction plus industrial permitted stormwater category.

4.3.3.1 Permitted Wastewater Sources

There are no permitted wastewater facilities in the Riley Creek Watershed.

4.3.3.2 Municipal Separate Storm Sewer Systems: Individual WLAs

MS4 boundaries were defined for the Riley Creek Watershed consistent with the discussion in Section 2.1.2. Figure 2.15 shows the Riley Creek MS4 boundaries. Overall, five MS4s cover the watershed area, including the cities of Chanhassen, Eden Prairie, Hennepin, and Carver Counties, and MnDOT. However, only Eden Prairie and Hennepin County manage developed land or MS4s downstream of Lake Riley, and as described in the following section, the watershed area tributary to Lake Riley was included as a boundary condition in the LA component. The WLAs for each MS4 were calculated based on their proportional drainage area applied to the loading capacity derived for each flow zone (as explained in the previous section). This assumes that stormwater runoff from each MS4 will not exceed the 65 mg/L TSS standard, which is reasonable because researchers report median event mean TSS concentrations for urban land uses that range from 52 to 101 mg/L for untreated stormwater runoff (EPA 1983; Lin 2004; Maestre and Pitt 2005). Since there are no stormwater monitoring data or modeling estimates specific to the urban runoff contributions in this watershed, a specific TSS load reduction could not be quantified for this component of the TMDL. However, Figure 1.17 shows that approximately half of the TSS sample results were between 65 and 530 mg/L, it is expected that a greater proportion of the required load reduction will necessitate BMPs that will stabilize near-channel sources of sediment and/or control the stormwater discharge rates/volumes to consistently meet the standard. Since many of the MS4 discharges to Riley Creek have varying levels of treatment and/or controls on discharge rate and volume, it is expected that MS4s will have a significant role in minimizing near-channel sources of sediment.

4.3.3.3 Construction/Industrial Stormwater: Categorical WLAs

The approach for allocating the construction plus industrial permitted stormwater category for the Riley Creek Watershed was based on the previous assumptions about these activities as a percentage of the watershed area. As a result, this component was assigned a WLA that is equal to 1% of the total WLA for each flow zone.

4.3.4 Margin of Safety

The MOS accounts for uncertainties in both characterizing current conditions and the relationship between the load, wasteload, monitored flows, and in-stream water quality to ensure the TMDL allocations result in attainment of water quality standards. An explicit MOS equal to 5% of the total load was applied whereby 5% of the loading capacity for each flow regime was subtracted before allocations were made among the wasteload and watershed load. Five percent was considered an appropriate MOS since the load duration curve approach minimizes a great deal of uncertainty associated with the development of TMDLs, because the calculation of the loading capacity is the product of monitored flow and the TSS target concentration. Most of the uncertainty with this calculation is therefore associated with the flows in the impaired reach that were calculated based on monitored flows at the WOMP station, which is a well-established continuous flow monitoring station with a long flow record.

4.3.5 Seasonal Variation

The EPA states that the critical condition "…can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence" (EPA 1999). As indicated in the load duration curve analysis, TSS loads vary significantly from high flow to low flow conditions. Most exceedances of the water quality standard for TSS occur at the very high- and high-range flow conditions during the seasons with highest precipitation. High-flow regimes are the critical condition for TMDL implementation. By using a duration curve approach in this TMDL the full range of flow conditions occurring over the year are fully captured and accounted for.

4.3.6 TSS TMDL Summary

The LA components and individual MS4 allocations were calculated by multiplying the respective LA areas and each MS4's percent watershed coverage area by the total watershed loading capacity (determined from the load duration curve), after the MOS and construction/industrial stormwater activities components were subtracted from the loading capacity for each flow zone. The TSS TMDL for Riley Creek was developed for a baseline year of 2011, which is the midpoint year for the date range of TSS data used for development of this TMDL (2006 through 2015). TSS load reductions that occur during or after the baseline year of 2011 are creditable toward the overall required load reduction.

Table 4.17 presents the total loading capacity, the MOS, the WLAs and the remaining watershed LAs for the impaired reach of Riley Creek. Allocations for this TMDL were established using the 65 mg/L TSS standard for class 2B waters in the Minnesota River Basin.

The 530 mg/L TSS concentration at the tenth percentile shown in Figure 3.15 provides an indication of the overall magnitude of the required load reduction to meet the 65 mg/L standard. This equates to a

(530 – 65)/530 = 88% overall reduction. This reduction percentage is only intended as a rough approximation, as it does not account for flow, and is not a required element of a TMDL. It serves to provide a starting point based on available water quality data for assessing the magnitude of the effort needed in the watershed to achieve the standard. This reduction percentage does not supersede the allocations provided in Table 4.17. In addition, because there is limited information or data available to estimate or quantitatively calculate the existing (current conditions) load contribution from each of the WLA and LA sources presented in Table 4.17, this reduction percentage is not intended to be applied uniformly across these sources. In fact, per the qualitative discussion of sources in Section 3.7.2.1, much of the reduction will need to come from near-channel sources (e.g., streambank erosion). However, these near-channel sources are often largely affected or driven by stormwater discharge rates/volume. Improvements in stormwater management should help to reduce sediment contributions from the near-channel sources.

Table 4.17 Riley Creek (AUID# 07020012-511) TSS TMDL and Allocations

		Flow Zones				
		Very High	High	Mid	Low	Very Low
		(lbs/day)				
TOTAL LOAD (Baseline Year: 2011)		**6,600**	**1,772**	**662**	**486**	**360**
Wasteload	**Total WLA**	**2,227**	**598**	**223**	**32**	**23**
	Eden Prairie (MS400015)	*2,059*	*553*	*206*	*29*	*21*
	Hennepin County (MS400138)	*146*	*39*	*15*	*2*	*1*
	Construction/Industrial SW	*22*	*6*	*2*	*1*	*1*
Load	**Total LA**	**4,043**	**1,085**	**406**	**430**	**319**
	Lake Riley Boundary Condition	*246*	*66*	*25*	*18*	*13*
	Watershed LA	*3,797*	*1,019*	*381*	*54*	*40*
	Unallocated Load				*358*	*266*
MOS (5%)		**330**	**89**	**33**	**24**	**18**
Estimated existing load reduction (%)		**88%**				

4.4 Streams, *E. coli*

Bacteria (*E. coli*) TMDLs for Nine Mile Creek (AUID# 07020012-809), Purgatory Creek (AUID# 07020012-828), and Riley Creek (AUID# 07020012-511) were developed using the load duration curve approach (EPA 2007) as described in Section 4.3.1. Development of the three stream *E. coli* TMDLs is described in the following subsections.

4.4.1 *E. coli* Loading Capacity Methodology

As described in Section 4.3.1, load duration curves describe the pollutant loading capacity of a stream over a variety of flow conditions. To develop a load duration curve, flow data must first be aggregated to create a flow duration curve for each reach. The flow duration curve describes how often a given flow rate is exceeded in a given stream reach (e.g., a flow rate of 10 cfs is exceeded 50% of the time within the Nine Mile Creek reach, see Figure 2.18). Flow duration curves for Nine Mile Creek, Purgatory Creek, and Riley Creek were aggregated from the sources described in Table 4.18 and are shown together in Figure 4.4.

Table 4.18 Stream flow rate data for *E. coli* TMDLs

Stream	Station ID	Years Flow Collected
Nine Mile Creek	05330900	1963-1973
	S007-901	1989-2016
	ECU7A/N1	1997-2014
	ECU7B	1997-2010
	ECU7C	1997-2010
	S005-377	2007-2014
	Station8	1987-2001
Purgatory Creek	5330800	1975-1980
	445002093265701	1980
	S007-907	2004-2016
	NA	2004-2015
	P1.6	2004-2006
Riley Creek	445023093305201	1981-1982
	S005-380	1999-2016

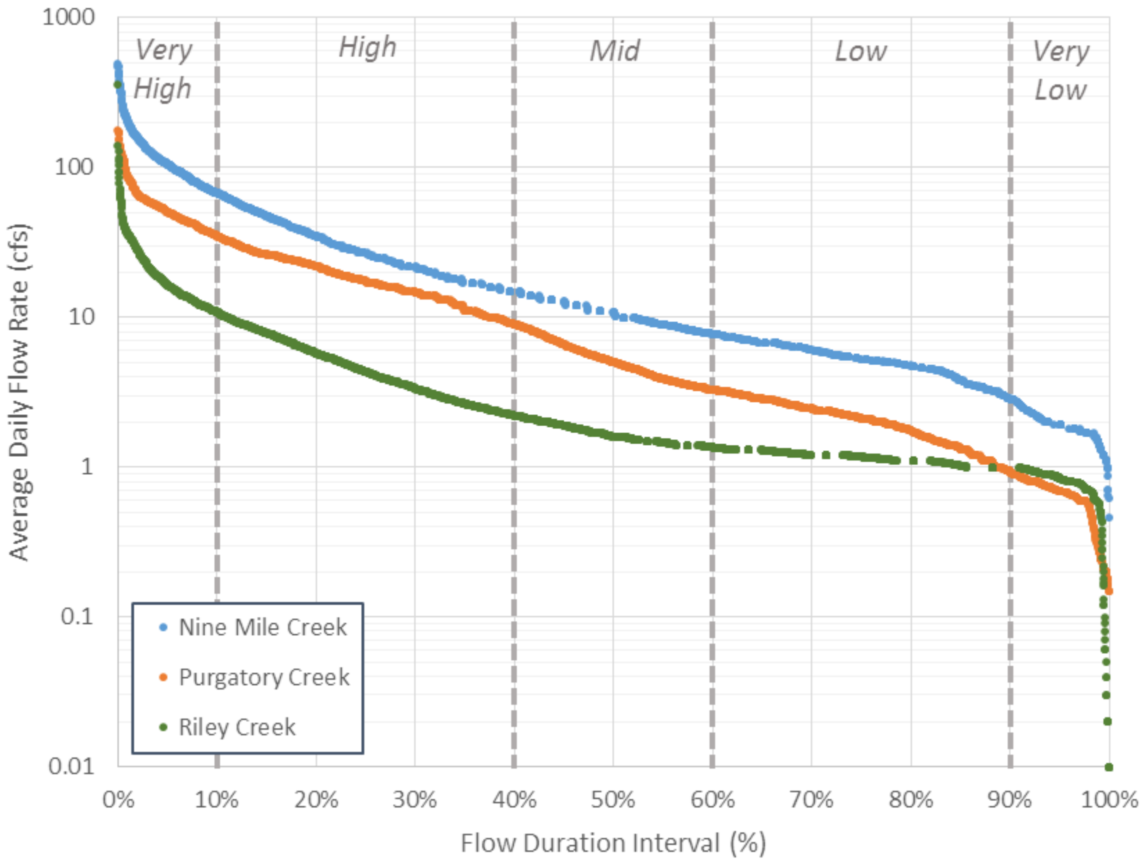


Figure 4.4 Flow Duration Curve for Nine Mile Creek, Purgatory Creek, and Riley Creek

Using the flow duration curves shown in Figure 4.4, the load duration curve for each stream is calculated by multiplying the flow rate at each point along the flow duration curve by the chronic *E. coli* standard of 126 organisms per 100 mL. Load duration curves and observed *E. coli* loads for each stream reach are shown in Figure 4.5 through Figure 4.7. The load duration curve represents the loading capacity of the stream for each daily flow and is divided into five flow zones: very high (0% to 10%), high (10% to 40%), mid (40% to 60%), low (60% to 90%) and very low (90% to 100%) flow conditions. For simplicity, the median value (or midpoint) of the load duration curve within each flow condition defines the TMDL for each flow condition. Because the chronic bacteria standard is developed based on the geometric mean of observed *E. coli* concentrations, the geometric mean of observed data within each flow condition defines the existing load for each flow condition. *E. coli* load reduction is required for stream reaches and flow zones for which the geometric mean load of observed data exceeds the median TMDL value. It is important to note that this depiction may not fully show all needed reductions. Specifically, in some cases the impairment was based on exceedances occurring during individual months (aggregated across years). For those cases, a separate reduction estimate is needed.

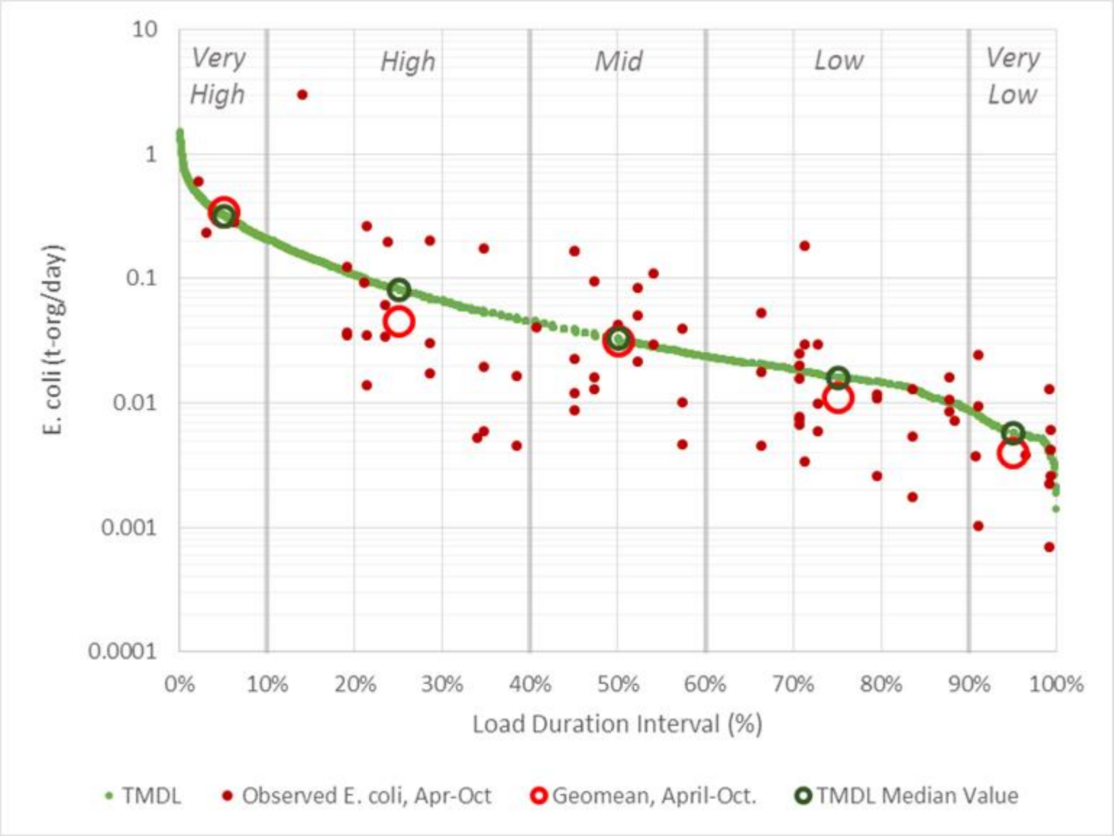


Figure 4.5 ***E. coli*** **Load Duration Curve for Nine Mile Creek (AUID# 07020012-809)**

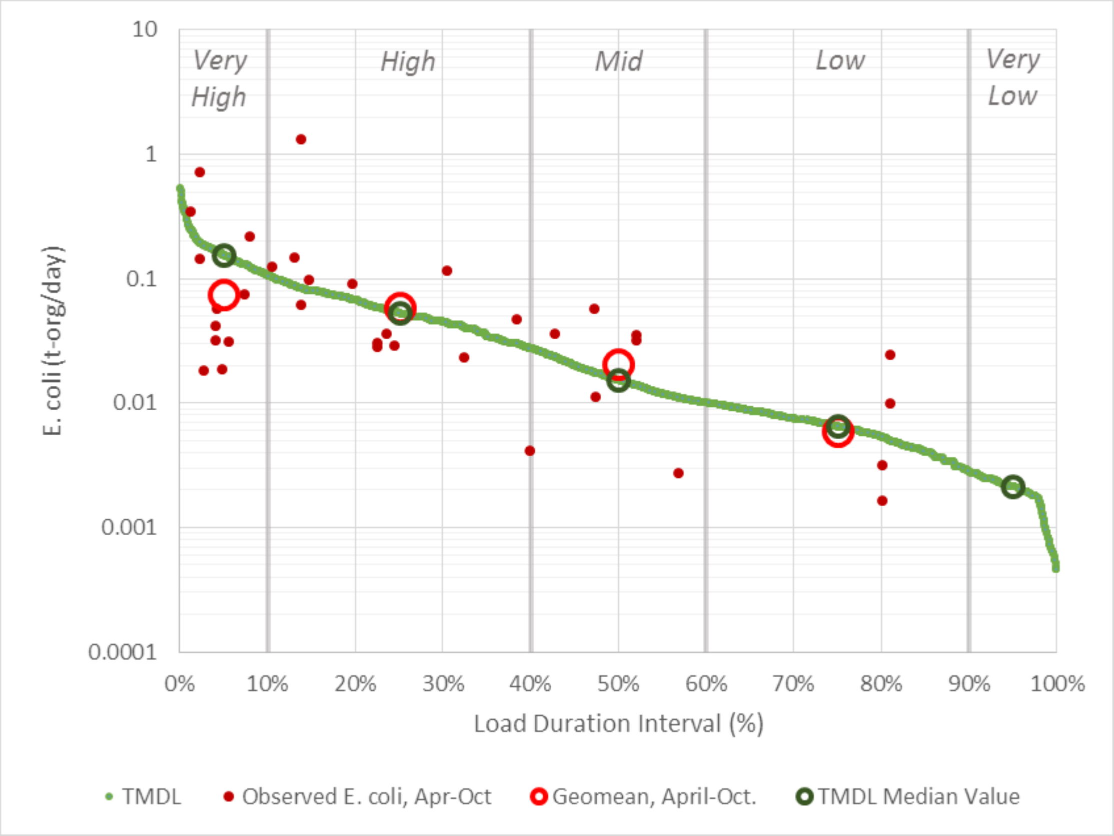


Figure 4.6 ***E. coli*** **Load Duration Curve for Purgatory Creek (AUID# 07020012-828)**

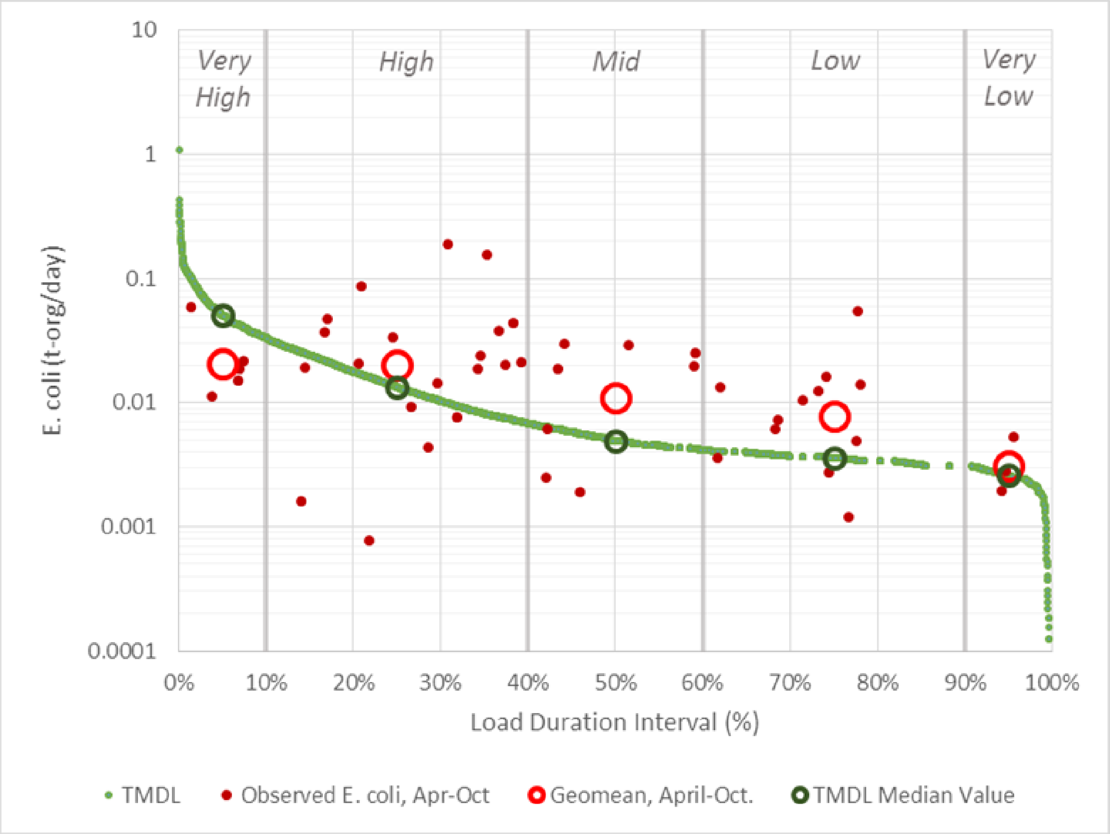


Figure 4.7 ***E. coli*** **Load Duration Curve for Riley Creek (AUID# 07020012-511)**

4.4.2 *E. coli* Load Allocation Methodology

Non-permitted sources of bacteria within the watersheds of Nine Mile Creek, Purgatory Creek, and Riley Creek downstream of Marsh Lake, Staring Lake, and Riley Lake, respectively, include runoff from areas that have the potential to transport bacterial from wildlife and loading from the upstream lakes (Marsh Lake, Starting Lake, and Riley Lake). There are no known SSTSs or livestock feedlots within the impaired reach watershed of the three streams.

4.4.2.1 Upstream Lakes

The LA applied to upstream lakes (Marsh Lake, Staring Lake, and Riley Lake) was determined by estimating the percentage of stream flow contributed by the upstream lakes and applying an estimated *E. coli* loading concentration to the lake outflow. A flow duration curve for each upstream lake was calculated by multiplying the stream flow duration curves shown in Figure 4.4 by the ratio of the drainage area of the impaired reach to the total drainage area of the entire stream. Because *E. coli* monitoring data at the lake outlets was not collected from the Riley-Purgatory Creek or Nine Mile Creek watersheds, a load duration curve was developed by multiplying the flow duration curve by an *E. coli* concentration of 11 organisms per 100 mLs. This value represents the average outflow concentration of Gray's Bay Dam from the Minnehaha Creek *E. coli* TMDL (MPCA 2013). Because lakes often act as a sink for fecal bacteria and are not believed to contribute to elevated *E. coli* concentration in impaired streams, this value is considered a reasonable estimate of the lake outflow concentration.

4.4.2.2 Non-regulated surface runoff

The remaining watershed LA applied to non-permitted sources, such as runoff from agricultural land, forested land, and non-regulated MS4 residential areas (such as direct runoff from backyard areas), was calculated as the remaining load after the MOS, WLAs and LA from upstream lakes was subtracted from the total load capacity of each flow zone. There are no available data or studies to partition natural background loads from the rest of the LA.

4.4.2.3 Unallocated load

For some flow zones, the existing pollutant load (as denoted by the geomean of observed data) fell below the allowable pollutant load (see Figure 4.3). To adhere to antidegradation requirements, the difference between the existing load and allocated load for these flow zones was classified as "unallocated" load. (The remaining allowable load (i.e., what falls below the geomean of observed data) is what is divided up among WLA and other LA sources.)

