Goose Creek Watershed Total Maximum Daily Load (TMDL)

(Lower Saint Croix Major Watershed)

The Goose Creek Watershed encompasses Rock, Rush, and Goose Creeks as well as Rock, Rush, and Goose Lakes along with many smaller lakes and tributaries.

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Acronyms

ac-ft/yr	acre feet per year
AF	Anoxic factor
AFO	Animal Feeding Operation
AU	Animal Unit
AUID	Assessment Unit ID
BD-P	Bicarbonate Dithionite extractable Phosphorus
BMP	Best Management Practice
CAFO	Concentrated Animal Feeding Operation
CAC	Citizens Advisory Committee
cfu	colony-forming unit
Chl-*a*	Chlorophyll-*a*
CRP	Conservation Reserve Program
CSO	Combined Sewer Overflow
CV	Coefficient of Variation
Deg C	Degrees Celsius
DNR	Minnesota Department of Natural Resources
DO	Dissolved Oxygen
E. coli	*Escherichia coli*
EPA	Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
EQuIS	Environmental Quality Information System
FWMC	Flow weighted mean concentration
GIS	Geographic Information Systems
GW	Groundwater
Hm^3/yr	Cubic hectometers per year = 1 million cubic meters per year = 817.66 acre feet per year
HUC	Hydrologic Unit Code
IBI	Index of Biological Integrity
in/yr	inches per year
ISTS	Individual Sewage Treatment System
ITPHS	Imminent Threat to Public Health and Safety
Kg	kilograms = 2.2 pounds
km^2	square kilometer = 247 acres
LA	Load Allocation
Lb	pound
lb/day	pounds per day
lb/yr	pounds per year
LDC	load duration curve
LGU	Local Government Unit
m	meter

MDH	Minnesota Department of Health
mg/L	milligrams per liter
mg/m^2-day	milligram per square meter per day = 0.009 pounds per acre per day
mL	milliliter
MLCCS	Minnesota Land Cover Classification System
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
MSDC	Minnesota State Demographic Center
NA	North American
NASS	National Agricultural Statistics Service
NCHF	North Central Hardwood Forests
NLCD	National Land Cover Dataset
NPDES	National Pollutant Discharge Elimination System
NRCS	National Resources Conservation Service
P	Phosphorus
RNR	River Nutrient Region
RR	Release rate
SDS	State Disposal System
SSTS	Subsurface Sewage Treatment Systems
STEPL	Spreadsheet Tool for Estimating Pollutant Load
SWCD	Soil and Water Conservation District
SWPPP	Stormwater Pollution Prevention Plan
T	Temperature
TMDL	Total Maximum Daily Load
TP	Total phosphorus
µg/L	microgram per liter
USDA	United States Department of Agriculture
USGS	United States Geological Survey
UV	Ultra Violet
WLA	Wasteload Allocation
WRAPS	Watershed Restoration and Protection Strategies
WWTF	Wastewater Treatment Facility

Executive Summary

The Clean Water Act (1972) requires that each State develop a plan to identify and restore any waterbody that is deemed impaired. A Total Maximum Daily Load Study (TMDL) is required by the Environmental Protection Agency (EPA) as a result of the federal Clean Water Act. A TMDL identifies the pollutant that is causing the impairment and how much of that pollutant can enter the waterbody and still meet water quality standards.

This TMDL study includes six lakes (excess nutrients) and three streams (E. coli) located in the Goose Creek Watershed (HUC 0703000502), a tributary to the St. Croix River in Eastern Minnesota, that are on the 2014 EPA's 303(d) list of impaired waters (or are expected to be listed on future lists). This watershed includes the smaller watersheds of Goose Creek, Rush Creek, and Rock Creek.

Information from multiple sources was used to evaluate the ecological health of each waterbody:

- All available water quality data over the past ten years
- Sediment phosphorus concentrations
- Fisheries surveys
- Plant surveys
- Stream field surveys
- Stressor identification investigations
- Stakeholder input

The following pollutant sources were evaluated for each lake or stream: watershed runoff, loading from upstream waterbodies, atmospheric deposition, lake internal loading, point sources, feedlots, septic systems, and in-stream alterations. An inventory of pollutant sources was used to develop a lake response model for each impaired lake and a load duration curve (LDC) model for each impaired stream. These models were then used to determine the pollutant reductions needed for the impaired waterbodies to meet water quality standards. Reductions in phosphorus ranging from 42% to 86% from baseline conditions are needed and reductions in *E. coli*, which vary depending upon flow regime, range from 0% to 72%.

The findings from this TMDL study will be used to aid the selection of implementation activities as part of the Goose Creek Watershed Restoration and Protection Strategy (WRAPS) process. The purpose of the WRAPS report is to support local working groups and jointly develop scientifically-supported restoration and protection strategies to be used for subsequent implementation planning. Following completion, the WRAPS report will be publically available on the Minnesota Pollution Control Agency (MPCA) Goose Creek Watershed website: http://www.pca.state.mn.us/hh89xpd.

1 Project Overview

1.1 Purpose

This TMDL study addresses aquatic recreation use impairments due to excess nutrients: phosphorus/ eutrophication in six lakes and aquatic recreation use impairments due to *E. coli* in three streams in the Goose Creek Watershed in Chisago and Pine Counties (Figure 1). The Goose Creek Watershed comprises the northern portion of the Lower St. Croix River Major Watershed (8-digit HUC: 07030005). This watershed is a 10-digit HUC (hydrologic unit code) and includes Goose Creek Watershed, Rush Creek Watershed, and Rock Creek Watershed, which are each 12-digit HUCs. The goal of this TMDL is to provide wasteload allocations (WLAs) and load allocations (LAs) and to quantify the pollutant reductions needed to meet the state water quality standards. These TMDLs are being established in accordance with section 303(d) of the Clean Water Act, because the State of Minnesota has determined that these lakes and streams exceed the state established standards.

Other completed studies for this watershed that were referenced in the development of this TMDL include:

- Rush Creek Watershed Surface Water Assessment Grant (SWAG) (Chisago SWCD 2009, 2010)
- Goose Creek Watershed SWAG (Chisago SWCD 2009, 2010)
- Rush Lake Clean Water Partnership Project (Steve McComas and Dave Schuler 2002)
- Lower St. Croix River Monitoring and Assessment Report (MPCA 2014)

The findings from this TMDL study will be used to aid the selection of implementation activities as part of the Goose Creek WRAPS. The purpose of the WRAPS report is to support local working groups and jointly develop scientifically-supported restoration and protection strategies to be used for subsequent implementation planning. Following completion, the TMDL and WRAPS reports will be publically available on the MPCA's Website:

Lower St. Croix River Watershed website: http://www.pca.state.mn.us/enzq104e

Goose Creek Watershed TMDL website: http://www.pca.state.mn.us/hh89xpd

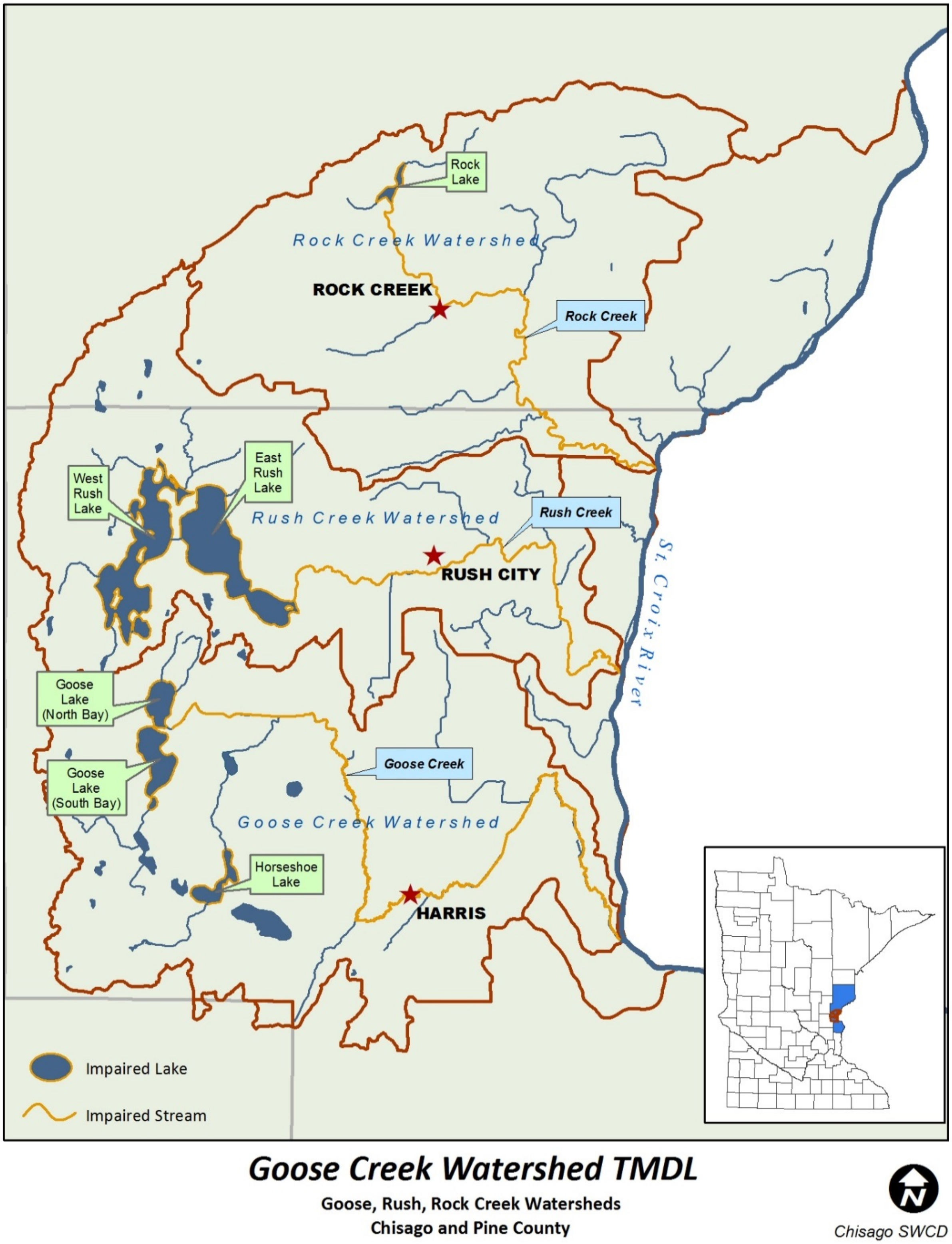

Figure 1. Goose Creek Watershed

1.2 Identification of Waterbodies

Table 1. Goose Creek Watershed Impaired Lakes and Streams

Affected Use: Pollutant/Stressor	AUID/ Lake ID	Stream or Lake Name	Location/Reach Description	Designated Use Class	Listing Year	Target Start/ Completion
Aquatic Recreation: Nutrient/Eutrophication Biological Indicators (Phosphorus)	13-0083-01	Goose Lake (North Bay)	5 miles SW of Rush City	2B, 3C	2008	2012/2015
	13-0083-02	Goose Lake (South Bay)	6 miles SW of Rush City	2B, 3C	2008	
	13-0073-00	Horseshoe Lake	4 miles WNW of Harris	2B, 3C	2010	
	58-0117-00	Rock Lake	Pine City	2B, 3C	2016*	
	13-0069-02	Rush Lake (West)	6 miles W of Rush City	2B, 3C	2008	
	13-0069-01	Rush Lake (East)	5 miles W of Rush City	2B, 3C	2008	
Aquatic Recreation: *Escherichia coli*	07030005-510	Goose Creek	Goose Lake to St. Croix River	2B, 3C	2012	
	07030005-584	Rock Creek	Rock Lake to St. Croix River	1B, 2Bd, 3C	2012	
	07030005-509	Rush Creek	Rush Lake to St. Croix River	1B, 2Bd, 3C	2010	

* Expected to be listed on the 2016 or 2018 303(d) Impaired Waters List.

1.3 Priority Ranking

The MPCA's projected schedule for TMDL completions, as indicated on the 303(d) impaired waters list, implicitly reflects Minnesota's priority ranking of this TMDL (Table 1). Ranking criteria for scheduling TMDL projects include, but are not limited to: impairment impacts on public health and aquatic life; public value of the impaired water resource; likelihood of completing the TMDL in an expedient manner, including a strong base of existing data and restorability of the waterbody; technical capability and willingness locally to assist with the TMDL; and appropriate sequencing of TMDLs within a watershed or basin.

1.4 Description of the Impairments and Stressors

1.4.1 Lake Eutrophication

The lake eutrophication impairments in the Goose Creek Watershed were characterized by phosphorus and chlorophyll-a (Chl-a) concentrations that exceed state water quality standards and Secchi transparency depths below the state water quality standards. Excessive nutrient loads, in particular total phosphorus, lead to an increase in algae blooms and reduced transparency – both of which may significantly impair or prohibit the use of lakes for aquatic recreation. Phosphorus lake response models and TMDLs were developed for all lake eutrophication impairments.

1.4.2 Stream *E. coli*

The stream bacteria impairments in the Goose Creek Watershed were characterized by high *E. coli* concentrations during April through October. Minnesota *E. coli* water quality standards were developed to directly protect for primary (swimming and other recreation where immersion and inadvertently ingesting water is likely) and secondary (boating and wading where the likelihood of ingesting water is much smaller) body contact during the warm season months since there is very little swimming in Minnesota in the cold season months. *E. coli* LDCs and TMDLs were developed for all stream *E. coli* impairments.

2 Applicable Water Quality Standards and Numeric Water Quality Targets

Each stream reach and lake has a Designated Use Classification defined by the MPCA, which defines the optimal purpose for that waterbody (see Table 1). The lakes and streams addressed by this TMDL fall into one of the following two designated use classifications:

1B, 2Bd, 3C – drinking water use after approved disinfectant; a healthy warm water aquatic community; industrial cooling and materials transport without a high level of treatment

2B, 3C – a healthy warm water aquatic community; industrial cooling and materials transport without a high level of treatment

Class 1 waters are protected for aquatic consumption, Class 2 waters are protected for aquatic life and aquatic recreation, and Class 3 waters are protected for industrial consumption as defined by Minn. R. ch. 7050.0140. The most protective of these classes is 1B, however water bodies are not currently being assessed by the MPCA for the beneficial use of domestic consumption; therefore water quality standards for the Class 1B waters are not presented here. The next most protective of these classes is 2B, for which water quality standards are provided below.

2.1 Lakes

Total phosphorus (TP) is often the limiting factor controlling primary production in freshwater lakes: as in-lake phosphorus concentrations increase, algal growth increases resulting in higher Chl-*a* concentrations and lower water transparency. In addition to meeting phosphorus limits, Chl-a and Secchi transparency depth standards must also be met. In developing the lake nutrient standards for Minnesota lakes (Minn. R. 7050), the MPCA evaluated data from a large cross-section of lakes within each of the state's ecoregions (Heiskary and Wilson 2005). Clear relationships were established between the causal factor TP and the response variables Chl-a and Secchi transparency. Based on these relationships it is expected that by meeting the phosphorus target in each lake, the Chl-a and Secchi standards will likewise be met. The impaired lakes within the Goose Creek Watershed are located within the Northern Central Hardwood Forests Ecoregion (NCHF). The applicable water quality standards by ecoregion are listed in Table 2.

In the NCHF Ecoregion, a separate water quality standard was developed for shallow lakes, which tend to have poorer water quality than deeper lakes in this ecoregion. According to the MPCA definition of shallow lakes, a lake is considered shallow if its maximum depth is less than 15 feet, or if the littoral zone (area where depth is less than 15 feet) covers at least 80% of the lake's surface area. North Goose Lake and Rock Lake are shallow according to this definition.

To be listed as impaired (Minn. R. 7050.0150, subp. 5), the summer growing season (June - September) monitoring data must show that the standards for both TP (the causal factor) and either Chl-a or Secchi transparency (the response variables) were violated. If a lake is impaired with respect to only one of these criteria, it may be placed on a review list; a weight of evidence approach is then used to determine if it will be listed as impaired. For more details regarding the listing process, see the *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 303(b) Report and 303(d) List* (MPCA 2012).

Table 2. Lake Eutrophication Standards

Ecoregion	TP (µg/L)	Chl-a (µg/L)	Secchi (m)
North Central Hardwood Forests: General (Deep) Including: Goose Lake (South Basin), Horseshoe Lake, Rush Lake (West), Rush Lake (East)	< 40	< 14	> 1.4
North Central Hardwood Forests: Shallow Lakes Including: Goose Lake (North Basin), Rock Lake	< 60	< 20	> 1.0

2.2 Streams

The Minnesota narrative water quality standard for all Class 2 waters (Minn. R. 7050.0150, subp. 3) states that "the aquatic habitat, which includes the waters of the state and stream bed, shall not be degraded in any material manner, there shall be no material increase in undesirable slime growths or aquatic plants, including algae, nor shall there be any significant increase in harmful pesticide or other residues in the waters, sediments, and aquatic flora and fauna; the normal fishery and lower aquatic biota upon which it is dependent and the use thereof shall not be seriously impaired or endangered, the species composition shall not be altered materially, and the propagation or migration of the fish and other biota normally present shall not be prevented or hindered by the discharge of any sewage, industrial waste, or other wastes to the waters".

Numeric water quality standards have been developed for bacteria (Minn. R. 7050.0222), in this case *Escherichia coli* (*E. coli*), which are protective concentrations for short- and long-term exposure to pathogens in water. The past fecal coliform and current *E. coli* numeric water quality standards for Class 2 waters are shown in Table 3. *E. coli* and fecal coliform are fecal bacteria used as indicators for waterborne pathogens that have the potential to cause human illness. Although most are harmless themselves, fecal indicator bacteria are used as an easy-to-measure surrogate to evaluate the suitability of recreational and drinking waters, specifically, the presence of pathogens and probability of illness. Pathogenic bacteria, viruses, and protozoa pose a health risk to humans, potentially causing illnesses with gastrointestinal symptoms (nausea, vomiting, fever, headache, and diarrhea), skin irritations, or other symptoms. Pathogen types and quantities vary among fecal sources; therefore, human health risk varies based on the source of fecal contamination.

This TMDL study will use the standard for *E. coli*. The change in the water quality standard from fecal coliform to *E. coli* is supported by an EPA guidance document on bacteriological criteria (EPA 1986). As of March 17, 2008, Minn. R. ch. 7050, water quality standards for *E. coli* are:

Escherichia (E.) coli - Not to exceed 126 organisms per 100 milliliters as a geometric mean of not less than five samples representative of conditions within any calendar month, nor shall more than 10% of all samples taken during any calendar month individually exceed 1,260 organisms per 100 milliliters. The standard applies only between April 1 and October 31.

Although surface water quality standards are now based on *E. coli*, wastewater treatment facilities (WWTFs) are permitted based on fecal coliform (not *E. coli*) concentrations.

Geometric mean is used in place of arithmetic mean in order to measure the central tendency of the data, dampening the effect that very high or very low values have on arithmetic means. The MPCA's *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List* provides details regarding how waters are assessed for conformance to the *E. coli* standard (MPCA 2012).

Table 3. Past and current numeric water quality standards of bacteria (fecal coliform and *E. coli*) for the beneficial use of aquatic recreation (primary and secondary body contact).

Past Standard	Units	Current Standard	Units	Notes
Fecal coliform	200 orgs per 100 ml	*E. coli*	126 orgs per 100 ml	Geometric mean of ≥5 samples per month (April - October)
Fecal coliform	2,000 orgs per 100 ml	*E. coli*	1,260 orgs per 100 ml	<10% of all samples per month (April - October) that individually exceed

3 Watershed and Water body Characterization

3.1 Lakes

The physical characteristics of the impaired lakes are listed in Table 4. Lake surface areas were digitized from 2010 aerial photography; lake volumes, mean depths, and littoral areas (< 15 feet) were calculated using the Minnesota Department of Natural Resources (DNR) depth contours and 2012 digitized surface areas; maximum depths were reported from the DNR Lake Finder website; and watershed areas and watershed to surface area ratios were calculated using DNR minor catchment Geographic Information Systems (GIS) data.

Table 4. Impaired lake physical characteristics. Note that the watershed area includes the surface area of the lake.

Lake	Surface area (ac)	Littoral area (% total area)	Volume (acre-feet)	Mean depth (feet)	Maximum depth (feet)	Watershed area (incl. lake area) (ac)	Watershed area : Surface area
Goose Lake (North Bay)	272	100	1,373	5.1	9	9,293	34:1
Goose Lake (South Bay)	447	45	6,409	14.3	55	7,696	17:1
Horseshoe Lake	224	59	2,917	13.0	53	4,055	18:1
Rock Lake	81	81	766	9.5	32	6,264	77:1
Rush Lake (West)	1,579	53	19,999	12.7	42	15,509	10:1
Rush Lake (East)	1,484	76	12,997	8.8	24	22,557	15:1

3.2 Streams

The direct drainage and total watershed areas of the impaired stream reaches are listed in Table 5. Total watershed and direct drainage areas were delineated from DNR minor catchment GIS data and USGS StreamStats (http://water.usgs.gov/osw/streamstats/). The direct drainage areas include only the area downstream of any impaired upstream lake or stream.

Table 5. Impaired stream direct drainage and total watershed areas

AUID	Name	Direct Drainage Area (ac)	Total Watershed Area (ac)	Upstream Impaired Water body
07030005-510	**Goose Creek**	31,461	44,809	Goose Lake (North Bay)
07030005-584	**Rock Creek**	29,818	36,141	Rock Lake
07030005-509	**Rush Creek**	14,600	36,514	Rush Lake (East)

3.3 Subwatersheds

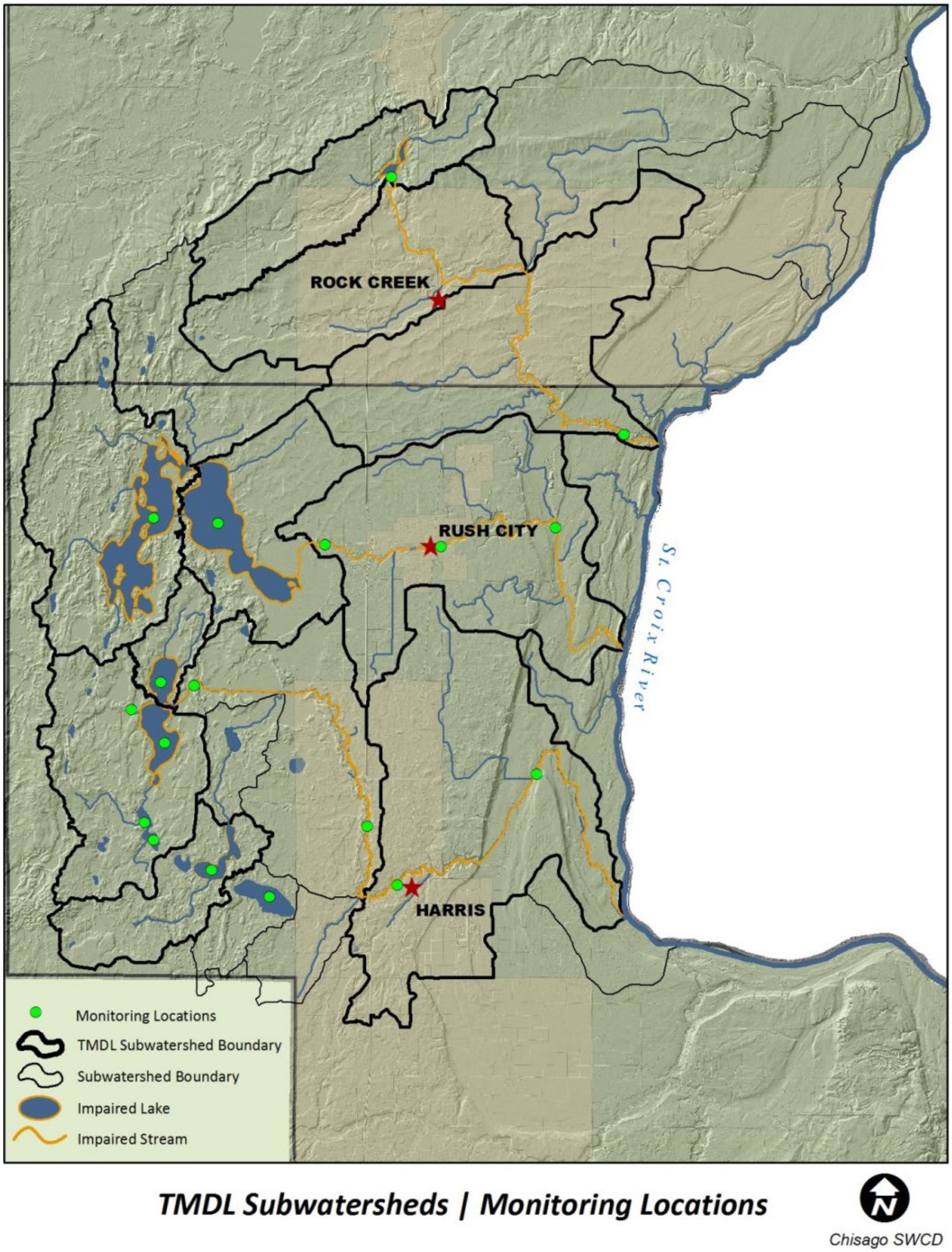

Figure 2. TMDL subwatersheds and monitoring locations

3.4 Land Use

The Goose Creek Watershed has varied cover types across the landscape. The northern half of the watershed is primarily row crop agriculture, while the southern half is a mixture of grassland, row crops, forest, and wetlands. The major lakes within the watershed are in the south western portion of the watershed. The majority of the land along the St. Croix River is forest and wetland. The watershed is sparsely populated outside the small communities of Harris and Rush City.