4.4.3 *E. coli* Wasteload Allocation Methodology

WLAs represent the portion of the *E. coli* load associated with permitted sources. WLAs are typically divided into three sub-categories: permitted wastewater sources, confined animal feeding operations, and MS4s.

4.4.3.1 Permitted Wastewater Sources

There are no permitted wastewater sources of *E. coli* in the Nine Mile Creek, Purgatory Creek, or Riley Creek watersheds.

4.4.3.2 Confined Animal Feeding Operations

There are no confined animal feeding operations in the Nine Mile Creek, Purgatory Creek, or Riley Creek watersheds.

4.4.3.3 Municipal Separate Storm Sewer Systems

The primary source of bacteria loading within MS4s comes from improperly managed pet waste and wildlife inputs (e.g., waterfowl, geese, etc.) directly to impervious surfaces and water features. Permitted MS4s within the Nine Mile Creek downstream of Marsh Lake, Purgatory Creek downstream of Staring Lake and Riley Creek downstream of Riley Lake are summarized in Table 2.21. Individual MS4 allocations were calculated by multiplying the percent watershed coverage of each MS4 by the *E. coli* loading capacity (determined from the load duration curves) after the MOS and estimated loading from upstream waterbodies (see Section 4.4.2) was subtracted.

As shown in Table 4.19, the Chanhassen area is completely pervious and is a very small percentage of the total drainage area to the impaired portion of Riley Creek. For this reason, Chanhassen will not be assigned a WLA for the Riley Creek *E. coli* TMDL.

Table 4.19 MS4 Area Summary for *E. coli* TMDLs

Stream	MS4	Area (ac)	Area (%)
Nine Mile Creek	Bloomington	2837	85%
	Hennepin County	62	2%
	MnDOT	53	2%
	Non-Permitted[a]	381	11%
Purgatory Creek	Bloomington	783	17%
	Eden Prairie	2303	51%
	Hennepin County	80	2%
	Hennepin Technical College	51	1%
	MnDOT	140	3%
	Non-Permitted[a]	1183	26%
Riley Creek	Chanhassen[b]	0.04	0.001%
	Eden Prairie	1264	43%
	Hennepin County	37	1%
	Non-Permitted[a]	1658	56%

a: Non-permitted sources and non-regulated MS4 residential areas (e.g., direct runoff from backyard areas). See Section 4.4.2.2

b: Chanhassen area is completely pervious and is a very small percentage of the Riley Creek impairment reach drainage area. For this reason, it should not be assigned a WLA.

4.4.3.4 Construction/Industrial Stormwater: Categorical WLAs

E. coli WLAs for regulated construction stormwater (permit # MNR100001) were not developed, since *E. coli* is not a typical pollutant from construction sites. WLAs for regulated industrial stormwater were also not developed. Industrial stormwater must receive a WLA only if the pollutant is part of benchmark monitoring for an industrial site in the watershed of an impaired waterbody. There are no bacteria or *E. coli* benchmarks associated with any of the industrial stormwater permit (Permit #MNR050000).

4.4.4 Margin of Safety

MOS accounts for uncertainties in both characterizing current conditions and the relationship between the load, wasteload, monitored flows, and in-stream water quality to ensure the TMDL allocations result in attainment of water quality standards. An explicit MOS equal to 5% of the total load was applied, whereby 5% of the loading capacity for each flow regime was subtracted before allocations were made among the wasteload and watershed load. Five percent was considered an appropriate MOS since the load duration curve approach minimizes a great deal of uncertainty associated with the development of TMDLs, because the calculation of the loading capacity is the product of monitored flow and the *E. coli* target concentration (126 organism per 100 mLs). Most of the uncertainty with this calculation is associated with the flows in the impaired reaches. Because the majority of available flow data was collected from WOMP stations with well-established, continuous flow monitoring records, it is assumed that the level of uncertainty in the flow monitoring data and resulting TMDL load duration curves is low.

4.4.5 Seasonal Variation

The EPA states that the critical condition "…can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence" (EPA 1999). As indicated in the load duration curve analysis, *E. coli* loads vary significantly from high flow to low flow conditions. Because the load duration curve approach covers a complete range of seasonal flow conditions, seasonal variation is inherently incorporated into the *E. coli* TMDLs.

4.4.6 *E. coli* TMDL Summary

Bacteria (*E. coli*) TMDL allocations for the impaired reaches of Nine Mile Creek, Purgatory Creek, and Riley Creek are shown in Table 4.20, Table 4.21, and Table 4.22, respectively. Allocations for these TMDLs were established using the 126 organisms/100 mL *E. coli* standard for class 2B waters in the Minnesota River Basin. As described in Section 4.4.2 and Section 4.4.3, allocations for each flow zone were calculated by first removing the MOS and the estimate of upstream lake loading from the total allocation, and then assigning the remaining allocation to MS4 WLA and watershed LA sources based on the percent contributing area in each impaired reach watershed (see Table 4.19).

The *E. coli* TMDLs for Nine Mile Creek, Purgatory Creek, and Riley Creek were developed for a baseline year of 2012, which is the midpoint year for the date range of *E. coli* data used for development of this TMDL (2006 through 2017). *E. coli* load reductions that occur during or after the baseline year of 2012 are creditable toward the overall required load reduction.

Table 4.20 Nine Mile Creek (AUID# 07020012-809) *E. coli* TMDL and Allocations

Load Category	Load Source	Flow Zone				
		Very High	High	Mid	Low	Very Low
		billion organisms per day (b-org/day)				
TOTAL LOAD (TMDL), Baseline Year: 2012		**324.8**	**82.9**	**33.1**	**16.2**	**5.9**
Waste-Load	**Total Wasteload Sources**	**251.0**	**31.6**	**24.7**	**8.1**	**2.9**
	Bloomington City MS4 (MS400005)	241.2	30.4	23.7	7.8	2.8
	Hennepin County MS4 (MS400138)	5.2	0.7	0.5	0.2	0.1
	MnDOT Metro District (MS400170)	4.5	0.6	0.4	0.1	0.05
Load	**Total Load Sources**	**57.6**	**47.1**	**6.8**	**7.3**	**2.7**
	Marsh Lake Boundary Condition	25.2	6.4	2.6	1.3	0.5
	Watershed LA	32.4	4.1	3.2	1.0	0.4
	Unallocated Load	0	36.6	1.1	5.0	1.8
Margin of Safety, 5%		**16.2**	**4.1**	**1.7**	**0.8**	**0.3**
Existing Concentration, Apr–Oct (org/100 mL)		116				
Maximum Monthly Geometric Mean (org/100 mL)		212				
Estimated Existing Load Reduction (%)		41%				

Table 4.21 Purgatory Creek (AUID# 07020012-828) *E. coli* TMDL and Allocations

Load Category	Load Source	Flow Zone				
		Very High	High	Mid	Low	Very Low
		billion organisms per day (b-org/day)				
TOTAL LOAD (TMDL) , Baseline Year: 2012		**155.0**	**53.4**	**15.4**	**6.5**	**2.1**
Waste-Load	**Total Wasteload Sources**	**40.4**	**34.1**	**9.8**	**3.8**	**1.4**
	Bloomington City MS4 (MS400005)	9.4	8.0	2.3	0.9	0.3
	Eden Prairie City MS4 (MS400015)	27.7	23.4	6.7	2.6	0.9
	Hennepin County MS4 (MS400138)	1.0	0.8	0.2	0.1	0.03
	Hennepin Technical College MS4 (MS400199)	0.6	0.5	0.1	0.1	0.02
	MnDOT Metro District (MS400170)	1.7	1.4	0.4	0.2	0.1
Load	**Total Load Sources**	**106.9**	**16.7**	**4.8**	**2.4**	**0.7**
	Staring Lake Boundary Condition	13.5	4.7	1.3	0.6	0.2
	Watershed LA	14.2	12.0	3.5	1.3	0.5
	Unallocated Load	79.1	0	0	0.5	0
Margin of Safety, 5%		**7.8**	**2.7**	**0.8**	**0.3**	**0.1**
Existing Concentration, Apr–Oct (org/100 mL)		55				
Maximum Monthly Geometric Mean (org/100 mL)		392				
Estimated Existing Load Reduction (%)		68%				

Table 4.22 Riley Creek (AUID# 07020012-511) *E. coli* TMDL and Allocations

Load Category	Load Source	Flow Zone				
		Very High	High	Mid	Low	Very Low
		billion organisms per day (b-org/day)				
TOTAL LOAD (TMDL) , Baseline Year: 2012		**50.6**	**13.3**	**4.9**	**3.6**	**2.6**
Waste-Load[1]	**Total Wasteload Sources[a]**	**6.1**	**5.1**	**1.9**	**1.4**	**1.0**
	Eden Prairie City MS4 (MS400015)	6.0	4.9	1.8	1.3	1.0
	Hennepin County MS4 (MS400138)	0.2	0.1	0.1	0.04	0.03
Load	**Total Load Sources**	**41.9**	**7.6**	**2.8**	**2.1**	**1.5**
	Riley Lake Boundary Condition	4.4	1.2	0.4	0.3	0.2
	Watershed LA	7.8	6.4	2.4	1.7	1.3
	Unallocated Load	29.7	0	0	0	0
Margin of Safety, 5%		**2.5**	**0.7**	**0.2**	**0.2**	**0.1**
Existing Concentration, Apr–Oct (org/100 mL)		123				
Maximum Monthly Geometric Mean (org/100 mL)		654				
Estimated Existing Load Reduction (%)		81%				

a: Chanhassen was not assigned a WLA for the Riley Creek *E. coli* TMDL as it represents less than 0.001% of the drainage area to the impaired portion of Riley Creek (Table 4.19).

5. Future Growth Considerations

The increase in impervious areas in the form of roads, parking lots, buildings, and landscape changes due to development has the potential to contribute additional runoff and TP, TSS and *E. coli* loading to the system. The WLAs for this TMDL are for communities subject to MS4 NPDES requirements.

5.1 New or Expanding Permitted MS4 WLA Transfer Process

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

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

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

5.2 New or Expanding Wastewater (TSS and *E. coli* TMDLs only)

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

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

6. Reasonable Assurance

Needed elements are in place for both point sources and nonpoint sources to make progress toward needed pollutant reductions in this TMDL. A range of local partners are involved in water resource management and implementation, including the NMCWD, RPBCWD, Carver County Land, and Water Services Division, the Carver Soil and Water Conservation District, the Hennepin Conservation District, and cities.

For these watersheds, the watershed districts are the primary drivers of action towards water quality improvement. The RPBCWD website and NMCWD website each contain much information on their roles and ongoing efforts.

6.1 Regulatory approaches

MS4 permitted sources

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

- Public education and outreach
- Public participation
- Illicit Discharge Detection and Elimination (IDDE) Program
- Construction site runoff controls
- Post-construction runoff controls
- Pollution prevention and municipal good housekeeping measures

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

This TMDL assigns TSS, TP, and *E. coli* WLAs to all regulated MS4s in the study, and as previously discussed in Section 5. The Small MS4 General Permit requires permittees to develop compliance schedules for EPA approved TMDL WLAs not already being met at the time of permit application. A compliance schedule includes BMPs that will be implemented over the permit term, a timeline for their implementation, and a long term strategy for continuing progress towards assigned WLAs. For WLAs being met at the time of permit application, the same level of treatment must be maintained in the future. Regardless of WLA attainment, all permitted MS4s are still required to reduce pollutant loadings to the MEP.

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

Regulated Construction Stormwater

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

Regulated Industrial Stormwater

As with regulated construction stormwater, ISW was lumped into a categorical stormwater WLA in this study. Industrial activities still require permit coverage under the State's NPDES/SDS ISW 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, their discharges are considered compliant with WLAs set in this study.

Watershed District rules

Both NMCWD and RPBCWD have comprehensive and similar rules that address water quantity and quality. For example, RPBCWD's rule components include: procedural requirements, floodplain management and drainage alterations, erosion and sediment control, wetland and creek buffers, dredging and sediment removal, shoreline and streambank stabilization, waterbody crossings and structures, appropriation of public surface waters, appropriation of groundwater, stormwater management, variances and exceptions, permit fees and financial assurances.

6.2 Nonregulatory approaches

Local planning

Minn. Stat. chs. 103B and 103D require watershed districts to prepare water management plans. Both NMCWD and RPBCWD have recently revised their plans and they include goals for several "major issues/program areas" including surface water management, impaired waters and TMDLs, urban stormwater management, wetland management, agricultural practices (where applicable) and education. A major part of the plans is for implementation, which provides a range of activities and strategies for all of the major issues/program areas above. The plan further outlines specific planned projects to be done over the 10-year timeframe of the plan, detailing the project type, partners, timeframe and costs. Examples projects include stormwater treatment practices or upgrades, streambank stabilization, wetland restorations and in-lake management. Other components of the plan include efforts for additional study, monitoring, education and outreach, technical assistance and permitting inspection and enforcement.

Successes by both watershed districts are outlined in their plans and websites. These efforts have included in-lake management (alum, invasive species management, lake drawdown), streambank stabilization and restoration, and various stormwater runoff improvement projects. Waterbodies in both districts have been delisted from the 303d list of impaired waters directly due to their efforts.

Funding availability

Both NMCWD and RPBCWD have established a stable source of funding through a watershed levies. These levies provide funding for significant water quality/quantity improvement projects, local grants, staff, monitoring, and engineering costs. In addition to local funding, potential state and federal funds available to the various watershed entities include grants from Clean Water, Land & Legacy funds, state Clean Water Partnership loans, EPA Clean Water Act Section 319 grants, and various NRCS programs.

Education and outreach

Both NMCWD and RPBCWD have active education and outreach efforts. These include education programs, volunteer opportunities, and useful web-based information and resources.

Groundwater Protection Rule

In June of 2019, the final Groundwater Protection Rule was finalized and published in the Minnesota State Register. This new rule will regulate nitrogen application in vulnerable groundwater areas. The rule will become effective January 1, 2020. The rule contains two parts and farmers may be subject to one part of the rule, both, or none at all depending on geographic location.

Part one restricts fall application of nitrogen fertilizer if a farm is located in a vulnerable groundwater area where at least 50% or more of a quarter section is designated as vulnerable or a public water drinking supply management area (DWSMA) with nitrate-nitrogen testing at least 5.4 mg/L in the previous 10 years. Once the rule is effective, fall application restrictions will being in the fall of 2020.

Part two will apply to farming operations in a DWSMA with elevated nitrate levels and farms will be subject to a sliding scale of voluntary and regulatory actions based on the concentration of nitrate in the well and the use of BMPs. In part two, no regulatory action will occur until after at least three growing seasons once a DWSMA is determined to meet the criteria for level two.

Agriculture Research, Education and Extension Technology Transfer Program (AGREETT)

The purpose of AGREETT is to support agricultural productivity growth through research, education and extension services. Since 2015, when the AGREETT program was established by the state legislature, significant progress has been made toward restoring and expanding capacity and research capabilities at the University of Minnesota in the College of Food, Agriculture and Natural Sciences, Extension and the College of Veterinary Medicine. As of February 2019, 21 faculty and extension educators have been hired along with needed infrastructure upgrades in the areas of crop and livestock productivity, soil fertility, water quality and pest resistance. Researchers who have been hired are pursuing work in the areas of manure management including strip till of liquid manure and precision application of manure based on nutrient content rather than volume, precision agriculture, agricultural practices to ensure good water quality under irrigation and promotion of BMPs for nitrogen and phosphorus management in row crop production. This addition of capacity at the University of Minnesota for public research covering several areas related to restoration and protection strategies will benefit water quality in the Minnesota River Basin long-term.

Drainage System Repair Cost Apportionment Option

Minnesota drainage law, Minn. R. ch. 103E, was updated in 2019 to add a voluntary, alternative method for cost apportionment that better utilizes technology to more equitably apportion drainage system repair costs, based on relative runoff and sediment contributions to the system, thus providing an incentive to reduce runoff and sediment contributions to the drainage system. This voluntary option is available for drainage authorities to use and is limited to repair costs only. The option also includes applicable due process hearings, findings, orders and appeal provisions consistent with other aspects of drainage law.

Tracking and monitoring progress

Monitoring components outlined in Section 7 constitute a sufficient means for tracking progress and supporting adaptive management.

7. Monitoring Overview

The goals of follow-up monitoring are generally to both evaluate progress toward the water quality targets provided in the TMDL and to inform and guide implementation activities. The impaired waterbodies will remain listed until water quality standards are met. Monitoring will primarily be conducted by local and regional staff.

Progress towards the achievement of TMDL goals will be tracked through regular monitoring of lake and stream water quality as well as BMP completion tracking. Continued monitoring of the lakes would include collection of water quality data, lake level data and biological data (such as macrophytes, zooplankton, and phytoplankton). Lake water quality monitoring should include depth profiles of TP, dissolved oxygen and temperature, surface concentration of Chl-*a*, and Secchi depth. Monitoring will occur during the open water with samples taken on a monthly basis at minimum.

In addition to monitoring the lakes themselves, ponds and wetlands throughout the watershed should be examined to determine contributions of phosphorus to the lake. This monitoring has been conducted in the past by the cities of Eden Prairie, Chanhassen, Bloomington, and the RPBCWD.

Stream monitoring for turbidity and flow is expected to continue at the WOMP sites on the Riley, Purgatory, and Nine Mile Creeks. This monitoring will occur during open water season and at a frequency and timing (15 minutes). These sites are currently being monitored by the Metropolitan Council, RPBCWD, and NMCWD through their respective WOMP programs. In addition to turbidity and flow, samples measuring TSS, total suspended volatile solids, *E. coli*, and Chl-*a* will continue to be analyzed at the monitoring stations to better target implementation efforts and conduct on-going assessment.

8. Implementation Strategy Summary

8.1 Permitted Sources

8.1.1 Construction Stormwater

The WLA for stormwater discharges from sites where there is construction activity reflects the number of construction sites greater than one acre expected to be active in the watershed at any one time, and the best management practices (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 Minnesota'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. Construction activity must also meet all local government construction stormwater requirements.

8.1.2 Industrial Stormwater

The WLA for stormwater discharges from sites where there is industrial activity reflects the number of sites in the watershed for which NPDES 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 Minnesota'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. Industrial activity must also meet all local government construction stormwater requirements.

8.1.3 MS4

All regulated MS4s are required to reduce their pollutant loads to meet the WLAs presented in this TMDL report. MS4 permittees are required to make progress towards meeting their WLA(s) over time as part of their MS4 SWPPP. MS4s must determine if they are currently meeting their WLA(s), and if not must provide a narrative strategy and compliance schedule to meet the WLA(s). BMPs are provided that will be implemented over the current five-year permit term.

Implementation strategies to improve urban stormwater management are detailed in the Minnesota Stormwater Manual and include filtration, infiltration, and sedimentation. Practices can be construction-related, post-construction, pre-treatment, non-structural, and structural. Implementation in the more urban areas will likely require retrofits, while practices in the more rural residential areas can target open areas and runoff from lawns and impervious surfaces associated with development.

It is important to note that while some water quality improvement efforts will be done independently by MS4s, much will be done in partnership with the watershed districts as described in Section 8.2.

8.2 Watershed District-Led Efforts

Locally produced lake studies (referred to as Lake Use Attainability Analyses or UAAs) for Lake Lucy, Lake Susan, and Lake Riley, as well as an updated management plan for all of Purgatory Creek, including Lotus and Staring Lakes, have been developed or are under development. UAA studies have also been conducted for Wing Lake, Lake Rose, Penn Lake, North and South Cornelia Lake, and Nine Mile Creek. These plans identify specific structural and nonstructural BMPs for the watershed of each of the lakes through the result of past studies, water quality monitoring, and the watershed and in-lake modeling performed. Similarly, the CRAS Report (Barr 2015) identified relative sources of erosion and prioritized areas for improvements along Riley and Purgatory Creeks, and will be used along with engineering feasibility studies to implement future projects. The NMCWD and RPBCWD have also developed water management plans (Barr 2017a and Barr 2017b) that describe water quality goals and potential BMP implementation strategies for improving the water quality in these lakes. Note: Pollutant reductions achieved for some implementation actions are creditable to the LAs in some cases and to WLAs in other cases. Examples of non-WLA-creditable projects include reductions in in-lake loading. For clarification on a particular project, the MPCA Stormwater Program staff should be contacted. A summary of the recommended BMPs are listed below.

- Structural BMPs
    - Implement BMPs at target locations to reduce flow, TP and TSS loading from the watershed to the lake, including iron-enhanced sand filters, stormwater ponds, and/or infiltration practices.
    - Prioritize and complete stormwater control and streambank stabilization projects at sites that are contributing inordinate sediment loads to the study lakes and stream reaches, including subreaches that are at high-risk of bank instability and excessive bedload.
    - Work with cities to identify potential redevelopment and road reconstruction projects that might provide the opportunity to retrofit additional BMPs into the watershed. Additionally, retrofit existing ponds as opportunities arise.
- In-Lake BMPs
    - Conduct alum treatment of the internal sediment phosphorus loading where internal reductions are required.
    - Continue or implement herbicidal treatments to control curly-leaf pondweed when applicable.
    - Continue carp management, including Staring Lake and the Purgatory Creek Recreation Area wetland. Lake Susan may also require more assessment of the carp population and control options.
- Nonstructural Measures and Programs

- Implement RPBCWD stormwater management rules to help minimize phosphorus load increase and degradation of water quality as future development occurs within the watersheds.
- Evaluate opportunities to work with landowners in the direct untreated watersheds in the riparian zones of the lakes. These efforts should focus on implementing stormwater BMPs on private parcels and educating about shoreline/vegetation management (if applicable). The RPBCWD could target the promotion of the cost-share program to residents in the watersheds directly contributing to Rice Marsh Lake and Lake Riley. Additionally, this could also include preservation of the currently undeveloped shorelines surrounding the lakes.
- Continue routine monitoring of the lakes. This would include the collection of water quality data, lake level data, and biological data (such as macrophytes, zooplankton, and phytoplankton).
  - Based on the recommendations from the University of Minnesota aquatic plant study, conduct macrophyte surveys one to two times per year where applicable, in early June to capture the curly-leaf pondweed and again in late summer.
  - Continue to monitor cyanobacteria levels within the lake.
  - Conduct water quality monitoring in select ponds and wetlands throughout the watershed to determine if they are potential sources of phosphorus to the lakes and to help refine future watershed models.

8.3 Cost

A TMDL is required to provide “a range of estimates” for implementation costs by the CWLA [Minn. Stat. 2007, § 114D.25]. Detailed analyses of costs were not completed for this TMDL study. A rough estimation of cost can be developed based on BMP cost studies. An EPA cost summary of BMPs developed in urban landscapes found a median cost of $2,200 per lb of phosphorus removed per year. Using that value with a total required reduction of 2,407 lbs of phosphorus would result in a cost of approximately $5.3 million. Based on the CRAS inventory, a rough estimate of costs associated with stabilizing the erosional areas of the lower valleys of Riley and Purgatory Creeks results in a cost of approximately $30 million. The costs to implement the activities to address *E. coli* impairments are approximately $4 million to $8 million dollars. This range reflects the level of uncertainty inherent in any fecal bacteria source assessment, and addresses the high priority sources identified in Section 3.8.3.

8.4 Adaptive Management

The implementation elements described above will require an adaptive management approach (Figure 8.1). Continued monitoring and “course corrections” responding to monitoring results are the most appropriate strategy for attaining the water quality goals established in this TMDL. Management activities will be changed or refined to efficiently meet the TMDL and lay the groundwork for de-listing the impaired waterbodies.

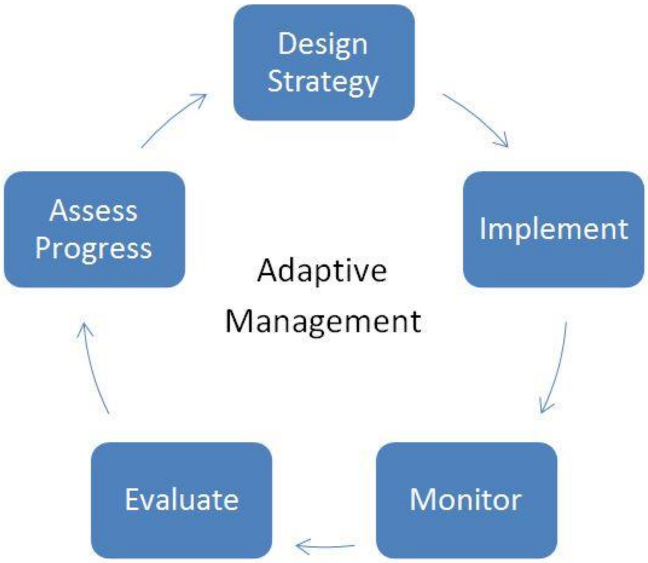


Figure 8.1. Adaptive Management

9. Public Participation

Multiple meetings were held with MS4 representatives, watershed district staff and other stakeholders at various points during the project. Opportunities were given to provide feedback on the TMDL methodology (including allocation setting) and review draft versions of the TMDL report. The original Northern Watersheds: Riley-Purgatory-Bluff Creek and Nine Mile Creek Watersheds TMDL subsequently was made a part of the Lower Minnesota River (HUC-8) TMDL/WRAPS project, which addresses dozens of additional impaired lakes and stream reaches. The MPCA conducted stakeholder meetings for the Lower Minnesota River project including coverage of the Riley-Purgatory-Bluff Creek and Nine Mile Creek Watersheds TMDL with local stakeholders including MS4s (the cities of Bloomington, Chanhassen, Deephaven, Eden Prairie, Edina, Minnetonka, Richfield, and Shorewood, Hennepin and Carver Counties, MnDOT, Hennepin Technical College) on August 27, 2017 and December 12, 2018.

An opportunity for public comment on the draft TMDL report was provided via a public notice in the State Register from July 22, 2019, through September 20, 2019. There were 12 comment letters received and responded to as a result of the public comment period.

10. Literature Cited

Adhikari, Hrishikesh, David L. Barnes, Silke Schiewer, and Daniel M. White. "Total Coliform Survival Characteristics in Frozen Soils." Journal of Environmental Engineering, Vol. 133, No. 12, pp: 1098–1105, December 2007.

Barr Engineering Company. 2007. Detailed Assessment of Phosphorus Sources to Minnesota Watersheds – Atmospheric Deposition: 2007 Update. Prepared for Minnesota Pollution Control Agency.

Barr Engineering Company. 2010. Lake Cornelia Use Attainability Analysis: Revised Draft. Prepared for Nine Mile Creek Watershed District.

Barr Engineering Company. 2013a. Lake Lucy and Lake Ann Use Attainability Analysis Update. Prepared for Riley-Purgatory-Bluff Creek Watershed District.

Barr Engineering Company. 2013b. Bluff Creek Watershed Total Maximum Daily Load Implementation Plan: Turbidity and Fish Bioassessment Impairments. Prepared for Minnesota Pollution Control Agency.

Barr Engineering Company. 2015. Creek Restoration Action Strategy. Prepared for the Riley-Purgatory-Bluff Creek Watershed District.

Barr Engineering Company. 2016. Rice Marsh Lake and Lake Riley: Use Attainability Analysis Update. Prepared for Riley-Purgatory-Bluff Creek Watershed District.

Barr Engineering Company. 2017a. Nine Mile Creek Watershed District Water Management Plan. Prepared for Nine Mile Creek Watershed District, October 2017.

Barr Engineering Company. 2017b. Riley-Purgatory-Bluff Creek Watershed District Watershed Management Plan-Draft. Prepared for Riley-Purgatory-Bluff Creek Watershed District.

Barr Engineering Company. 2017c. Lotus, Silver, Duck, Round Mitchell, Red Rock Use Attainability Analysis Update; Lake Idlewild and Staring Lake Use Attainability Analysis; and Lower Purgatory Creek Stabilization Study. Prepared for Riley-Purgatory-Bluff Creek Watershed District.

Chandrasekaran, Ramyavardhanee, Matthew J. Hamilton, Ping Wanga, Christopher Staley, Scott Matteson, Adam Birr, and Michael J. Sadowsky. "Geographic Isolation of *Escherichia coli* Genotypes in Sediments and Water of the Seven Mile Creek — A Constructed Riverine Watershed." *Science of the Total Environment* 538:78–85, 2015.

EPA (U.S. Environmental Protection Agency). 1983. Results of the Nationwide Urban Runoff Program: Volume 1 - Final Report.

EPA (U.S. Environmental Protection Agency). 1999. Protocol for Developing Nutrient TMDLs. First Edition.

EPA (U.S. Environmental Protection Agency). 2007. An Approach for Using Load Duration Curves in the Development of TMDLs. EPA 841-B-07-006. Washington, D.C.

Huser, B.J., P.L. Brezonik and R.M. Newman. 2011. Effects of alum treatment on water quality and sediment in the Minneapolis Chain of Lakes, Minnesota, U.S.A. *Lake and Reservoir Management* 27(3): 220-228.

In re Little Rock Creek TMDL, No. A16-0123 (Minn. App. Nov. 28, 2016), *review denied* (Minn. Feb. 14, 2017;

In re Crystal Lake TMDL, No. A18-0581 review denied (Minn. App. April. 24, 2019)

Ishii, Satoshi, Tao Yan, Hung Vu, Dennis L. Hansen, Randall E. Hicks, and Michael J. Sadowsky. "Factors Controlling Long-Term Survival and Growth of Naturalized Escherichia coli Populations in Temperate Field Soils." *Microbes and Environments,* Vol. 25, No. 1, pp. 8−14, 2010.

Lin, J.P. 2004. Review of Published Export Coefficient and Event Mean Concentration (EMC) Data. WRAP Technical Notes Collection (ERDC TN-WRAP-04-3), U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Maestre, A. and R. Pitt. 2005. The National Stormwater Quality Database, Version 1.1, A Compilation and Analysis of NPDES Stormwater Monitoring Information. Washington, DC: EPA Office of Water.

Marino, Robert P, and John J. Gannon. "Survival of Fecal Coliforms and Fecal Streptococci in Storm Drain Sediments." *Water Research*, Vol. 25 No. 9, pp. 1089–1098, 1991.

Minnesota Department of Natural Resources. 2011. LiDAR Data.

Metropolitan Council. 2010. Generalized Land Use - Historical 2010 for the Twin Cities Metropolitan Area.

MPCA. 2005. Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria, 3rd Edition. September 2005.

MPCA. 2013. Minnehaha Creek *E. coli* Bacteria / Lake Hiawatha Nutrients Total Maximum Daily Load. Prepared by Tetra Tech, Inc.

MPCA. 2018. Lower Minnesota Watershed Stressor Identification Report.

Pilgrim, K.M., B.J. Huser and P. Brezonik. 2007. "A Method for Comparative Evaluation of Whole-Lake and Inflow Alum Treatment." *Water Research* 41:1215-1224.

Welch, E. B. & Cooke, G. D., 1999. Effectiveness and Longevity of Phosphorus Inactivation with Alum. *Journal of Lake and Reservoir Management*, pp. 5-27.

Wenck Associates, Inc. 2013. Lake Susan Use Attainability Assessment Update. Prepared for Riley-Purgatory-Bluff Creek Watershed District.

Appendix A: Watershed and Lake Modeling Methodology

A.1 P8 Watershed Modeling

Water quality modeling was conducted using the P8 Urban Catchment Model (Program for Predicting Polluting Particle Passage thru Pits, Puddles, and Ponds). P8 is a model used for predicting the generation and transport of stormwater runoff and pollutants in urban watersheds. The model tracks the movement of particulate matter (fine sand, dust, soil particles, etc.) as it is carried along by stormwater runoff traveling over land and pavement. Particle deposition in ponds/infiltration practices are tracked in order to estimate the amount of pollutants that eventually reach a water body. P8 is a diagnostic tool used for evaluating and designing watershed improvements and BMPs. P8 version 3.4 or 3.5 was used for all model development and updates, except Wing Lake and Lake Rose, which did not need to be updated and used version 2.4.

When evaluating the results of the modeling, it is important to consider that the results provided are more accurate in terms of relative differences than in absolute results. The model will predict the percent difference in phosphorus reduction between various BMP options in the watershed fairly accurately. It also provides a realistic estimate of the relative differences in phosphorus and water loadings from the various subwatersheds and major inflow points to the lake. However, since runoff quality is highly variable with time and location, the phosphorus loadings estimated by the model for a specific watershed may not necessarily reflect the actual loadings, in absolute terms. Various site-specific factors, such as lawn care practices, illicit point discharges, and erosion due to construction, are not accounted for in the model. The model provides values that are considered typical of the region, given the watershed's respective land uses.

A.1.1 Watershed boundaries

Watershed boundaries were delineated for each lake. Watersheds were delineated to existing BMPs, wetlands, other waterbodies, or large section of stormsewer. Each BMP was delineated with its own subwatershed. Existing subwatersheds from the city of Eden Prairie and previous P8 models were reviewed and updated when appropriate based on 2011 DNR LiDAR topographic data, storm sewer data, record drawings, and other information provided by the RPBCWD and NMCWD as well as the cities.

A.1.1.1 Staring Lake Watersheds

The total watershed area of Staring Lake is over 10,000 acres. P8 has a limit of 76 devices that can be placed into one model. Therefore, the P8 model for Staring Lake was divided into two models. The first model covered areas contributing to the Purgatory Creek Recreational Wetland (PCR model). The second model covered areas directly contributing to Staring Lake. All upstream lakes (Duck Lake, Silver Lake, Lotus Lake, Round Lake, Mitchell Lake, and Red Rock Lake) were modeled independently from Staring Lake. The PCR model was divided into two sections above and below the intersection of Purgatory Creek and Valley View Road. A single watershed represents the contributing areas to

Purgatory Creek north of the Purgatory Creek Valley View Road intersection (Valley View Watershed). South of this intersection watershed are drawn to individual BMPs. Flow and TP from the Valley View Watershed were calibrated to flow and TP concentrations measured at the Valley View WOMP station.

A single infiltration device was created to collect flow from the Valley View watershed. Parameters of the infiltration basin were calibrated to match the flows and TP loads leaving this watershed. Water infiltration through percolation from the watershed and the infiltration basin were accumulated in an aquifer device and rerouted back as an outflow to account for baseflow conditions of Purgatory Creek. Modeled flow and TP loads exiting the device were compared with flow measurement recorded and composite storm TP concentrations recorded at the Purgatory Creek Valley View station. The calibration was conducted between June 3, 2015 and September 30, 2015. Over the calibration period, the total measured flow was recorded as 1763 acre-ft. The modeled flows were calculated as 1773 acre-ft. Event mean TP concentrations (EMC) were also compared for six events. Table A.1 shows the comparison between the measured and modeled EMC values.

Table A.1 Comparison between measured and modeled TP EMC values at Purgatory Creek Valley View Station

date	Measured TP EMC (mg/l)	P8 modeled TP EMC (mg/l)
6/22/2015	0.244	0.228
6/30/2015	0.173	0.186
7/6/2015	0.233	0.203
7/13/2015	0.195	0.201
8/18/2015	0.254	0.178
9/17/2015	0.246	0.255

A.1.2 Land Use

Land use data was obtained to estimate both the percentage of directly and indirectly connected imperviousness within each watershed. The directly connected impervious fraction consists of the impervious surfaces that are “connected” directly to stormwater conveyance systems, meaning that flows do not cross over pervious areas. The indirectly connected impervious fraction represents impervious areas that flow over pervious areas before reaching the stormwater conveyance system. Percent imperviousness was calculated 2010 land use data from the Metropolitan Council. Table A.2 shows the 2010 land use categories with the assigned percent impervious and percent directly connected impervious areas.

Table A.2 Impervious Assumption by 2010 Land Use Category

2010 Land Use Categories	Total Percent Impervious	Percent Directly Connected Impervious
Agricultural	5	1
Airport	5	1
Retail and Other Commercial	86	85
Mixed use commercial	86	85
Golf course	6	5
Manufactured Housing Parks	68	50
Major highway	50	50
Railway	65	65
Office	73	72
Industrial and Utility	73	72
Mixed use industrial	73	72
Mixed use residential	59	37
Institutional	49	40
Single family detached	35	20
Multifamily	59	37
Single family attached	50	30
Seasonal/Vacation	30	20
Park, Recreational, or Preserve	6	5
Undeveloped	3	0
Open Water	100	100
Extractive	60	50
Farmstead	25	12

A.1.3 Curve Numbers

The pervious curve number (a measure of how easily water can percolate into the soil) was determined for each P8 drainage basin. Data from the 2015 gridded soil survey geographic (gSSURGO) database (Soil Survey Staff 2015) were used to determine the hydrologic soils group (HSG) in each watershed. The HSG serves as an indicatory of a soils infiltration capacity. HSG s range from type A soils that are well drained with high infiltration capacities to HSG type D soils that are poorly drained with the lowest infiltration capacities. Some areas in the county soil surveys are not defined. For these areas, a HSG of type B was assumed. Using the curve number classifications, a composite pervious area curve number was calculated for each of the subwatersheds. Curve numbers were assigned based on soil type (Table A.3) and an area weighted average curve number for each subwatershed was calculated.

Table A.3: Pervious area curve number classification by HSG soil type

HSG Soil Type	Curve Number
A	39
B	61
C	74
A/D	80
B/D	80
C/D	80
D	80

A.1.4 Drainage Patterns

Drainage patterns were reviewed and updated from previous P8 models where appropriate or determined based on 2011 DNR LiDAR topographic data, storm sewer data, record drawings, and other information provided by the RPBCWD, the NMCWD and the cities. Development plans submitted as part of the RPBCWD permit review process for projects implemented after the original UAA was completed were also used as a data source.

A.1.5 Pollutant Removal Device Information

The P8 water quality model can predict pollutant removal efficiency for a variety of treatment practices such as detention ponds and infiltration basins. The model can also be used to simulate pollutant removal from alternative BMPs such as underground treatment devices. The modeled treatment practices are referred to in the P8 model as pollutant removal 'devices'.

Inputs for the ponds and wetlands included in the previously developed models were reviewed and adjusted if more current data were available. Pond outlets were checked against the GIS storm-sewer and as-built data from the cities of Bloomington, Chanhassen, Eden Prairie, Edina, and Richfield. The water volumes below the pond outlet (i.e., dead storage) were checked against field survey data and as-built plans when available. Pond live storage was adjusted using volumes calculated from the DNR's 2011 LiDAR data. In some cases, there were existing ponds that were not included in the original P8 modeling without readily available data to develop the pond inputs. In these cases, the pond removal efficiencies were calculated using the ratio of the contributing watershed impervious area to the pond surface area and an assumed pond depth following the method described in the document Phosphorus Removal by Urban Runoff Detention Basins (Walker 1987). The watershed impervious-surface-to-pond-surface ratio curves are available in Appendix A. The new ponds and wetland areas included in the updated P8 model were developed using the same data sources listed above. In cases where no data was available, the new ponds, without available as-built or survey data, were assumed to be built to NURP specifications.

A.1.6 Other Model Parameters

- **Time Steps Per Hour (Integer) = 10 to 20.** Modified as needed to eliminate continuity errors greater than 2%.
- **Minimum Inter-Event Time (Hours) = 10.** Use of this parameter resulted in a good fit between the observed and modeled lake volumes and has been used in a number of previous studies of these lakes. It should be noted that the average minimum inter-event time in the Minneapolis area is six hours.
- **Snowmelt Melt Coef (Inches/Day-Deg-F) = 0.06**. This selection was based on the snowmelt rate that provided the best match between observed and predicted snowmelt in previous studies.
- **Snowmelt Scale Factor for Max Abstraction = 1**. This factor controls the quantity of snowmelt runoff (i.e., controls losses due to infiltration). Selection was based upon the factor that resulted in the closest fit between modeled and observed runoff volumes, based on the original Lake Riley P8 model calibration from the 2004 Lake Riley UAA.

- **Growing Season Antecedent Moisture Conditions AMC-II: 0, 0.50, or 1.4 and AMC-III 0, 1.10, or 2.10**. This factor was adjusted to more accurately predicted runoff water volumes based on the runoff volumes needed to complete the water balance in the in-lake model spreadsheets. The P8 default values worked for many of the lakes; however, some of the lakes experienced more runoff and these values were then adjusted to extend AMC-III conditions.
- **Particle Scale Factor for TP = 1.** The particle scale factor determines the TP load generated by the particles predicted by the model in watershed runoff. Modified from the original UAA P8 model (1.42) in order to reduce the loading to the lakes and produce a better fit to observed lake data.
- **Particle File = NURP50.PAR.** The NURP 50 particle file was found to most accurately predict phosphorus loading to Round Lake. Preserved from the original UAA P8 model.
- **Precipitation File Selection = MSP_FC4915_Corr.pcp and Msp4916.pcp.** The RPBCWD lakes used the MSP_FC4915_Corr.pcp continuous hourly precipitation file that was developed based on data from the Flying Cloud Airport weather station. For any gaps in the airport record, the hourly data from the Minneapolis-St. Paul International Airport NWS station (MSP) was used and adjusted based on comparison of the daily precipitation amounts at MSP to the daily data collected at the Chanhassen NWS station. The NMCWD lakes used the Msp4916.pcp file developed from the Minneapolis-St. Paul International Airport NWS station (MSP).
- **Air Temperature File Selection MSP_FC4915.tmp and Msp4916.tem.** The RPBCWD lakes used the MSP_FC4915.tmp continuous daily average temperature file that was developed based on data from the Flying Cloud Airport weather station. The NMCWD lakes used the Msp4916.tem continuous daily average temperature file that was developed based on data from the MSP.
- **Particle Removal Scale Factor.** 0.3 for ponds less than 2 feet deep and 1 for all ponds 3 feet deep or greater. The particle removal factor for watershed devices determines particle removal by devices. The factor was selected to match observed phosphorus loads and modeled loads. Insufficient information was available to say with certainty the particle removal scale factor for ponds 2 to 3 feet deep. A factor of 0.6 was used for all ponds of this depth.
- **Swept/Not Swept. =** An “Unswept” assumption was made for the entire impervious watershed area. A Sweeping Frequency of 0 was selected. Selected parameters were placed in the “Swept” column since a sweeping frequency of 0 was selected.
- **Impervious Depression Storage = 0.0065.** Value used in previous models of these lakes.
- **Impervious Runoff Coefficient = 1.** Default P8 value and was used in previous models of these lakes.

The Wing Lake and Lake Rose P8 models were developed for the 2010 Holiday-Wing-Rose Lake UAA report (Barr 2010) and the input parameters were not modified for this study.

A.2 In-Lake Water Quality Mass Balance Modeling

For the majority of Minnesota lakes, phosphorus is the limiting nutrient for algae, and an increase in phosphorus results in an increase in Chl-*a* concentrations and a decrease in water clarity. Eutrophic lakes can be restored by reducing phosphorus concentrations. An in-lake mass balance model for phosphorus was developed for each lake in order to quantify phosphorus source loads to the lake. In-lake modeling for each lake was accomplished through the creation of a daily time-step mass balance model that tracked the flow of water and phosphorus through the lake over the range of observed climatic conditions. The following sections discuss the methodology used for the in-lake water quality mass balance modeling that first includes the development of a water balance model followed by the development of a phosphorus mass balance model.

A.2.1 Lake Model Water Balance

The first step of the in-lake water quality mass balance modeling is to develop and calibrate the water balance portion of the model. The water balance is a daily time-step model that tracks the inflows to and outflow from the lake system. Typical inflows of water to a lake include direct precipitation and watershed runoff (as generated by the watershed model), and can also include inflows from upstream lakes and/or inflows from groundwater (depending on the lake system). Losses from a lake include evaporation from the lake surface and discharge through the outlet (if applicable), and can also include losses to the groundwater (depending on the lake system). By estimating the change in storage in the lake on a daily time step, the model can be used to predict lake levels, which can then be compared to observed lake levels, which can then be used to estimate groundwater exchange and verify the estimated watershed model runoff volumes.

The lake water balance calculated the total lake water volume through the simulated daily gains and losses into the lake. The water balance is represented by the following equation:

$$V_i = V_{i-1} + (I_W + I_{LC}) + P * A_S - E * A_{S,(i-1)} - O + G$$

Where:

V = Lake volume (acre-ft)

i = Daily time step

I_W = Inflow from modeled lake’s direct watershed (acre-ft/day)

I_{LC} = Total daily inflow from upstream lake (acre-ft/day)

P = Daily precipitation depth (ft/day)

E = Daily evaporation depth (ft/day)

A_S = Lake surface area (acres)

O = Outflow (acre-ft/day)

G = Groundwater flow (acre-ft/day)

Key input parameters into the lake models include lake depth recorded every 15 minutes while the level sensor is in place during ice free period, lake volume estimated using a relationship between lake elevation and lake cumulative volume (Table A.4 through Table A.17), daily inflow rate from the direct watershed calculated using the P8 watershed model, daily inflow rate from upstream lakes, daily outflow rates estimated using lake water elevation data with the creation of outflow rating curves (Table A.4 through Table A.17), daily precipitation data recorded at the Flying Cloud airport weather station over the lakes surface area, and evaporation calculated using the Lake Hefner equation (Marciano and Harbeck 1954) described below:

$$E = 0.00177u(e_o - e_a)$$

$$e_0 = 6.11 * 10^{\frac{7.5*T_W}{237.7+T_W}}$$

$$e_a = 6.11 * 10^{\frac{7.5*T_A}{237.7+T_A}}$$

Where:

E = evaporation (inches)

U = wind speed (mph)

e_o = vapor pressure of the saturates area at the temperature of the water surface

e_a = vapor pressure of the air

T_W = surface water temperature in (°C)

T_A = air temperature in (°C)

Climate data (wind speed, air temperature, and relative humidity) were obtained from the Minneapolis-St. Paul International Airport. Surface water temperatures (TW) were obtained from lake monitoring data.

Groundwater flows were not available for the study lakes. Net groundwater flows were estimated for the study lakes such that model predicted changes in lake volume agreed with observed changes in lake volume.