Table 6. Land cover by impaired lake subwatershed (NLCD 2006)

Land Cover Type	Goose Lake North Bay	Goose Lake South Bay	Horseshoe	Rock	West Rush	East Rush
Open Water	16.7%	7.7%	6.4%	1.6%	11.4%	21.8%
Developed	4.5%	6.0%	6.1%	6.7%	5.2%	4.6%
Woodland	8.7%	16.7%	20.4%	6.4%	11.2%	8.8%
Grass/Pasture/Hay	24.8%	31.3%	29.7%	41.1%	29.5%	17.0%
Cropland	23.0%	18.9%	24.2%	29.8%	20.4%	24.3%
Wetland	22.3%	19.5%	13.3%	14.5%	22.3%	23.5%

Table 7. Land cover by stream subwatershed (NLCD 2006)

Land Cover Type	Rock Creek	Rock - St. Croix	Rush Creek	Rush/ Goose - St. Croix	Goose Creek	Total Watershed
Open Water	0.3%	1.8%	9.3%	4.3%	3.5%	3.9%
Developed	6.5%	3.3%	6.7%	4.2%	6.4%	5.8%
Woodland	7.8%	41.4%	13.2%	42.9%	21.0%	19.4%
Grass/Pasture/Hay	37.4%	10.7%	27.9%	12.6%	28.4%	27.9%
Cropland	38.6%	10.0%	24.0%	13.5%	22.8%	26.5%
Wetland	9.3%	32.8%	18.9%	22.6%	18.0%	16.5%

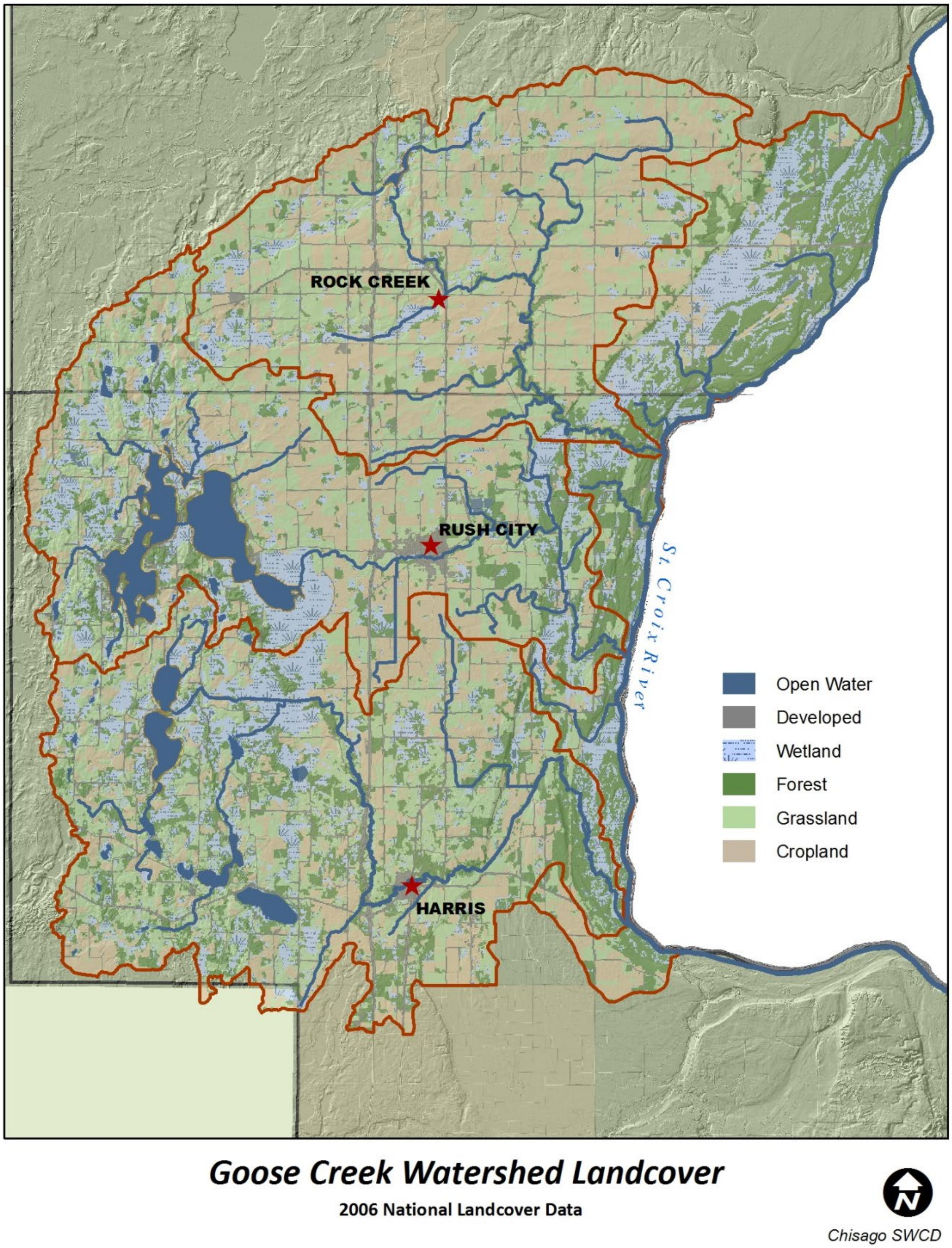

Figure 3. Goose Creek Watershed land cover

3.5 Current/Historic Water Quality

3.5.1 Lakes

The existing in-lake water quality conditions were quantified using data downloaded from the MPCA EQuIS database and available for the most recent 15-year time period (1998-2012). This time period was extended beyond the typical 10-year time period that the MPCA used to assess these lakes for nutrient impairments in the 2012 assessment cycle (MPCA 2012) to include intensive lake monitoring conducted in the watershed in 1998-2000. Growing season means of TP, Chl-a, and Secchi depth were calculated using monitoring data from the growing season (June through September). Information on the species and abundance of macrophyte and fish present within the lakes was compiled from DNR fisheries surveys and information from volunteer lake monitors, and summarized in Appendix D: Lake Summaries. The 15-year growing season mean TP, Chl-a, and Secchi for each impaired lake is listed in Table 8.

Table 8. 15-year growing season mean TP, Chl-*a*, and Secchi (1998-2012)

Lake Name	15-year (1998-2012) Growing Season Mean (June – September)					
	TP		Chl-*a*		Secchi	
	(µg/L)	CV	(µg/L)	CV	(m)	CV
NCHF – Shallow Lakes Standard	**< 60**	**--**	**< 20**	**--**	**> 1.0**	**--**
Goose Lake (North Basin)	170	16%	84	34%	0.7	4%
Rock Lake	193	7%	29	38%	1.1	30%
NCHF – General Standard	**< 40**	**--**	**< 14**	**--**	**> 1.4**	**--**
Goose Lake (South Basin)	55	41%	16	13%	1.9	3%
Horseshoe Lake	53	7%	26	20%	1.3	21%
Rush Lake (West)	65	7%	51	19%	1.0	16%
Rush Lake (East)	61	26%	33	39%	1.0	23%

CV = coefficient of variation, defined in BATHTUB as the standard error divided by the mean

3.5.2 Streams

Using data from the most recent 10-year period (2003-2012), geometric mean E. coli concentrations were calculated by month for the 3 stream reaches impaired for E. coli (Table 9, Figure 6, Figure 5, Figure 8, Figure 9). In general, E. coli concentrations in the impaired reaches were highest between June and August. The geometric means at each monitoring station, with the exception of S004-362 in Rock Creek, exceeded the water quality standard (126 org/100mL) in at least one month during the 10-year period.

Goose Creek

Table 9. 10-year geometric mean E. coli (org/100mL) concentrations by month in Goose Creek, 2003-2012
Geometric means that exceed the water quality standard of 126 org/100mL for which there are at least 5 samples are highlighted in bold font.

Monitoring Station (Upstream to downstream)	Month	Number of Samples	Geometric Mean (org/100mL)	Min – Max (org/100mL)
S005-526	July	4	253	78 - 816
	August	5	**334**	122 - 613
S000-410	April	3	9	4 - 15
	May	4	123	42 - 570
	June	9	**279**	98 - 730
	July	9	**198**	60 - 1,200
	August	9	**246**	130 - 490
	September	4	243	77 - 2,400
	October	2	99	98 - 100

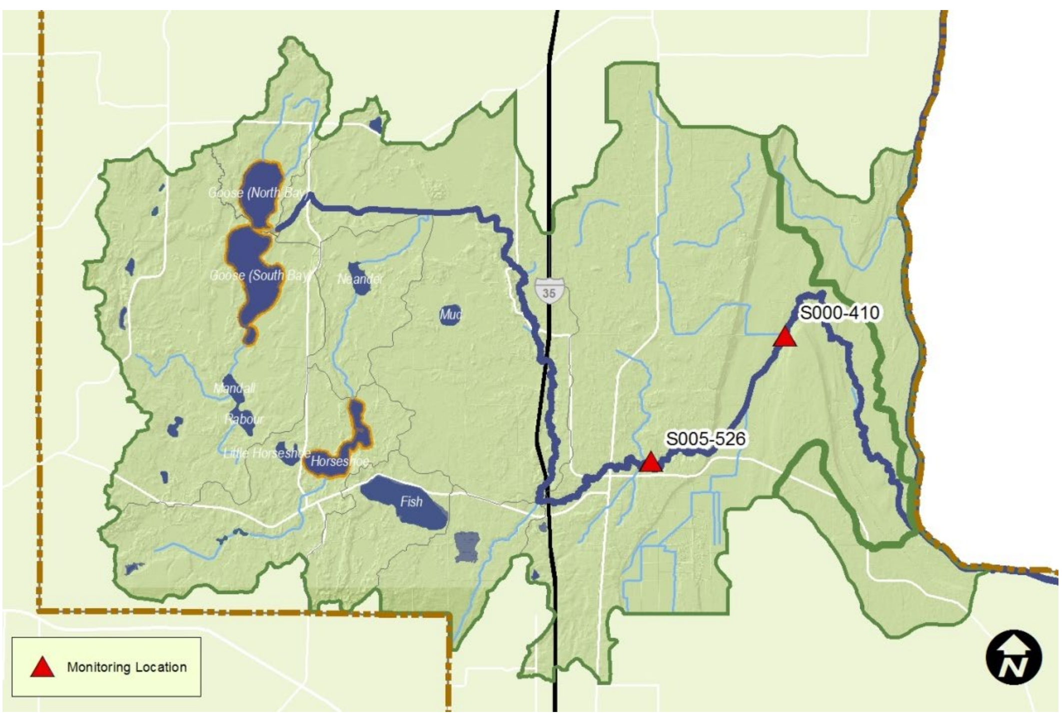

Figure 4. Goose Creek *E. coli* Monitoring Locations

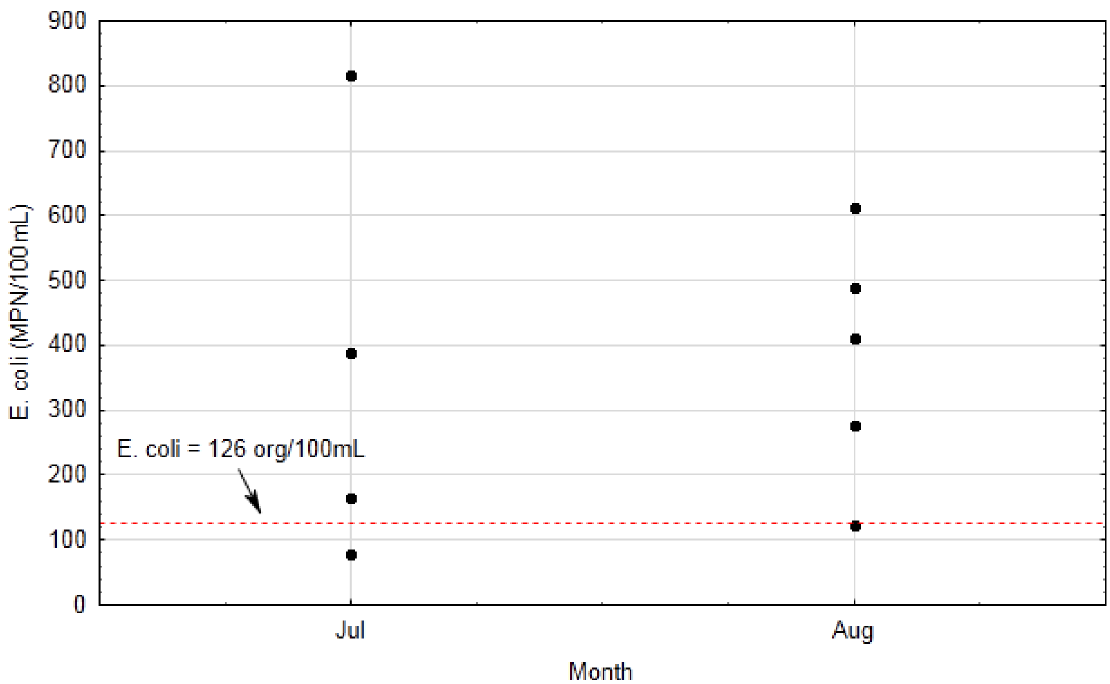

Figure 5. E. coli (MPN/100mL) by month in Goose Creek at monitoring station S005-526, 2003-2012
The dashed line represents the stream water quality standard (126 org/100mL)

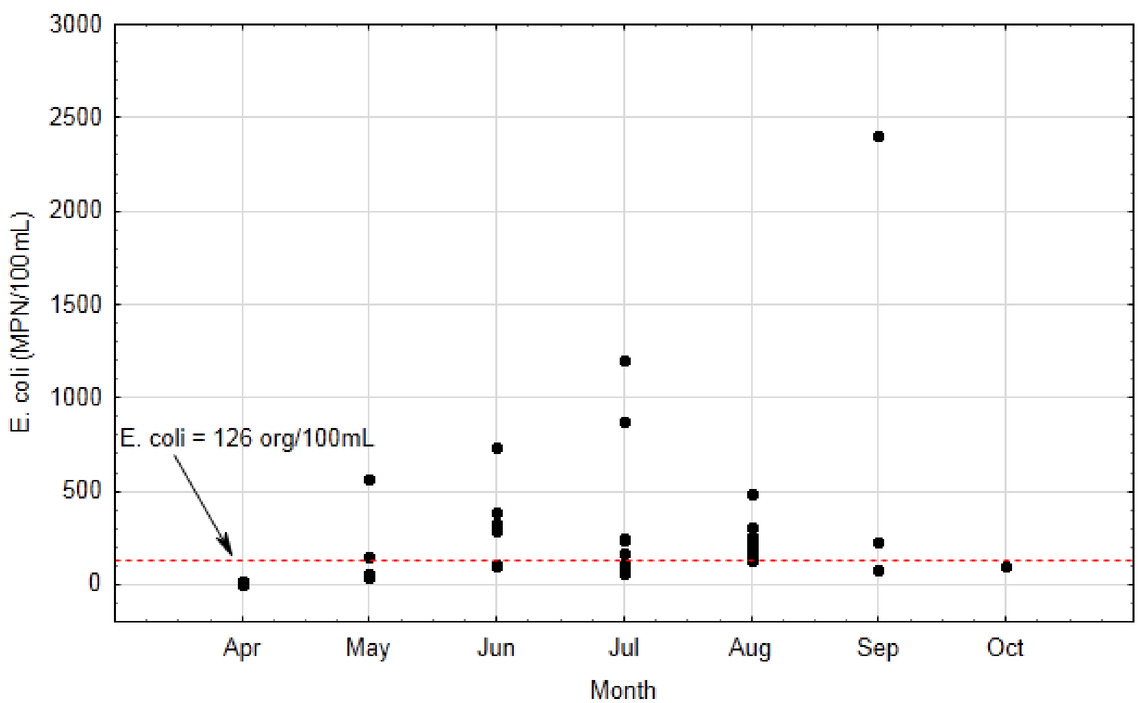

Figure 6. E. coli (MPN/100mL) by month in Goose Creek at monitoring station S000-410, 2003-2012
The dashed line represents the stream water quality standard (126 org/100mL)

Rock Creek

Table 10. 10-year geometric mean *E. coli* (org/100mL) concentrations by month in Rock Creek, 2003-2012
Geometric means that exceed the water quality standard of 126 org/100mL for which there are at least 5 samples are highlighted in bold font.

Monitoring Station	Month	Number of Samples	Geometric Mean (org/100mL)	Min – Max (org/100mL)
S005-532	June	5	**154**	50 - 770
	July	5	**238**	130 - 650
	August	5	**210**	74 - 1,300
S004-362	April	4	28	6 - 120
	May	4	136	34 - 2,400
	June	4	351	120 - 980
	July	4	100	59 - 130
	August	4	718	210 - 1,400
	September	4	217	91 - 1,000
	October	2	88	43 - 180

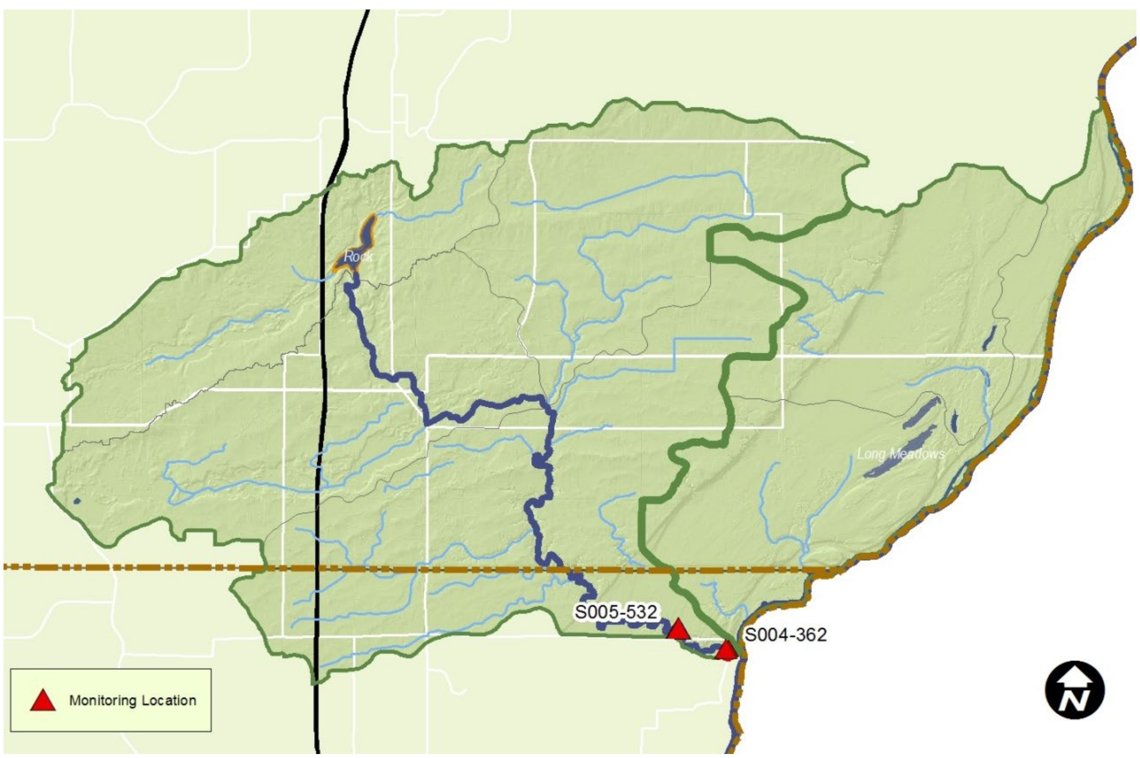

Figure 7. Rock Creek *E. coli* Monitoring Locations

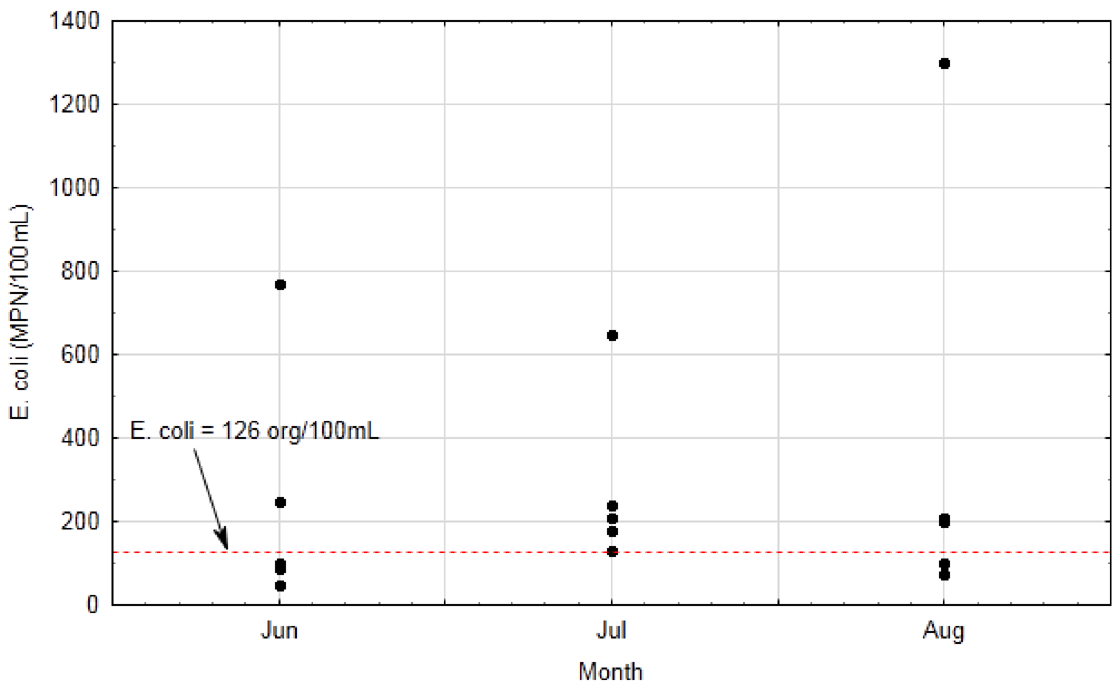

Figure 8. E. coli (MPN/100mL) by month in Rock Creek at monitoring station S005-532, 2003-2012
The dashed line represents the stream water quality standard (126 org/100mL)

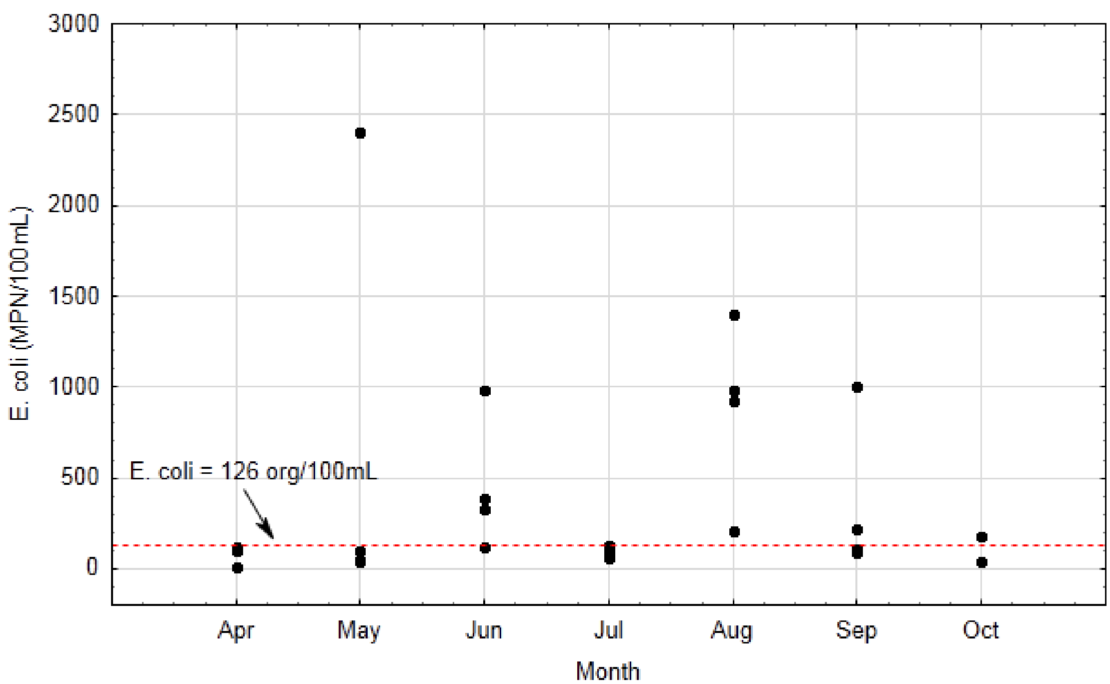

Figure 9. E. coli (MPN/100mL) by month in Rock Creek at monitoring station S004-362, 2003-2012
The dashed line represents the stream water quality standard (126 org/100mL)

Rush Creek

Table 11. 10-year geometric mean *E. coli* (org/100mL) concentrations by month in Rush Creek, 2003-2012
Geometric means that exceed the water quality standard of 126 org/100mL for which there are at least 5 samples are highlighted in bold font.