Table A.4 Silver Lake Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow (cfs)
885.00	0.00	0.00	0.00
886.00	0.01	0.00	0.00
887.00	0.12	0.07	0.00
888.00	0.37	0.31	0.00
889.00	0.74	0.87	0.00
890.00	1.18	1.83	0.00
891.00	1.78	3.31	0.00
892.00	3.17	5.78	0.00
893.00	6.84	10.79	0.00
894.00	19.45	23.93	0.00
895.00	29.83	48.57	0.00
896.00	41.08	84.02	0.00
897.00	58.39	133.76	0.00
898.00	67.93	196.92	0.00
898.50	69.11	232.06	0.00
898.60	69.34	239.09	0.12
899.00	70.28	267.20	3.04
899.50	71.46	302.34	8.52
900.00	72.64	337.48	9.59

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow (cfs)
900.50	74.11	375.28	10.10
901.00	75.58	413.07	10.53
902.00	78.52	488.65	11.35

Table A.5 Lotus Lake Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow (cfs)
864.60	0.00	0.00	0.00
870.60	2.80	8.42	0.00
875.60	16.59	56.89	0.00
880.60	63.25	256.48	0.00
885.60	127.89	734.31	0.00
890.60	176.72	1,495.84	0.00
895.00	233.76	2,427.43	0.00
895.40	238.95	2,512.12	0.00
895.50	240.24	2,533.29	1.15
896.00	246.73	2,639.15	14.77
897.00	262.96	2,902.12	18.55
898.00	279.20	3,165.08	21.05

Table A.6 Staring Lake Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow (cfs)
798.60	0.00	0.00	0.00
799.60	9.03	4.52	0.00
804.60	42.35	132.97	0.00
809.60	106.10	504.08	0.00
813.90	159.26	1,077.27	0.03
814.00	160.50	1,090.60	0.27
814.50	164.06	1,174.41	9.25
815.00	167.62	1,258.22	20.40
816.00	174.74	1,425.84	62.13
817.00	190.55	1,616.39	140.36
818.00	206.37	1,806.95	263.25

Table A.7 Lake Lucy Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow1, Lake Anne W.S.E. <955.45 (cfs)	Outflow2, Lake Anne W.S.E. >956.1 (cfs)	Outflow3, Lake Anne W.S.E. Between 955.45 & 956.1 (cfs)
935.30	0.00	0.00	0	0	0
941.60	6.80	21.42	0	0	0
946.60	24.80	100.42	0	0	0
951.60	50.80	289.42	0	0	0
955.20	86.20	536.02	0	0	0
955.45	87.98	558.01	0	0	0
955.50	88.33	562.41	0.006	0	0.003
955.60	89.04	571.21	0.04	0	0.02
955.70	89.75	580.01	0.11	0	0.05
955.80	90.86	589.09	0.19	0	0.09
955.90	91.97	598.18	0.31	0	0.16
956.00	93.31	607.45	0.43	0	0.22
956.10	94.50	617.06	0.62	0	0.31
956.20	95.69	626.68	0.96	0.02	0.49
957.00	105.72	706.76	8.04	1.41	4.72
957.11	107.15	718.79	9.76	4.46	7.11
957.50	112.34	761.94	17.86	13.15	15.51
957.80	116.31	794.97	25.44	25.07	25.25
958.00	118.96	816.98	33.01	33.01	33.01

Note: Lake Lucy outflows are dependent on the water surface elevations in Lake Ann. To account for this dependency, three rating curves were developed to model the Lake Lucy outflows based on a range of observed water surface elevations in Lake Ann.

Table A.8 Lake Susan Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow (cfs)
865.00	0.00	0	0
867.00	16.52	16.52	0
872.00	51.87	187.51	0
877.00	67.91	486.95	0
880.73	86.46	774.85	0
880.90	87.31	789.62	0.25
881.00	87.81	798.37	0.62
881.20	88.07	815.96	1.86
881.50	88.46	842.44	4.61
881.70	88.72	860.16	6.95
882.00	89.11	886.83	11.09
882.50	90.38	931.70	19.50
883.00	91.65	977.21	30.77
883.50	93.62	1,023.53	43.62
884.00	95.58	1,070.82	56.44
884.50	97.35	1,119.06	68.10
885.00	99.11	1,168.17	78.73
885.50	100.37	1,218.04	86.92
886.00	101.63	1,268.54	94.76
887.00	103.60	1,371.15	107.87

Table A.9 Rice Marsh Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow (cfs)
865.00	0.62	0	0
866.00	1.24	0.93	0
867.00	3.09	3.09	0
868.00	7.41	8.34	0
869.00	11.74	17.91	0
870.00	25.33	36.45	0
871.00	48.18	73.20	0
872.00	67.95	131.27	0
873.00	80.92	205.71	0
874.00	87.10	289.72	0
875.00	87.45	376.99	0
875.20	88.10	394.55	0.09
875.40	90.97	412.46	0.17
875.60	95.58	431.11	0.26
875.79	101.30	450.11	0.38
875.80	101.53	450.82	0.39
875.90	104.89	461.14	0.66
876.00	108.44	471.81	1.32
876.10	112.16	482.84	2.04
876.20	116.00	494.24	2.82
876.30	119.94	506.04	3.49
876.40	123.93	518.23	4.34
876.50	127.96	530.83	5.56
876.60	132.00	543.83	6.75
876.80	140.02	571.03	9.46
877.00	147.82	599.81	14.61
877.20	155.28	630.12	19.94
877.40	162.32	661.88	25.93
877.60	168.86	695.00	32.62
878.00	180.29	764.83	54.51
878.50	191.49	857.78	88.77
879.00	199.63	955.56	125.79
879.50	205.46	1056.83	165.71
880.00	209.84	1160.65	208.33
880.50	213.43	1266.47	255.01
881.00	216.45	1373.94	304.86
881.50	218.37	1482.65	356.43
882.00	217.68	1591.66	410.23

Table A.10 Lake Riley Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow (cfs)
815.00	0.00	0.00	0
820.00	6.52	17.02	0
825.00	21.50	87.80	0
830.00	50.18	280.98	0
835.00	81.36	621.86	0
840.00	120.78	1144.68	0
845.00	162.20	1877.80	0
850.00	191.86	2781.46	0
855.00	216.34	3809.84	0
860.00	253.40	4995.00	0
864.50	296.57	6232.42	0
864.62	289.85	6258.45	0.82
864.70	290.30	6281.32	1.48
864.80	290.84	6309.60	2.40
864.90	291.39	6337.95	3.49
865.00	291.93	6366.35	4.97
865.10	292.47	6394.82	6.99
865.20	293.00	6423.34	9.35
865.30	293.54	6451.93	12.00
865.40	294.07	6480.57	15.20
865.50	294.60	6509.28	19.22
866.00	297.21	6653.74	45.86
866.50	299.76	6799.75	84.03
867.00	302.24	6947.32	126.13
867.50	304.65	7096.48	160.46
868.00	306.95	7244.23	183.08

Table A.11 Hyland Lake Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow (cfs)
804.00	0.00	0.00	0.00
805.00	25.93	12.97	0.00
810.00	74.06	262.93	0.00
815.00	82.02	653.12	0.00
816.00	84.52	736.39	0.00
816.50	85.39	778.87	0.00
816.70	85.73	795.98	0.19
816.80	85.90	804.56	0.49
816.90	86.08	813.16	0.79
817.00	86.25	821.77	1.09
817.50	87.06	865.10	3.17
818.00	87.86	908.83	5.43
818.20	88.32	926.45	7.19
818.40	88.77	944.16	9.72
818.50	89.00	953.05	12.20
818.80	89.67	979.85	23.54
819.00	90.13	997.83	38.11
819.50	91.17	1,043.15	81.45
820.00	92.20	1,088.99	134.67
821.00	94.26	1,182.22	265.36
821.50	95.37	1,229.63	342.44
821.60	95.59	1,239.18	358.59
822.00	96.48	1,277.59	426.50

Table A.12 Wing Lake Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow (cfs)
931.50	0.00	0.00	0.00
933.00	0.55	0.41	0.00
934.00	3.28	2.32	0.00
935.00	6.15	7.03	0.00
936.00	9.27	14.74	0.00
937.00	12.04	25.40	0.00
938.00	13.15	37.99	0.00
938.80	13.60	48.69	0.00
938.90	13.68	50.06	0.00
939.00	13.74	51.43	0.02
939.10	13.81	52.80	0.05
939.20	13.89	54.19	0.10
939.30	13.96	55.58	0.14
939.40	14.03	56.98	0.16
939.50	14.10	58.39	0.19
939.60	14.18	59.80	0.21
939.70	14.25	61.22	0.23
939.80	14.32	62.65	0.24
939.90	14.39	64.09	0.40
940.00	14.46	65.53	0.88
940.10	14.52	66.98	1.41
940.20	14.57	68.43	2.09
940.30	14.63	69.89	2.71
940.40	14.68	71.36	3.32
940.50	14.73	72.83	3.95
941.00	14.97	80.26	7.54
941.50	15.36	87.84	10.85

Table A.13 Lake Rose Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow (cfs)
912.20	0.00	0.00	0.00
912.60	0.06	0.01	0.00
913.60	0.19	0.13	0.00
914.60	0.34	0.40	0.00
915.60	0.55	0.84	0.00
916.60	0.83	1.53	0.00
917.60	1.18	2.53	0.00
918.60	1.89	4.07	0.00
919.60	3.39	6.71	0.00
920.60	4.91	10.86	0.00
921.60	9.23	17.93	0.00
922.60	16.42	30.76	0.00
923.60	19.69	48.81	0.00
924.60	22.16	69.74	0.00
925.60	25.98	93.80	0.00
926.50	29.54	118.79	0.00
926.60	29.72	121.75	0.40
926.70	29.87	124.73	1.37
926.80	30.01	127.72	2.61
926.90	30.16	130.73	4.01
927.00	30.30	133.75	5.35
927.10	30.44	136.79	6.56
927.20	30.59	139.84	7.98
927.30	30.73	142.91	9.21
927.40	30.88	145.99	10.44
928.00	31.90	164.82	17.81
928.60	33.02	184.30	21.40

Table A.14 North Cornelia Lake Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow (cfs)
852.00	0.20	0.00	0.00
853.00	0.65	0.42	0.00
854.00	2.26	1.88	0.00
855.00	10.51	8.27	0.00
856.00	15.62	21.33	0.00
857.00	16.73	37.50	0.00
858.00	17.60	54.67	0.00
859.00	18.70	72.82	0.00
859.25	19.30	77.57	0.10
859.50	19.80	82.46	0.45
860.00	20.90	92.63	1.53
860.50	31.10	105.63	2.54
862.00	32.70	153.48	4.31
863.00	36.34	188.00	15.00

Table A.15 South Cornelia Lake Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow (cfs)
851.00	0.37	0.00	0.00
852.00	4.22	2.29	0.00
853.00	11.45	10.13	0.00
854.00	17.92	24.81	0.00
855.00	23.36	45.45	0.00
856.00	27.72	70.99	0.00
857.00	29.92	99.81	0.00
858.00	31.31	130.43	0.00
859.00	33.15	162.74	0.00
859.10	33.21	166.05	0.30
859.25	33.31	171.04	2.20
859.50	33.46	179.39	6.50
859.75	33.62	187.77	10.00
860.00	33.78	196.20	10.77
861.00	34.67	230.42	23.53
861.10	35.01	233.91	23.92
862.10	36.73	269.78	27.82
863.10	39.03	307.66	31.73
864.00	40.15	343.29	35.24
865.80	41.23	416.53	60.37
868.00	49.46	516.28	92.09

Table A.16 Lake Edina Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow (cfs)
817.00	0.00	0.00	0.00
818.00	0.10	0.05	0.00
819.00	11.51	5.86	0.00
820.00	20.55	21.89	0.00
821.00	23.59	43.96	0.00
822.00	24.63	68.07	0.00
822.20	24.81	73.01	1.60
822.50	25.09	80.50	4.33
823.00	25.55	93.16	9.30
824.00	27.14	119.51	21.80
826.00	34.61	181.26	57.00
827.00	37.31	217.22	100.00
828.50	410.26	552.90	115.00

Table A.17 Penn Lake Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow (cfs)
801.00	0.01	0.00	0.00
802.00	2.74	1.37	0.00
803.00	9.27	7.38	0.00
804.00	19.54	21.79	0.00
805.00	26.23	44.67	0.00
806.00	30.57	73.07	0.00
806.62	31.69	92.38	0.00
806.65	31.74	93.33	0.00
807.00	32.38	104.55	0.00
807.10	32.47	107.79	0.40
807.30	32.65	114.30	1.40
807.50	32.84	120.85	2.92
807.80	33.12	130.75	6.07
808.00	33.30	137.39	8.35
809.00	34.58	171.33	19.99
810.00	36.70	206.97	29.00
811.00	38.66	244.65	33.00
812.00	40.59	284.28	35.00

A.2.2 Lake Model Total Phosphorus Balance

While the watershed model is a useful tool for evaluating runoff volumes and pollutant concentrations from a watershed, another method is needed to predict the in-lake phosphorus concentrations that are likely to result from the various phosphorus loads. In-lake phosphorus modeling was accomplished through the creation of a daily time-step mass balance model that tracked the flow of water and phosphorus through the lake over a range of climatic conditions. A daily time-step model was chosen because of the high variability in the nutrient-related water quality parameters. Using a daily time-step model (instead of an annual model, e.g., BATHTUB), allowed for the determination of the critical components (i.e., internal vs. external phosphorus sources), causing water quality standard exceedance as well as allowing for lake response modeling of management methods during the periods of standard exceedance. Once calibrated, the models could be used predictively to evaluate the lake phosphorus concentrations under a variety of scenarios, including future land use conditions, and following the implementation of remedial watershed BMPs and in-lake management strategies.

The lake phosphorus budgets are based on the Vollenweider (1969) mass balance equation:

$$TP = (L + L_{int})/(\bar{Z} * (\rho + \sigma))$$

Where:

$\bar{Z}$ = average lake depth in meters
ρ = flushing rate in yr^{-1}
σ = sedimentation rate in yr^{-1}
L = areal loading rate in $mg/(m^2 * yr)$
L_{int} = internal loading rate in $mg/(m^2 * yr)$

A difference between Vollenweider's equation and the model used for this study is that the parameters in the above equation were used on a daily timestep as opposed to an annual basis. Also, the magnitude of the net internal phosphorus load to the lake surface was determined by comparing the observed water quality in the lake to the water quality predicted by the in-lake model under existing conditions.

The in-lake phosphorus mass balance model assumed a fully mixed lake volume, i.e. the phosphorus concentration is uniform throughout the lake volume. The change in the TP mass within the lake was calculated with the following mass balance equation:

Δ Phosphorus Mass = Watershed Inputs + Direct Deposition to Lake Surface + Internal Loading – Surface Outflow – Groundwater Outflow – Settling of In-Lake Phosphorus

Key input parameters in the lake phosphorus budget include phosphorus loads from upstream lakes, atmospheric deposition and from the direct watershed; internal loading from the lake sediments; loading or losses from groundwater depending if the groundwater is flowing into or out of the lake; and loses through settling and outflow.

The loading from upstream lakes was calculated using existing daily in-lake models for the lake upstream if available. This method was used for Staring Lake, Lake Riley, Wing Lake, Lake Rose, South Cornelia Lake, and Lake Edina. If an existing model was not available upstream loads were calculated using inflow rates estimated from the upstream lake's water surface elevation and rating curve combined with the surface phosphorus concentration recorded in the lake. This method was used for Lake Susan and Rice Marsh Lake (Lake Susan was calibrated to a different year than Rice Marsh Lake so the Susan output could not be used for the Rice Marsh upstream lake input). The phosphorus load from the lakes direct watersheds was calculated using the P8 modeling results. Atmospheric deposition of phosphorus onto the lakes water surfaces was calculated by using the estimated statewide phosphorus atmospheric deposition rate of 0.42 kg/ha/year (Barr 2007) combined with the lakes water surface areas based on the current water elevation. Groundwater loads were either a source or a sink for phosphorus depending on if water was flowing into or out of the lake respectively. If the net daily groundwater flow was into the lake, the load of phosphorus was calculated using the groundwater flow rate and an estimate for groundwater phosphorus concentration of 0.035 mg/l. If the net flow was out of the lake then the loss of phosphorus was estimated using the flow rate and the average lake phosphorus concentration. The loss of phosphorus through outflow from the lakes was calculated using the measured surface concentrations of TP and the outflow rate calculated in the water balance.

The final two parameters, settling and internal loading, were used to calibrate the model to the recorded lake concentrations. Lake mixing and anoxic conditions can create an environment in the lake that is conducive to internal loads at times. At other times, the lake does not experience a significant internal load (generally spring and fall). Monitoring data (phosphorus, temperature, and dissolved oxygen profiles) provided useful information in determining when the lake is susceptible to internal loading from the sediment. Dissolved oxygen data was used to determine when anoxic conditions were present what area was under anoxic conditions. When the dissolved oxygen concentration was below 1 mg/l the sediments at that depth were considered to be anoxic resulting in internal loading of iron-bound phosphorus. The rate of phosphorus loading was calibrated for each year to match the measured data.

The sedimentation rates for the lakes were calibrated using in-lake TP monitoring data from well mixed periods without the conditions necessary for internal phosphorus loading. At these times (generally in spring and fall after turnover), phosphorus concentration in the surface waters of the lake is only affected by sedimentation, flushing, and incoming external loads of phosphorus from the watershed and atmosphere. This was accomplished by setting the internal loading rate (Lint) in the above equation by Vollenweider to zero and adjusting the settling rate so that the calculated, in-lake phosphorus concentration matched the monitored phosphorus during the spring period.

A.2.3 Lake Surface Model Concentration

Surface water phosphorus concentration are required to determine if a lake is meeting or exceeding the phosphorus standard. Therefore, the volumetric average lake models were further divided into two completely mixed models representing the lake epilimnion and hypolimnion for lakes that displayed persistent stratification throughout the summer (Lotus, Riley, Lucy, Susan). All parameters in the volumetric model remained the same in the lake surface models. The main change between the two approaches was the internal loading and groundwater sources were only applied to the hypolimnion and all other phosphorus sources (atmospheric, direct watershed, and Lake Calhoun inflow) were applied to the epilimnion. Mixing between the hypolimnion and the epilimnion were determined based on temperature profiles. The point of the maximum temperature gradient was used as the dividing depth between the two layers. Temperature profiles taken during open water periods were used to calculate the thermocline depth. As this depth moved up or down in the lake water was mixed between the two layers appropriately. The parameters were then applied to the whole lake volumetric model to check that they produced a reasonable result in this analysis as well.

A.2.4 Silver Model Calibration

The Silver Lake water and TP balance portion of the in lake model were calibrated for the 2015 water year (October 2014 through September 2015). The Silver Lake daily water balance was adjusted using the “groundwater” calibration parameter. Groundwater inflows were used to match the observed spring water surface elevation. TP concentrations were balanced on a whole lake basis since Silver Lake does not have a stable thermal stratification during the growing season. The Silver Lake model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity.

Figure A.1 shows the results of the Nash Sutcliffe statistical comparison between the 2015 modeled and measured volumetric averaged epilimnetic TP concentrations. Figure A.2 shows the comparison between the modeled and monitored epilimnetic volumetric averaged TP concentrations over the course of the 2015 water year.

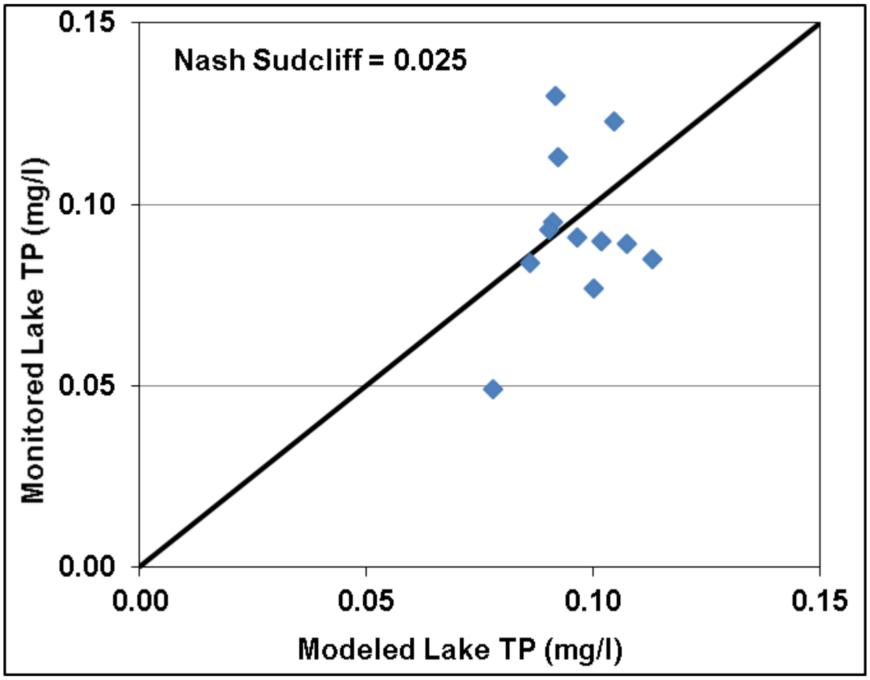


Figure A.1 Silver Lake comparison between modeled volumetric average TP concentration and measured concentrations for the 2015 water year.

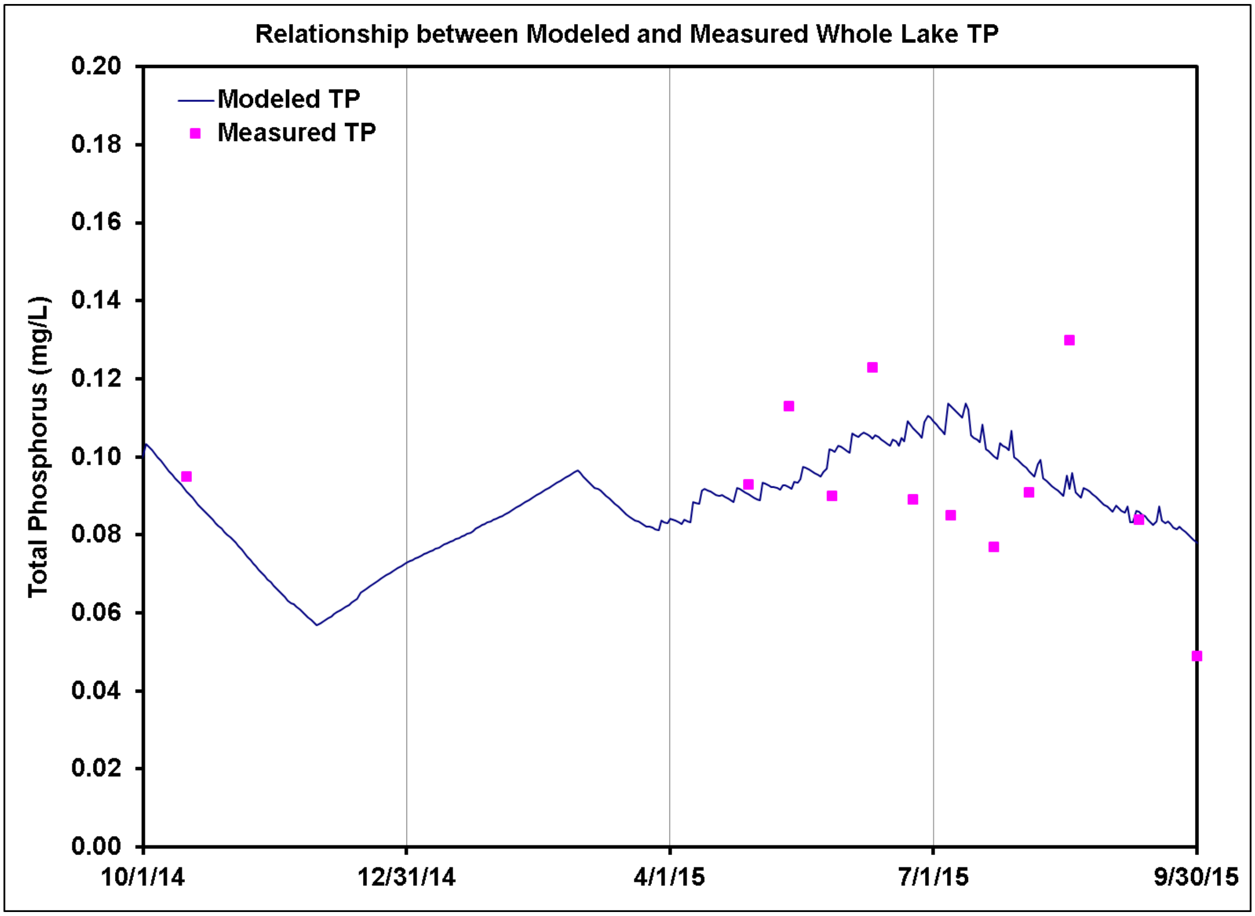


Figure A.2 Silver Lake time series comparison between modeled and measured whole lake TP concentrations for the 2015 water year.

A.2.5 Lotus Lake Model Calibration

The Lotus Lake water and TP balance portion of the in lake model were calibrated for the 2015 water year (October 2014 through September 2015). The Lotus Lake daily water balance was adjusted using the "groundwater" calibration parameter. Groundwater inflows were used to match the observed spring water surface elevation. Both the epilimnion and hypolimnion TP concentrations were modeled in Lotus Lake due to its thermally stratifying during the growing season. Dividing the lake model into these separate layers enabled a more accurate estimate of internal loading. The Lotus Lake model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity.

Figure A.3 shows the results of the Nash Sutcliffe statistical comparison between the 2015 modeled and measured volumetric averaged epilimnetic TP concentrations. Figure A.4 shows the comparison between the modeled and monitored epilimnetic volumetric averaged TP concentrations over the course of the 2015 water year.

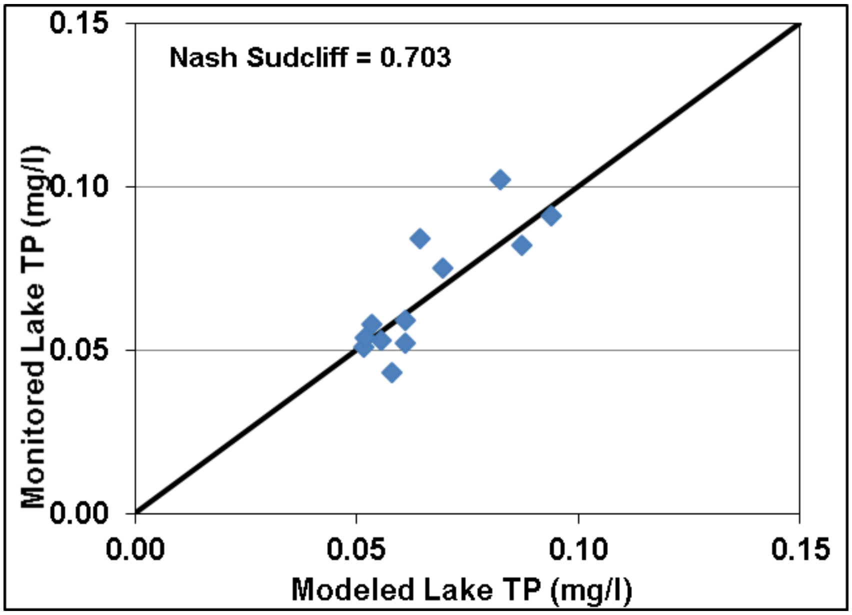


Figure A.3 Lotus Lake comparison between modeled volumetric average TP concentration and measured concentrations for the 2015 water year.

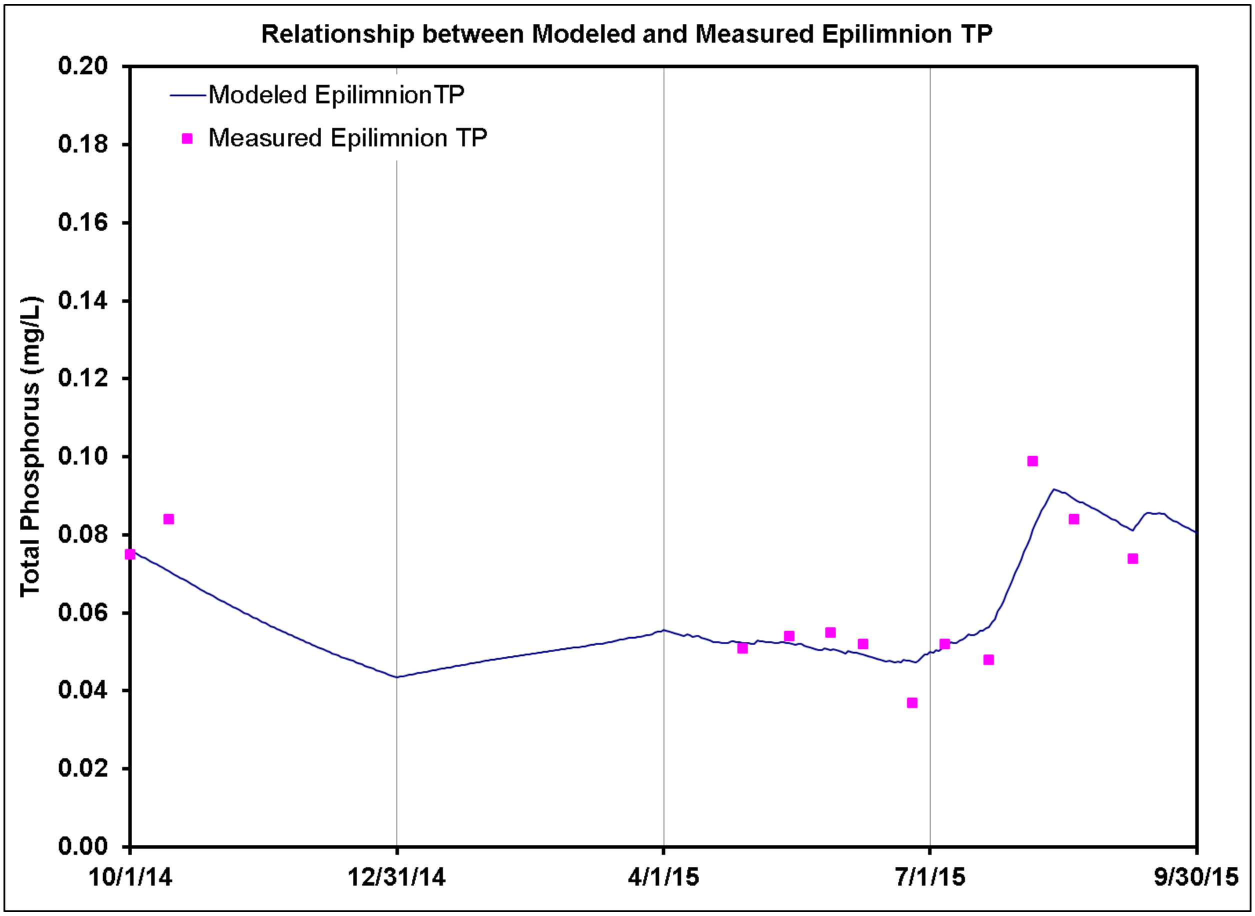


Figure A.4 Lotus Lake time series comparison between modeled and measured surface water TP concentrations for the 2015 water year.

A.2.6 Staring Lake Model Calibration

The Staring Lake water and TP balance portion of the in lake model were calibrated for the 2015 water year (October 2014 through September 2015). The Staring Lake daily water balance was adjusted using the “groundwater” calibration parameter. Groundwater outflows were used to match the observed water surface elevation throughout the year. TP concentrations were balanced on a whole lake basis since Staring Lake does not have a stable thermal stratification during the growing season. The Staring Lake model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity. Inflows from upstream lakes were entered based on in-lake models constructed for Red Rock Lake, Duck Lake, Lotus Lake, and Silver Lake as part of the ongoing Purgatory Creek Watershed Assessment. Inflows from Red Rock Lake were adjusted based on modeled removal efficiencies of downstream ponds including Lake McCoy before it enters Staring Lake.

Figure A.5 shows the results of the Nash Sutcliffe statistical comparison between the 2015 modeled and measured volumetric averaged TP concentrations for the entire water column. Figure A.6 shows the comparison between the modeled and monitored volumetric averaged TP concentrations over the course of the 2015 water year.

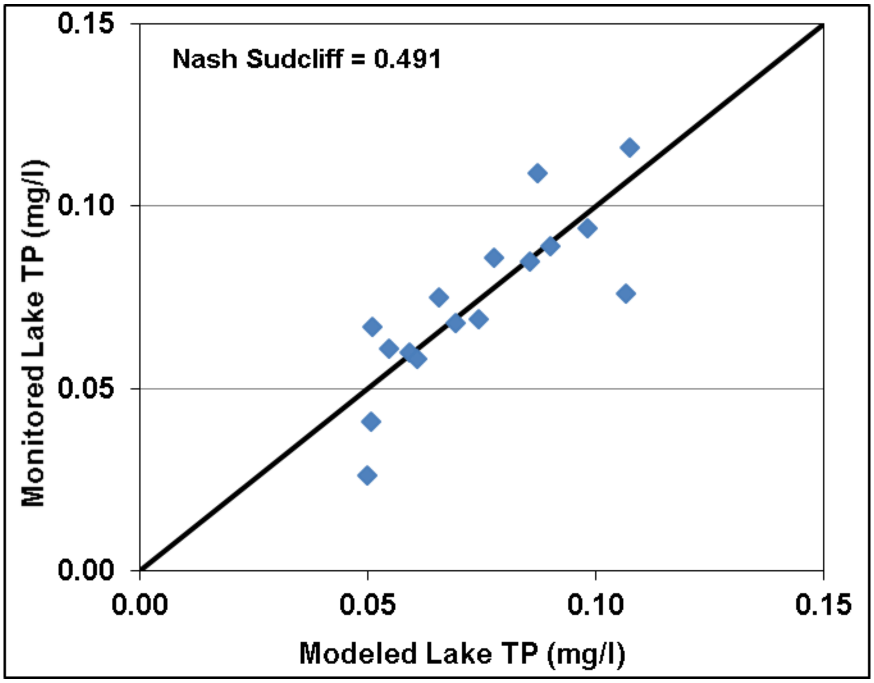


Figure A.5 Staring Lake comparison between modeled volumetric average TP concentration and measured concentrations for the 2015 water year.

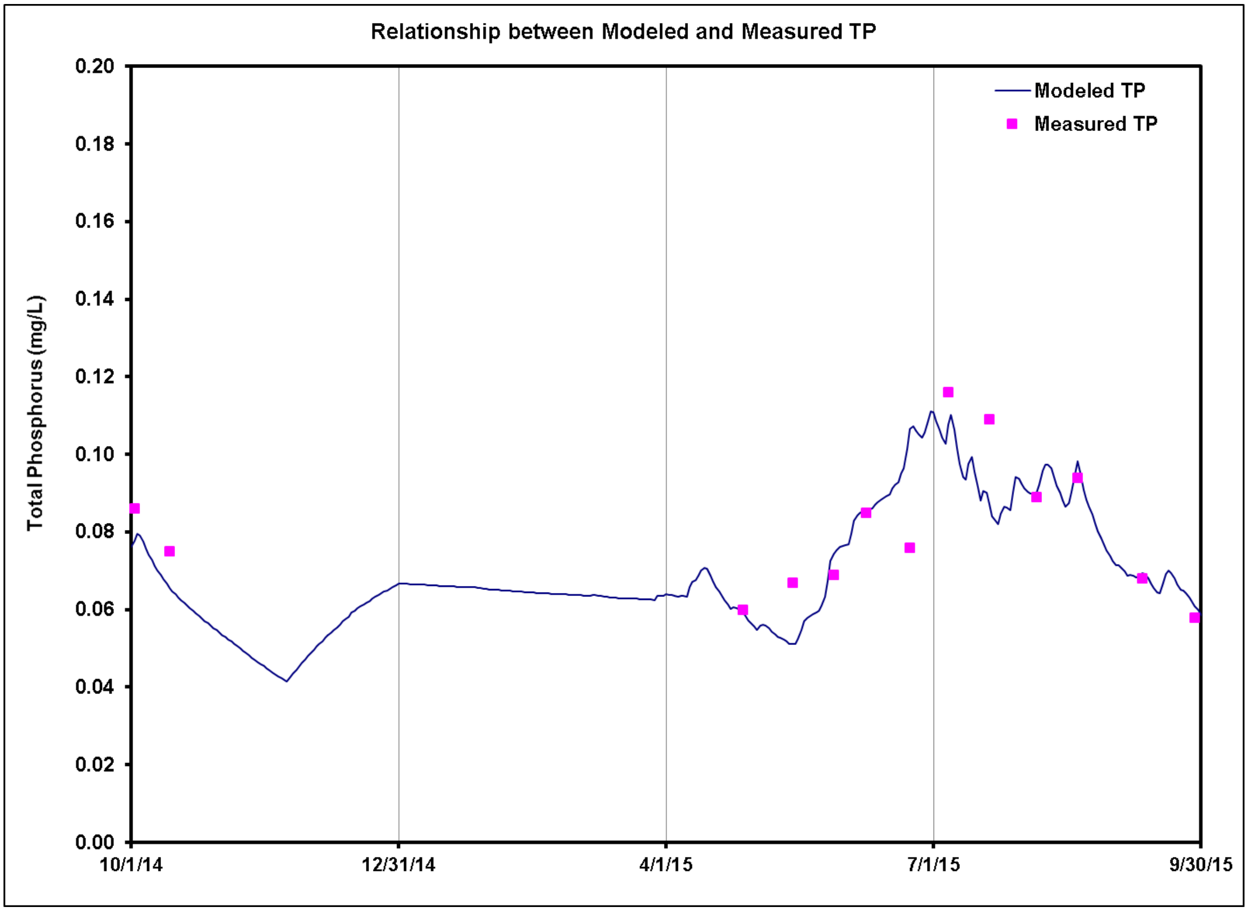


Figure A.6 Staring Lake time series comparison between modeled and measured surface water TP concentrations for the 2015 water year.

A.2.7 Lake Lucy Model Calibration

The Lake Lucy water and TP balance portion of the in lake model were calibrated for the 2015 water year (October 2014 through September 2015). The Lake Lucy daily water balance was adjusted using the “groundwater” calibration parameter. Daily groundwater adjustments were very small, less than ±1.0 cfs. Lake Lucy outflows are dependent on the water surface elevations in Lake Ann. To account for this dependency, three rating curves were developed to model the Lake Lucy outflows based on a range of observed water surface elevations in Lake Ann. Both the epilimnion and hypolimnion TP concentrations were modeled in Lake Lucy due to its thermally stratifying during the growing season. Dividing the lake model into these separate layers enabled a more accurate estimate of internal loading. The Lake Lucy model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity. Separate settling velocities were used in the hypolimnion and epilimnion and during the summer and winter periods to more accurately match the observed TP concentrations in these layers and during these time periods.

Figure A.7 shows the results of the Nash Sutcliffe statistical comparison between the 2015 modeled and measured volumetric averaged epilimnetic TP concentrations. Figure A.8 shows the comparison between the modeled and monitored epilimnetic volumetric averaged TP concentrations over the course of the 2015 water year.

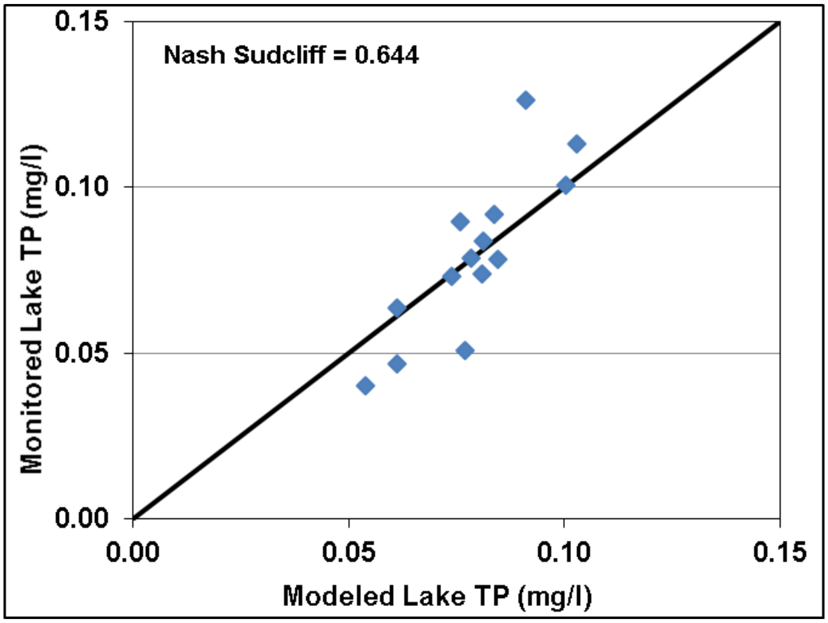


Figure A.7 Lake Lucy comparison between modeled volumetric average TP concentration and measured concentrations for the 2015 water year.

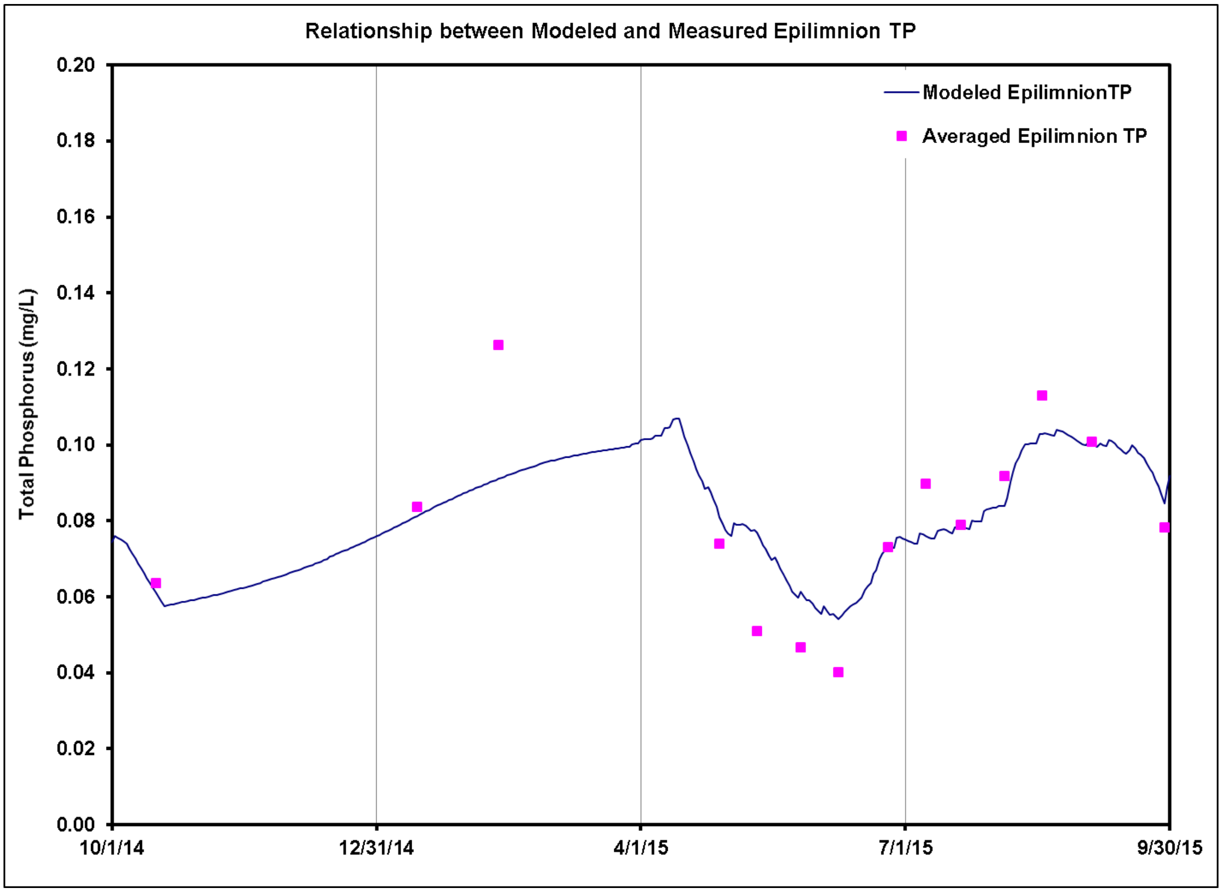


Figure A.8 Lake Lucy time series comparison between modeled and measured surface water TP concentrations for the 2015 water year.

A.2.8 Lake Susan Model Calibration

The Lake Susan water and TP balance portion of the in lake model were calibrated for the 2015 water year (October 2014 through September 2015). The Lake Susan daily water balance was adjusted using the "groundwater" calibration parameter. Groundwater inflows were used to match the observed spring water surface elevation. Both the epilimnion and hypolimnion TP concentrations were modeled in Lake Susan due to its thermally stratifying during the growing season. Dividing the lake model into these separate layers enabled a more accurate estimate of internal loading. The Lake Susan model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity. Separate settling velocities were used in the hypolimnion and epilimnion and during the summer and winter periods to more accurately match the observed TP concentrations in these layers and during these time periods. Inflow loads from Lake Ann were estimated using the Lake Ann outflow rating curve, observed water surface elevations and surface TP concentrations. The loading from Riley Creek stream bank erosion was estimated to be 400 lbs/year. This annual load was distributed on a daily basis based on the percentage of the annual creek inflow volume occurring on that day.

Figure A.9 shows the results of the Nash Sutcliffe statistical comparison between the 2015 modeled and measured volumetric averaged epilimnetic TP concentrations. Figure A.10 shows the comparison between the modeled and monitored epilimnetic volumetric averaged TP concentrations over the course of the 2015 water year.