Monitoring Station	Month	Number of Samples	Geometric Mean (org/100mL)	Min – Max (org/100mL)
S000-125	April	2	6	4-8
	May	4	165	32-2,400
	June	9	**148**	52-1,400
	July	9	122	39-490
	August	9	**419**	110-1,600
	September	4	417	170-2,400
	October	2	38	23-64

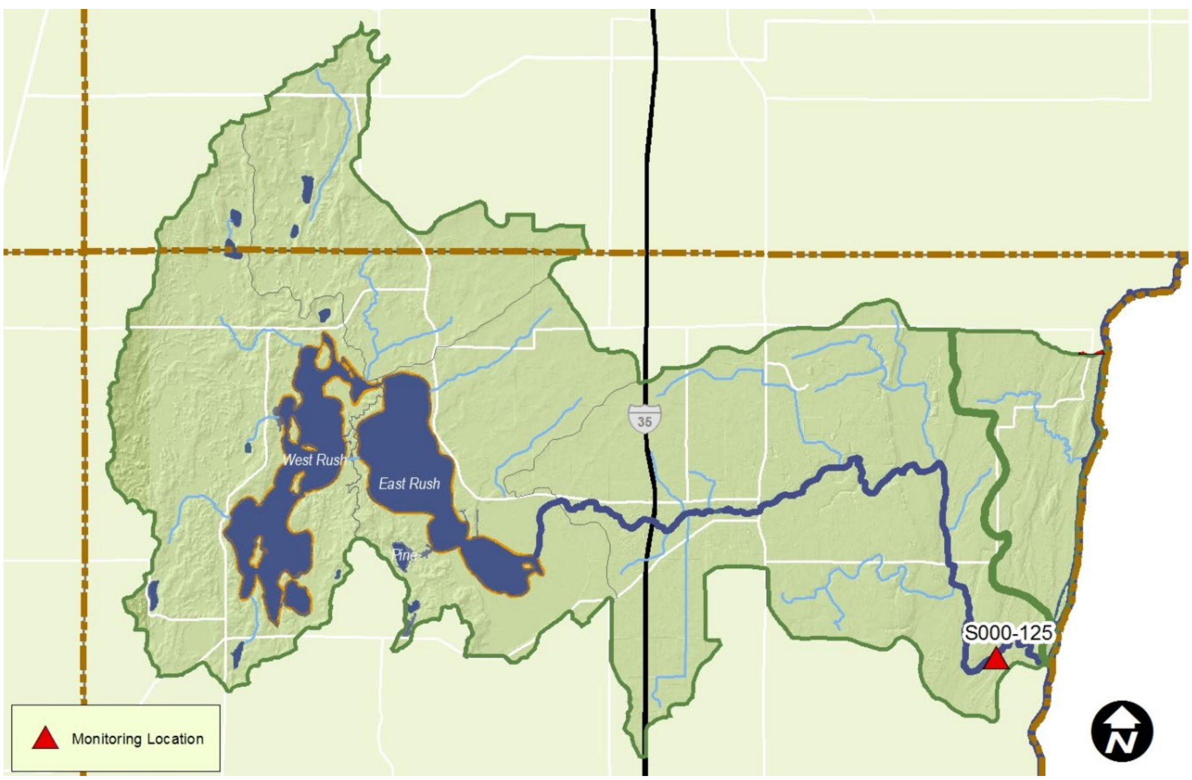

Figure 10. Rush Creek *E. coli* Monitoring Locations

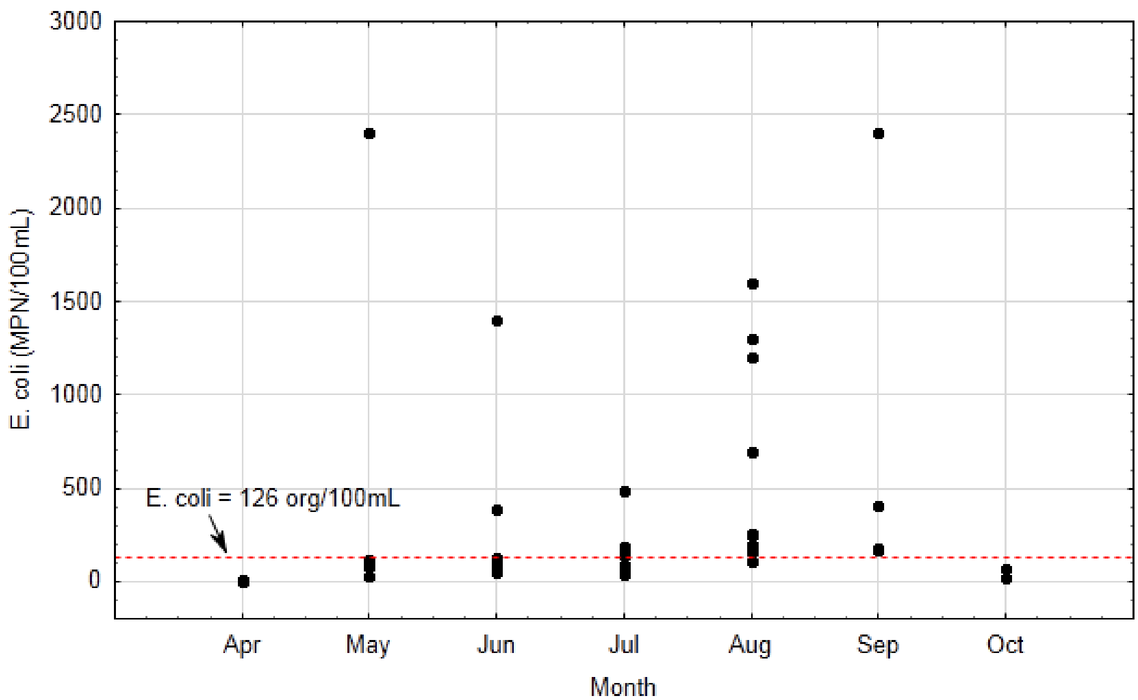

Figure 11. E. coli (MPN/100mL) by month in Rush Creek at monitoring station S000-125, 2003-2012
The dashed line represents the stream water quality standard (126 org/100mL)

3.6 Pollutant Source Summary

3.6.1 Total Phosphorus

A key component to developing a nutrient TMDL is an understanding of the sources contributing to the impairment. This section provides a brief description of the potential sources in the watershed contributing to excess nutrients in the impaired lakes and Goose and Rush Creeks addressed in this TMDL. The following sections discuss the major pollutant sources that have been quantified using collected monitoring data and water quality modeling to both assess the existing contributions of pollutant sources and target pollutant load reductions.

Phosphorus in lakes and streams often originates on land (called watershed runoff). Phosphorus from sources such as phosphorus-containing fertilizer, manure, and the decay of organic matter can adsorb to soil particles. Wind and water action erode the soil, detaching particles and conveying them in stormwater runoff to nearby waterbodies where the phosphorus becomes available for algal growth. Organic material such as leaves and grass clippings can leach dissolved phosphorus into standing water and runoff or be conveyed directly to waterbodies where biological action breaks down the organic matter and releases phosphorus.

Permitted Sources

The regulated sources of phosphorus within the watersheds of the eutrophication impairments addressed in this TMDL study include effluent from WWTF, construction sites, and industrial sites.

Phosphorus loads from WWTFs, construction, and industrial stormwater runoff were accounted for using the methods described in Section 4.1.3 below.

3.6.1.1 Non-permitted Sources

The following sources of phosphorus not requiring National Pollutant Discharge Elimination System (NPDES) Permit coverage were evaluated:

- Watershed runoff
- Loading from upstream waters
- Runoff from feedlots not requiring NPDES Permit coverage
- Shoreline septic systems
- Atmospheric deposition
- Lake internal loading

Direct drainage overland runoff

The EPA Spreadsheet Tool for Estimating Pollutant Load (STEPL) was used to estimate watershed runoff volumes and phosphorus loads from the direct drainage area of impaired lakes and streams (http://it.tetratech-ffx.com/steplweb/default.htm). The STEPL model estimates annual average overland runoff flow and phosphorus load by individual subwatershed based on land cover, runoff curve numbers, annual rainfall, and event mean concentrations. Note that the STEPL model resolution is coarse and intended as a planning tool. Watershed load estimates for lake water quality response models are usually derived based on the inputs used in this STEPL model and was an appropriate tool for these nutrient TMDLs. The STEPL model inputs and outputs are summarized in Appendix A. The STEPL model default CN values by land cover were used.

Phosphorus loads from specific sources within the watershed (upstream waters, feedlots not requiring NPDES Permit coverage, and subsurface sewage treatment systems (SSTS)) were also independently estimated to determine their relative contributions to the impaired lakes, as described below.

Table 12. STEPL annual average runoff flow and phosphorus loads for impaired and upstream lakes.
Note the direct drainage area excludes the lake area and the area of upstream lakes and their watersheds (see Table 13). Upstream lakes are in italics.

Impaired or Upstream Lake	Drainage Area* (ac)	Flow (ac-ft/yr)	TP Conc. (µg/L)	TP Load (lb/yr)
Goose Lake (North Bay)	1,325	985	206	546
Goose Lake (South Bay)	3,534	2,401	176	1,137
Horseshoe Lake	3,347	1,897	240	1,225
Rock Lake	6,182	3,696	262	2,608

Impaired or Upstream Lake	Drainage Area* (ac)	Flow (ac-ft/yr)	TP Conc. (µg/L)	TP Load (lb/yr)
Rush Lake (West)	13,930	9,804	161	4,245
Rush Lake (East)	5,563	4,342	169	1,973
Little Horseshoe Lake (upstream of Horseshoe)	*436*	*257*	*240*	*166*
Mandall Lake (upstream of Goose South)	*2,210*	*1,361*	*176*	*645*
Rabour Lake (upstream of Mandall)	*1,406*	*879*	*176*	*416*

*Drainage area excludes the lake area and the area of upstream lakes and their watersheds (see Table 13)

Upstream lakes

Upstream lakes can contribute significant phosphorus loads to downstream impaired lakes and streams. In-lake 15-year growing season mean phosphorus concentrations and BATHTUB modeled flow for upstream lakes were used to estimate their phosphorus loads to downstream impaired waters and are summarized in Table 13. For impaired lakes not listed in Table 13, no upstream lakes or tributaries were explicitly modeled. In-lake nutrient concentrations for Rabour, Mandall, and Little Horseshoe lakes were estimated using BATHTUB because monitored water quality data was not available.

Table 13. Existing upstream phosphorus loads to impaired lakes

Upstream Lake (Lake ID)	Impaired Lake	Upstream Lake Watershed Area, including lake (ac)	Flow (ac-ft/yr)	TP Conc. (µg/L)	TP Load (lb/yr)
Goose Lake (South Bay) (13-0083-02)	Goose Lake (North Bay)	7,696	4,442	55.4	664
Mandall Lake (13-0074-00)	Goose Lake (South Bay)	3,714	2,204	84.6	503
Little Horseshoe Lake (13-0080-00)	Horseshoe Lake	484	239	54.5	35
Rush Lake (West) (13-0069-02)	Rush Lake (East)	15,509	9,229	64.5	1,605

Feedlots not requiring NPDES permit coverage

Runoff during precipitation and snow melt can carry phosphorus from uncovered feedlots to nearby surface waters. For the purpose of this study, non-permitted feedlots are defined as being all registered feedlots without an NPDES/SDS Permit that house under 1,000 animal units (AUs). While these feedlots do not fall under NPDES regulation, other regulations still apply. Phosphorus loads from non-permitted registered feedlots were estimated based on assumptions described in Appendix D of the *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds* (MPCA 2004, http://www.pca.state.mn.us/index.php/view-document.html?gid=3980) and a windshield survey conducted by the Chisago County Soil and Water Conservation District (SWCD) in 2014 listed in Table 14.

Table 14. Feedlot assumptions and phosphorus loads to impaired lakes and streams

Impaired Lake	Beef Cattle		Dairy cows		Total P generated	Fraction of feedlots contributing to waters	P fraction lost to surface waters (average flow)	Total Annual Feedlot Load
	AU	lb/ AU-yr*	AU	lb/ AU-yr*	lb/yr	%*	%**	lb/yr
Goose Lake (North Bay)	10	33.5	0	47.8	335	35	0.62	1
Goose Lake (South Bay)	153	33.5	0	47.8	5,126	35	0.62	11
Horseshoe Lake	0	33.5	0	47.8	0	35	n/a	0
Rock Lake	101	33.5	320	47.8	18,680	35	0.57	38
Rush Lake (West)	55	33.5	30	47.8	3,277	35	0.60	7
Rush Lake (East)	55	33.5	0	47.8	1,843	35	0.62	4

* Values from Table 1 in Appendix D of MPCA 2004, http://www.pca.state.mn.us/index.php/view-document.html?gid=3980

**Based on weighted average P fraction lost to surface waters based on animal type in the St. Croix Basin for average flow condition (Beef = 0.62%, Dairy = 0.56%) from Table 1 in Appendix D of MPCA 2004, http://www.pca.state.mn.us/index.php/view-document.html?gid=3980

Subsurface sewage treatment systems (SSTS)

Phosphorus loads from SSTS were estimated based on assumptions described in the *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds* (MPCA 2004) and county specific estimates of failing septic system rates, as listed in Table 15. The number and failure rate of SSTS were determined from the *2012 SSTS Annual Report* (MPCA 2012). In 2012 Chisago County inspected 8,121 individual septic systems representing 64% of all systems in the county. Of the systems inspected, 1,461, or 18%, were found to be failing. Pine County inspected 4,895 individual septic systems representing 47% of all systems in the county. Of the systems inspected, 3,133, or 64%, were found to be failing. The Pine County failure rate of 64% applies to Rock Lake; the Chisago County failure rate (18%) applies to the other five lakes.

Table 15. SSTS phosphorus loads to impaired lakes and assumptions

Impaired Lake	Shoreline SSTS	Seasonal residence (4 mo/yr)	Permanent Residence	Conforming Systems	Failing Systems	Capita per Residence*	P Production per Capita***	Conforming SSTS %P "passing"	Failing SSTS %P "passing"	Conforming Systems	Failing Systems	P Load Conforming SSTS***	P Load Failing SSTS***	Total Shoreline SSTS P Load**	Total Shoreline SSTS P Load due to Failing
	#	%	%	%	%	#	lb/yr	%	%	#	#	lb/yr	lb/yr	lb/yr	lb/yr
Goose Lake (North Bay)	38	10%	90%	82%	18%	2.63	1.95	20%	43%	31	7	30	14	44	8
Goose Lake (South Bay)	54	10%	90%	82%	18%	2.63	1.95	20%	43%	44	10	42	21	63	11
Horseshoe Lake	51	10%	90%	82%	18%	2.63	1.95	20%	43%	42	9	40	19	59	10
Rock Lake	5	10%	90%	36%	64%	2.32	1.95	20%	43%	2	3	2	5	7	3
Rush Lake (West)	192	10%	90%	82%	18%	2.60	1.95	20%	43%	157	35	149	71	220	38
Rush Lake (East)	262	10%	90%	82%	18%	2.55	1.95	20%	43%	215	47	200	94	294	50

*2007-2011, U.S. census bureau, http://quickfacts.census.gov/qfd/maps/minnesota_map.html

**Used to estimate a total watershed load in BATHTUB.

***From MPCA 2004

Atmospheric Deposition

Atmospheric deposition represents the phosphorus that is bound to particulates in the atmosphere and is deposited directly onto surface waters. Average phosphorus atmospheric deposition loading rates were 0.24 lb/ac of TP per year for an average rainfall year for the St. Croix River Basin (Barr 2007 addendum to MPCA 2004). This rate was applied to the lake surface area to determine the total atmospheric deposition load per year to the impaired lakes and streams.

Table 16. Atmospheric deposition phosphorus loads to impaired lakes [MPCA 2004]

Impaired Lake	Atmospheric Deposition Phosphorus Load (lb/yr)
Goose Lake (North Bay)	66
Goose Lake (South Bay)	108
Horseshoe Lake	55
Rock Lake	20
Rush Lake (West)	381
Rush Lake (East)	357

Internal Loading

Internal loading in lakes refers to the phosphorus load that originates in the bottom sediments or macrophytes and is released back into the water column. Internal loading can occur via:

1. **Chemical release from the sediments** caused by anoxic (lack of oxygen) conditions in the overlying waters or high pH (>9). If a lake's hypolimnion (bottom area) remains anoxic for a portion of the growing season, the phosphorus released due to anoxia will be mixed throughout the water column when the lake loses its stratification at the time of fall mixing. In shallow lakes, the periods of anoxia can last for short periods of time and occur frequently.
2. **Physical disturbance of the sediments** caused by bottom-feeding fish behaviors (such as carp and bullhead), motorized boat activity, and wind mixing. This is more common in shallow lakes than in deeper lakes.
3. **Decaying plant matter**, specifically curly-leaf pondweed (Potamogeton crispus), which is an invasive plant that dies back mid-summer. This is during the season to which the TMDL will apply and when water temperatures can accelerate algal growth.

Internal loading due to the anoxic release from the sediments of each lake was estimated in this study based on the expected release rate (RR) of phosphorus from the lakebed sediment, the lake anoxic factor (AF), and the lake area. Lake sediment samples were taken and tested for concentration of TP and bicarbonate dithionite extractable phosphorus (BD-P), which analyzes iron-bound phosphorus.

Phosphorus RRs were calculated using statistical regression equations developed using measured RRs and sediment P concentrations from a large set of North American lakes (Nürnberg 1988; Nürnberg 1996). Internal loading due to physical disturbance and decaying curly-leaf pondweed is difficult to estimate reliably and was therefore not included in the lake phosphorus analyses. In lakes where internal loading due to these sources is believed to be substantial, the internal load estimates derived from lake sediment data presented here are likely an underestimate of the actual internal load.

Because some amount of internal loading is explicit in the BATHTUB lake water quality model and uncertainty exists around the amount of internal loading estimated by the Nurnberg regression equations, the estimated total sediment phosphorus RRs per anoxic day converted to a 365-calendar day were used as a reference point for calibrating each impaired lake BATHTUB model to observed in-lake phosphorus concentrations (see Section 4.1.1.1: Internal Load). Moreover, the internal loading rates estimated by the Nurnberg regression equations represent the total potential sediment RR while the calibrated internal loading rates from the BATHTUB model represents the excess sediment RR beyond the average background RR accounted for by the model development lake dataset.

The estimated sediment phosphorus RRs using the Nurnberg regression equations are typically smaller than the calibrated BATHTUB RRs for shallow lakes because the BATHTUB model development lake dataset is less representative of this lake type and therefore accounts for less implicit internal loading in shallow lakes. This was the case for Rock Lake and Goose Lake North. Both lakes are very shallow and sediments can easily be disturbed by wind-driven mixing of the water column or physical disturbance from boats, fish and grazing animals. Curly leaf pondweed has also been present in Goose Lake North since 1971 and can contribute to phosphorus internal loading due to its unique life cycle and senescence during mid-summer.

For Goose Lake South, Horseshoe Lake, Rush lake East and Rush Lake West, the calibrated BATHTUB RRs were less than the estimated sediment phosphorus RRs using the Nurnberg regression equations or zero, indicating that some or all of the internal loading in these lakes was accounted for by average background RRs from the model development lake dataset.

Table 17. Internal phosphorus load assumptions and summary

Lake	Lake Type	Monitored Sediment P Concentration (mg/kg dry)		Calculated Anoxic Factor	Calculated Total Sediment Release Rate** (mg/m^2-anoxic day)			Calculated Total Sediment P Release Rate***	BATHTUB Modeled Excess Release Rate	BATHTUB Modeled Excess Internal Load
		Iron P*	Total P	(days)	Iron P*	Total P	Average	(mg/m^2-day)	(mg/m^2-day)	(lb/yr)
Goose Lake (North Bay)	Shallow	41	1,300	77	-	0.72	0.72	0.15	4.505	3,993
Goose Lake (South Bay)	General	530	2,400	53	6.69	4.87	5.78	0.84	0.157	229
Horseshoe Lake	General	440	7,300	53	5.46	23.34	14.40	2.10	0	0
Rock Lake	Shallow	140	5,400	82	1.34	16.18	8.76	1.97	19.08	5,035
Rush Lake (West)	General	490	4,700	56	6.14	13.54	9.84	1.50	0.375	1,929
Rush Lake (East)	General	240	1,200	56	2.71	0.34	1.53	0.23	0.31	1,499

* Iron adsorbed phosphorus bicarbonate dithionite extractable phosphorus

** Phosphorus RRs were calculated from the monitored sediment iron P and total P concentrations for each lake using statistical regression equations developed using measured RRs and sediment P concentrations from a large set of North American lakes (Nürnberg 1988; Nürnberg 1996)

*** Total sediment phosphorus RRs per anoxic day were multiplied by the number of anoxic days and divided by 365 days

3.6.2 *E. coli*

Humans, pets, livestock, and wildlife all contribute bacteria to the environment. These bacteria, after appearing in animal waste, are dispersed throughout the environment by an array of natural and man-made mechanisms. Bacteria fate and transport is affected by disposal and treatment mechanisms, methods of manure reuse, imperviousness of land surfaces, and natural decay and die-off due to environmental factors such as ultraviolet (UV) exposure and detention time in the landscape. The following discussion highlights sources of bacteria in the environment and mechanisms that drive the delivery of bacteria to surface waters.

To evaluate the potential sources of bacteria to surface waters a windshield survey of livestock was conducted in the Goose Creek Watershed. In addition, a desktop analysis was conducted for other sources that are potentially contributing *E. coli* in the watershed. These populations may include humans, companion animals (horses, cats and dogs), and wildlife (deer, geese, ducks, and raccoons).

Populations were calculated using published estimates for each source on an individual subwatershed basis in the TMDL Project Area. This is typically a GIS exercise where population estimates are clipped to the individual subwatershed boundaries. In some cases, these population estimates are clipped to individual land uses (defined using the 2006 National Land Cover Dataset, NLCD) within a subwatershed. For example, duck population estimates are assigned to open water land uses.

Bacteria production estimates are based on the bacteria content in feces and an average excretion rate (with units of colony forming units (cfu)/day-head; where *head* implies an individual animal). Bacteria content and excretion rates vary by animal type, as shown in Table 18. All production rates obtained from the literature are for fecal coliform rather than *E. coli* due to the lack of *E. coli* data. The fecal coliform production rates were converted to E. coli production rates based on 200 fecal coliforms to 126 E. coli per 100 mL (see discussion of E. coli water quality standard in Section 2.2).

Table 18. Bacteria production by source

Source Category	Producer	*E. coli* Production Rate [cfu/day-head]	Literature Source
Humans	Humans	1.26×10^{9}	Metcalf and Eddy 1991
Companion Animals	Dogs & Cats	3.15×10^{9}	Horsley and Witten 1996
Livestock	Horses	2.65×10^{10}	Zeckoski et al. 2005
	Cattle	2.08×10^{10}	Zeckoski et al. 2005
	Hogs	6.93×10^{9}	Zeckoski et al. 2005
	Sheep	7.56×10^{9}	Zeckoski et al. 2005
	Goats	1.76×10^{10}	Zeckoski et al. 2005
	Chickens & Turkeys	6.76×10^{7}	Zeckoski et al. 2005
Wildlife	Deer	2.21×10^{8}	Zeckoski et al. 2005
	Geese	5.04×10^{8}	Zeckoski et al. 2005
	Ducks	1.51×10^{9}	Zeckoski et al. 2005
	Raccoons	3.15×10^{7}	Zeckoski et al. 2005
	Beavers	1.3×10^{8}	EPA Best Professional Judgment in Bacterial Indicator Tool

3.6.2.1 Permitted

Wastewater Treatment Facilities

The WWTFs are required to test fecal coliform bacteria levels in effluent on a weekly basis. Dischargers to Class 2 waters are required to disinfect from April through October. Wastewater disinfection is required during all months for dischargers within 25 miles of a water intake for a potable water supply system (Minn. R. ch. 7053.0215, subp. 1). The geometric mean for all samples collected in a month must not exceed 200 cfu/ 100 mL fecal coliform bacteria. The WWTFs located in the Goose Creek Watershed with surface water discharges are summarized in Table 19. Bacteria loads from NPDES-permitted WWTFs was estimated based on the design flow and permitted bacteria effluent limit of 200 org/ 100 mL (Table 19).

Table 19. WWTF design flows and permitted bacteria loads

Subbasin	Name of WWTF	Permit No.	Design Flow [mgd]	Permitted Bacteria Load as Fecal Coliform: 200 org/ 100 mL [billion org/day]	Equivalent Bacteria Load as *E. coli*: 126 org / 100 mL[1] [billion org/day]
Lower Goose Creek	Harris WWTP	MN0050130	0.121	0.92	0.58
Rush Creek	Rush City WWTP	MN0021342	0.3995	3.02	1.91
Rush Creek	Shorewood Park Sanitary District	MN0051390	0.015	0.11	0.07

[1] WWTF permits are regulated for fecal coliform, not *E. coli*. The MPCA surface water quality standard for *E. coli* (126 org / 100 ml) was used in place of the fecal coliform permitted limit of 200 org / 100 ml, which was also the MPCA surface water quality standard prior to the March 2008 revisions to Minn. R. ch. 7050.

Land Application of Biosolids

The application of biosolids from WWTFs is highly regulated, monitored, and tracked (see Minn. R. ch. 7041, *Sewage Sludge Management*). Biosolids disposal methods that inject or incorporate within 24-hours of land application result in minimal possibility for mobilization of bacteria to downstream surface waters. While surface application could conceivably present a risk to surface waters, little to no runoff and bacteria transport is expected if permit restrictions are followed. Therefore, land application of biosolids was not included as a source of bacteria.

3.6.2.2 Non-permitted

Humans

Sewered (connected to a WWTF) and unsewered (connected to an SSTS) populations and number of households were determined using the 2010 Census data (U.S. Census Bureau 2011). Total population and the number of households were obtained for each subwatershed using block groups[1]; census block groups that overlap subwatershed boundaries were distributed between each applicable subwatershed on an area-weighted basis. Populations located in a sewered community were estimated from census block group data and municipal sewered boundaries provided by the city of Harris and Rush City. A summary of the sewered and unsewered population and households by subwatershed are shown in Table 20.

Table 20. Sewered and unsewered population and households by subwatershed

Subbasin	Population			Households		
	Sewered	Unsewered	Total	Sewered	Unsewered	Total
Fish Lake	0	166	166	0	94	94
Goose Lake North Bay	0	161	161	0	72	72
Goose Lake South Bay	0	711	711	0	340	340
Horseshoe Lake	0	490	490	0	198	198
Lagoo Creek-St. Croix River	0	316	316	0	118	118
Long Meadows Lake-St. Croix River N	0	231	231	0	99	99
Long Meadows Lake-St. Croix River S	0	193	193	0	119	119
Lower Goose Creek	88	1,453	1,541	40	549	589
Mud Lake	0	458	458	0	196	196
Neander Lake	0	108	108	0	49	49
Rock Creek E	0	566	566	0	227	227
Rock Creek N	0	309	309	0	131	131
Rock Creek S	0	852	852	0	324	324
Rock Lake	0	474	474	0	191	191
Rush Creek	1,959	1,583	3,542	845	246	1,091
Rush Lake	0	275	275	0	98	98
Rush Lake E	0	508	508	0	278	278
Rush Lake W	0	827	827	0	473	473
Upper Goose Creek	0	113	113	0	44	44

Combined Sewer Overflows

[1] A census block in an urban area typically corresponds to individual city blocks bounded by streets; blocks in rural areas may include many square miles and may have some boundaries that are not streets. A block group is a group of census blocks. A block group is smaller than a census tract, which is a small statistical subdivision of a county (e.g. a municipality or a portion of a large city).

Combined sewer systems are designed to collect sanitary sewage and stormwater runoff in a single pipe system. These systems overflow occasionally when heavy rain or melting snow causes the wastewater volume to exceed the capacity of the sewer system or treatment plant. An overflow event is called a combined sewer overflow (CSO), which entails a mix of raw sewage and stormwater runoff (from buildings, parking lots, and streets) flowing untreated into surface waters. The occurrence of CSOs is not known to be an issue in the Goose Creek Watershed.

Illicit Discharges from Unsewered Communities

In many cases, onsite or small community cluster systems to treat wastewater are installed and forgotten until problems arise. Residential lots in small communities throughout Minnesota cannot accommodate modern septic systems that meet the requirements of current codes due to small lot size and/or inadequate soils. In addition, many small communities are characterized by outdated, malfunctioning septic systems serving older residences. Small lots, poor soils, and inadequate septic system designs and installations may be implicated in bacterial contamination of groundwater (GW) but the link to surface water contamination is tenuous.

"Failing" SSTS are specifically defined as systems that are failing to protect GW from contamination. Failing SSTS were not considered a source of fecal pollution to surface water. However, systems which discharge partially treated sewage to the ground surface, road ditches, tile lines, and directly into streams, rivers and lakes are considered an imminent threat to public health and safety (ITPHS). The ITPHS systems also include illicit discharges from unsewered communities (sometimes called "straight-pipes"). Straight pipes are illegal and pose an imminent threat to public health as they convey raw sewage from homes and businesses directly to surface water. Community straight pipes are more commonly found in small rural communities.

The MPCA's 2012, SSTS Annual Report identifies percent of systems in unsewered communities that are ITPHS for each county in Minnesota (MPCA 2013; Table 21). Bacteria load from ITPHS was estimated by subwatershed based on these percentages, the unsewered population (Table 20), and the bacteria production rate of humans (Table 18). Note that ITPHS data are derived from surveys of County staff and County level Subsurface Sewage Treatment System (SSTS) status inventories. The table is not intended to suggest that ITPHS systems contribute excess bacteria to specific waterbodies addressed in this report; rather it suggests that, in general, ITPHS are believed to occur in the project area.

Table 21. Estimate of % Imminent Threat to Public Health & Safety Systems (ITPHSS) by County (MPCA 2013)

County	%ITPHSS
Chisago	0%
Pine	26%

Land Application of Septage

A state SSTS license applicable to the type of work being performed is required for any business that conducts work to design, install, repair, maintain, operate, or inspect all or part of an SSTS. A license is also required to land spread septage and operate a sewage collection system discharging to an SSTS. Disposal contractors are required to properly treat and disinfect septage through processing or lime stabilization. Treated septage may then be disposed of onto agricultural and forest lands. The EPA Standards Section 503 provides general requirements, pollutant limits, management practices, and operational standards for the final use or disposal of septage generated during the treatment of domestic sewage in a treatment works.

The MPCA does not directly regulate the land application of septage, but management guidelines entail site suitability requirements with respect to soil conditions, slope, and minimum separation distances (MPCA 2002). Some cities and townships have SSTS septage ordinances (a list is available at http://www.pca.state.mn.us/index.php/view-document.html?gid=10139); these were not reviewed as a part of this study, and application of septage was not included as a source of fecal pollution in this study.

Companion Animals

Companion animals (dogs and cats) can contribute bacteria to a watershed when their waste is not properly managed. When this occurs, bacteria can be introduced to waterways from:

- Dog parks
- Residential yard runoff (spring runoff after winter accumulation)
- Rural areas where there are no pet cleanup ordinances
- Animal elimination of excrement directly into waterbodies

Dog waste can be a significant source of pathogen contamination of water resources (Geldreich 1996). Dog waste in the immediate vicinity of a waterway could be a significant local source with local water quality impacts. However, it is generally thought that these sources may be only minor contributors of fecal contamination on a watershed scale because the estimated magnitude of this source is very small compared to other sources. According to the American Veterinary Medical Association's (AVMA) 2006 data, 34.2% of Minnesota households own dogs with a mean number of 1.4 dogs in each of those households (AVMA 2007). In addition, it was assumed that only 38% of dog waste is not collected by owners and can contribute fecal pollution to surface waters (TBEP 2012). Bacteria load from dogs was estimated based on total households in each subwatershed (Table 20), the assumptions mentioned in this paragraph, and the bacteria production rate of dogs (Table 18).

Domestic cats, even those that spend some time outdoors, are most likely to have their waste collected indoors and were not considered a source of bacteria for this study. Feral cats may contribute significantly to bacteria levels in urban streams and rivers (Ram et al. 2007). However, feral cat populations are unknown and were not included in this study.

Livestock

The total number of livestock in each subwatershed was estimated through a windshield survey conducted by Chisago SWCD and Pine County staff during the summer of 2014 (Table 22).

Table 22. Livestock windshield survey results by subwatershed

	Grazing				Confined
Subbasin	Cows	Horses	Goats	Sheep	Cows
Fish Lake	8	12	0	0	0

Goose Lake North Bay	10	0	0	0	0
Goose Lake South Bay	46	12	0	7	0
Horseshoe Lake	57	17	7	0	0
Lagoo Creek-St. Croix River	70	37	0	0	0
Little Horseshoe Lake	3	2	0	0	0
Long Meadows Lake-St. Croix River N	0	15	0	0	0
Long Meadows Lake-St. Croix River S	43	2	0	0	0
Lower Goose Creek	221	121	55	30	0
Mandall Lake	65	19	0	0	0
Mud Lake	182	12	2	0	0
Neander Lake	40	2	0	0	0
Rabour Lake	40	41	0	0	0
Rock Creek E	751	61	0	0	0
Rock Creek N	455	21	0	47	0
Rock Creek S	263	32	0	20	0
Rock Lake	421	21	0	0	0
Rush Creek	464	79	0	200	250
Rush Lake	98	30	0	0	0
Rush Lake E	255	0	0	0	0
Rush Lake W	80	75	0	0	0
Upper Goose Creek	40	26	0	0	0

Animal Feeding Operations

Animal waste containing fecal bacteria can be transported in watershed runoff to surface waters. The MPCA regulates animal feedlots in Minnesota though counties may be delegated by the MPCA to administer the program for feedlots that are not under federal regulation. The primary goal of the state program for animal feeding operations (AFO) is to ensure that surface waters are not contaminated by the runoff from feeding facilities, manure storage or stockpiles, and cropland with improperly applied manure. Livestock also occur at hobby farms, small-scale farms that are not large enough to require registration but may have small-scale feeding operations and associated manure application or stockpiles.

Livestock manure is often either surface applied or incorporated into farm fields as a fertilizer and soil amendment. This land application of manure has the potential to be a substantial source of fecal contamination, entering waterways from overland runoff and drain tile intakes. Research shows high concentrations of fecal bacteria leaving fields with incorporated manure and open tile intakes (Jamieson et al. 2002). The Minn. R. ch. 7020, contains manure application setback requirements based on research related to phosphorus transport, and not bacterial transport, and the effectiveness of these current setbacks on bacterial transport to surface waters is not known.

Only one AFO is known to exist in the Goose Creek Watershed. Manure from this facility is applied to nearby fields located in the Rush Creek Watershed. The bacteria load from this operation was estimated based on the number of animals (Table 22) and the bacteria production rate of cows (Table 18).

Grazing

Pastured areas are those where grass or other growing plants are used for grazing and where the concentration of animals allows a vegetative cover to be maintained during the growing season. Pastures are neither permitted nor registered with the state. Technically, agricultural land uses adjacent to lakes, rivers, and streams require a buffer strip of permanent vegetation that is 50 feet wide unless the areas are part of a resource management system plan (Minn. R. 6120.330, subp. 7). Additionally, for any new ditches or ditch improvements, the land adjacent to public ditches must include a buffer strip of permanent vegetation that is usually 16.5 feet wide on each side (Minn. Stat. 103E.021). These rules have limited enforcement statewide.

The number of grazing animals was determined through a windshield survey conducted by Chisago SWCD and Pine County staff during the summer of 2014. Grazing cattle, sheep, and goats are present in the Goose Creek Watershed. The bacteria load from grazing livestock was estimated based on the number of animals (Table 22) and the bacteria production rate of those animals (Table 18).

Wildlife

Bacteria can be contributed to surface water by wildlife (e.g. raccoons, deer, geese, and ducks) dwelling in waterbodies, within conveyances to waterbodies, or when their waste is carried to stormwater inlets, creeks, and ditches during stormwater runoff events. Areas such as DNR designated wildlife management areas, State Parks, National Parks, National Wildlife Refuges, golf courses, state forests, and for some animals, urban areas (e.g. raccoons) provide wildlife habitat encouraging congregation and could be potential sources of higher fecal coliform due to the high densities of animals. There are likely many areas within the project area where wildlife congregates.

Wildlife populations were estimated based on DNR population data for permit areas and zones. Because permit areas or zones do not align with subwatershed boundaries, population data for any single permit area or zone were distributed among subwatersheds on an area-weighted basis. Populations of wildlife (breeding ducks, deer, geese, pigeons, and raccoons) were estimated from the data sources and assumptions listed in Table 24. Bacteria loads from wildlife were estimated based on the population (Table 23) and bacteria production rates of wildlife (Table 18).

Table 23. Wildlife population estimates by subwatershed

Subwatershed	Raccoons	Deer	Ducks	Geese
Fish Lake	25	36	177	52
Goose Lake North Bay	23	32	89	44
Goose Lake South Bay	122	173	615	118
Horseshoe Lake	65	92	362	60
Lagoo Creek-St. Croix River	126	187	255	71
Long Meadows Lake-St. Croix River N	116	199	239	17
Long Meadows Lake-St. Croix River S	135	209	437	77
Lower Goose Creek	295	420	659	81
Mud Lake	149	212	573	49
Neander Lake	29	41	104	21
Rock Creek E	220	322	366	52
Rock Creek N	136	248	142	5
Rock Creek S	155	242	322	17
Rock Lake	106	195	246	2

Subwatershed	Raccoons	Deer	Ducks	Geese
Rush Creek	237	340	541	104
Rush Lake	94	137	259	18
Rush Lake E	94	135	245	262
Rush Lake W	141	202	533	309
Upper Goose Creek	33	48	173	21

Table 24. Population Estimate Data Sources and Habitat Assumptions for Wildlife

Wildlife	Population Estimate Data Sources and Habitat Assumptions
Ducks	According to a presentation by Steve Cordts of the Minnesota DNR Wetland Wildlife Population and Research Group at the 2010 Minnesota DNR Roundtable (http://files.dnr.state.mn.us/fish_wildlife/roundtable/2010/wildlife/wf_pop-harvest.pdf), Minnesota's annual breeding duck population averaged 550,000 between the years 2005-2009. While the breeding range of the canvasback and lesser scaup is typically outside of the project area, the majority of the breeding duck population (including blue-winged teal, mallards, ring-necked ducks, and wood ducks) has a state-wide breeding range. Statewide there is approximately 90,555,611 acres of suitable open water NWI habitat, equivalent to 0.061 ducks per acre of open water. This duck population density was distributed over all suitable open water NWI land covers plus a 100 foot buffer within each subwatershed on an area-weighted basis.
Deer	The DNR report Status of Wildlife Populations, Fall 2009, includes a collection of studies that estimate wildlife populations of various species (Dexter 2009). Pre-fawn deer densities were reported by DNR deer permit area. Permit area deer population densities over all 2006 NLCD land covers except open water within each subwatershed on an area-weighted basis.
Geese	The DNR report Status of Wildlife Populations, Fall 2009, also includes a collection of studies that estimate wildlife populations of various species by Minnesota ecoregion (Dexter 2009). Geese population data were distributed over and within a 100 foot buffer of all open water areas (PWI basins, streams, ditches and rivers, and 2006 NLCD *Open Water*) on an area-weighted basis within each subwatershed.
Raccoons	Raccoon population data were provided by a state-wide DNR estimate of 800,000 to one million individuals (DNR 2011). An average value of 900,000 was used. Raccoon habitat is known to consist of prairie, woodland, and developed area (DNR 2011), and Barding and Nelson (2008) document raccoon foraging in wetland, cropland, and forest. Statewide, there is approximately 44,561,624 acres of raccoon habitat, or 0.02 raccoons per acre. This raccoon density was distributed over all 2006 NLCD land covers except open water within each subwatershed on an area-weighted basis.

3.6.2.3 Strengths and Limitations

The bacteria production estimates are provided at the subwatershed scale. The results inform stakeholders as to the types and relative magnitude of bacteria produced in their watershed. This information is a valuable tool for the planning and management of water bodies with respect to bacteria contamination. The potential bacteria source estimates in the project area were calculated using a GIS-based approach. However, available data sources are at different scales and have different boundaries than that of the study subwatersheds. A limitation to the estimation process is that population data at a statewide or ecoregion scale must be distributed to the subwatershed scale based on average population density. As a result, there is a probable minimum scale at which bacteria production estimates are useful.

A significant portion of bacteria producers were accounted for in the potential bacteria sources. However, several animals were not included: birds other than geese and ducks (e.g. song birds and wading birds) and many wild animals (e.g. beavers, bear and wild turkey). Data, resource limitations, and consideration for the major bacteria producers in the project area led to the selected set of bacteria producers accounted for in these estimates. The project area estimates of potential bacteria sources is also limited by the fact that bacteria delivery is not addressed (e.g. treatment of human waste at WWTF prior to discharge to receiving waters, pet waste management, zero discharge feedlot facilities, incorporation of manure into soil, geese gathering directly on stormwater ponds). The potential bacteria source estimates also do not account for the relative risk among different types of bacteria. Instead, *E. coli* production is estimated as an indicator of the likelihood of pathogen contamination of our waterbodies.

3.6.2.4 Summary

Table 25 lists the contributing HUC 12 subwatersheds to each impaired stream reach. Bacteria production estimates by subwatershed are listed by producer in Table 26 and for all producers in Table 27.

Table 25. Contributing HUC 12 subwatersheds to the *E. coli* impaired stream reaches

Impaired stream AUID	Impaired stream name	Contributing subwatershed
07030005-510	Goose Creek	Lower Goose Creek
		Upper Goose Creek
07030005-584	Rock Creek	Rock Creek E
		Rock Creek N
		Rock Creek S
07030005-509	Rush Creek	Rush Creek

Table 26. Annual *E. coli* production estimates by producer
Shaded rows indicate a subwatershed containing an impaired reach

Annual *E. coli* production estimate (billion org/ day)	Humans		Livestock					Pets	Wildlife			
	WWTF Effluent	ITPH SSTS	Grazing Cattle	Grazing Goats	Grazing Sheep	AFO Cattle	Horses	Dogs	Raccoons	Deer	Ducks	Geese
Fish Lake	0	0	166	0	0	0	318	54	0.8	8	268	26
Goose Lake North Bay	0	0	208	0	0	0	0	41	0.7	7	135	22
Goose Lake South Bay	0	0	956	0	53	0	318	195	3.8	38	930	60
Horseshoe Lake	0	0	1,185	123	0	0	450	114	2.0	20	547	30
Lagoo Creek-St. Croix River	0	0	1,455	0	0	0	979	68	4.0	41	386	36
Long Meadows Lake-St. Croix River N	0	76	0	0	0	0	397	56	3.6	44	361	8
Long Meadows Lake-St. Croix River S	0	62	894	0	0	0	53	68	4.3	46	661	39
Lower Goose Creek	1	0	4,595	970	227	0	3,202	338	9.3	93	996	41
Mud Lake	0	0	3,784	35	0	0	318	112	4.7	47	866	25
Neander Lake	0	0	832	0	0	0	53	28	0.9	9	157	11
Rock Creek E	0	133	15,613	0	0	0	1,614	130	6.9	71	553	26
Rock Creek N	0	101	9,459	0	355	0	556	75	4.3	55	215	3
Rock Creek S	0	279	5,468	0	151	0	847	186	4.9	53	487	8
Rock Lake	0	155	8,753	0	0	0	556	109	3.3	43	372	1
Rush Creek	2	0	9,647	0	1,512	5,198	2,090	626	7.5	75	818	53
Rush Lake	0	54	2,037	0	0	0	794	56	3.0	30	392	9
Rush Lake E	0	0	5,301	0	0	0	0	160	3.0	30	370	132
Rush Lake W	0	8	1,663	0	0	0	1,985	271	4.5	45	806	156
Upper Goose Creek	0	0	832	0	0	0	688	25	1.1	11	262	10

Table 27. Total annual *E. coli* production estimates
Shaded rows indicate a subwatershed containing an impaired reach

Annual *E. coli* production estimate (billion org/ day)	Area	Total	Total	Humans	Livestock	Pets	Wildlife
	(ac)	(billion org/d)	(billion org/ac/d)	(% Total)			
Fish Lake	1,777	841	0.47	0%	20%	44%	36%
Goose Lake North Bay	1,597	414	0.26	0%	50%	10%	40%
Goose Lake South Bay	7,695	2,553	0.33	0%	40%	20%	40%
Horseshoe Lake	4,055	2,472	0.61	0%	53%	23%	24%
Lagoo Creek-St. Croix River	7,679	2,969	0.39	0%	49%	35%	16%
Long Meadows Lake-St. Croix River N	6,792	946	0.14	8%	0%	48%	44%
Long Meadows Lake-St. Croix River S	8,137	1,828	0.22	3%	49%	7%	41%
Lower Goose Creek	17,252	10,471	0.61	0%	55%	34%	11%
Mud Lake	8,754	5,192	0.59	0%	74%	8%	18%
Neander Lake	1,723	1,090	0.63	0%	76%	7%	16%
Rock Creek E	12,834	18,148	1.41	1%	86%	10%	4%
Rock Creek N	7,970	10,823	1.36	1%	91%	6%	3%
Rock Creek S	9,073	7,484	0.82	4%	75%	14%	7%
Rock Lake	6,264	9,992	1.60	2%	88%	7%	4%
Rush Creek	13,958	20,027	1.43	0%	82%	14%	5%
Rush Lake	5,528	3,375	0.61	2%	60%	25%	13%
Rush Lake E	7,047	5,996	0.85	0%	88%	3%	9%
Rush Lake W	9,982	4,938	0.49	0%	34%	46%	20%
Upper Goose Creek	1,956	1,828	0.93	0%	45%	39%	16%

4 TMDL Development

This section presents the overall approach to estimating the components of the TMDL. The pollutant sources were first identified and estimated in the pollutant source assessment. The loading capacity TMDL of each lake or stream was then estimated using an in-lake water quality response model or stream LDC and was divided among WLAs and LAs. A TMDL for a waterbody that is impaired as the result of excessive loading of a particular pollutant can be described by the following equation:

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

Where:

Loading capacity (LC): the greatest pollutant load a waterbody can receive without violating water quality standards;

Wasteload allocation (WLA): the pollutant load that is allocated to point sources, including WWTF, regulated construction stormwater, and regulated industrial stormwater, all covered under NPDES permits for a current or future permitted pollutant source;

Load allocation (LA): the pollutant load that is allocated to sources not requiring NPDES permit coverage, including non-regulated stormwater runoff, atmospheric deposition, and internal loading;

Margin of Safety (MOS): an accounting of uncertainty about the relationship between pollutant loads and receiving water quality;

Reserve Capacity (RC): the portion of the loading capacity attributed to the growth of existing and future load sources.

4.1 Phosphorus

4.1.1 Loading Capacity

4.1.1.1 Lake Response Model

The modeling software BATHTUB (Version 6.1) was selected to link phosphorus loads with in-lake water quality. A publicly available model, BATHTUB was developed by William W. Walker for the U.S. Army Corps of Engineers (Walker 1999). It has been used successfully in many lake studies in Minnesota and throughout the United States. BATHTUB is a steady-state annual or seasonal model that predicts a lake's summer (June through September) mean surface water quality. BATHTUB's time-scales are appropriate because watershed phosphorus loads are determined on an annual or seasonal basis, and the summer season is critical for lake use and ecological health. BATHTUB has built-in statistical calculations that account for data variability and provide a means for estimating confidence in model predictions. The heart of BATHTUB is a mass-balance phosphorus model that accounts for water and phosphorus inputs from tributaries, watershed runoff, the atmosphere, sources internal to the lake, and GW; and outputs through the lake outlet, water loss via evaporation, and phosphorus sedimentation and retention in the lake sediments.

System Representation in Model

In typical applications of BATHTUB, lake and reservoir systems are represented by a set of segments and tributaries. Segments are the basins (lakes, reservoirs, etc.) or portions of basins for which water quality parameters are being estimated, and tributaries are the defined inputs of flow and pollutant loading to a particular segment. For this study, the direct drainage area and outflow from an upstream lake for which TP concentration is known was defined as separate tributaries for each lake (i.e., segment). BATHTUB was used to estimate the in-lake phosphorus concentration for upstream lakes without in-lake monitoring data, including: Little Horseshoe, Rabour and Mandall Lakes.

Model Inputs

The input required to run the BATHTUB model includes lake geometry, climate data, and water quality and flow data for runoff contributing to the lake. Observed lake water quality data are also entered into the BATHTUB program in order to facilitate model verification and calibration. Lake segment inputs are listed in Table 28, and tributary inputs are listed in Table 12 and Table 13 from Section 3.6.1.1. Precipitation rates were estimated at 0.75 m per year and evaporation rates were estimated to be 0.86 m per year based on data from the Minnesota Hydrology Guide (SCS 1992). Precipitation and evaporation rates apply only to the lake surface areas. Average phosphorus atmospheric deposition loading rates were estimated to be 0.24 lb/ac-yr for the St. Croix River Basin (Barr 2007), applied over each lake's surface area. See discussion titled *Atmospheric Deposition* in *Section 3.6.1.1* for more details.

Table 28. BATHTUB segment input data for impaired lakes and unmonitored upstream lakes (italics)

Impaired Lake	Surface area (sq km)	Lake fetch (km)	Mean depth (m)	Total Phosphorus	
				(µg/L)	CV (%)
Goose Lake (North Bay)	1.1008	1.60	1.54	170.3	16%
Goose Lake (South Bay)	1.8107	2.74	4.37	55.4	41%
Horseshoe Lake	0.9066	1.56	3.97	52.6	7%
Rock Lake	0.3278	1.05	2.88	193.3	7%
Rush Lake (West)	6.3912	4.95	3.86	64.5	7%
Rush Lake (East)	6.0071	5.68	2.67	61.0	26%
Little Horsehoe	*0.1970*	*0.62*	*4.92*	*N/A*	
Mandall	*0.1895*	*0.77*	*2.89*	*N/A*	
Rabour	*0.2088*	*0.76*	*3.45*	*N/A*	

CV = coefficient of variation, defined in BATHTUB as the standard error divided by the mean

Model Equations

BATHTUB allows a choice among several different phosphorus sedimentation models. For non-shallow lakes in Minnesota, the option of the Canfield-Bachmann Lakes model (Canfield and Bachmann 1981) has proven to be appropriate in most cases. In order to perform a uniform analysis it was selected as the standard equation for this study except for the case of Rock Lake in which the Canfield-Bachmann Reservoir model was used to better represent the short hydrologic residence time of the lake.

Model Calibration

The models were calibrated to existing water quality data according to Table 29, and then were used to determine the phosphorus loading capacity (TMDL) of each lake. When the predicted in-lake TP concentration was *lower* than the average observed (monitored) concentration, an explicit additional load was added to calibrate the model. It is widely recognized that Minnesota lakes in agricultural and urban regions have histories of high phosphorus loading and/or very poor water quality. For this reason, it is reasonable that internal loading may be higher than that of the lakes in the data set used to derive the Canfield-Bachmann lakes and reservoir formulation. It is also possible that the watershed model loading estimates did not account for certain hot spots of phosphorus loading such as above average application of lawn fertilizer runoff and/or animal waste. When the predicted in-lake TP concentration was *higher* than the average monitored concentration; the phosphorus calibration coefficient was increased to calibrate the model.

Table 29. Model calibration summary for the impaired lakes

Impaired Lake	P Sedimentation Model	Calibration Mode	Calibration Value
Goose Lake (North Bay)	Canfield & Bachmann, Lakes	Added Internal Load	4.505 mg/m^2-day
Goose Lake (South Bay)	Canfield & Bachmann, Lakes	Added Internal Load	0.157 mg/m^2-day
Horseshoe Lake	Canfield & Bachmann, Lakes	TP Calibration Factor	1.513
Rock Lake	Canfield & Bachmann, Reservoir	Added Internal Load	19.08 mg/m^2-day
Rush Lake (West)	Canfield & Bachmann, Lakes	Added Internal Load	0.375 mg/m^2-day
Rush Lake (East)	Canfield & Bachmann, Lakes	Added Internal Load	0.310 mg/m^2-day

Determination of Lake Loading Capacity

Using the calibrated existing conditions model as a starting point, the phosphorus concentrations associated with tributaries were reduced until the model indicated that the TP state standard was met, to the nearest tenth of a whole number. First, upstream impaired lake phosphorus concentrations were assumed to meet lake water quality standards. Next, the direct drainage flow weighted mean TP concentration was reduced to no less than 100 µg/L until in-lake phosphorus concentration met the lake water quality standard. A flow weighted mean concentration goal of 100 µg/L was chosen to represent reasonable baseline loading conditions from the mostly rural and agricultural watershed. No reductions of the direct drainage flow weighted mean TP concentration was made if the calibrated existing condition was less than or equal to 100 µg/L. If further reductions were needed, any added internal loads were reduced until the in-lake phosphorus concentration met the lake water quality standard. Minnesota lake water quality standards assume that once the TP goals are met, the Chl-a and Secchi transparency standards will likewise be met (see *Section 1.2 Applicable Water Quality Standards*). With this process, a series of models were developed that included a level of phosphorus loading consistent with lake water quality state standards, or the TMDL goal. Actual load values are calculated within the BATHTUB software, so loads from the TMDL goal models could be compared to the loads from the existing conditions models to determine the amount of load reduction required.

4.1.2 Load Allocation Methodology

The LA includes all sources of phosphorus that do not require NPDES Permit coverage: watershed runoff, internal loading, atmospheric deposition, and any other identified loads described in Section 3.6.1. The remainder of the loading capacity (TMDL) after subtraction of the MOS and calculation of the WLA was used to determine the LA for each impaired lake, on an areal basis. Loads from failing septic systems are assigned a LA of 0 because conforming septic systems are not considered a significant source of nutrients to surface waters.

4.1.3 Wasteload Allocation Methodology

All regulated stormwater and wastewater were assigned a WLA based on the methods described in the following section. The remainder of the loading capacity (TMDL) after subtraction of the MOS, atmospheric deposition, and internal loading was used to determine the WLA for each impaired lake on an areal basis. Note that the MOS was distributed proportionately among internal loading and watershed runoff based on existing loads relative to the loading capacity, but not to atmospheric deposition and lake outflow from an upstream impaired lake.

4.1.3.1 Regulated Construction Stormwater

Construction stormwater is regulated by NPDES Permits for any construction activity disturbing a) one acre or more of soil, b) less than one acre of soil if that activity is part of a "larger common plan of development or sale" that is greater than one acre, or c) less than one acre of soil, but the MPCA determines that the activity poses a risk to water resources. The WLA for stormwater discharges from sites where there is construction activities reflects the number of construction sites > 1 acre expected to be active in the impaired lake subwatershed at any one time.

A categorical WLA was assigned to all construction activity in the each impaired lake subwatershed. First, the average annual fraction of the impaired subwatershed area under construction activity over the past 5 years was calculated based on the MPCA Construction Stormwater Permit data from January 1, 2007 to October 6, 2012 (Table 30), area weighted based on the fraction of the subwatershed located in each county. This percentage was multiplied by the watershed runoff load component to determine the construction stormwater WLA. The watershed runoff load component is equal to the total TMDL (loading capacity) minus the sum of the non-watershed runoff load components (atmospheric load, upstream lake loads, internal loads, and MOS).

Table 30. Average Annual NPDES/SDS Construction Stormwater Permit Activity by County (1/1/2007-10/6/2012)

County	Total County Area (ac)	Average Annual Construction Activity (% Total Area)
Chisago	283,030	0.07%
Pine	917,167	0.01%

4.1.3.2 Regulated Industrial Stormwater

Industrial stormwater is regulated by NPDES Permits if the industrial activity has the potential for significant materials and activities to be exposed to stormwater discharges. The WLA for stormwater discharges from sites where there is industrial activity reflects the number of sites in an impaired lake subwatershed for which NPDES industrial stormwater permit coverage is required.