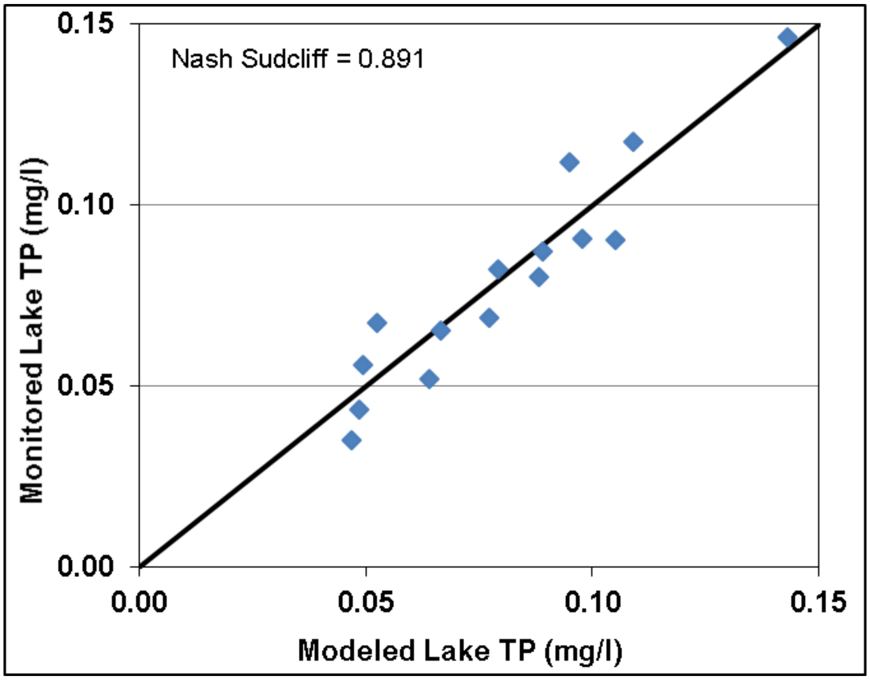


Figure A.9 Lake Susan comparison between modeled volumetric average TP concentration and measured concentrations for the 2015 water year

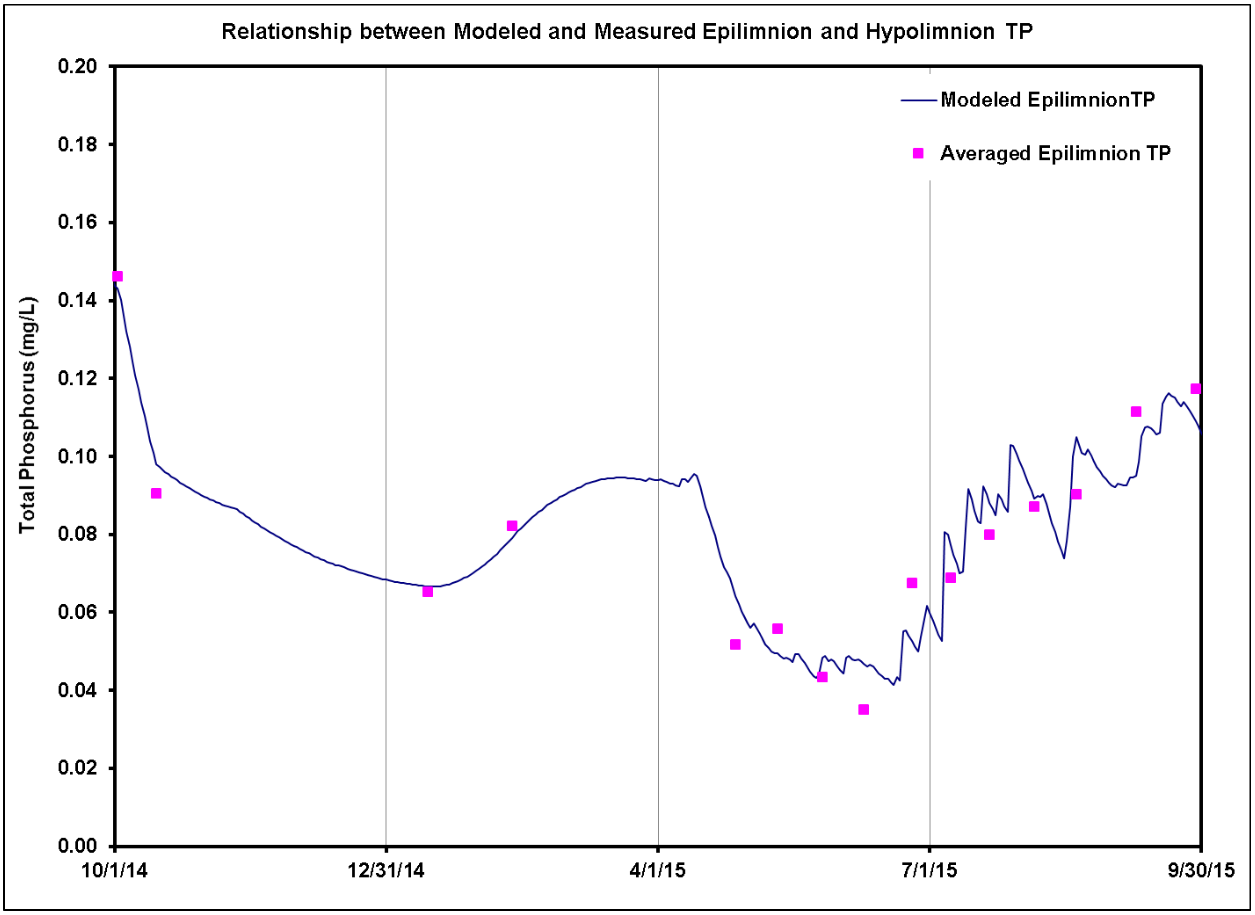


Figure A.10 Lake Susan time series comparison between modeled and measured surface water TP concentrations.

A.2.9 Rice Marsh Lake Model Calibration

The Rice Marsh Lake water and TP balance portion of the in lake model were calibrated for the 2014 water year (October 2013 through September 2014). The Rice Marsh Lake daily water balance was adjusted using the "groundwater" calibration parameter. Groundwater outflows were used to match the observed spring through fall water surface elevations. TP concentrations were balanced on a whole lake basis since Rice Marsh Lake does not have a stable thermal stratification during the growing season. The Rice Marsh Lake model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity. Separate settling velocities were used during the summer and winter periods to more accurately match the observed TP concentrations in these layers and during these time periods. The inflow loads from Lake Susan were estimated using the Lake Susan outflow rating curve, observed water surface elevations and surface TP concentrations.

Figure A.11 shows the results of the Nash Sutcliffe statistical comparison between the 2014 modeled and measured volumetric averaged TP concentrations for the entire water column. Figure A.12 shows the comparison between the modeled and monitored volumetric averaged TP concentrations over the course of the 2014 water year.

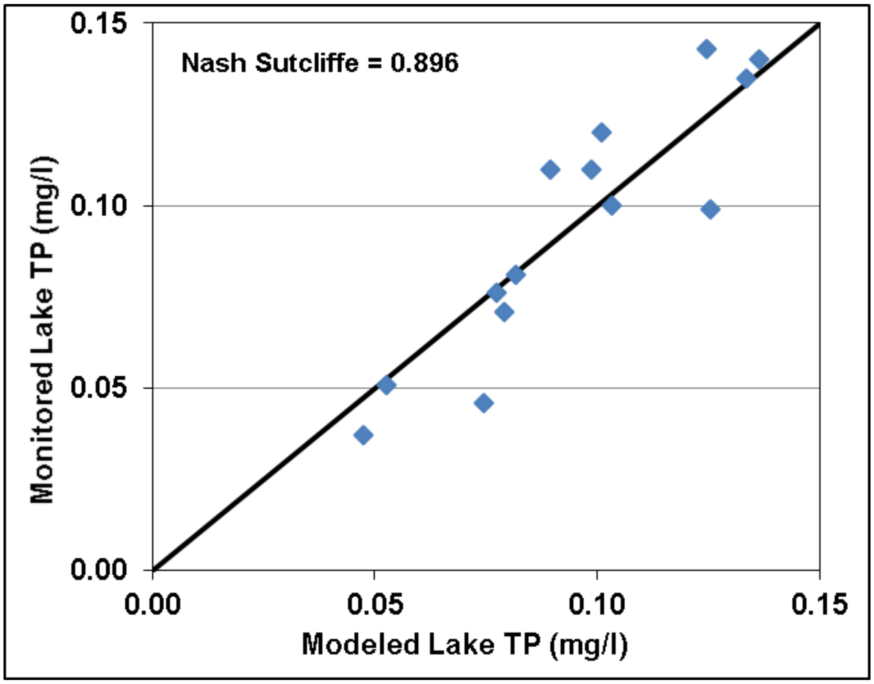


Figure A.11 Rice Marsh Lake comparison between modeled volumetric average TP concentration and measured concentrations for the 2014 water year.

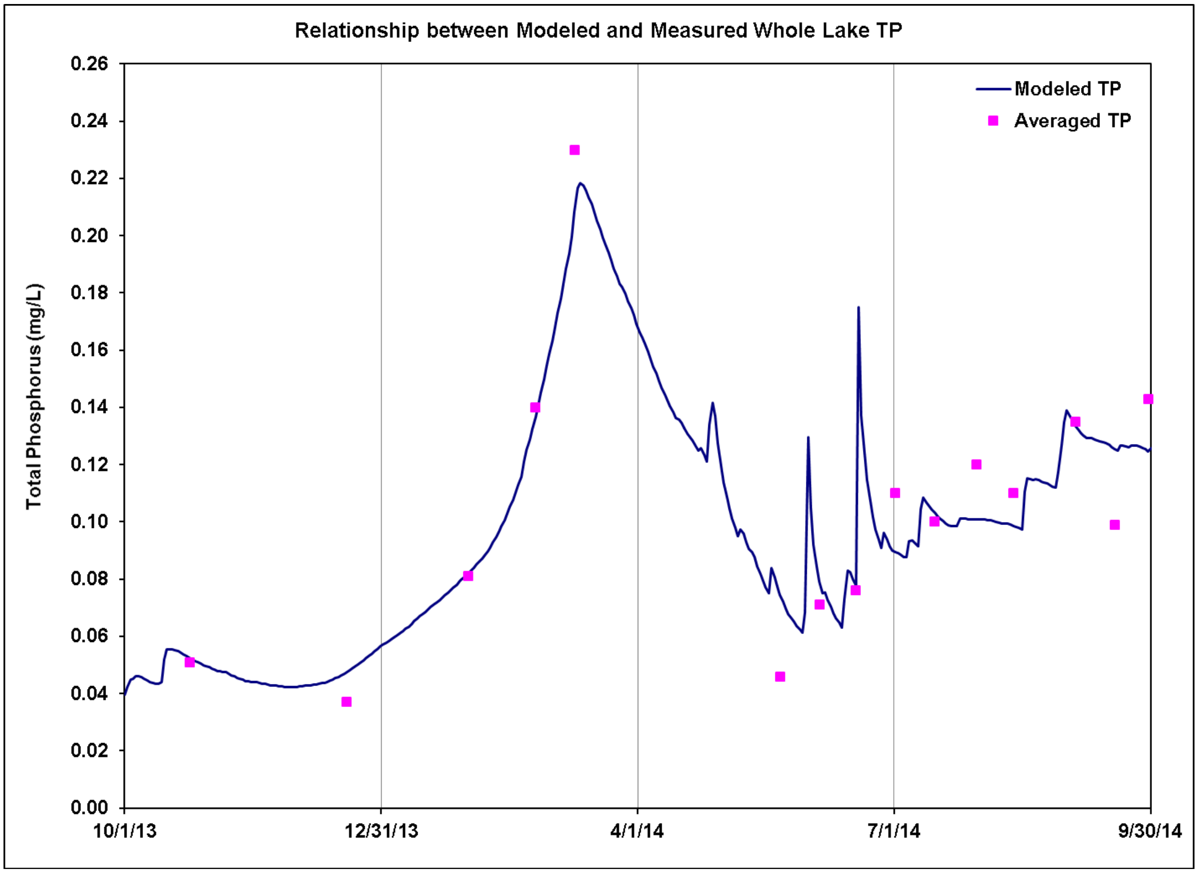


Figure A.12 Rice Marsh Lake time series comparison between modeled and measured surface water TP concentrations for the 2014 water year.

A.2.10 Riley Lake Model Calibration

The Lake Riley water and TP balance portion of the in lake model were calibrated for the 2014 water year (October 2013 through September 2014). The Lake Riley daily water balance was adjusted using the "groundwater" calibration parameter. Groundwater outflows were used to match the observed fall water surface elevations. Both the epilimnion and hypolimnion TP concentrations were modeled in Lake Riley due to its thermally stratifying during the growing season. Dividing the lake model into these separate layers enabled a more accurate estimate of internal loading. The Lake Riley model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity. Separate settling velocities were used in the hypolimnion and epilimnion and during the summer and winter periods to more accurately match the observed TP concentrations in these layers and during these time periods. The inflow loads from Rice Marsh Lake were estimated from the Rice Marsh Lake in-lake model.

Figure A.13 shows the results of the Nash Sutcliffe statistical comparison between the 2014 modeled and measured volumetric averaged epilimnetic TP concentrations. Figure A.14 shows the comparison between the modeled and monitored epilimnetic volumetric averaged TP concentrations over the course of the 2014 water year.

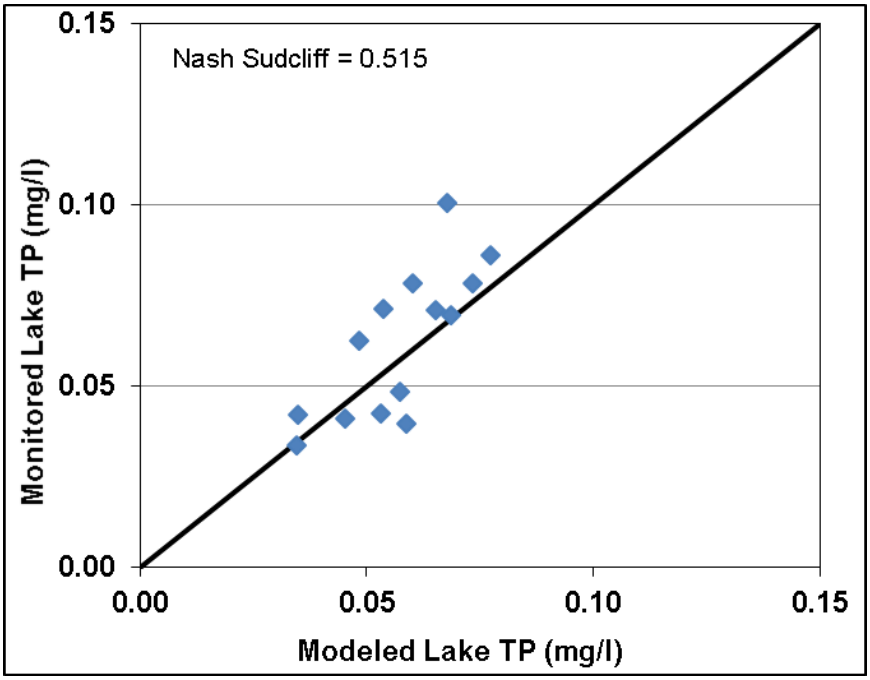


Figure A.13 Lake Riley comparison between modeled volumetric average TP concentration and measured concentrations for the 2014 water year.

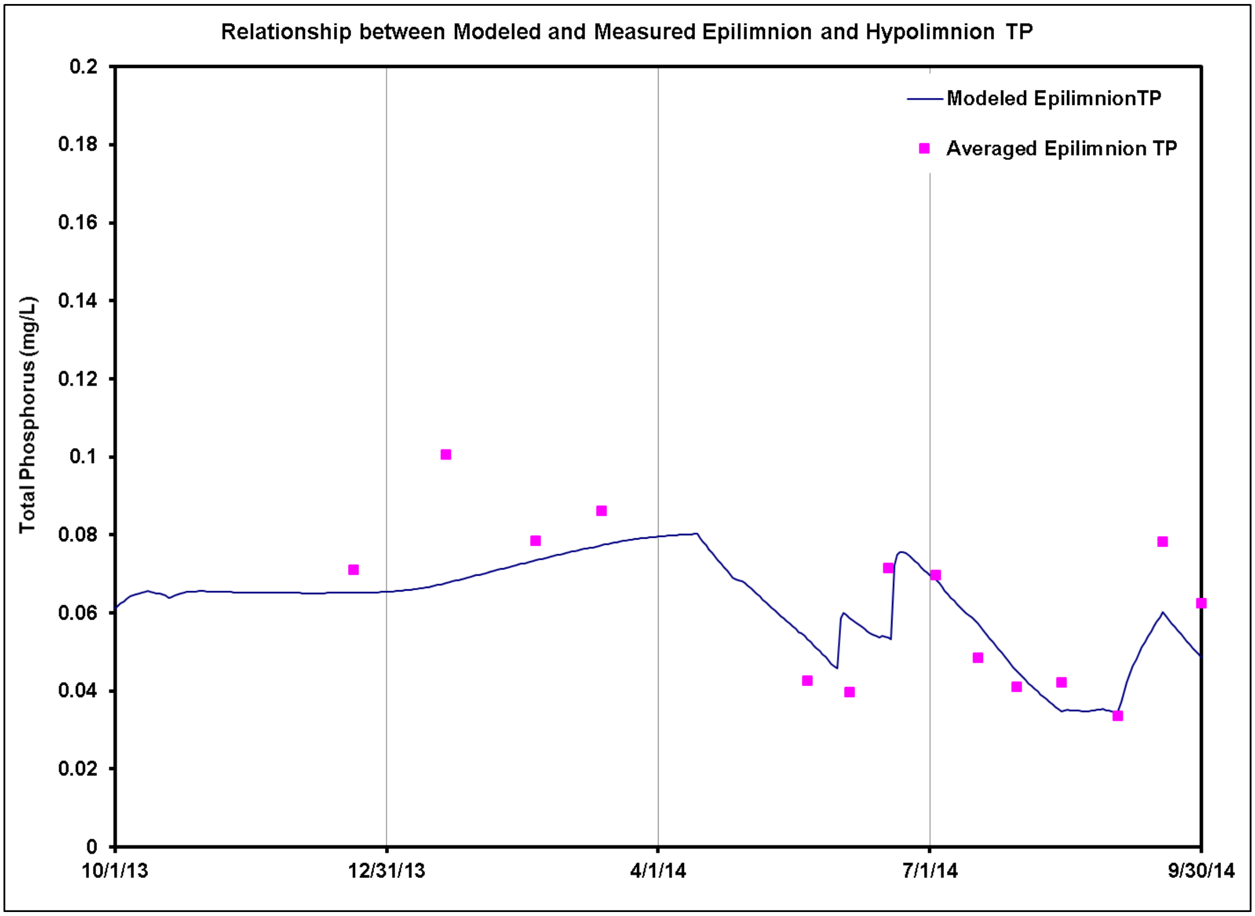


Figure A.14 Lake Riley time series comparison between modeled and measured surface water TP concentrations for the 2014 water year.

A.2.11 Hyland Lake Model Calibration

The Hyland Lake water and TP balance portion of the in lake model were calibrated for the 2015 water year (October 2014 through September 2015). The Hyland Lake daily water balance was adjusted using the "groundwater" calibration parameter. Groundwater outflows were used to match the observed water surface elevation throughout the year. TP concentrations were balanced on a whole lake basis since Hyland Lake does not have a stable thermal stratification during the growing season. The Hyland Lake model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity. Separate settling velocities were used during the summer and winter periods to more accurately match the observed TP concentrations during these time periods.

Figure A.15 shows the results of the Nash Sutcliffe statistical comparison between the 2015 modeled and measured volumetric averaged TP concentrations for the entire water column. Figure A.16 shows the comparison between the modeled and monitored volumetric averaged TP concentrations over the course of the 2015 water year.

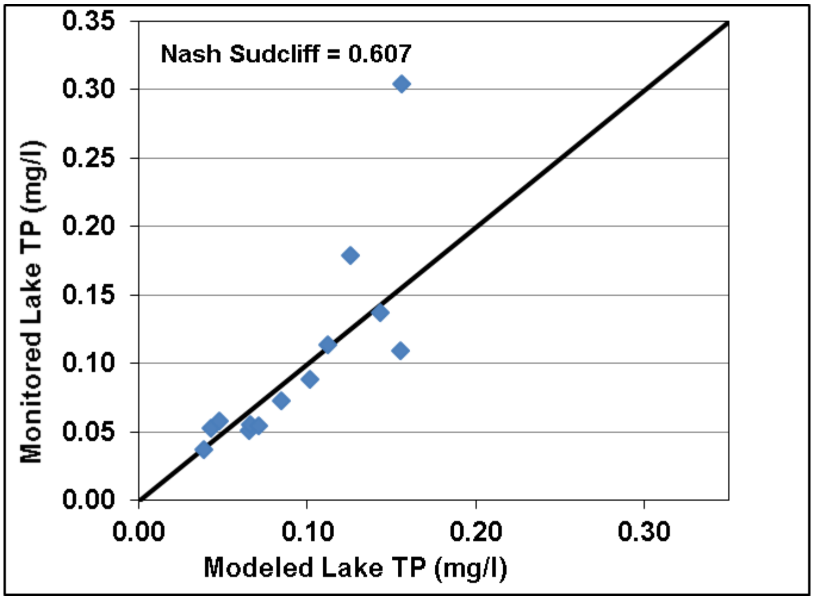


Figure A.15 Hyland Lake comparison between modeled volumetric average TP concentration and measured concentrations for the 2015 water year.

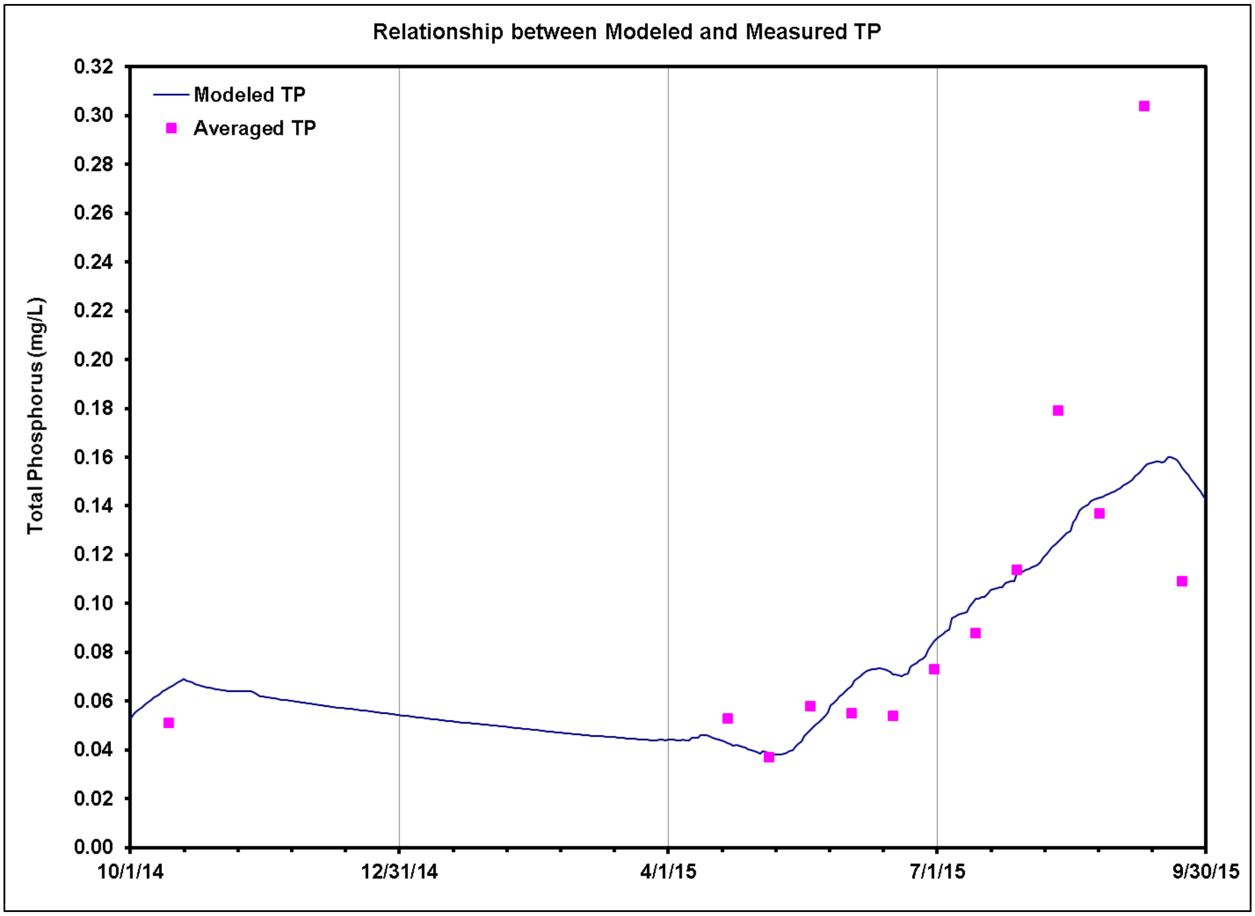


Figure A.16 Hyland Lake time series comparison between modeled and measured surface water TP concentrations for the 2015 water year.