A categorical WLA was assigned to all industrial activity in each impaired lake subwatershed. The industrial stormwater WLA was set equal to the construction stormwater WLA because industrial activities make up a very small fraction of the watershed area.

4.1.3.3 MS4 Regulated Stormwater

Stormwater from municipal separate storm sewer systems (MS4s) - a conveyance or system of conveyances (roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, storm drains) - is regulated by NPDES permits for all mandatory, designated, or petition MS4s. All MS4s in the project area are mandatory MS4s, which is based on the U.S. Census definition of an urbanized area: a land area comprising one or more places ("central places") and the adjacent densely settled surrounding area ("urban fringe") that together have a residential population of at least 50,000 and a density of at least 1,000 people per square mile. The definition also includes any other public storm sewer system located fully or partially within an urbanized area.

There is no regulated MS4 stormwater in any of the impaired lake subwatersheds. If MS4 communities come under permit coverage in the future, a portion of the LA will be shifted to the WLA to account for the regulated MS4 stormwater. The MS4 Permits for state (MnDOT) and county road authorities apply to roads within the U.S. Census Bureau Urban Area. None of the impaired lake subwatersheds are located within the U.S. Census Bureau Urban Area. Therefore, no roads are currently under permit coverage and no WLAs were assigned to the corresponding road authorities. If, in the future, the U.S. Census Bureau Urban Area extends into an impaired lake subwatershed and these roads come under permit coverage, a portion of the LA will be shifted to the WLA.

4.1.3.4 Regulated Wastewater

There is no regulated wastewater in the impaired lake subwatersheds.

4.1.3.5 Feedlots Requiring NPDES/SDS Permit Coverage

An AFO is a general term for an area intended for the confined holding of animals, where manure may accumulate, and where vegetative cover cannot be maintained within the enclosure due to the density of animals. AFOs that either (a) have a capacity of 1,000 AUs or more, or (b) meet or exceed the EPA's Concentrated Animal Feeding Operation (CAFO) threshold and discharge to Waters of the United States, are required to apply for permit coverage through the MPCA. If item (a) is triggered, the permit can be an SDS or NPDES/SDS Permit; if item (b) is triggered, the permit must be an NPDES Permit. These permits require that the feedlots have zero discharge to surface water. Based on a desktop review of the MPCA data there are no permitted feedlots within this watershed.

There are feedlots within this watershed, but none are large enough to trigger the MPCA permit requirements. The non-permitted feedlots are referenced in Section 3.6.1.

4.1.4 Margin of Safety

An explicit 10% MOS was accounted for in the TMDL for each impaired lake. This MOS is sufficient to account for uncertainties in predicting phosphorus loads to lakes and predicting how lakes respond to changes in phosphorus loading. This explicit MOS is considered to be appropriate based on the generally good agreement between the water quality models' predicted and observed values. Since the models reasonably reflect the conditions in the lakes and their subwatersheds, the 10% MOS is considered to be adequate to address the uncertainty in the TMDL, based upon the data available.

4.1.5 Seasonal Variation

In-lake water quality varies seasonally. In Minnesota lakes, the majority of the watershed phosphorus load often enters the lake during the spring. During the growing season months (June through September), phosphorus concentrations may not change drastically if major runoff events do not occur. However, Chl-a concentration may still increase throughout the growing season due to warmer temperatures fostering higher algal growth rates. In shallow lakes, the phosphorus concentration more frequently increases throughout the growing season due to the additional phosphorus load from internal sources. This can lead to even greater increases in Chl-a since not only is there more phosphorus but temperatures are also higher. This seasonal variation is taken into account in the TMDL by using the eutrophication standards (which are based on growing season averages) as the TMDL goals. The eutrophication standards were set with seasonal variability in mind. The load reductions are designed so that the lakes will meet the water quality standards over the course of the growing season (June through September).

Critical conditions in these lakes occur during the growing season, which is when the lakes are used for aquatic recreation. Similar to the manner in which the standards take into account seasonal variation, since the TMDL is based on growing season averages, the critical condition is covered by the TMDL.

4.1.6 TMDL Summary

The individual impaired lake TMDL and allocations are summarized in the following tables.

4.1.6.1 Goose Lake North (13-0083-01) Phosphorus TMDL

Table 31. Goose Lake North TP TMDL and Allocations

Goose Lake North Load Component		Existing	TMDL		Reduction[2]	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.455	0.455	0.00125	0.0	0%
	Industrial stormwater (MNR50000)	0.455	0.455	0.00125	0.0	0%
	Total WLA	**0.9**	**0.9**	**0.00249**	**0.0**	
Load Allocations[1]	*Watershed runoff*	*583.3*	*236.7*	*0.648*	*346.6*	*60%*
	Failing septics	*7.7*	*0.0*	*0.000*	*7.7*	*100%*
	Goose Lake South Outflow	*663.1*	*428.8*	*1.175*	*234.3*	*35%*
	Internal load	*3,993.2*	*539.5*	*1.478*	*3,453.7*	*86%*
	Total Watershed/In-lake	5,247.4	1,205.0	3.301	4,042.3	77%
	Atmospheric	65.5	65.5	0.179	0.0	0%
	Total LA	**5,312.8**	**1,270.5**	**3.480**	**4,042.3**	
MOS			**141.3**	**0.387**		
TOTAL		**5,313.7**	**1,412.7**	**3.869**	**4,042.3**	**76%**

[1] LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

[2] Net reduction from current load to TMDL is 3,901 lbs/yr; but gross load reduction from all sources must accommodate the MOS as well, and hence is 3,901 + 141.3 = 4,042.3 lbs/yr.

Phosphorus Source Summary

- Approximately 30% of the watershed is cropland or developed.
- There are an estimated 10 livestock animals in the watershed.
- There are approximately 38 shoreline private on-site septic systems, which are estimated to have an 18% failure rate (7 failing).
- One impaired lake (Goose Lake South) discharges into Goose Lake North.
- The lake is extremely shallow (max depth of 9 feet) and mixing of sediments into the water column can contribute to internal phosphorus load.
- Curly leaf pondweed is present in the lake which can contribute to internal phosphorus load.

4.1.6.2 Goose Lake South (13-0083-02) Phosphorus TMDL

Table 32. Goose Lake South TP TMDL and Allocations

Goose Lake South Load Component		Existing (lb/yr)	TMDL (lb/yr)	TMDL (lb/day)	Reduction[2] (lb/yr)	Reduction[2] (%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.42	0.42	0.0012	0.0	0%
	Industrial stormwater (MNR50000)	0.42	0.42	0.0012	0.0	0%
	Total WLA	**0.8**	**0.8**	**0.0023**	**0.0**	
Load Allocations[1]	*Watershed runoff*	*1,202.0*	*616.8*	*1.690*	*585.2*	*49%*
	Failing septics	*11.0*	*0.0*	*0.000*	*11.0*	*100%*
	Mandall Lake Outflow	*502.9*	*237.7*	*0.651*	*265.2*	*53%*
	Internal Load	*228.8*	*197.6*	*0.541*	*31.3*	*14%*
	Total Watershed/In-lake	1,944.7	1,052.1	2.882	892.7	46%
	Atmospheric	107.8	107.8	0.295	0.0	0%
	Total LA	**2,052.5**	**1,159.9**	**3.177**	**892.7**	
MOS			**129.0**	**0.353**		
TOTAL		**2,053.4**	**1,289.7**	**3.532**	**892.7**	**43%**

[1] LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

[2] Net reduction from current load to TMDL is 763.7 lbs/yr; but gross load reduction from all sources must accommodate the MOS as well, and hence is 763.7 + 129.0 = 892.7 lbs/yr.

Phosphorus Source Summary

- Approximately 30% of the watershed is cropland or developed.
- There are an estimated 153 livestock animals in the watershed.
- Approximately 54 shoreline private on-site septic systems, which are estimated to have an 18% failure rate (10 failing).
- Curly leaf pondweed and carp are present in the lake which can contribute to internal phosphorus load.

4.1.6.3 Horseshoe Lake (13-0073-00) Phosphorus TMDL

Table 33. Horseshoe Lake TP TMDL and Allocations

Horseshoe Lake Load Component		Existing	TMDL		Reduction[2]	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.494	0.494	0.0014	0.0	0%
	Industrial stormwater (MNR50000)	0.494	0.494	0.0014	0.0	0%
	Total WLA	**1.0**	**1.0**	**0.0028**	**0.0**	
Load Allocations[1]	*Watershed runoff*	*1,275.9*	*722.8*	*1.980*	*553.1*	*44%*
	Failing septics	*9.9*	*0.0*	*0.000*	*9.9*	*100%*
	Little Horseshoe Lake Outflow	*35.3*	*25.8*	*0.071*	*9.5*	*27%*
	Total Watershed/In-lake	1,321.1	748.6	2.051	572.5	43%
	Atmospheric	54.0	54.0	0.148	0.0	0%
	Total LA	**1,375.1**	**802.6**	**2.199**	**572.5**	
MOS			**89.3**	**0.245**		
TOTAL		**1,376.1**	**892.9**	**2.447**	**572.5**	**42%**

[1] LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.
[2] Net reduction from current load to TMDL is 483.2 lbs/yr; but gross load reduction from all sources must accommodate the MOS as well, and hence is 482.3 + 89.3 = 572.5 lbs/yr.

Phosphorus Source Summary

- Approximately 20% of the watershed is cropland or developed.
- There are approximately 51 shoreline private on-site septic systems, which are estimated to have an 18% failure rate (9 failing).
- Common carp was identified in 2000 and can contribute to internal phosphorus load.
- Curly leaf pondweed is present which can contribute to internal phosphorus load.

4.1.6.4 Rock Lake (58-0117-00) Phosphorus TMDL

Table 34. Rock Lake TP TMDL and Allocations

Rock Lake Load Component		Existing	TMDL		Reduction[2]	
		(lb/yr)	(lb/yr)	(lb/day)	(lb/yr)	(%)
Wasteload Allocations	Construction stormwater (MNR100001)	0.12	0.12	0.0003	0.0	0%
	Industrial stormwater (MNR50000)	0.12	0.12	0.0003	0.0	0%
	Total WLA	**0.2**	**0.2**	**0.0006**	**0.0**	
Load Allocations[1]	*Watershed runoff*	*2,655.4*	*894.9*	*2.452*	*1,760.4*	*66%*
	Failing septics	*2.9*	*0.0*	*0.000*	*2.9*	*100%*
	Internal load	*5,036.2*	*158.8*	*0.435*	*4,877.3*	*97%*
	Total Watershed/In-lake	7,694.5	1,053.8	2.890	6,640.7	86%
	Atmospheric	19.6	19.6	0.054	0.0	0%
	Total LA	**7,714.1**	**1,073.4**	**2.944**	**6,640.7**	
MOS			**119.3**	**0.327**		
TOTAL		**7,714.3**	**1,192.9**	**3.272**	**6,640.7**	**86%**

[1] LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.
[2] Net reduction from current load to TMDL is 6,521.4 lbs/yr; but gross load reduction from all sources must accommodate the MOS as well, and hence is 6,521.4 + 119.3 = 6,640.7 lbs/yr.

Phosphorus Source Summary

- Approximately 45% of the watershed is cropland or developed.
- There are an estimated 421 livestock animals in the watershed.
- Approximately 50 livestock have access to the water and a feedlot runs up to the shoreline.
- Approximately five shoreline private on-site septic systems, which are estimated to have a 64% failure rate (3 failing).
- A golf course is adjacent to the lake.

4.1.6.5 Rush Lake West (13-0069-02) Phosphorus TMDL

Table 35. Rush Lake West TP TMDL and Allocations

Rush Lake West Load Component		Existing (lb/yr)	TMDL (lb/yr)	TMDL (lb/day)	Reduction[2] (lb/yr)	Reduction[2] (%)
Wasteload Allocations	Construction stormwater (MNR100001)	1.5	1.5	0.004	0.0	0%
	Industrial stormwater (MNR50000)	1.5	1.5	0.004	0.0	0%
	Total WLA	**3.0**	**3.0**	**0.008**	**0.0**	
Load Allocations[1]	*Watershed runoff*	*4,440.6*	*2,341.6*	*6.415*	*2,099.0*	*48%*
	Failing septics	*38.2*	*0.0*	*0.000*	*38.2*	*100%*
	Internal load	*1,929.9*	*251.1*	*0.688*	*1,678.8*	*87%*
	Total Watershed/In-lake	6,408.7	2,592.7	7.103	3,816.0	60%
	Atmospheric	380.5	380.5	1.043	0.0	0%
	Total LA	**6,789.2**	**2,973.2**	**8.146**	**3,816.0**	
MOS			**330.7**	**0.906**		
TOTAL		**6,792.2**	**3,306.9**	**9.060**	**3,816.0**	**56%**

[1] LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.
[2] Net reduction from current load to TMDL is 3,485.3 lbs/yr; but gross load reduction from all sources must accommodate the MOS as well, and hence is 3,485.3 + 330.7 = 3,816.0 lbs/yr.

Phosphorus Source Summary

- Approximately 40% of the watershed is cropland or developed.
- There are an estimated 85 livestock animals in the watershed.
- Approximately 192 shoreline private on-site septic systems, which are estimated to have an 18% failure rate (36 failing).
- Curly leaf pondweed has been present in the lake since 1972 or earlier which can contribute to phosphorus internal load.

4.1.6.6 Rush Lake East (13-0069-01) Phosphorus TMDL

Table 36. Rush Lake East TP TMDL and Allocations

Rush Lake East Load Component		Existing (lb/yr)	TMDL (lb/yr)	TMDL (lb/day)	Reduction[3] (lb/yr)	Reduction[3] (%)
Wasteload Allocations	Construction stormwater (MNR100001)	1.1	1.1	0.003	0.0	0%
	Industrial stormwater (MNR50000)	1.1	1.1	0.003	0.0	0%
	Total WLA	**2.2**	**2.2**	**0.006**	**0.0**	
Load Allocations[1]	*Watershed runoff*	*2,222.7*	*1,036.7*	*2.840*	*1,186.0*	*54%*
	Failing septics	*50.2*	*0.0*	*0.000*	*50.2*	*100%*
	Rush Lake West Outflow[2]	*1,604.3*	*883.4*	*2.420*	*720.9*	*45%*
	Internal load	*1,499.6*	*609.6*	*1.670*	*889.9*	*59%*
	Total Watershed/In-lake	5,376.8	2,529.8	6.931	2,847.0	53%
	Atmospheric	357.6	357.6	0.980	0.0	0%
	Total LA	**5,734.4**	**2,887.4**	**7.911**	**2,847.0**	
MOS			**321.0**	**0.879**		
TOTAL		**5,736.6**	**3,210.6**	**8.796**	**2,847.0**	**50%**

[1] LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

[2] The load from Rush Lake West under the TMDL scenario assumes it meets its water quality standards

[3] Net reduction from current load to TMDL is 2,526 lbs/yr; but gross load reduction from all sources must accommodate the MOS as well, and hence is 2,526 + 321.0 = 2,847.0 lbs/yr.

Phosphorus Source Summary

- Approximately 40% of the watershed in cropland or developed.
- There are an estimated 55 livestock animals in the watershed.
- Approximately 262 shoreline private on-site septic systems, which are estimated to have an 18% failure rate (47 failing).
- One impaired lake (Rush Lake West) discharges in to Rush Lake East.
- Curly leaf pondweed has been present since 1972 or earlier which can contribute to internal phosphorus load.

4.1.7 TMDL Baseline

The lake TMDLs are based on data from the 15-year period 1998-2012. Any activities implemented during or after 2012 that lead to a reduction in loads or an improvement in an impaired lake water quality may be considered as progress towards meeting a WLA or LA.

4.2 Bacteria (*E. coli*)

4.2.1 Loading Capacity Methodology

The loading capacities for impaired stream reaches receiving a TMDL as a part of this study were determined using LDCs. Flow and LDCs are used to determine the flow conditions (flow regimes) under which exceedances occur. Flow duration curves provide a visual display of the variation in flow rate for the stream. The x-axis of the plot indicates the percentage of time that a flow exceeds the corresponding flow rate as expressed by the y-axis. The LDCs take the flow distribution information constructed for the stream and factor in pollutant loading to the analysis. A standard curve is developed by applying a particular pollutant standard or criteria to the stream flow duration curve and is expressed as a load of pollutant per day. The standard curve represents the upper limit of the allowable in-stream pollutant load (loading capacity) at a particular flow. Monitored loads of a pollutant are plotted against this curve to display how they compare to the standard. Monitored values that fall above the curve represent an exceedance of the standard.

For the stream TMDL derivation, flow records for the MPCA gage H37024001 – Goose Creek (2006-2010), the MPCA gage H37022001 – Rush Creek (2010-2011), and USGS gage 05339490 – Rock Creek (2006-2010), were used to develop flow duration curves. The loading capacities were determined by applying the *E. coli* water quality standard (126 org/ 100 mL) to the flow duration curve to produce a bacteria standard curve. Loading capacities were calculated as the median value of the *E. coli* load (in billion org/day) along the bacteria standard curve within each flow regime. A bacteria LDC with monitored data and a TMDL summary table are provided for each stream in Section 4.2.7.

The LDC method is based on an analysis that encompasses the cumulative frequency of historic flow data over a specified period. Because this method uses a long-term record of daily flow volumes virtually the full spectrum of allowable loading capacities is represented by the resulting curve. In the TMDL equation tables of this report (**Error! Reference source not found.**Table 38, Table 39, Table 40) only five points on the entire loading capacity curve are depicted (the midpoints of the designated flow zones). However, it should be understood that the entire curve represents the TMDL and is what is ultimately approved by the EPA.

4.2.2 Load Allocation Methodology

The LAs represent the portion of the loading capacity that is designated for non-regulated sources of *E. coli*, as described in Section 3.6.2, that are located downstream of any other impaired waters with TMDLs located in the watershed. The remainder of the loading capacity (TMDL) after subtraction of the MOS and calculation of the WLA was used to determine the LA for each impaired stream, on an areal basis. Loads from septic systems are assigned a LA of 0 because conforming septic systems are not considered a significant source of bacteria to surface waters.

4.2.3 Wasteload Allocation Methodology

4.2.3.1 MS4 Regulated Stormwater

There is one regulated MS4 stormwater community, city of North Branch (MS400260), which lies within the very southern portion of the Goose Creek Sub-watershed (Figure 12). However, they were not given a WLA at this because the land uses within these areas are not covered by their permit. If these areas or other MS4 communities come under permit coverage in the future, a portion of the LA will be shifted to the WLA to account for the regulated MS4 stormwater. The MS4 Permits for state (MnDOT) and county road authorities apply to roads within the U.S. Census Bureau Urban Area. None of the impaired lake subwatersheds are located within the U.S. Census Bureau Urban Area. Therefore, no roads are currently under permit coverage and no WLAs were assigned to the corresponding road authorities. If, in the future, the U.S. Census Bureau Urban Area extends into an impaired lake subwatershed and these roads come under permit coverage, a portion of the LA will be shifted to the WLA.

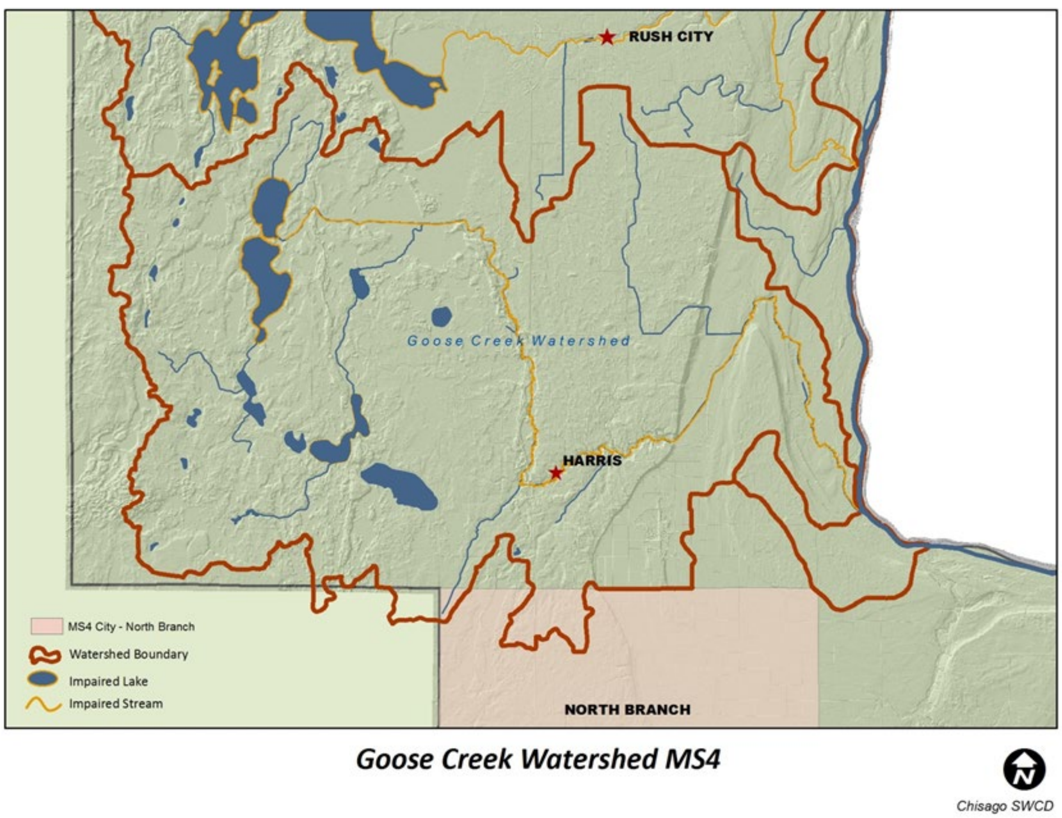

Figure 12. City of North Branch Boundary in the Goose Creek Watershed

4.2.3.2 Regulated Wastewater

An individual WLA was provided for all NPDES-permitted WWTFs that have fecal coliform discharge limits (200 org/100mL, April 1 through October 31) and whose surface discharge stations fall within an impaired stream subwatershed. The WLA was calculated as the pollutant effluent limit multiplied by the permitted facility design flow. Continuously discharging municipal WWTF WLAs were calculated based on the average wet weather design flow, equivalent to the wettest 30-days of influent flow expected over the course of a year. Municipal controlled (pond) discharge WWTF WLAs were calculated based on the maximum daily volume that may be discharged in a 24-hour period.

The WLAs are based on *E. coli* loads even though the facilities' discharge limits are based on fecal coliform. If a discharger is meeting the fecal coliform limits of their permit, it is assumed that they are also meeting the *E. coli* WLA in these TMDLs. Expanding and new dischargers permitted at the fecal coliform limit will be added to the *E. coli* WLA via the NPDES Permit public notice process (see Section 5).

Table 37. NPDES Permitted Facilities with *E. coli* effluent limits located in the Goose Creek Watershed TMDL Project Area

Facility Name	NPDES Permit	TMDL	Design Flow (MGD)	Effluent Limit, Concentration (org/100 mL)	WLA (bill org/day)
Harris WWTF	MN0050130	Goose Creek	0.121	126	0.6
Rush City WWTF	MN0021342	Rush Creek	0.3995	126	1.9
Shorewood Park Sanitary District	MN0051390	Rush Creek	0.015	126	0.1

* Daily WLAs for Minnesota facilities in the SM1 category are calculated from the 2 mg/L concentration assumption and the maximum permitted effluent flow rate of 6"/day over the area of the facility's discharging cells(s). These controlled discharge facilities are designed to store 180 days' worth of influent flow and /or low receiving water temperature. Since these facilities discharge intermittently, their daily WLAs do not represent their annual WLAs divided by the days in a year. Rather they reflect the permitted daily effluent loads as described above.

4.2.3.3 Feedlots Requiring NPDES/SDS Permit Coverage

An AFO is a general term for an area intended for the confined holding of animals, where manure may accumulate, and where vegetative cover cannot be maintained within the enclosure due to the density of animals. AFOs that either (a) have a capacity of 1,000 AUs or more, or (b) meet or exceed the EPA's CAFO threshold and discharge to Waters of the United States, are required to apply for permit coverage through the MPCA. If item (a) is triggered, the permit can be an SDS or NPDES/SDS Permit; if item (b) is triggered, the permit must be an NPDES Permit. These permits require that the feedlots have zero discharge to surface water. Based on a desktop review of the MPCA data there are no permitted feedlots within this watershed. There are feedlots within this watershed, but none are large enough to trigger the MPCA permit requirements. The non-permitted feedlots are referenced in Section 3.6.2.

4.2.4 Margin of Safety

An explicit MOS equal to 10% of the loading capacity was used for the stream TMDLs based on the following considerations:

- Most of the uncertainty in flow is a result of extrapolating flows (area-weighting and the use of regression equations) from the hydrologically-nearest stream gage. The explicit MOS, in part, accounts for this. See Section 14.2 for further LDC error analysis.
- Allocations are a function of flow, which varies from high to low flows. This variability is accounted for through the development of a TMDL for each of five flow regimes.

- With respect to the *E. coli* TMDLs, the load duration analysis does not address bacteria re-growth in sediments, die-off, and natural background levels. The MOS helps to account for the variability associated with these conditions.

4.2.5 Seasonal Variation

Use of these water bodies for aquatic recreation occurs from April through October, which includes all or portions of the spring, summer and fall seasons. *E. coli* loading varies with the flow regime and season. Spring is associated with large flows from snowmelt, the summer is associated with the growing season as well as periodic storm events and receding streamflow's, and the fall brings increasing precipitation and rapidly changing agricultural landscapes.

Critical conditions and seasonal variation are addressed in this TMDL through several mechanisms. The *E. coli* standard applies during the recreational period, and data was collected throughout this period. The water quality analysis conducted on these data evaluated variability in flow through the use of five flow regimes: from high flows, such as flood events, to low flows, such as baseflow. Through the use of LDCs and monthly summary figures, *E. coli* loading was evaluated at actual flow conditions at the time of sampling (and by month), and monthly *E. coli* concentrations were evaluated against precipitation and streamflow.

4.2.6 TMDL Summary

4.2.6.1 Goose Creek (07030005-510) *E. coli* TMDL and allocations

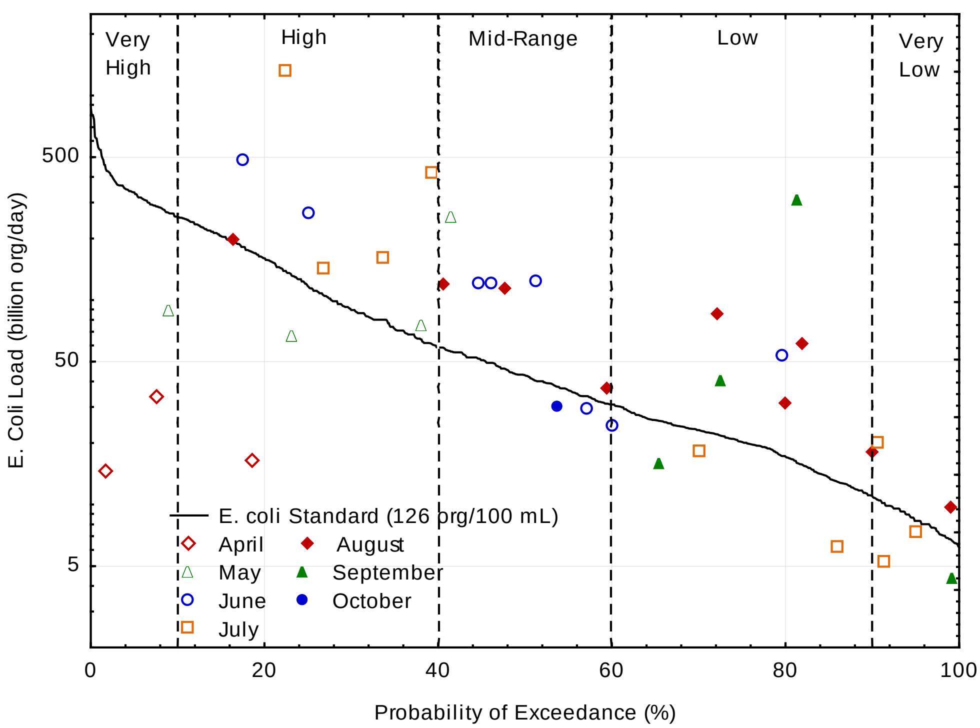

Figure 13. *E. coli* load duration curve for Goose Creek (07030005-510)

Table 38. Goose Creek *E. coli* TMDL and allocations

Goose Creek 07030005-510 Load Component		Flow Regime				
		Very High	High	Mid	Low	Very Low
		Billion organisms per day				
Existing Load		***34.1***	***179.7***	***118.9***	***36.0***	***8.5***
Wasteload Allocations	*Harris WWTP MN00500130*	*0.6*	*0.6*	*0.6*	*0.6*	*0.6*
	Total WLA	**0.6**	**0.6**	**0.6**	**0.6**	**0.6**
Load Allocations	*Goose Lake (North) outflow*	*61.3*	*20.8*	*8.4*	*4.0*	*1.7*
	Horseshoe Lake outflow	*26.9*	*9.1*	*3.7*	*1.8*	*0.8*
	Watershed runoff	*247.8*	*89.9*	*26.5*	*11.7*	*4.7*
	Total LA	**336.0**	**119.8**	**38.6**	**17.5**	**7.2**
MOS		**37.4**	**13.4**	**4.3**	**2.0**	**0.9**
Total Loading Capacity		**374.0**	**133.8**	**43.5**	**20.1**	**8.7**
Estimated Load Reduction		*0*	*45.9*	*75.4*	*15.9*	*0*
		0%	*26%*	*63%*	*44%*	*0%*

***Existing loads estimated with limited water quality monitoring data**

4.2.6.2 Rush Creek (07030005-509) *E. coli* TMDL and allocations

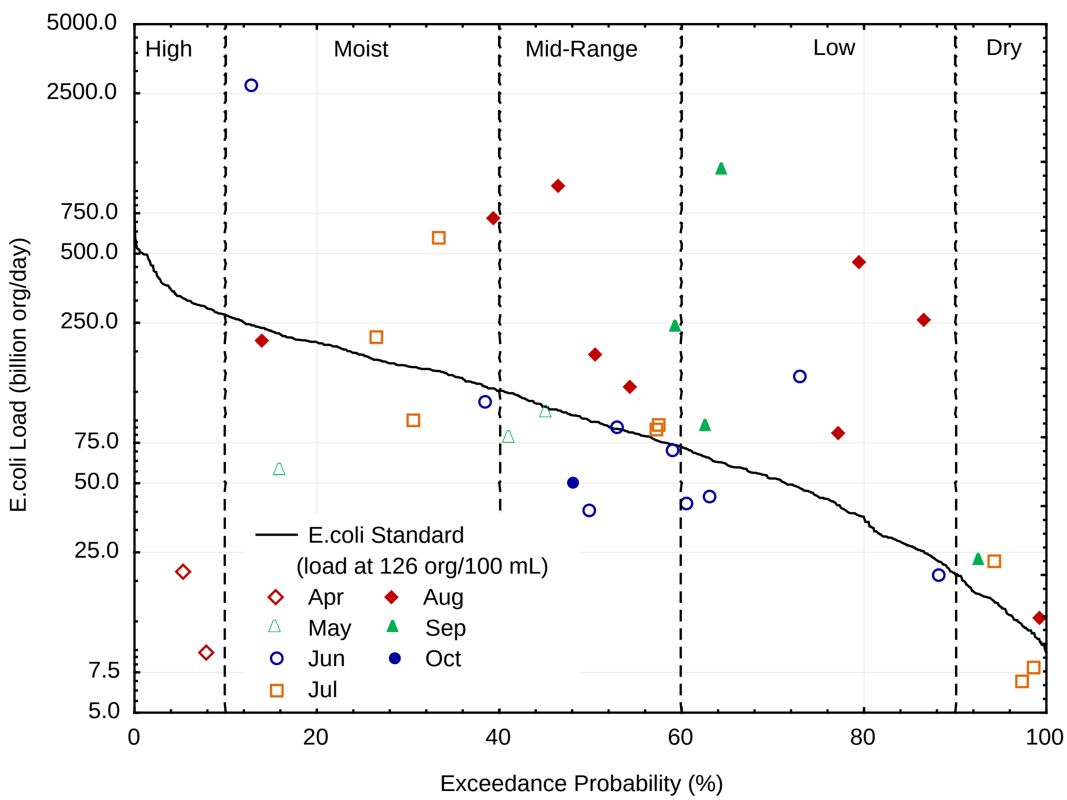

Figure 14. *E. coli* load duration curve for Rush Creek

Table 39. Rush Creek *E. coli* TMDL and allocations

Rush Creek 07030005-509 Load Component		Flow Regime				
		Very High	High	Mid	Low	Very Low
		Billion organisms per day				
Existing Load		*20.5**	*207.2*	*89.1*	*87.9*	*10.5*
Wasteload Allocations	*Shorewood Park Sanitary District, MN0051390*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
	Rush City WWTP, MN0021342	*1.9*	*1.9*	*1.9*	*1.9*	*1.9*
	Total WLA	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**
Load Allocations	*Rush Lake (East)*	*177.4*	*97.7*	*50.9*	*22.8*	*8.1*
	Watershed runoff	*145.5*	*68.1*	*33.5*	*14.6*	*2.9*
	Total LA	**322.9**	**165.8**	**84.4**	**37.4**	**11.0**
MOS		**36.1**	**18.7**	**9.6**	**4.4**	**1.5**
Total Loading Capacity		**361.0**	**186.5**	**96.0**	**43.8**	**14.5**
Estimated Load Reduction		*0.0* *0%*	*40.3* *15%*	*0.0* *0%*	*65.6* *54%*	*0.0* *0%*

*** Existing loads estimated with limited water quality monitoring data**

4.2.6.3 Rock Creek (07030005-584) *E. coli* TMDL and allocations

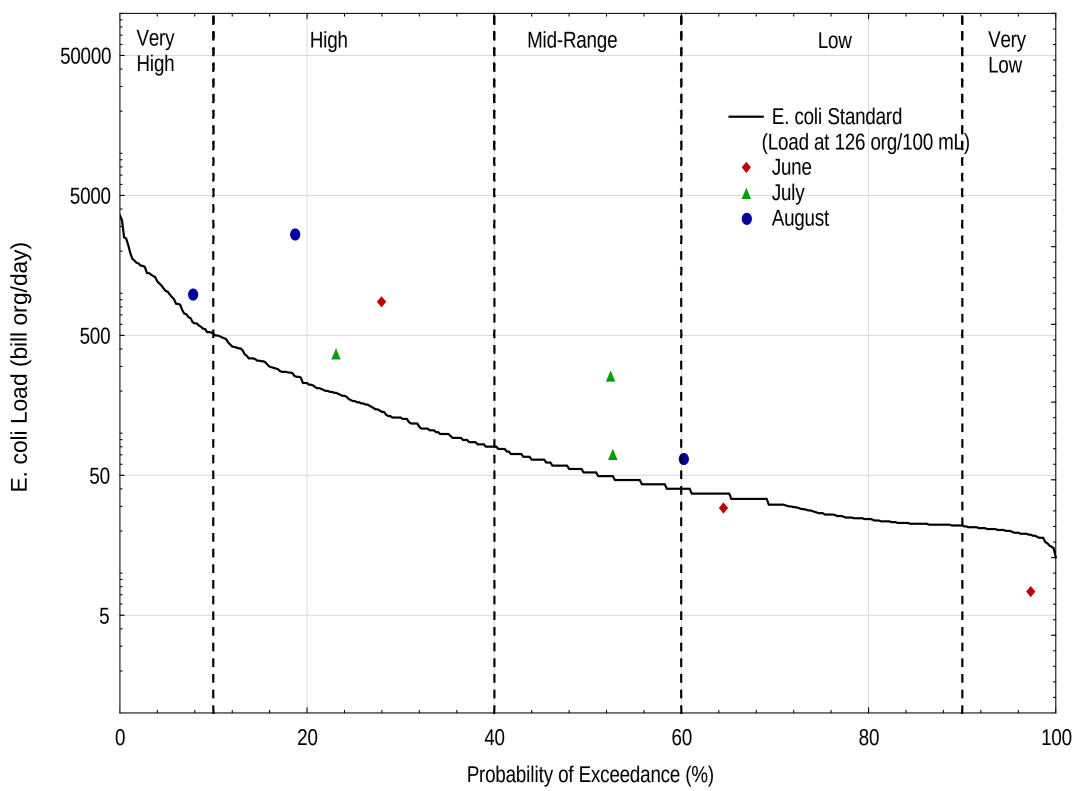

Figure 15. E. coli load duration curve for Rock Creek (07030005-584)

Table 40. Rock Creek E. coli TMDL and allocations

Rock Creek 07030005-584 Load Component		Flow Regime				
		Very High	High	Mid	Low	Very Low
		Billion organisms per day				
Existing Load*		*983.5*	*945.9*	*133.9*	*44.3*	*7.5*
Load Allocations	*Rock Lake outflow*	*181.6*	*31.4*	*10.2*	*5.5*	*3.7*
	Watershed runoff	*753.5*	*121.2*	*36.9*	*18.6*	*14.4*
	Total LA	**935.1**	**152.6**	**47.2**	**24.1**	**18.0**
MOS		**103.9**	**17.0**	**5.2**	**2.7**	**2.0**
Total Loading Capacity		**1039.0**	**169.6**	**52.4**	**26.8**	**20.0**
Estimated Load Reduction		*0.0* *0%*	*776.3* *82%*	*81.49* *61%*	*17.5* *39%*	*0.0* *0%*

*** Existing loads estimated with limited water quality monitoring data at all flow regimes**

4.2.7 TMDL Baseline

E. coli TMDLs are based on data from the period 2006-2011. Any activities implemented during or after 2011 that lead to a reduction in loads or an improvement in an impaired stream water quality may be considered as progress towards meeting a WLA or LA.

5 Future Growth/Reserve Capacity

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.

Phosphorus load transfers will be based on methods consistent with those used in setting the allocations in this TMDL (see Section 4.1.3). One transfer rate was defined for each impaired lake as the total WLA (kg/day) divided by the watershed area downstream of any upstream impaired waterbody (acres). In the case of a load transfer, the amount transferred from LA to WLA will be based on the area (acres) of land coming under permit coverage multiplied by the transfer rate (kg/ac-day). The MPCA will make these allocation shifts. 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.

Bacteria load transfers will be based on methods consistent with those used in setting the allocations in this TMDL (see Section 4.2.3). One transfer rate was defined for each impaired stream as the total WLA (billion org/day) divided by the watershed area downstream of any upstream impaired waterbody (acres). In the case of a load transfer, the amount transferred from LA to WLA will be based on the area (acres) of land coming under permit coverage multiplied by the transfer rate (billion org/ac-day). The MPCA will make these allocation shifts. 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

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

6.1 Non-regulatory

At the local level, the Chisago SWCD, Pine SWCD, and other local entities currently implement programs that target improving water quality and have been actively involved in projects to improve water quality in the past. Willing landowners within this watershed have implemented many practices in the past including: conservation tillage, buffer strips, urban Best Management Practices (BMPs), gully stabilizations, prescribed grazing, manure management, etc. It is assumed that these activities will continue. Potential state funding sources of Restoration and Protection projects are Clean Water Fund grants from the Clean Water, Land, and Legacy Amendment. At the federal level, funding can be provided through Section 319 grants or United States Department of Agriculture (USDA) programs that provide cost-share dollars to implement activities in the watershed. Various other funding and cost-share sources exist, which will be listed in the Goose Creek WRAPS. The implementation strategies described in this plan have demonstrated to be effective in reducing nutrient loading to lakes and streams. When funding is obtained programs will be established within the watershed to continue implementing the recommended activities. Monitoring will continue and adaptive management will be in place to evaluate the progress made towards achieving water quality goals.

6.2 Regulatory

6.2.1 Regulated Construction Stormwater

State implementation of the TMDL will be through action on NPDES Permits for regulated construction stormwater. To meet the WLA for construction stormwater, construction stormwater activities are required to meet the conditions of the Construction General Permit under the NPDES program and properly select, install, and maintain 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 meet local construction stormwater requirements if they are more restrictive than requirements of the State General Permit.

6.2.2 Regulated Industrial Stormwater

To meet the WLA for industrial stormwater, industrial stormwater activities are required to meet the conditions of the industrial stormwater general permit or Nonmetallic Mining & Associated Activities general permit (MNG49) under the NPDES program and properly select, install and maintain all BMPs required under the permit.

6.2.3 Municipal Separate Storm Sewer System (MS4) Permits

At the time of the TMDL there are no permitted MS4 comminutes within the watershed. If an MS4 exists in the future, stormwater discharges associated with MS4s are regulated through NPDES/State Disposal System (SDS) Permits. The Stormwater Program for MS4s is designed to reduce the amount of sediment and pollution that enters surface and ground water from storm sewer systems to the maximum extent practicable. MS4 Permits require the implementation of BMPs to address WLAs. In addition, the owner or operator is required to develop a stormwater pollution prevention program (SWPPP) that incorporates BMPs applicable to their MS4. The SWPPP must cover six minimum control measures:

- Public education and outreach;
- Public participation/involvement;
- Illicit discharge, detection and elimination;
- Construction site runoff control;
- Post-construction site runoff control; and
- Pollution prevention/good housekeeping.

6.2.4 Wastewater & State Disposal System (SDS) Permits

The MPCA issues permits for WWTF that discharges into waters of the state. The permits have site specific limits on bacteria that are based on water quality standards. Permits regulate discharges with the goals of 1) protecting public health and aquatic life, and 2) assuring that every facility treats wastewater. In addition, SDS permits set limits and establish controls for land application of sewage.

6.2.5 Subsurface Sewage Treatment Systems Program

The SSTS, commonly known as septic systems, are regulated by Minn. Stat. 115.55 and 115.56.

These regulations detail:

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

6.2.6 Feedlot Rules

The MPCA regulates the collection, transportation, storage, processing and disposal of animal manure and other livestock operation wastes. The MPCA Feedlot Program implements rules governing these activities, and provides assistance to counties and the livestock industry. The feedlot rules apply to most aspects of livestock waste management including the location, design, construction, operation and management of feedlots and manure handling facilities.

There are two primary concerns about feedlots in protecting water:

- Ensuring that manure on a feedlot or manure storage area does not run into water;
- Ensuring that manure is applied to cropland at a rate, time and method that prevents bacteria and other possible contaminants from entering streams, lakes and ground water.

7 Monitoring Plan

7.1 Stream Monitoring

Each stream reach within the Goose Creek Watershed has a different monitoring schedule depending on who monitors the site. Many Goose Creek Watershed sites in Chisago and Pine counties have been monitored through the years. There is currently not a watershed wide stream monitoring program. Pour point monitoring at Goose Creek (AUID 07030005-510), Rush Creek (AUID 07030005-509), and Rock Creek (AUID 07030005-584), was done by the Chisago SWCD from 2006-2009 through the MPCA's Load Monitoring Program that is funded through the Clean Water Fund for a variety of parameters including: continuous flow, total suspended solids, TP, total Kjeldahl nitrogen, E. coli, and nitrates. Additional monitoring was completed throughout the Goose Creek and Rush Creek watersheds, specifically focused around Goose and Rush Lakes, from 2009-2010. This monitoring was completed by the SWCD and volunteers from the Goose Chain of Lakes Association and the Rush Lake Improvement Association through SWAG from the MPCA.

If funding is available, the SWCDs and Counties will set up a monitoring program to monitor for nutrients, E. coli, and flow. Ideally it would be a twice per month plus storm event monitoring program. If funding is not available for new monitoring programs, the monitoring that is completed will be done following MPCA's 10-year monitoring cycle and through competitive grants when available.

7.2 Lake Monitoring

The large lakes within this watershed have been monitored by volunteers and staff over the years. This monitoring is planned to continue on a monthly basis to record the changing water quality. Currently, Chisago County staff monitor West Rush Lake, East Rush Lake, Goose Lake (2 locations), Horseshoe Lake, Mandall Lake, Rabour Lake, and Fish Lake. Rock Lake was monitored by volunteers through the Pine SWCD's SWAG from the MPCA from 2011-2012. The lakes are generally monitored for Chl-a, TP, and Secchi disk transparency. Many of the smaller lakes and lakes without public accesses are monitored by volunteers through the MPCA's Citizen Lake Monitoring Program.

The DNR Section of Fisheries will continue to conduct macrophyte, habitat, and fish surveys as allowed by their regular schedule. Full lake surveys are generally done every 10 years. This sampling will include emergent and floating leaf macrophyte bed delineation, submerged vegetation sampling using transects or point intercept method, and Score the Shore, which is a tool to assess habitat conditions of developed lake lots. A plant-based Index of Biological Integrity (IBI) is being developed for lakes. Currently fish surveys are conducted every five years on large lakes (every 10 years on small lakes).

7.3 BMP Monitoring

On-site monitoring of implementation practices should also take place in order to better assess BMP effectiveness. A variety of criteria such as land use, soil type, and other watershed characteristics, as well as monitoring feasibility, will be used to determine which BMPs to monitor. Under these criteria, monitoring of a specific type of implementation practice can be accomplished at one site but can be applied to similar practices under similar criteria and scenarios. Effectiveness of other BMPs can be extrapolated based on monitoring results.

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 BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in the State's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). If a construction site owner/operator obtains coverage under the NPDES/SDS General Stormwater Permit and properly selects, installs and maintains all BMPs required under the permit, including those related to impaired waters discharges and any applicable additional requirements found in Appendix A of the Construction General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. It should be noted that all local construction stormwater requirements must also be met.

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 the State's NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000), or NPDES/SDS General Permit for Construction Sand & Gravel, Rock Quarrying and Hot Mix Asphalt Production facilities (MNG490000). If a facility owner/operator obtains stormwater coverage under the appropriate NPDES/SDS Permit and properly selects, installs and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. It should be noted that all local stormwater management requirements must also be met.

8.2 Adaptive Management

The response of the lakes and streams will be evaluated as management practices are implemented. This evaluation will occur every five years after the commencement of implementation actions, for the next 25 years. Data will be evaluated and decisions will be made as to how to proceed for the next five years. The management approach to achieving the goals should be adapted as new information is collected and evaluated.

8.3 Subwatershed Assessments

Urban and rural subwatershed assessments have been developed or are in progress for portions of the Goose Creek Watershed. These assessments help guide implementation activities by determining the potential runoff load as well as identifying the most logical locations to start with BMP implementation.

Local decision makers and the SWCDs use the subwatershed assessments to prioritize implementation activities and apply for funding.

Table 41. Subwatershed Assessments

Assessment Name	Sector	Year	Data Location
Chisago SWCD Assessments			
Rush Creek	Rural	2014	Contact Chisago SWCD
East Rush Lake (east side)	Rural	2013	
City of Harris	Urban	In progress	

8.4 Prioritization

Prioritization of implementation activities will be key in achieving the necessary reductions with the current level of funds and staff time available. Examples of prioritizing BMPs will include focusing on watershed loading reductions for lakes and stream reaches before implementing any major in-lake treatment efforts.

We use subwatershed assessments, land cover mapping, and GIS to prioritize project workload and BMP placement. During the WRAPS process, we will utilize GIS tools like the Stream Power Index (SPI), Flow Accumulation, NRCS Watershed tools, and other Digital Terrain Analysis tools to obtain a list of locations where BMPs should be considered.

8.5 Education and Outreach

A crucial element of success for the Restoration and Protection planning process to clean up impaired lakes and streams and protect non-impaired water bodies will be participation from local citizens. In order to gain support from these citizens, education and civic engagement opportunities will be necessary. A variety of educational avenues can and will be used throughout the watershed. These include (but are not limited to): press releases, meetings, workshops, focus groups, trainings, and websites. Local staff (conservation district, county, etc.) and board members will work to educate the residents of the watersheds about ways to clean up their lakes and streams on a regular basis. Education will continue throughout the watershed.

8.6 Technical Assistance

The Chisago SWCD and Pine SWCD provide assistance to landowners for a variety of projects that benefit water quality throughout the Goose Creek BMPs management practices to urban and lakeshore BMPs. This technical assistance includes education and one-on-one training. Many opportunities for technical assistance are a direct result of educational workshops and trainings. It is important that these outreach opportunities for watershed residents continue. Marketing is necessary to motivate landowners to participate in voluntary cost-share assistance programs.

Technical assistance is provided by a variety of entities, including but not limited to the Chisago SWCD, Pine SWCD, and USDA Natural Resources Conservation Service. Programs such as State cost-share, Clean Water Legacy funding, Environmental Quality Incentives Program (EQIP), and the Conservation Reserve

Program (CRP) are available to help implement the best conservation practices that each parcel of land is eligible for to target the best conservation practices per site. Conservation practices may include, but are not limited to: stormwater bioretention, septic system upgrades, feedlot improvements, invasive species control, wastewater treatment practices, agricultural and rural BMPs and internal loading reduction. More information about types of practices and implementation of BMPs will be discussed in the Goose Creek Watershed Restoration and Protection Plan.

8.7 Partnerships

Partnerships with counties, cities, townships, citizens, businesses, watersheds, and lake associations are one mechanism through which the Chisago SWCD and Pine SWCD will protect and improve water quality. Strong partnerships with state and local government to protect and improve water resources and to bring waters within the Goose Creek Watershed into compliance with State standards will continue. A partnership with local government units and regulatory agencies such as cities, townships and counties may be formed to develop and update ordinances to protect the area's water resources.

8.8 Cost

The Clean Water Legacy Act requires that a TMDL include an overall approximation of the cost to implement a TMDL [Minn. Stat. 2007, § 114D.25]. The initial estimate for implementing the Goose Creek Watershed TMDL is approximately $3,000,000 to $5,500,000.

9 Public Participation

9.1 Steering Committee

On July 24, 2013, a joint Steering Committee Meeting and Public Meeting were held in Rush City, Minnesota. There were 16 total attendees – five of which were invited as part of the Steering Committee meeting, 11 of which were citizens and lake association members. An overview of the TMDL/WRAPS process was given to attendees. Discussion took place about the following items:

- Impaired vs. Unimpaired = Restoration vs. Protection
- Invasive/Undesirable species – carp, curly-leaf pondweed, etc.
- How deep and shallow lakes are different and how they act different from each other
- Septic System – landowners feel that there are still imminent threat to public health septic systems out there – ones that were flagged and never fixed, etc.
- How do these studies correspond with the items that have already been completed in the Rush Lake watershed?
- How do we get grant funding for invasive species and watershed problems?

9.2 Public Meetings

On October 15th, 2014, the Chisago SWCD and Emmons and Oliver Resources (EOR) presented data and findings from the Goose Creek Watershed TMDL for six lakes and three streams. A factsheet was handed out that summarized the findings of all the individual TMDLs, watershed land cover, existing water quality data, and loading information.

We also introduced the WRAPS project that will include all waterbodies in the whole watershed (regardless of their impairment status). This document will outline projects that can be completed to obtain the pollution reductions that we need to restore the lakes that are impaired and protect those that aren't impaired.

Meeting attendees (six total attendees) were asked four questions – and the answers that they came up with are provided below:

1) What do you believe is the biggest nutrient contributor to your lake?

- *Phosphorus – cattle, runoff, golf course*
- *Decomposition of weeds*
- *Watershed runoff*

2) What could you do to help?

- *Educate landowners in the watershed*
- *Educate people about dumping leaves and grass clippings in the lake and watershed*
- *Promote buffer zones*

3) Are you looking for any information regarding your lake?

- *Are there any farms and feedlots directly affecting the lake?*
- *A list of projects/concepts that are very likely/likely/unlikely*

a) Do you know where to find it, or could you use help?

4) Are there other concerns besides nutrients?

- *E. coli bacteria*
- *Septic Systems*

<u>Other ideas that came from the meeting:</u>

- *Welcome to the lake packet*
- *Door knocking to get more interest from lake association members and non-members*
- *Door hangers to educate about leaves and grass clippings*

<u>Timeline for the TMDL, WRAPS, and Implementation:</u>

- *Draft TMDL – Will be to the MPCA and EPA within 2-3 months.*
- *The WRAPS will be worked on simultaneously – this is likely to be completed in the summer of 2015 Grant funding – We continuously apply for grant funding for this watershed. We have yet to be successful. We will continue to apply each time there is an opportunity.*

9.3 Farmer Focus Group Meetings

A Farmer Focus Group meeting was held on April 3, 2012 with a group of influential agricultural producers within Chisago County, local Agronomists, along with Chisago SWCD and USDA Natural Resources Conservation Service staff. The focus of the meeting was the local TMDL studies currently happening in Chisago County. Statistics were shared with the group that included pollutant runoff potentials from different land uses; this showed that due to the large amount of land in agricultural production, there is the potential to reduce pollutant runoff in large quantities. The producers are interested in maximizing their production while preventing soil and nutrient loss.

On February 5, 2014, a larger group of people from Chisago, Isanti and Pine Counties in Minnesota and Polk and St. Croix Counties in Wisconsin along with several USDA employees and crop consultants got together to discuss how soil health leads to better agricultural production. Discussions on tillage, no-tillage, cover crops, and other management systems took place. From this meeting, many producers used their new knowledge to plant cover crops in 2014.