Large portions of the Hyland Lake Watershed did not contribute loading to the lake during the 2015 water year based on the P8 model results. These areas include the areas draining to Colorado Pond as well as large portions of the parkland around the lake. The Hyland lake Subwatershed boundaries, flow path directions, 2015 water year contributing areas and TP loadings to the lake from the various potential inflow points are shown in Figure A.17 and summarized in Table A.18.

Table A.18 Hyland Lake contributing and non-contributing areas, total phosphorus watershed loads and total phosphorus loads to the lake based on P8 modeled results for the 2015 water year.

Contributing Areas

Inflow Point	Upstream Area (ac)	Watershed TP Load (lbs)	Watershed TP Load (lbs/ac)	TP Load to the Lake (lbs)	TP Load to the Lake (lbs/ac)
Direct Watershed	95.1	31.0	0.33	31.0	0.33
68D32_O	121.0	18.7	0.15	5.5	0.05
68-04	269.1	132.4	0.49	53.9	0.20
Total	**485.3**	**182.1**	**0.38**	**90.4**	**0.19**

Non-contributing Areas

Inflow Point	Upstream Area (ac)	Watershed TP Load (lbs)	Watershed TP Load (lbs/ac)	TP Load to the Lake (lbs)	TP Load to the Lake (lbs/ac)
Colorado Pond	233.9	88.0	0.38	0	0
HYL001	7.1	0.8	0.11	0	0
HYL002	9.2	2.2	0.23	0	0
HYL005	66.5	7.3	0.11	0	0
HYL007	10.0	2.8	0.28	0	0
HYL008	27.2	3.0	0.11	0	0
Total	**353.8**	**104.1**	**0.29**	**0**	**0**
Overall Total	**839.1**	**286.2**	**0.34**	**90.4**	**0.11**

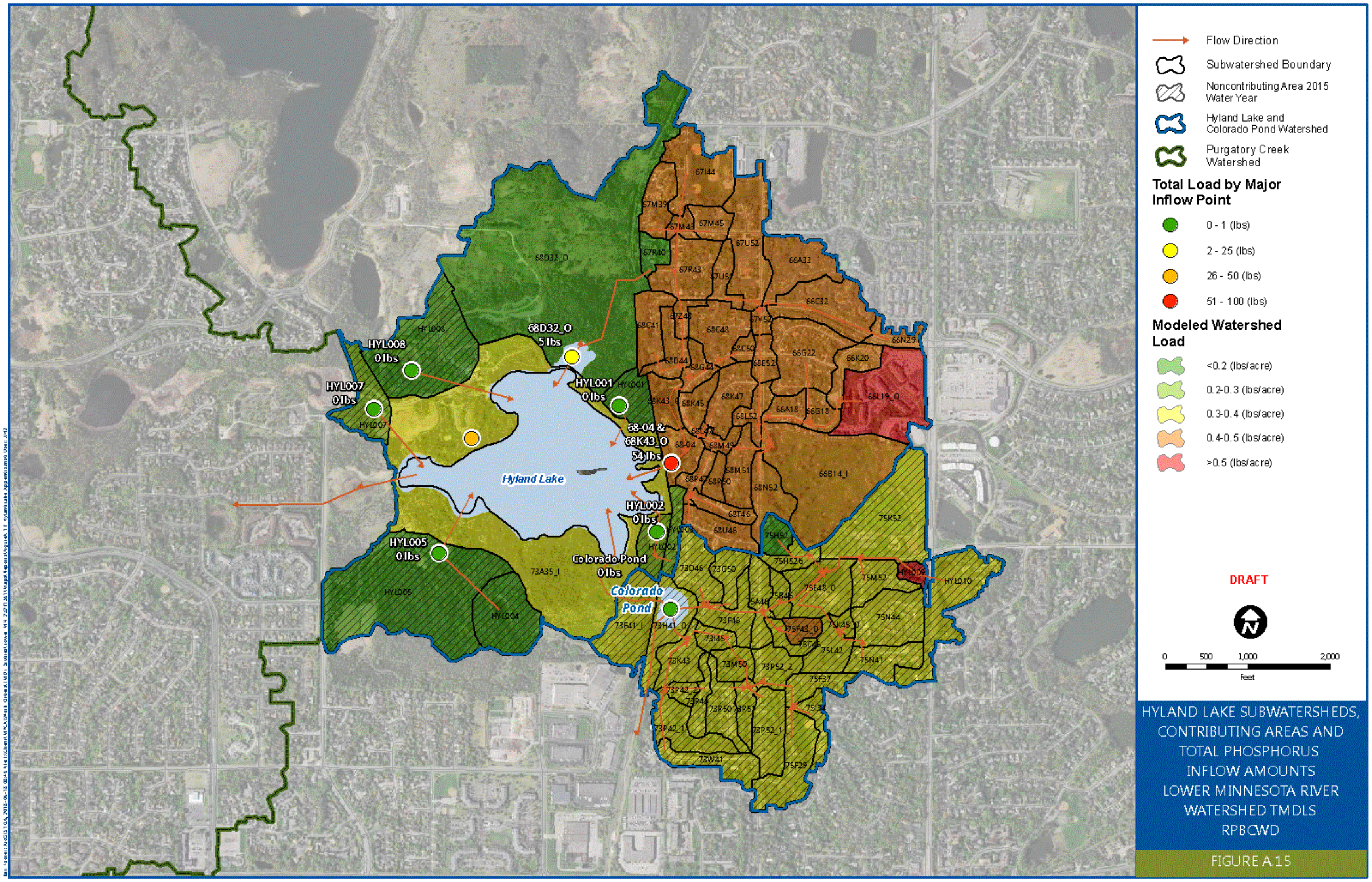


Figure A.17 Hyland Lake subwatersheds, flowpath directions, contributing areas and total phosphorus loads to the lake for the 2015 water year

A.2.12 Wing Lake Model Calibration

The Wing Lake water and TP balance portion of the in lake model were calibrated for the 2016 growing season (June 2016 through September 2016). The Wing Lake daily water balance was adjusted using the "groundwater" calibration parameter. Groundwater inflows were used to match the spring water surface elevations while outflows were used to match the observed water surface elevations in later in the growing season. TP concentrations were balanced on a whole lake basis since Wing Lake does not have a stable thermal stratification during the growing season. The Wing Lake model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity. The upstream lake inflow loads from Lake Holiday were estimated from a water quality model developed for Lake Holiday.

Figure A.18 shows the results of the Nash Sutcliffe statistical comparison between the 2016 modeled and measured volumetric averaged TP concentrations for the entire water column. Figure A.19 shows the comparison between the modeled and monitored volumetric averaged TP concentrations over the course of the 2016 growing season.

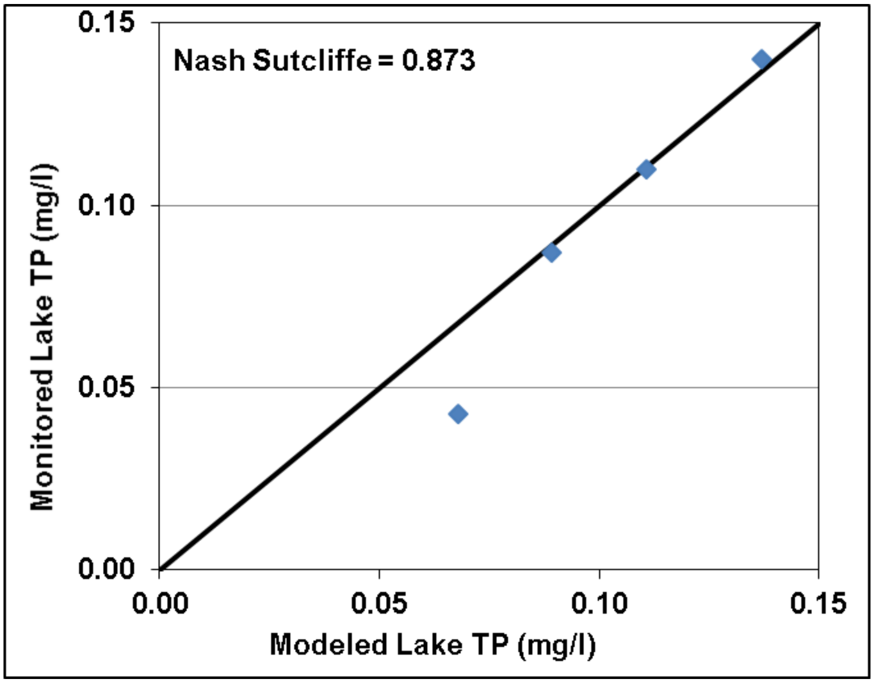


Figure A.18 Wing Lake comparison between modeled volumetric average TP concentration and measured concentrations for the 2016 growing season.

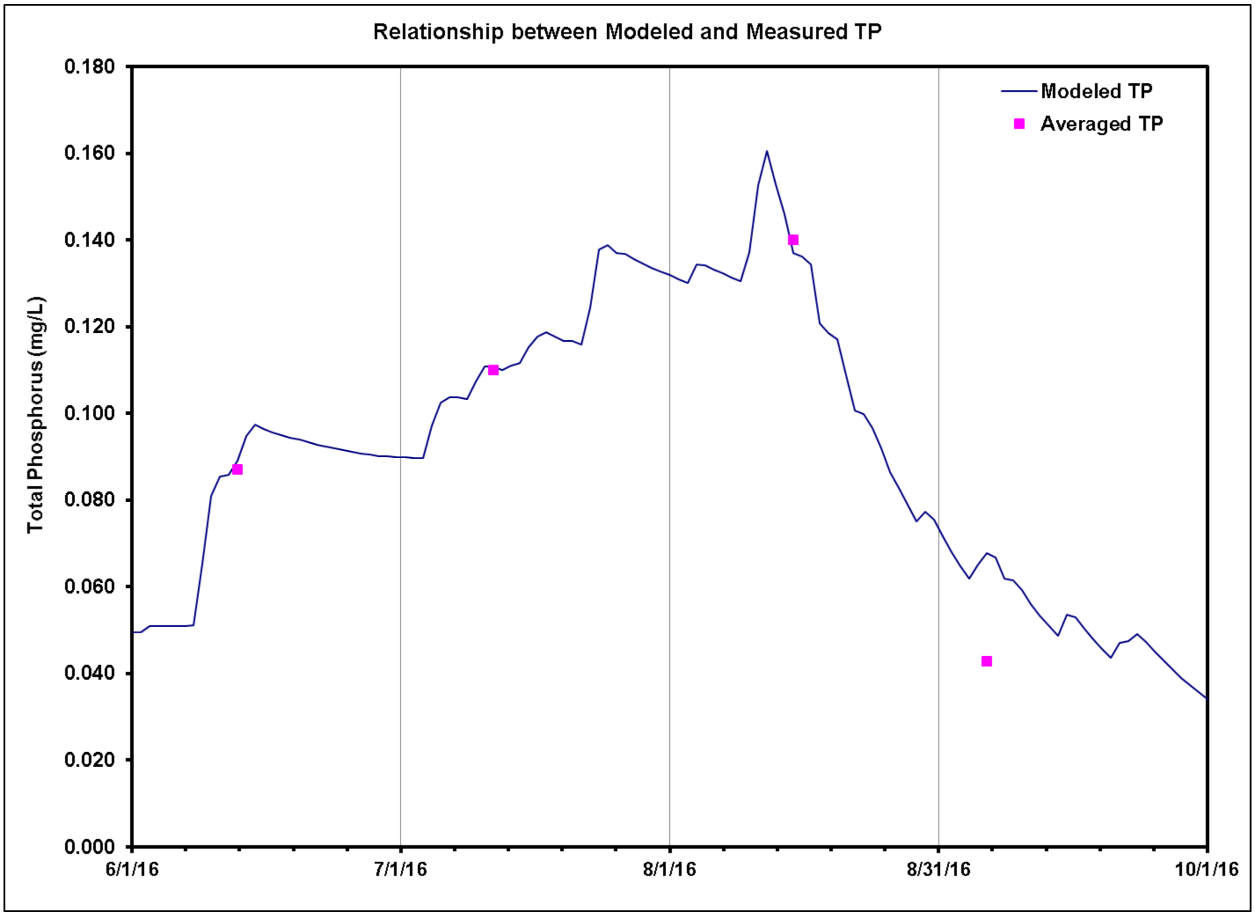


Figure A.19 Wing Lake time series comparison between modeled and measured surface water TP concentrations for the 2016 growing season.

A.2.13 Lake Rose Model Calibration

The Lake Rose water and TP balance portion of the in lake model were calibrated for the 2016 growing season (June 2016 through September 2016). The Lake Rose daily water balance was adjusted using the "groundwater" calibration parameter. Groundwater outflows were used to match the observed water surface elevations throughout the growing season. TP concentrations were balanced on a whole lake basis since Lake Rose does not have a stable thermal stratification during the growing season. The Lake Rose model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity. The upstream lake inflow loads from Wing Lake were estimated from the Wing Lake in-lake model output.

Figure A.20 shows the results of the Nash Sutcliffe statistical comparison between the 2016 modeled and measured volumetric averaged TP concentrations for the entire water column. Figure A.21 shows the comparison between the modeled and monitored volumetric averaged TP concentrations over the course of the 2016 growing season.

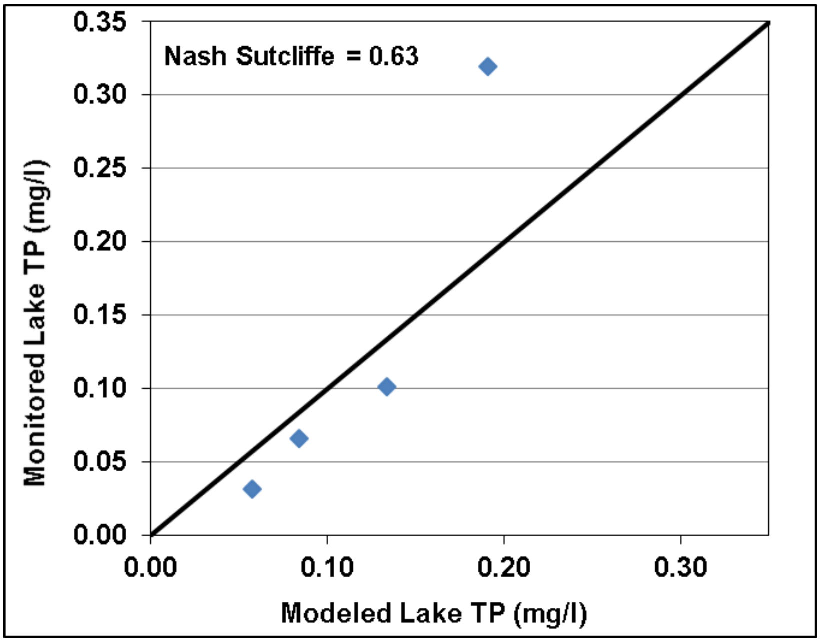


Figure A.20 Lake Rose comparison between modeled volumetric average TP concentration and measured concentrations for the 2016 growing season.

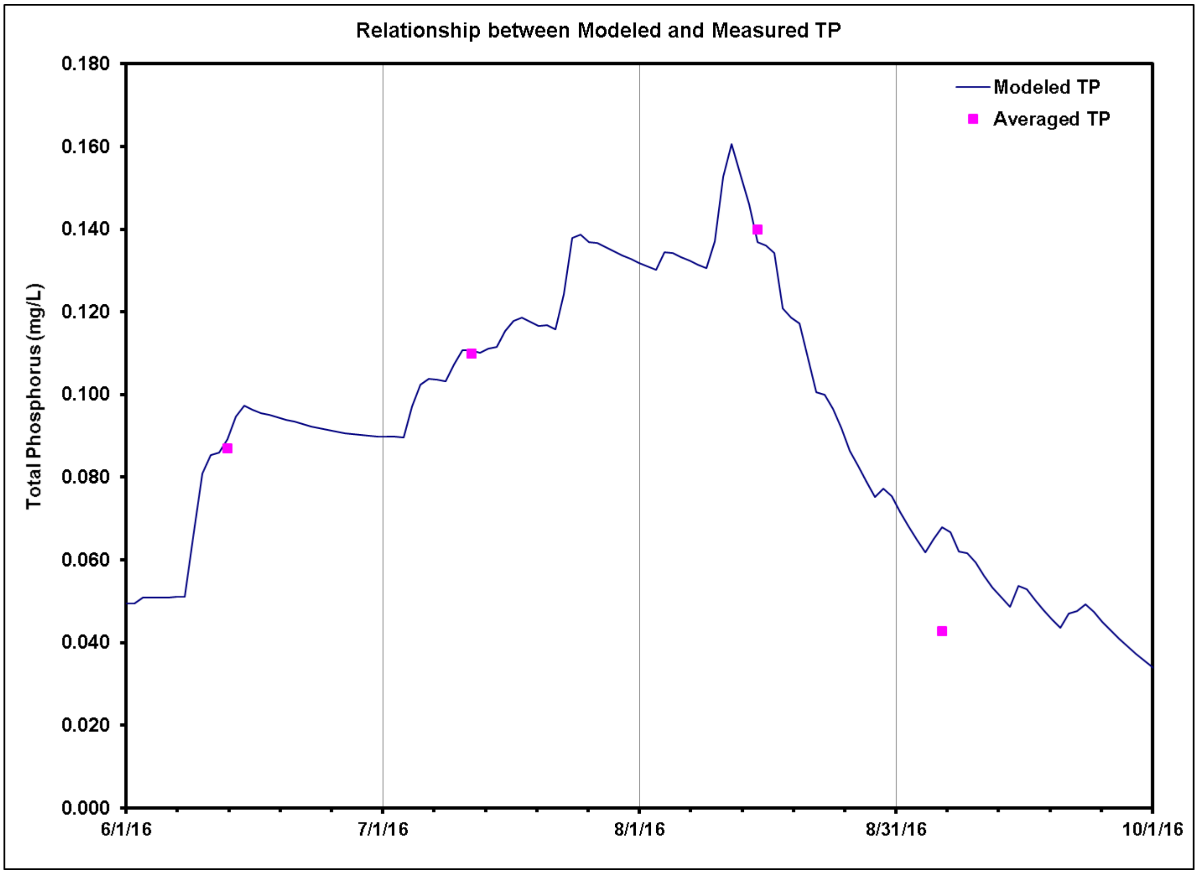


Figure A.21 Lake Rose time series comparison between modeled and measured surface water TP concentrations for the 2016 growing season.

A.2.14 North Cornelia Lake Model Calibration

The North Cornelia Lake water and TP balance portion of the in lake model were calibrated for the 2015 growing season (June 2015 through September 2015). The North Cornelia Lake daily water balance did not need to be adjusted using the “groundwater” calibration parameter during the 2015 growing season. TP concentrations were balanced on a whole lake basis since North Cornelia Lake does not have a stable thermal stratification during the growing season. The North Cornelia Lake model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity.

Figure A.22 shows the results of the Nash Sutcliffe statistical comparison between the 2015 modeled and measured volumetric averaged TP concentrations for the entire water column. Figure A.23 shows the comparison between the modeled and monitored volumetric averaged TP concentrations over the course of the 2015 growing season.

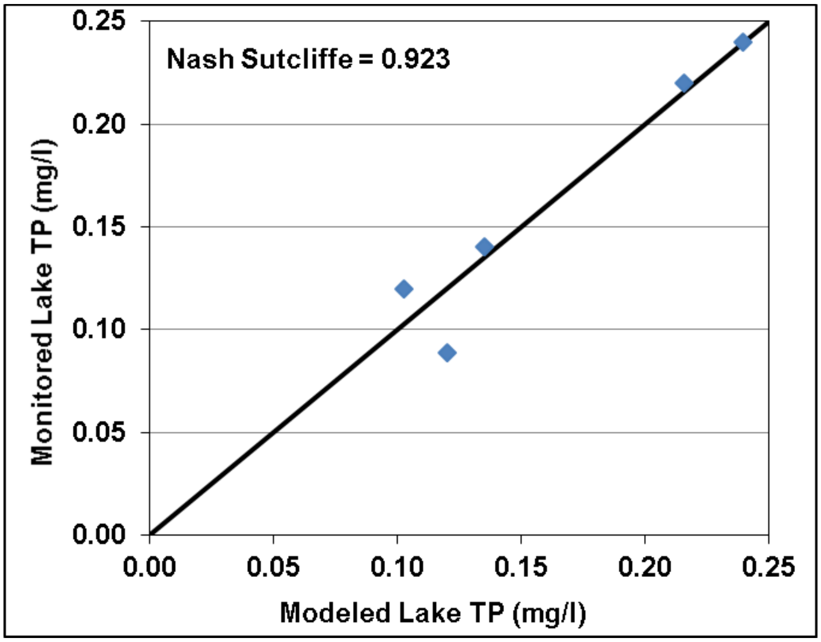


Figure A.22 North Cornelia Lake comparison between modeled volumetric average TP concentration and measured concentrations for the 2015 growing season.

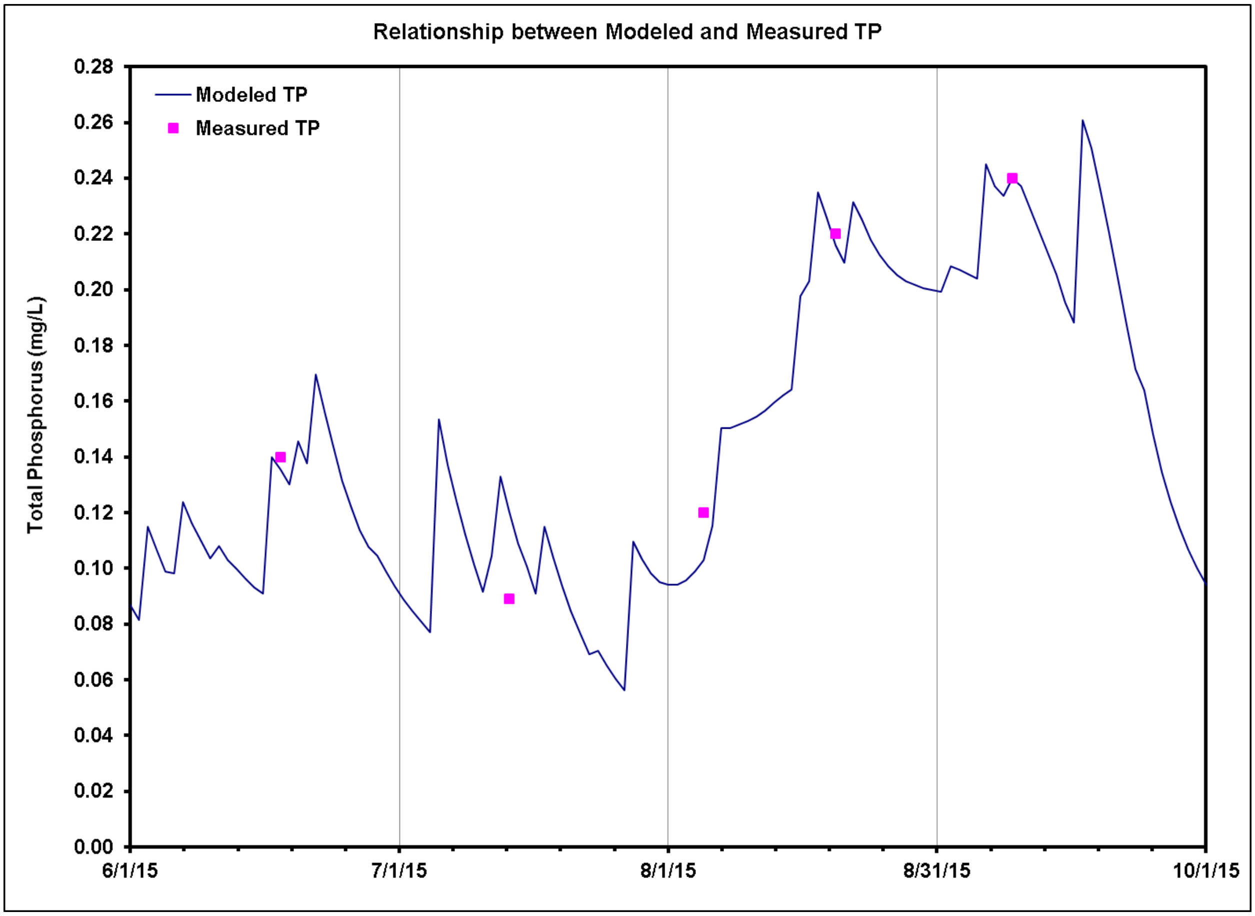


Figure A.23 North Cornelia Lake time series comparison between modeled and measured surface water TP concentrations for the 2015 growing season.

A.2.15 South Cornelia Lake Model Calibration

The South Cornelia Lake water and TP balance portion of the in lake model were calibrated for the 2016 growing season (June 2016 through September 2016). The South Cornelia Lake daily water balance did not need to be adjusted using the "groundwater" calibration parameter during the 2016 growing season. TP concentrations were balanced on a whole lake basis since South Cornelia Lake does not have a stable thermal stratification during the growing season. The South Cornelia Lake model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity. The upstream lake inflow loads from North Cornelia Lake were estimated from the North Cornelia Lake in-lake model output.

Figure A.24 shows the results of the Nash Sutcliffe statistical comparison between the 2016 modeled and measured volumetric averaged TP concentrations for the entire water column. Figure A.25 shows the comparison between the modeled and monitored volumetric averaged TP concentrations over the course of the 2016 growing season.

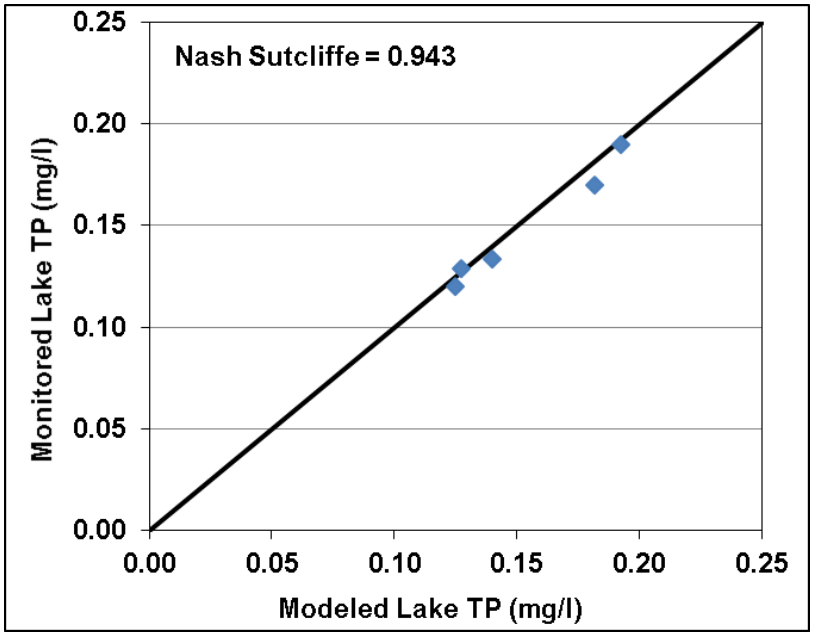


Figure A.24 South Cornelia Lake comparison between modeled volumetric average TP concentration and measured concentrations for the 2016 growing season.

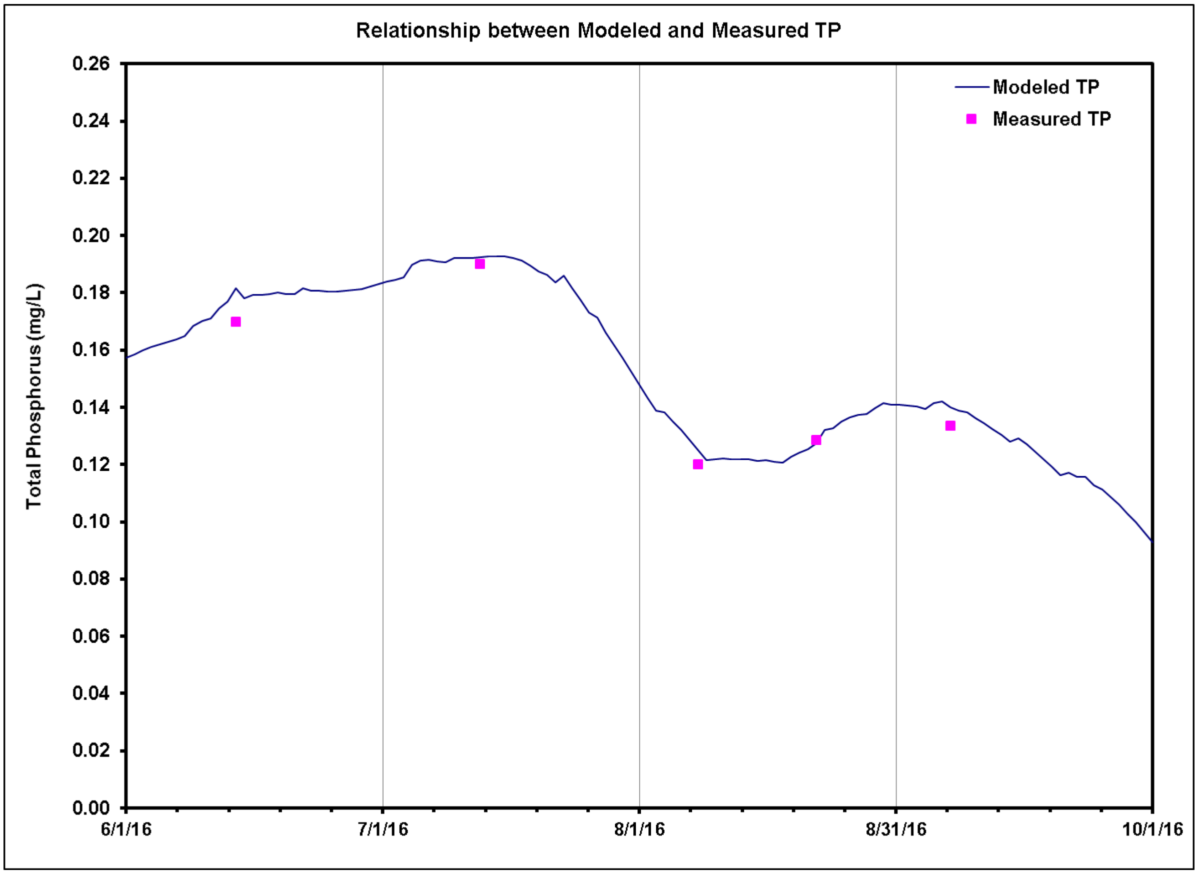


Figure A.25 South Cornelia Lake time series comparison between modeled and measured surface water TP concentrations for the 2016 growing season.

A.2.16 Lake Edina Model Calibration

The Lake Edina water and TP balance portion of the in lake model were calibrated for the 2015 growing season (June 2015 through September 2015). The Lake Edina daily water balance was adjusted using the "groundwater" calibration parameter. Groundwater outflows were used to match the spring water surface elevations. TP concentrations were balanced on a whole lake basis since Lake Edina does not have a stable thermal stratification during the growing season. The Lake Edina model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity. The upstream lake inflow loads from South Cornelia Lake were estimated from the South Cornelia Lake in-lake model output.

Figure A.26Figure A.24 shows the results of the Nash Sutcliffe statistical comparison between the 2015 modeled and measured volumetric averaged TP concentrations for the entire water column. Figure A.27 shows the comparison between the modeled and monitored volumetric averaged TP concentrations over the course of the 2015 growing season.

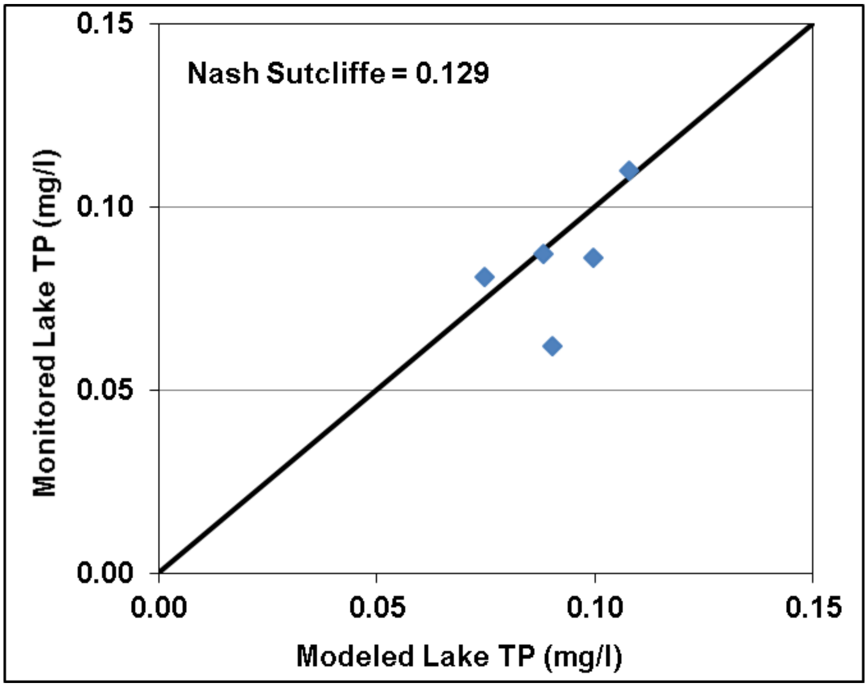


Figure A.26 Lake Edina comparison between modeled volumetric average TP concentration and measured concentrations for the 2015 growing season.

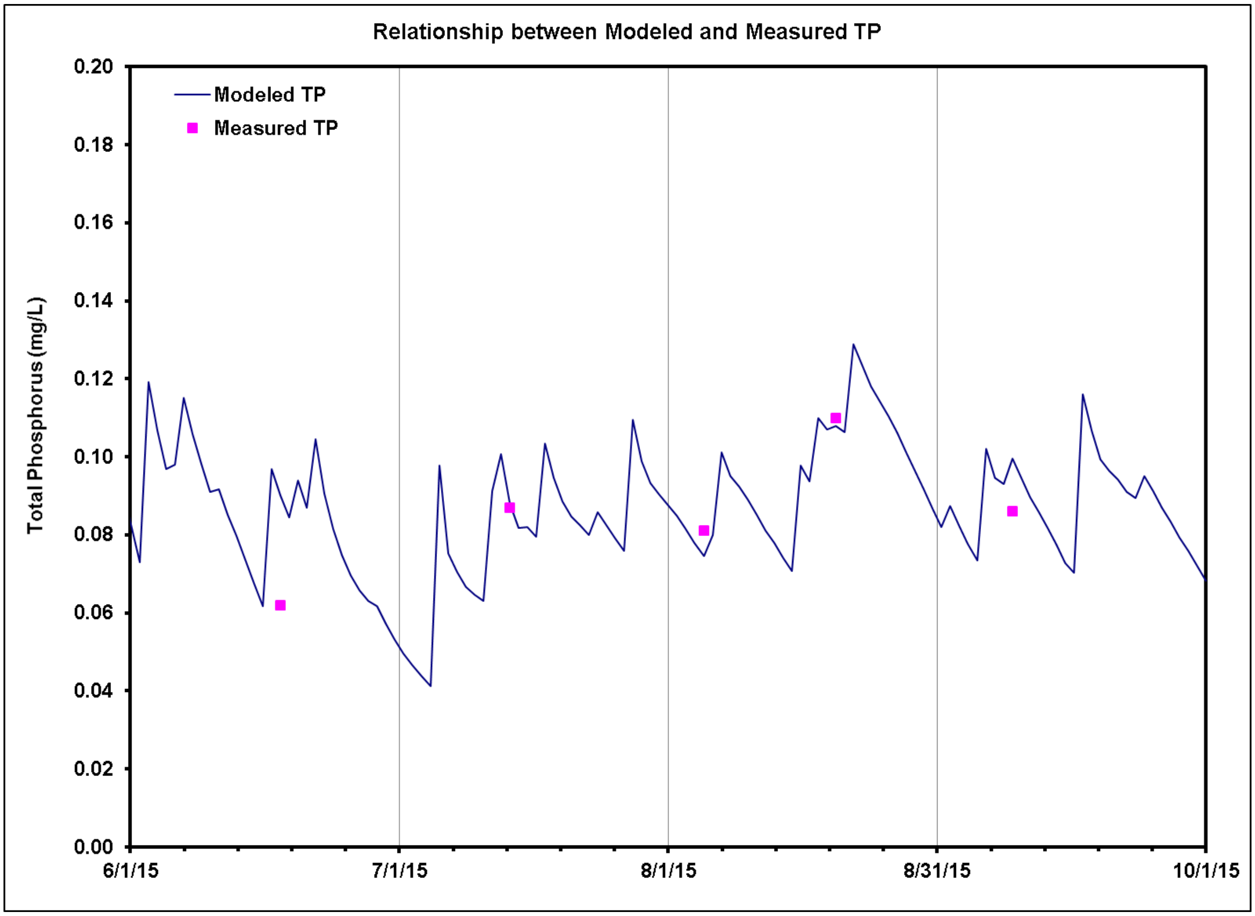


Figure A.27 Lake Edina time series comparison between modeled and measured surface water TP concentrations for the 2015 growing season.

A.2.17 Penn Lake Model Calibration

The Penn Lake water and TP balance portion of the in lake model were calibrated for the 2016 growing season (June 2016 through September 2016). The Penn Lake daily water balance was adjusted using the "groundwater" calibration parameter. Groundwater outflows were used to match the spring water surface elevations. TP concentrations were balanced on a whole lake basis since Penn Lake does not have a stable thermal stratification during the growing season. The Penn Lake model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity.

Figure A.28 shows the results of the Nash Sutcliffe statistical comparison between the 2016 modeled and measured volumetric averaged TP concentrations for the entire water column. Figure A.29 shows the comparison between the modeled and monitored volumetric averaged TP concentrations over the course of the 2016 growing season.

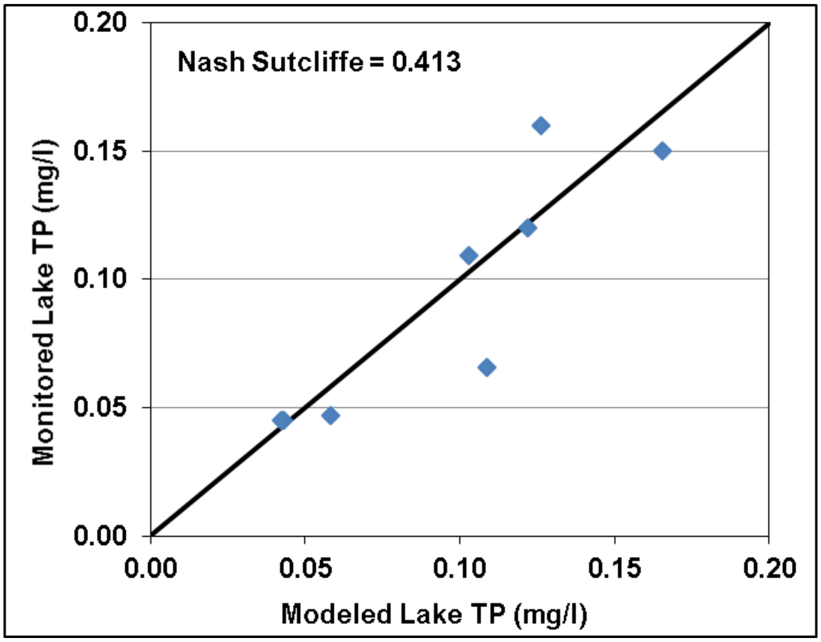


Figure A.28 Penn Lake comparison between modeled volumetric average TP concentration and measured concentrations for the 2016 growing season.

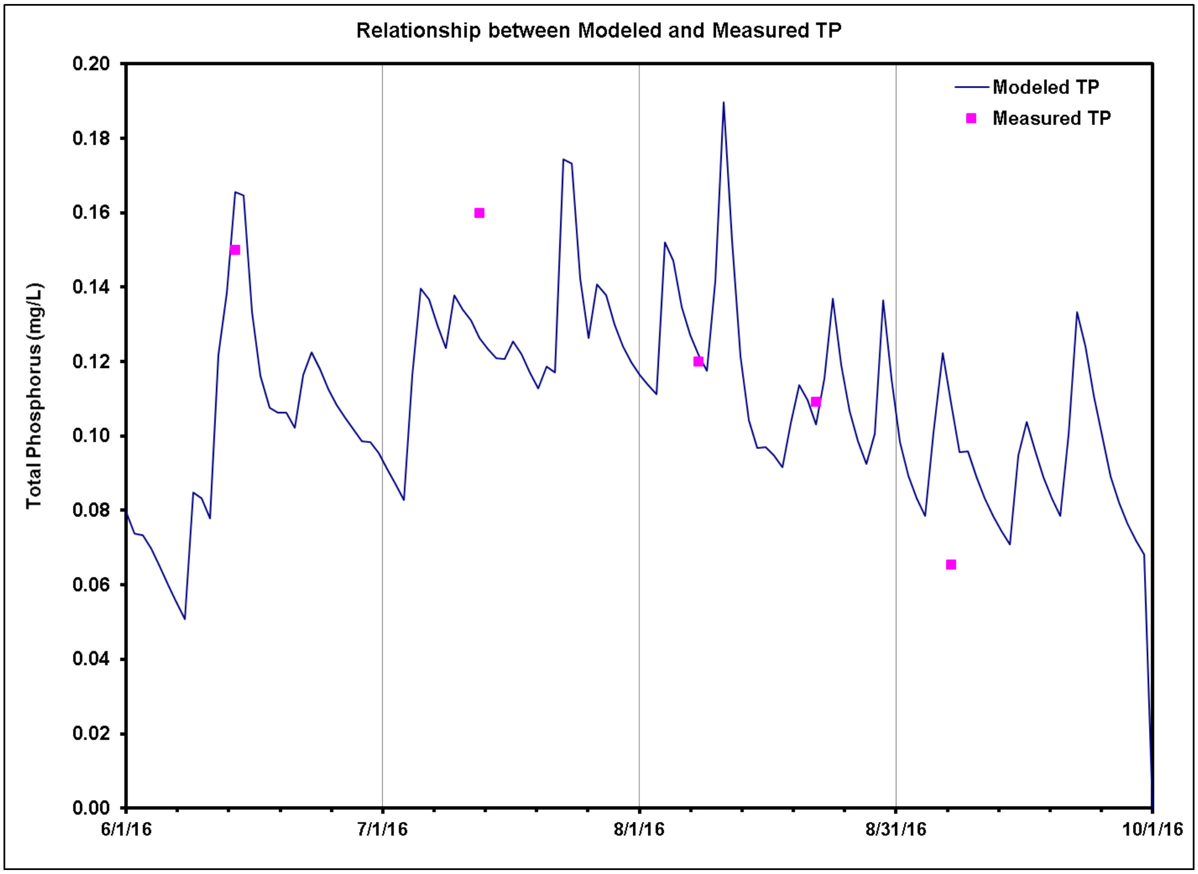


Figure A.29 Penn Lake time series comparison between modeled and measured surface water TP concentrations for the 2016 growing season.

References

Barr Engineering Company. 2007. Detailed Assessment of Phosphorus Sources to Minnesota Watersheds – Atmospheric Deposition: 2007 Update. Prepared for Minnesota Pollution Control Agency.

Barr Engineering Company. 2010. Use Attainability Analysis for Lake Holiday, Wing Lake and Lake Rose. Prepared for Nine Mile Creek Watershed District.

Barr Engineering Company. 2010. Use Attainability Analysis for Lake Holiday, Wing Lake and Lake Rose. Prepared for Nine Mile Creek Watershed District.

Marciano, J.J. and Harbeck, G.E., 1954. Mass-transfer studies. In: USGS (Editor), Water-Loss Investigations: Lake Hefner Studies, Technical Report. United States Geological Survey, Washington, D.C., pp. 46-70.

Nash, J. E. and J. V. Sutcliffe. 1970. River flow forecasting through conceptual models part I — A discussion of principles, *Journal of Hydrology*, 10 (3), 282–290.

Soil Survey Staff. (2015) Gridded Soil Survey Geographic (gSSURGO) Database for *Minnesota*. United States Department of Agriculture, Natural Resources Conservation Service. Available online at https://gdg.sc.egov.usda.gov/. (FY2015 official release).

Vollenweider, R.A. 1969. “Possibilities and Limits of Elementary Models Concerning the Budget of Substances in Lakes.” *Archiv fur Hydrobiologie*., 66, 1-36.