9.4 Public Notice

A formal 30 day public notice period for the Goose Creek Watershed TMDL Report and WRAPS Report was held from November 2nd, 2015 through December 4th, 2015.

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11 Appendix A: STEPL Supporting Information

11.1 STEPL Input Data

Table 42. STEPL watershed land use area (acres) input.

Watershed	Urban (ac)	Cropland (ac)	Pastureland (ac)	Forest (ac)	User Defined (ac)	Feedlots (ac)	Total (ac)
Goose Lake North Bay	72.61	366.84	423.22	111.35	356.65	0	1,330.67
Goose Lake South Bay (incl. Mandall and Rabour)*	459.26	1,452.19	2,482.12	1,205.08	1,501.51	1.26	7,101.42
Horseshoe Lake (incl. Little Horseshoe)*	244.25	979.76	1,210.88	819.13	539.20	0.58	3,793.80
Rock Lake	420.43	1,867.16	2,714.93	254.63	906.57	0.87	6,164.59
Rush Lake (West)	808.92	3,163.30	5,036.34	1,272.04	3,457.36	0.94	13,738.90
Rush Lake (East)	323.83	1,712.73	1,313.96	504.82	1,653.76	1.43	5,510.53

* Watershed loads for upstream lakes were estimated based on an area-weighted fraction of the total watershed load according to Table 43

Table 43. Upstream lake watershed area as a fraction of the total impaired lake watershed area

Upstream Lake	Impaired Lake	Fraction of Total Area (%)
Mandall	Goose Lake South Bay	29%
Rabour	Goose Lake South Bay	19%
Little Horseshoe	Horseshoe Lake	12%

Table 44. STEPL watershed precipitation (in) input.

Annual Rainfall (in)	Number of Rain Days	Average Rain per Event (in)
28.87	97.1	0.728

Table 45. STEPL phosphorus concentration in runoff (mg/L) input.

Land use	P (mg/L)
1. L-Cropland	0.3
1a. w/ manure	2
2. M-Cropland	0.4
2a. w/ manure	3
3. H-Cropland	0.5
3a. w/ manure	4
4. Pastureland	0.3
5. Forest	0.1
6. User Defined	0

11.2 STEPL Output Data

Table 46. STEPL annual runoff (ac-ft) and phosphorus load (lb/yr) by watershed.

Lake	Runoff (ac-ft/yr)	P Load (lb/yr)
Goose Lake North Bay	984.9	545.9
Goose Lake South Bay (Direct Drainage)	2,400.5	1,137.2
Mandall (upstream of Goose Lake South Bay)	1,360.9	644.7
Rabour (upstream of Goose Lake South Bay)	879.2	416.5
Horseshoe Lake (Direct Drainage)	1,896.8	1,225.2
Little Horseshoe (upstream of Horseshoe)	257.2	166.2
Rock Lake	3,695.6	3,172.1
Rush Lake West	9,803.7	4,854.2
Rush Lake East	4,342.2	2,899.9

12 Appendix B: BATHTUB Supporting Information

Table 47. Goose Lake (North Bay) Calibrated Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1	North Goose				
	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	170.3	0.24	92.1%	170.3	0.16	92.1%

Table 48. Goose Lake (North Bay) Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct Drainage Area	5.4	1.2	0.00E+00	0.00	0.22
2	1	1	South Goose	31.1	5.4	0.00E+00	0.00	0.17
PRECIPITATION				1.1	0.8	0.00E+00	0.00	0.75
TRIBUTARY INFLOW				36.5	6.6	0.00E+00	0.00	0.18
***TOTAL INFLOW				37.6	7.5	0.00E+00	0.00	0.20
ADVECTIVE OUTFLOW				37.6	6.5	0.00E+00	0.00	0.17
***TOTAL OUTFLOW				37.6	6.5	0.00E+00	0.00	0.17
***EVAPORATION					0.9	0.00E+00	0.00	

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

Component: TOTAL P

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct Drainage Area	268.5	11.1%	4.51E+03	22.6%	0.25	222.9	50.1
2	1	1	South Goose	300.8	12.5%	1.52E+04	76.3%	0.41	55.4	9.7
PRECIPITATION				29.7	1.2%	2.21E+02	1.1%	0.50	36.0	27.0
INTERNAL LOAD				1811.3	75.1%	0.00E+00		0.00		
TRIBUTARY INFLOW				569.3	23.6%	1.97E+04	98.9%	0.25	85.8	15.6
***TOTAL INFLOW				2410.3	100.0%	1.99E+04	100.0%	0.06	323.0	64.1
ADVECTIVE OUTFLOW				1110.0	46.1%	7.27E+04		0.24	170.3	29.5
***TOTAL OUTFLOW				1110.0	46.1%	7.27E+04		0.24	170.3	29.5
***RETENTION				1300.3	53.9%	7.88E+04		0.22		

Overflow Rate (m/yr)	5.9	Nutrient Resid. Time (yrs)	0.1198
Hydraulic Resid. Time (yrs)	0.2601	Turnover Ratio	8.3
Reservoir Conc (mg/m3)	170	Retention Coef.	0.539

Table 49. Goose Lake (North Bay) TMDL Goal Scenario Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1 North Goose					
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	60.0	0.21	59.9%	170.3	0.16	92.1%

Table 50. Goose Lake (North Bay) TMDL Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct Drainage Area	5.4	1.2	0.00E+00	0.00	0.22
2	1	1	South Goose	31.1	5.4	0.00E+00	0.00	0.17
PRECIPITATION				1.1	0.8	0.00E+00	0.00	0.75
TRIBUTARY INFLOW				36.5	6.6	0.00E+00	0.00	0.18
***TOTAL INFLOW				37.6	7.5	0.00E+00	0.00	0.20
ADVECTIVE OUTFLOW				37.6	6.5	0.00E+00	0.00	0.17
***TOTAL OUTFLOW				37.6	6.5	0.00E+00	0.00	0.17
***EVAPORATION					0.9	0.00E+00	0.00	

Overall Mass Balance Based Upon Predicted TOTAL P

Component: Outflow & Reservoir Concentrations

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct Drainage Area	120.4	18.8%	9.07E+02	10.0%	0.25	100.0	22.5
2	1	1	South Goose	217.3	33.9%	7.94E+03	87.6%	0.41	40.0	7.0
PRECIPITATION				29.7	4.6%	2.21E+02	2.4%	0.50	36.0	27.0
INTERNAL LOAD				273.4	42.7%	0.00E+00		0.00		
TRIBUTARY INFLOW				337.8	52.7%	8.85E+03	97.6%	0.28	50.9	9.3
***TOTAL INFLOW				640.9	100.0%	9.07E+03	100.0%	0.15	85.9	17.0
ADVECTIVE OUTFLOW				391.1	61.0%	6.87E+03		0.21	60.0	10.4
***TOTAL OUTFLOW				391.1	61.0%	6.87E+03		0.21	60.0	10.4
***RETENTION				249.8	39.0%	6.86E+03		0.33		

Overflow Rate (m/yr)	5.9	Nutrient Resid. Time (yrs)	0.1588
Hydraulic Resid. Time (yrs)	0.2601	Turnover Ratio	6.3
Reservoir Conc (mg/m3)	60	Retention Coef.	0.390

Table 51. Goose Lake (South Bay) Calibrated Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset							
Segment:		**1**	**South Goose**				
		Predicted Values--->			**Observed Values--->**		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	55.4	0.32	56.4%	55.4	0.41	56.4%

Table 52. Goose Lake (South Bay) Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance					**Averaging Period =**		**1.00**	**years**
				Area	**Flow**	**Variance**	**CV**	**Runoff**
Trb	**Type**	**Seg**	**Name**	**km²**	**hm³/yr**	**(hm3/yr)²**	**-**	**m/yr**
1	1	1	Direct Drainage Area	14.3	2.9	0.00E+00	0.00	0.21
2	1	1	Mandall	15.0	2.7	0.00E+00	0.00	0.18
PRECIPITATION				1.8	1.4	0.00E+00	0.00	0.75
TRIBUTARY INFLOW				29.3	5.6	0.00E+00	0.00	0.19
***TOTAL INFLOW				31.1	7.0	0.00E+00	0.00	0.22
ADVECTIVE OUTFLOW				31.1	5.4	0.00E+00	0.00	0.17
***TOTAL OUTFLOW				31.1	5.4	0.00E+00	0.00	0.17
***EVAPORATION					1.6	0.00E+00	0.00	

Overall Mass Balance Based Upon				**Predicted**		**Outflow & Reservoir Concentrations**				
Component:				**TOTAL P**						
				Load		**Load Variance**			**Conc**	**Export**
Trb	**Type**	**Seg**	**Name**	**kg/yr**	**%Total**	**(kg/yr)²**	**%Total**	**CV**	**mg/m³**	**kg/km²/yr**
1	1	1	Direct Drainage Area	550.6	59.1%	1.89E+04	83.1%	0.25	187.5	38.5
2	1	1	Mandall	228.1	24.5%	3.25E+03	14.3%	0.25	84.6	15.2
PRECIPITATION				48.9	5.2%	5.98E+02	2.6%	0.50	36.0	27.0
INTERNAL LOAD				103.8	11.1%	0.00E+00		0.00		
TRIBUTARY INFLOW				778.7	83.6%	2.22E+04	97.4%	0.19	138.3	26.5
***TOTAL INFLOW				931.4	100.0%	2.28E+04	100.0%	0.16	133.2	29.9
ADVECTIVE OUTFLOW				300.9	32.3%	9.20E+03		0.32	55.4	9.7
***TOTAL OUTFLOW				300.9	32.3%	9.20E+03		0.32	55.4	9.7
***RETENTION				630.5	67.7%	2.19E+04		0.23		

Overflow Rate (m/yr)	3.0	Nutrient Resid. Time (yrs)	0.4705
Hydraulic Resid. Time (yrs)	1.4564	Turnover Ratio	2.1
Reservoir Conc (mg/m3)	55	Retention Coef.	0.677

Table 53. Goose Lake (South Bay) TMDL Goal Scenario Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1 South Goose					
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	40.0	0.30	42.0%	55.4	0.41	56.4%

Table 54. Goose Lake (South Bay) TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct Drainage Area	14.3	2.9	0.00E+00	0.00	0.21
2	1	1	Mandall	15.0	2.7	0.00E+00	0.00	0.18
PRECIPITATION				1.8	1.4	0.00E+00	0.00	0.75
TRIBUTARY INFLOW				29.3	5.6	0.00E+00	0.00	0.19
***TOTAL INFLOW				31.1	7.0	0.00E+00	0.00	0.22
ADVECTIVE OUTFLOW				31.1	5.4	0.00E+00	0.00	0.17
***TOTAL OUTFLOW				31.1	5.4	0.00E+00	0.00	0.17
***EVAPORATION					1.6	0.00E+00	0.00	

Overall Mass Balance Based Upon Predicted TOTAL P — Outflow & Reservoir Concentrations

Component:

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct Drainage Area	324.5	55.5%	6.58E+03	83.2%	0.25	110.5	22.7
2	1	1	Mandall	107.8	18.4%	7.27E+02	9.2%	0.25	40.0	7.2
PRECIPITATION				48.9	8.4%	5.98E+02	7.6%	0.50	36.0	27.0
INTERNAL LOAD				103.8	17.7%	0.00E+00		0.00		
TRIBUTARY INFLOW				432.3	73.9%	7.31E+03	92.4%	0.20	76.8	14.7
***TOTAL INFLOW				585.0	100.0%	7.90E+03	100.0%	0.15	83.7	18.8
ADVECTIVE OUTFLOW				217.2	37.1%	4.19E+03		0.30	40.0	7.0
***TOTAL OUTFLOW				217.2	37.1%	4.19E+03		0.30	40.0	7.0
***RETENTION				367.8	62.9%	7.92E+03		0.24		

Overflow Rate (m/yr)	3.0	Nutrient Resid. Time (yrs)	0.5408
Hydraulic Resid. Time (yrs)	1.4564	Turnover Ratio	1.8
Reservoir Conc (mg/m3)	40	Retention Coef.	0.629

Table 55. Horseshoe Lake Calibrated Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset							
Segment:		**1**	**Horseshoe**				
		Predicted Values--->			**Observed Values--->**		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	52.6	0.38	54.1%	52.6	0.07	54.1%

Table 56. Horseshoe Lake Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

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

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct Drainage Area	14.5	2.3	0.00E+00	0.00	0.16
2	1	1	Little Horseshoe	2.0	0.3	0.00E+00	0.00	0.15
PRECIPITATION				0.9	0.7	0.00E+00	0.00	0.75
TRIBUTARY INFLOW				16.4	2.6	0.00E+00	0.00	0.16
***TOTAL INFLOW				17.3	3.3	0.00E+00	0.00	0.19
ADVECTIVE OUTFLOW				17.3	2.5	0.00E+00	0.00	0.15
***TOTAL OUTFLOW				17.3	2.5	0.00E+00	0.00	0.15
***EVAPORATION					0.8	0.00E+00	0.00	

Overall Mass Balance Based Upon Predicted TOTAL P

Component: — **Outflow & Reservoir Concentrations**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct Drainage Area	583.7	93.5%	2.13E+04	99.2%	0.25	251.6	40.4
2	1	1	Little Horseshoe	16.0	2.6%	1.59E+01	0.1%	0.25	54.5	8.1
PRECIPITATION				24.5	3.9%	1.50E+02	0.7%	0.50	36.0	27.0
TRIBUTARY INFLOW				599.6	96.1%	2.13E+04	99.3%	0.24	229.5	36.5
***TOTAL INFLOW				624.1	100.0%	2.15E+04	100.0%	0.23	189.5	36.0
ADVECTIVE OUTFLOW				132.1	21.2%	2.49E+03		0.38	52.6	7.6
***TOTAL OUTFLOW				132.1	21.2%	2.49E+03		0.38	52.6	7.6
***RETENTION				492.0	78.8%	1.82E+04		0.27		

Overflow Rate (m/yr)	2.8	Nutrient Resid. Time (yrs)	0.3033
Hydraulic Resid. Time (yrs)	1.4322	Turnover Ratio	3.3
Reservoir Conc (mg/m3)	53	Retention Coef.	0.788

Table 57. Horseshoe Lake TMDL Goal Scenario Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset							
Segment:		1	Horseshoe				
		Predicted Values--->			Observed Values--->		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	40.0	0.36	42.0%	52.6	0.07	54.1%

Table 58. Horseshoe Lake TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance					Averaging Period =		1.00	years
				Area	Flow	Variance	CV	Runoff
Trb	**Type**	**Seg**	**Name**	**km^2**	**hm^3/yr**	**$(hm3/yr)^2$**	**-**	**m/yr**
1	1	1	Direct Drainage Area	14.5	2.3	0.00E+00	0.00	0.16
2	1	1	Little Horseshoe	2.0	0.3	0.00E+00	0.00	0.15
PRECIPITATION				0.9	0.7	0.00E+00	0.00	0.75
TRIBUTARY INFLOW				16.4	2.6	0.00E+00	0.00	0.16
***TOTAL INFLOW				17.3	3.3	0.00E+00	0.00	0.19
ADVECTIVE OUTFLOW				17.3	2.5	0.00E+00	0.00	0.15
***TOTAL OUTFLOW				17.3	2.5	0.00E+00	0.00	0.15
***EVAPORATION					0.8	0.00E+00	0.00	

Overall Mass Balance Based Upon				Predicted		Outflow & Reservoir Concentrations				
Component:				TOTAL P						
				Load		Load Variance			Conc	Export
Trb	**Type**	**Seg**	**Name**	**kg/yr**	**%Total**	**$(kg/yr)^2$**	**%Total**	**CV**	**mg/m^3**	**$kg/km^2/yr$**
1	1	1	Direct Drainage Area	372.3	91.1%	8.66E+03	98.2%	0.25	160.5	25.8
2	1	1	Little Horseshoe	11.7	2.9%	8.58E+00	0.1%	0.25	40.0	6.0
PRECIPITATION				24.5	6.0%	1.50E+02	1.7%	0.50	36.0	27.0
TRIBUTARY INFLOW				384.0	94.0%	8.67E+03	98.3%	0.24	147.0	23.4
***TOTAL INFLOW				408.5	100.0%	8.82E+03	100.0%	0.23	124.1	23.6
ADVECTIVE OUTFLOW				100.5	24.6%	1.34E+03		0.36	40.0	5.8
***TOTAL OUTFLOW				100.5	24.6%	1.34E+03		0.36	40.0	5.8
***RETENTION				308.0	75.4%	7.33E+03		0.28		

Overflow Rate (m/yr)	2.8	Nutrient Resid. Time (yrs)	0.3523
Hydraulic Resid. Time (yrs)	1.4322	Turnover Ratio	2.8
Reservoir Conc (mg/m3)	40	Retention Coef.	0.754

Table 59. Rock Lake Calibrated Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset							
Segment:	1	Rock					
	Predicted Values--->			Observed Values--->			
Variable		Mean	CV	Rank	Mean	CV	Rank
TOTAL P	MG/M3	193.3	0.33	93.9%	193.3	0.07	93.9%

Table 60. Rock Lake Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Direct Drainage Area	25.0	4.5	0.00E+00	0.00	0.18
PRECIPITATION				0.3	0.2	0.00E+00	0.00	0.75
TRIBUTARY INFLOW				25.0	4.5	0.00E+00	0.00	0.18
***TOTAL INFLOW				25.3	4.8	0.00E+00	0.00	0.19
ADVECTIVE OUTFLOW				25.3	4.5	0.00E+00	0.00	0.18
***TOTAL OUTFLOW				25.3	4.5	0.00E+00	0.00	0.18
***EVAPORATION					0.3	0.00E+00	0.00	

Overall Mass Balance Based Upon Predicted Outflow & Reservoir Concentrations
Component: TOTAL P

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Direct Drainage Area	1205.9	34.5%	9.09E+04	100.0%	0.25	266.8	48.2
PRECIPITATION				8.9	0.3%	1.96E+01	0.0%	0.50	36.0	27.0
INTERNAL LOAD				2284.4	65.3%	0.00E+00		0.00		
TRIBUTARY INFLOW				1205.9	34.5%	9.09E+04	100.0%	0.25	266.8	48.2
***TOTAL INFLOW				3499.1	100.0%	9.09E+04	100.0%	0.09	734.3	138.1
ADVECTIVE OUTFLOW				866.8	24.8%	8.41E+04		0.33	193.3	34.2
***TOTAL OUTFLOW				866.8	24.8%	8.41E+04		0.33	193.3	34.2
***RETENTION				2632.3	75.2%	1.50E+05		0.15		

Overflow Rate (m/yr)	13.7	Nutrient Resid. Time (yrs)	0.0522
Hydraulic Resid. Time (yrs)	0.2106	Turnover Ratio	19.2
Reservoir Conc (mg/m3)	193	Retention Coef.	0.752

Table 61. Rock Lake TMDL Goal Scenario Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset							
Segment:		**1**	**Rock**				
		Predicted Values--->			**Observed Values--->**		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	60.0	0.27	59.9%	193.3	0.07	93.9%

Table 62. Rock Lake TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

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

Trb	Type	Seg	Name	Area km²	Flow hm³/yr	Variance (hm3/yr)²	CV -	Runoff m/yr
1	1	1	Direct Drainage Area	25.0	4.5	0.00E+00	0.00	0.18
PRECIPITATION				0.3	0.2	0.00E+00	0.00	0.75
TRIBUTARY INFLOW				25.0	4.5	0.00E+00	0.00	0.18
***TOTAL INFLOW				25.3	4.8	0.00E+00	0.00	0.19
ADVECTIVE OUTFLOW				25.3	4.5	0.00E+00	0.00	0.18
***TOTAL OUTFLOW				25.3	4.5	0.00E+00	0.00	0.18
***EVAPORATION					0.3	0.00E+00	0.00	

Overall Mass Balance Based Upon Predicted Outflow & Reservoir Concentrations
Component: TOTAL P

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)²	%Total	CV	Conc mg/m³	Export kg/km²/yr
1	1	1	Direct Drainage Area	452.0	83.5%	1.28E+04	99.8%	0.25	100.0	18.1
PRECIPITATION				8.9	1.6%	1.96E+01	0.2%	0.50	36.0	27.0
INTERNAL LOAD				80.2	14.8%	0.00E+00		0.00		
TRIBUTARY INFLOW				452.0	83.5%	1.28E+04	99.8%	0.25	100.0	18.1
***TOTAL INFLOW				541.0	100.0%	1.28E+04	100.0%	0.21	113.5	21.3
ADVECTIVE OUTFLOW				269.0	49.7%	5.15E+03		0.27	60.0	10.6
***TOTAL OUTFLOW				269.0	49.7%	5.15E+03		0.27	60.0	10.6
***RETENTION				272.0	50.3%	9.03E+03		0.35		

Overflow Rate (m/yr)	13.7	Nutrient Resid. Time (yrs)	0.1047
Hydraulic Resid. Time (yrs)	0.2106	Turnover Ratio	9.6
Reservoir Conc (mg/m3)	60	Retention Coef.	0.503

Table 63. Rush Lake West Calibrated Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset							
Segment:	1	West Rush					
	Predicted Values--->			Observed Values--->			
Variable		Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3		64.5	0.35	63.0%	64.5	0.07	63.0%

Table 64. Rush Lake West Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Direct Drainage Area	56.4	12.0	0.00E+00	0.00	0.21
PRECIPITATION				6.4	4.8	0.00E+00	0.00	0.75
TRIBUTARY INFLOW				56.4	12.0	0.00E+00	0.00	0.21
***TOTAL INFLOW				62.8	16.8	0.00E+00	0.00	0.27
ADVECTIVE OUTFLOW				62.8	11.3	0.00E+00	0.00	0.18
***TOTAL OUTFLOW				62.8	11.3	0.00E+00	0.00	0.18
***EVAPORATION					5.5	0.00E+00	0.00	

Overall Mass Balance Based Upon Predicted Outflow & Reservoir Concentrations

Component: TOTAL P

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Direct Drainage Area	2032.9	66.0%	2.58E+05	97.2%	0.25	169.6	36.1
PRECIPITATION				172.6	5.6%	7.44E+03	2.8%	0.50	36.0	27.0
INTERNAL LOAD				875.4	28.4%	0.00E+00		0.00		
TRIBUTARY INFLOW				2032.9	66.0%	2.58E+05	97.2%	0.25	169.6	36.1
***TOTAL INFLOW				3080.8	100.0%	2.66E+05	100.0%	0.17	183.6	49.1
ADVECTIVE OUTFLOW				728.2	23.6%	6.61E+04		0.35	64.5	11.6
***TOTAL OUTFLOW				728.2	23.6%	6.61E+04		0.35	64.5	11.6
***RETENTION				2352.6	76.4%	2.50E+05		0.21		

Overflow Rate (m/yr)	1.8	Nutrient Resid. Time (yrs)	0.5166
Hydraulic Resid. Time (yrs)	2.1857	Turnover Ratio	1.9
Reservoir Conc (mg/m3)	65	Retention Coef.	0.764

Table 65. Rush Lake West TMDL Goal Scenario Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset							
Segment:	**1**	**West Rush**					
	Predicted Values--->			**Observed Values--->**			
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3		40.0	0.34	42.0%	64.5	0.07	63.0%

Table 66. Rush Lake West TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

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

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct Drainage Area	56.4	12.0	0.00E+00	0.00	0.21
PRECIPITATION				6.4	4.8	0.00E+00	0.00	0.75
TRIBUTARY INFLOW				56.4	12.0	0.00E+00	0.00	0.21
***TOTAL INFLOW				62.8	16.8	0.00E+00	0.00	0.27
ADVECTIVE OUTFLOW				62.8	11.3	0.00E+00	0.00	0.18
***TOTAL OUTFLOW				62.8	11.3	0.00E+00	0.00	0.18
***EVAPORATION					5.5	0.00E+00	0.00	

Overall Mass Balance Based Upon Predicted TOTAL P Component: — **Outflow & Reservoir Concentrations**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct Drainage Area	1199.0	79.9%	8.98E+04	92.3%	0.25	100.0	21.3
PRECIPITATION				172.6	11.5%	7.44E+03	7.7%	0.50	36.0	27.0
INTERNAL LOAD				128.4	8.6%	0.00E+00		0.00		
TRIBUTARY INFLOW				1199.0	79.9%	8.98E+04	92.3%	0.25	100.0	21.3
***TOTAL INFLOW				1499.9	100.0%	9.73E+04	100.0%	0.21	89.4	23.9
ADVECTIVE OUTFLOW				451.3	30.1%	2.34E+04		0.34	40.0	7.2
***TOTAL OUTFLOW				451.3	30.1%	2.34E+04		0.34	40.0	7.2
***RETENTION				1048.6	69.9%	8.10E+04		0.27		

Overflow Rate (m/yr)	1.8	Nutrient Resid. Time (yrs)	0.6577
Hydraulic Resid. Time (yrs)	2.1857	Turnover Ratio	1.5
Reservoir Conc (mg/m3)	40	Retention Coef.	0.699

Table 67. Rush Lake East Calibrated Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1	East Rush				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	61.0	0.29	60.6%	61.0	0.26	60.6%

Table 68. Rush Lake East Calibrated Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	Direct Drainage Area	22.5	5.3	0.00E+00	0.00	0.24
2	1	1	West Rush	62.8	11.3	0.00E+00	0.00	0.18
PRECIPITATION				6.0	4.5	0.00E+00	0.00	0.75
TRIBUTARY INFLOW				85.3	16.6	0.00E+00	0.00	0.19
***TOTAL INFLOW				91.3	21.1	0.00E+00	0.00	0.23
ADVECTIVE OUTFLOW				91.3	15.9	0.00E+00	0.00	0.17
***TOTAL OUTFLOW				91.3	15.9	0.00E+00	0.00	0.17
***EVAPORATION					5.2	0.00E+00	0.00	

Overall Mass Balance Based Upon Predicted Outflow & Reservoir Concentrations

Component: TOTAL P

Trb	Type	Seg	Name	Load kg/yr	Load %Total	Load Variance $(kg/yr)^2$	Load Variance %Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct Drainage Area	1032.0	39.7%	6.66E+04	87.9%	0.25	194.3	45.8
2	1	1	West Rush	727.7	28.0%	2.59E+03	3.4%	0.07	64.5	11.6
PRECIPITATION				162.2	6.2%	6.58E+03	8.7%	0.50	36.0	27.0
INTERNAL LOAD				680.2	26.1%	0.00E+00		0.00		
TRIBUTARY INFLOW				1759.7	67.6%	6.92E+04	91.3%	0.15	106.0	20.6
***TOTAL INFLOW				2602.0	100.0%	7.57E+04	100.0%	0.11	123.3	28.5
ADVECTIVE OUTFLOW				972.0	37.4%	7.77E+04		0.29	61.0	10.6
***TOTAL OUTFLOW				972.0	37.4%	7.77E+04		0.29	61.0	10.6
***RETENTION				1630.0	62.6%	1.13E+05		0.21		

Overflow Rate (m/yr)	2.7	Nutrient Resid. Time (yrs)	0.3759
Hydraulic Resid. Time (yrs)	1.0064	Turnover Ratio	2.7
Reservoir Conc (mg/m3)	61	Retention Coef.	0.626

Table 69. Rush Lake East TMDL Goal Scenario Model Predicted & Observed Values

Predicted & Observed Values Ranked Against CE Model Development Dataset							
Segment:	**1**	**East Rush**					
		Predicted Values--->			**Observed Values--->**		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	40.0	0.26	42.0%	61.0	0.26	60.6%

Table 70. Rush Lake East TMDL Goal Scenario Model Water and Phosphorus Balances

Overall Water & Nutrient Balances

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

Trb	Type	Seg	Name	Area (km^2)	Flow (hm^3/yr)	Variance ($(hm3/yr)^2$)	CV (-)	Runoff (m/yr)
1	1	1	Direct Drainage Area	22.5	5.3	0.00E+00	0.00	0.24
2	1	1	West Rush	62.8	11.3	0.00E+00	0.00	0.18
PRECIPITATION				6.0	4.5	0.00E+00	0.00	0.75
TRIBUTARY INFLOW				85.3	16.6	0.00E+00	0.00	0.19
***TOTAL INFLOW				91.3	21.1	0.00E+00	0.00	0.23
ADVECTIVE OUTFLOW				91.3	15.9	0.00E+00	0.00	0.17
***TOTAL OUTFLOW				91.3	15.9	0.00E+00	0.00	0.17
***EVAPORATION					5.2	0.00E+00	0.00	

Overall Mass Balance Based Upon Predicted TOTAL P Component: — **Outflow & Reservoir Concentrations**

Trb	Type	Seg	Name	Load (kg/yr)	%Total	Load Variance ($(kg/yr)^2$)	%Total	CV	Conc (mg/m^3)	Export ($kg/km^2/yr$)
1	1	1	Direct Drainage Area	531.0	36.5%	1.76E+04	69.9%	0.25	100.0	23.6
2	1	1	West Rush	451.5	31.0%	9.99E+02	4.0%	0.07	40.0	7.2
PRECIPITATION				162.2	11.1%	6.58E+03	26.1%	0.50	36.0	27.0
INTERNAL LOAD				311.6	21.4%	0.00E+00		0.00		
TRIBUTARY INFLOW				982.5	67.5%	1.86E+04	73.9%	0.14	59.2	11.5
***TOTAL INFLOW				1456.3	100.0%	2.52E+04	100.0%	0.11	69.0	16.0
ADVECTIVE OUTFLOW				637.2	43.8%	2.78E+04		0.26	40.0	7.0
***TOTAL OUTFLOW				637.2	43.8%	2.78E+04		0.26	40.0	7.0
***RETENTION				819.1	56.2%	3.67E+04		0.23		

Overflow Rate (m/yr)	2.7	Nutrient Resid. Time (yrs)	0.4403
Hydraulic Resid. Time (yrs)	1.0064	Turnover Ratio	2.3
Reservoir Conc (mg/m3)	40	Retention Coef.	0.562

Table 71. Mandall Lake Modeled Water and Phosphorus Balances

Overall Water & Nutrient Balances

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

Trb	Type	Seg	Name	Area km²	Flow hm³/yr	Variance (hm3/yr)²	CV -	Runoff m/yr
1	1	1	Direct Drainage Area	8.9	1.7	0.00E+00	0.00	0.19
2	1	1	Rabour	5.9	1.1	0.00E+00	0.00	0.18
PRECIPITATION				0.2	0.1	0.00E+00	0.00	0.75
TRIBUTARY INFLOW				14.8	2.7	0.00E+00	0.00	0.18
***TOTAL INFLOW				15.0	2.9	0.00E+00	0.00	0.19
ADVECTIVE OUTFLOW				15.0	2.7	0.00E+00	0.00	0.18
***TOTAL OUTFLOW				15.0	2.7	0.00E+00	0.00	0.18
***EVAPORATION					0.2	0.00E+00	0.00	

Overall Mass Balance Based Upon Predicted Outflow & Reservoir Concentrations

Component: TOTAL P

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)²	%Total	CV	Conc mg/m³	Export kg/km²/yr
1	1	1	Direct Drainage Area	293.1	77.5%	5.37E+03	93.0%	0.25	176.1	32.8
2	1	1	Rabour	79.9	21.1%	3.99E+02	6.9%	0.25	75.9	13.5
PRECIPITATION				5.1	1.4%	6.54E+00	0.1%	0.50	36.0	27.0
TRIBUTARY INFLOW				372.9	98.6%	5.77E+03	99.9%	0.20	137.3	25.1
***TOTAL INFLOW				378.1	100.0%	5.77E+03	100.0%	0.20	132.2	25.1
ADVECTIVE OUTFLOW				228.1	60.3%	3.02E+03		0.24	84.6	15.2
***TOTAL OUTFLOW				228.1	60.3%	3.02E+03		0.24	84.6	15.2
***RETENTION				149.9	39.7%	3.11E+03		0.37		

Overflow Rate (m/yr)	14.2	Nutrient Resid. Time (yrs)	0.1226
Hydraulic Resid. Time (yrs)	0.2031	Turnover Ratio	8.2
Reservoir Conc (mg/m3)	85	Retention Coef.	0.397

Table 72. Rabour Lake Modeled Water and Phosphorus Balance

Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km²	Flow hm³/yr	Variance (hm3/yr)²	CV -	Runoff m/yr
1	1	1	Direct Drainage Area	5.7	1.1	0.00E+00	0.00	0.19
PRECIPITATION				0.2	0.2	0.00E+00	0.00	0.75
TRIBUTARY INFLOW				5.7	1.1	0.00E+00	0.00	0.19
***TOTAL INFLOW				5.9	1.2	0.00E+00	0.00	0.21
ADVECTIVE OUTFLOW				5.9	1.1	0.00E+00	0.00	0.18
***TOTAL OUTFLOW				5.9	1.1	0.00E+00	0.00	0.18
***EVAPORATION					0.2	0.00E+00	0.00	

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

Component: — **TOTAL P**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)²	%Total	CV	Conc mg/m³	Export kg/km²/yr
1	1	1	Direct Drainage Area	189.3	97.1%	0.00E+00		0.00	176.1	33.3
PRECIPITATION				5.6	2.9%	7.95E+00	100.0%	0.50	36.0	27.0
TRIBUTARY INFLOW				189.3	97.1%	0.00E+00		0.00	176.1	33.3
***TOTAL INFLOW				195.0	100.0%	7.95E+00	100.0%	0.01	158.3	33.0
ADVECTIVE OUTFLOW				79.8	41.0%	4.35E+02		0.26	75.9	13.5
***TOTAL OUTFLOW				79.8	41.0%	4.35E+02		0.26	75.9	13.5
***RETENTION				115.1	59.0%	4.39E+02		0.18		

Overflow Rate (m/yr)	5.0	Nutrient Resid. Time (yrs)	0.2803
Hydraulic Resid. Time (yrs)	0.6845	Turnover Ratio	3.6
Reservoir Conc (mg/m3)	76	Retention Coef.	0.590

Table 73. Little Horseshoe Lake Modeled Water and Phosphorus Balance

Overall Water & Nutrient Balances

Overall Water Balance						**Averaging Period =**		**1.00**	**years**
				Area	**Flow**	**Variance**		**CV**	**Runoff**
Trb	**Type**	**Seg**	**Name**	**km^2**	**hm^3/yr**	**$(hm3/yr)^2$**		**-**	**m/yr**
1	1	1	Trib 1	1.8	0.3	0.00E+00		0.00	0.18
PRECIPITATION				0.2	0.1	0.00E+00		0.00	0.75
TRIBUTARY INFLOW				1.8	0.3	0.00E+00		0.00	0.18
***TOTAL INFLOW				2.0	0.5	0.00E+00		0.00	0.24
ADVECTIVE OUTFLOW				2.0	0.3	0.00E+00		0.00	0.15
***TOTAL OUTFLOW				2.0	0.3	0.00E+00		0.00	0.15
***EVAPORATION					0.2	0.00E+00		0.00	

Overall Mass Balance Based Upon				**Predicted**		**Outflow & Reservoir Concentrations**				
Component:				**TOTAL P**						
				Load		**Load Variance**			**Conc**	**Export**
Trb	**Type**	**Seg**	**Name**	**kg/yr**	**%Total**	**$(kg/yr)^2$**	**%Total**	**CV**	**mg/m^3**	**$kg/km^2/yr$**
1	1	1	Trib 1	75.5	93.4%	3.57E+02	98.1%	0.25	240.1	42.8
PRECIPITATION				5.3	6.6%	7.07E+00	1.9%	0.50	36.0	27.0
TRIBUTARY INFLOW				75.5	93.4%	3.57E+02	98.1%	0.25	240.1	42.8
***TOTAL INFLOW				80.9	100.0%	3.64E+02	100.0%	0.24	174.9	41.3
ADVECTIVE OUTFLOW				16.0	19.7%	3.73E+01		0.38	54.5	8.1
***TOTAL OUTFLOW				16.0	19.7%	3.73E+01		0.38	54.5	8.1
***RETENTION				64.9	80.3%	3.11E+02		0.27		

Overflow Rate (m/yr)	1.5	Nutrient Resid. Time (yrs)	0.6532
Hydraulic Resid. Time (yrs)	3.3088	Turnover Ratio	1.5
Reservoir Conc (mg/m3)	54	Retention Coef.	0.803

13 Appendix C: LDC Supporting Information

Load duration analysis requires paired flow and water quality data and uncertainty in either of these records contributes to uncertainty in stream loads. Since loading capacity is calculated by applying the relevant water quality standard to the flow record, sources of uncertainty in loading capacity are limited to uncertainty in the flow record.

Since stream flows are dependent on surface runoff, variation in annual precipitation for the period of record offers one measure of how likely the flow record is to represent the full range of flow conditions. Historical rankings for annual precipitation at climate stations within the project area were as low as the 10th percentile and as high as the 99th percentile over the period 2006-2010. Historical rankings for annual precipitation for the period 2010-2011 range from as low as the 20th percentile to as high as the 99th percentile (Minnesota Climatology Working Group, http://climate.umn.edu/doc/historical.htm). Given the range of wet and dry conditions represented in the time period of flow records, flow records should offer a reasonable representation of the full range of flow condition in the project area.

Table 74. Data Sources for *E. coli* Load Duration Curves

Stream	Flow Gage ID	Years of Flow Data	EQuIS Site ID	Years of Chemical Data	Site Location
Goose Creek 07030005-510	MPCA Gage H37024001	2006-2010	S000-410	2007 - 2010	Gage and water quality station located approximately 5.8 miles upstream of the reach outlet.
Rush Creek 07030005-509	MPCA Gage H37022001	2006-2010	S000-125	2007-2010	Gage and water quality station located approximately 1.6 miles upstream of the reach outlet.
Rock Creek 07030005-584	USGS Gage 05339490	2010-2011	S005-532	2009-2010	Gage and water quality station located approximately 1.1 miles upstream of the reach outlet.

14 Appendix D: Lake Summaries

14.1 Goose Lake (North Bay)

14.1.1 Physical Characteristics

Goose Lake (North Bay) (DNR Lake ID 13-0083-01) and its watershed are located entirely in Chisago County. The watershed is in the western portion of the Goose Creek watershed. The lake is downstream of the southern bay and is much shallower. Table 75 summarizes the physical characteristics of the lake, illustrates the available bathymetry and shows the 2011 aerial photograph.

Table 75. Goose (North Bay) Lake Physical Characteristics

Characteristic	Value	Source
Lake total surface area (acre)	272	0 m depth contour digitized from 2010 aerial photography
Percent lake littoral surface area (%)	100%	Calculated from DNR bathymetry using 2010 surface (aerial photo) and 1991-92 depth contours
Lake volume (acre-feet)	1,373	
Mean depth (feet)	5.1	Lake volume ÷ surface area
Maximum depth (feet)	9	DNR Lake Finder
Watershed area, including lake area (acre)	9,293	DNR Catchments
Watershed area: Lake area	34:1	Calculated

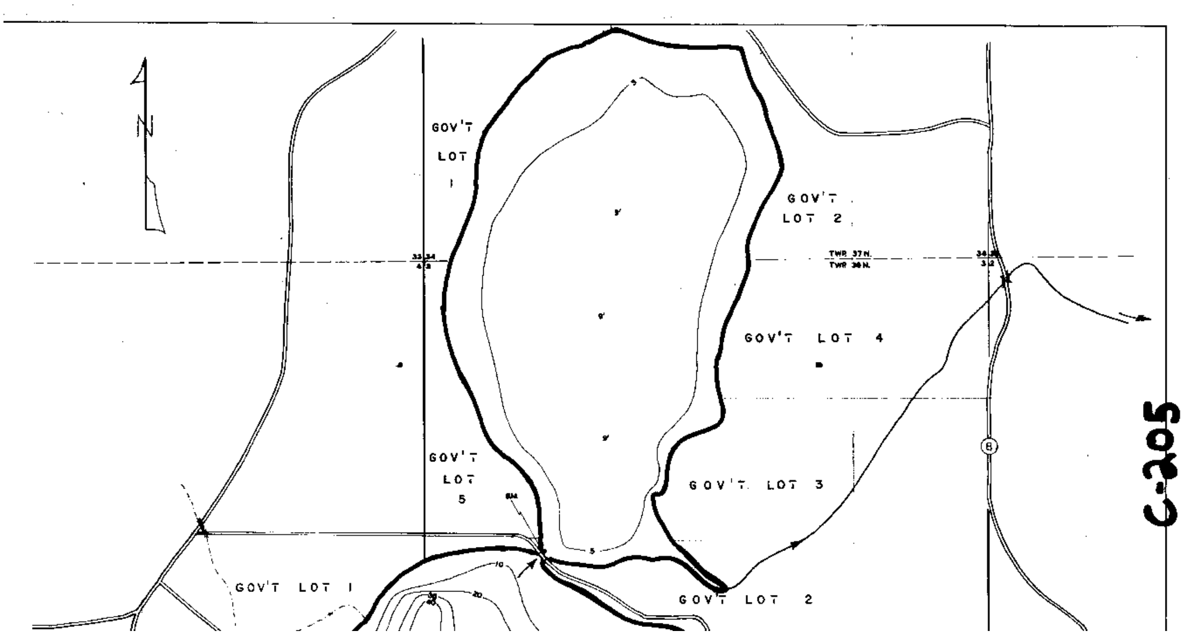

Figure 16. Goose (North Bay) Lake Bathymetry (DNR)

14.1.2 Water Quality

Table 76. 15-year Growing Season Mean TP, Chl-*a*, and Secchi, Goose Lake (North Bay), 1998-2012

Parameter	Growing Season Mean (June – September)	Growing Season CV (June – September)	NCHF Shallow Lake Standard
Total phosphorus (µg/L)	170	16%	< 60
Chl-a (µg/L)	84	34%	< 20
Secchi transparency (m)	0.7	4%	> 1.0

*CV, coefficient of variation, defined in BATHTUB as the standard error divided by the mean.

Figure 17. Aerial photograph of Goose Lake (North Bay) (Google Earth, August 2011)

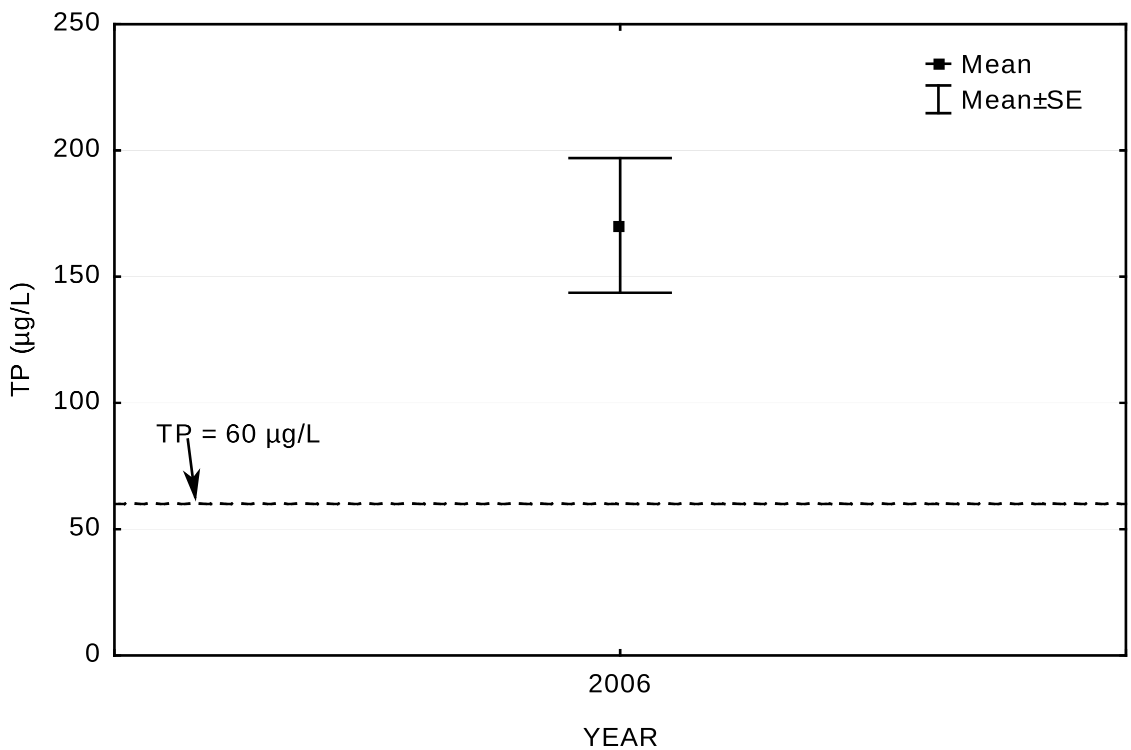

Figure 18. Growing Season Means ± SE of Total Phosphorus for Goose Lake (North Bay) by Year. The dashed line represents the water quality standard for TP (60 µg/L).

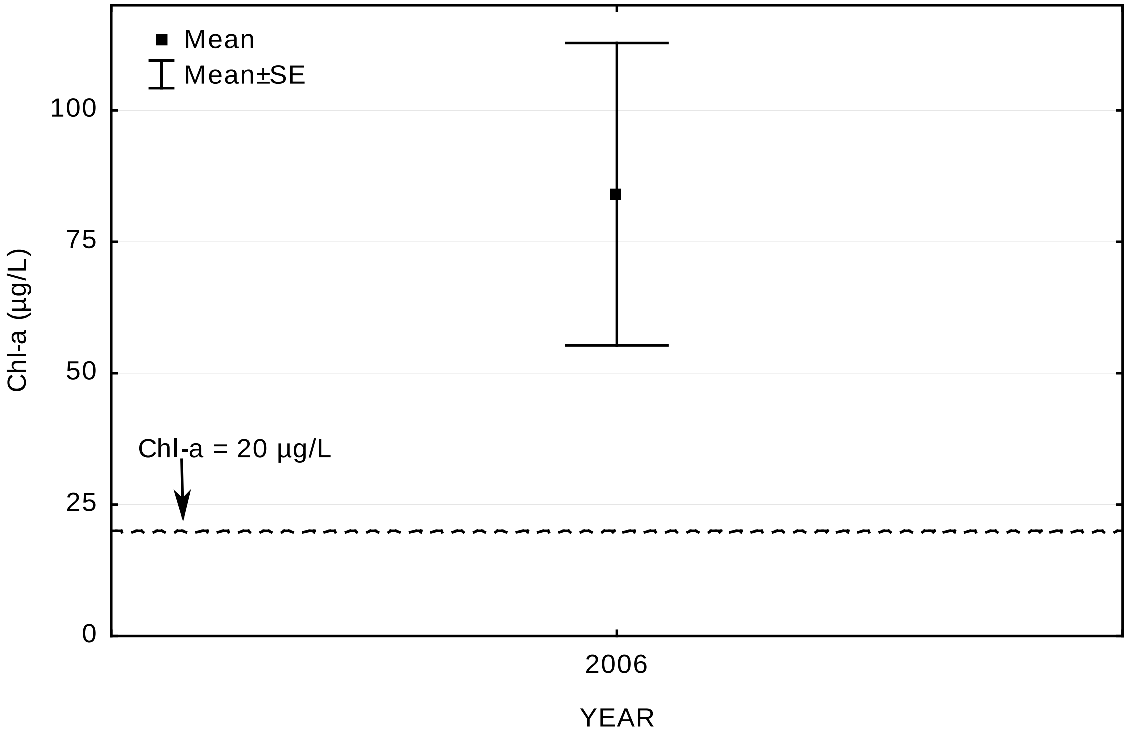

Figure 19. Growing Season Means ± SE of Chlorophyll-*a* for Goose Lake (North Bay) by Year. The dashed line represents the water quality standard for Chl-*a* (20 µg/L).

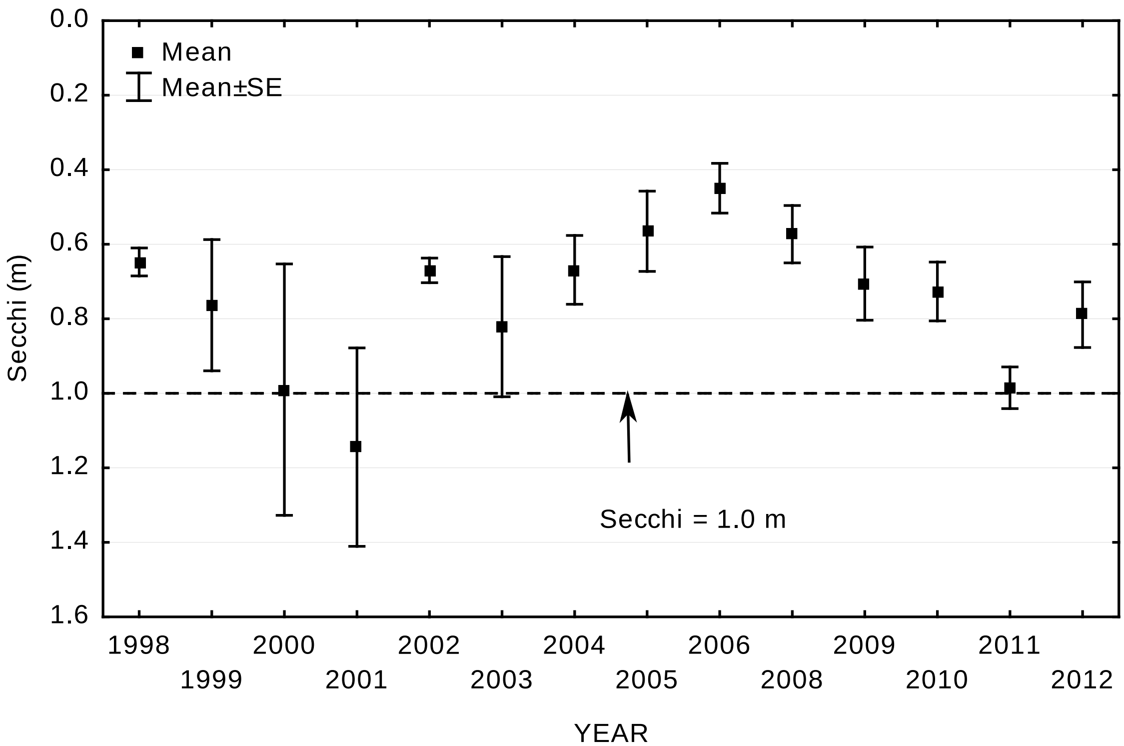

Figure 20. Growing Season Means ± SE of Secchi transparency for Goose Lake (North Bay) by Year. The dashed line represents the lake water quality standard for transparency (1.0 m).

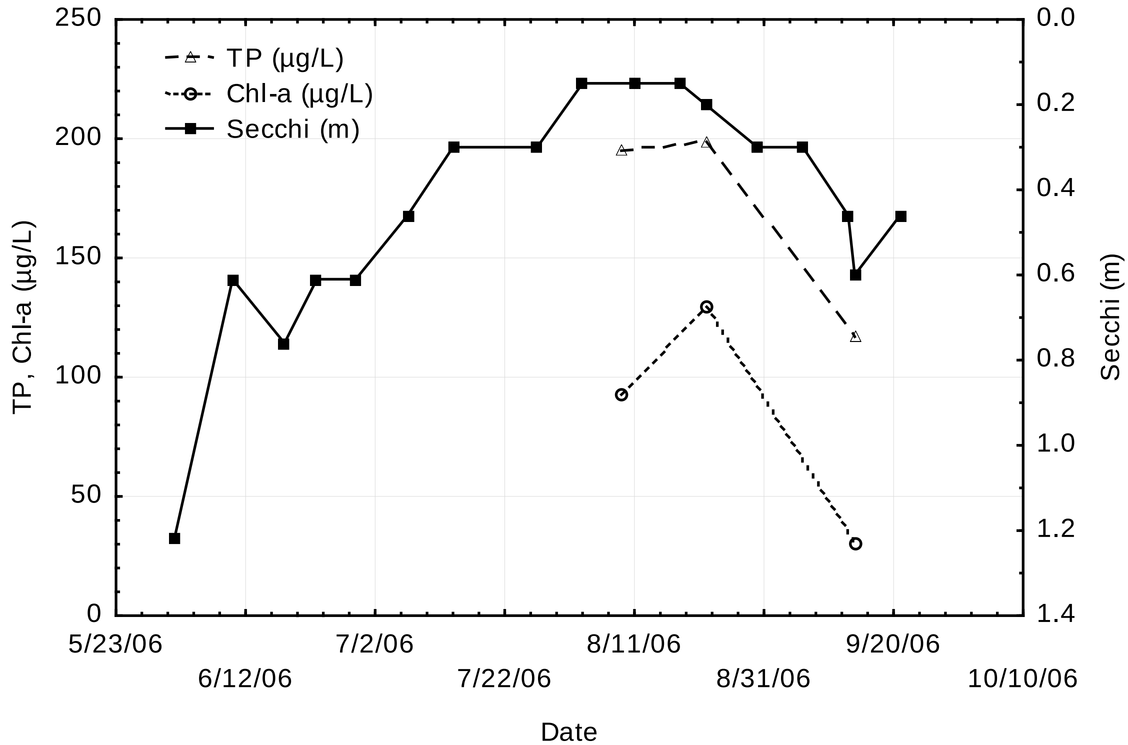

Figure 21. Growing Season Trends of Chl-*a*, TP, and Secchi depth for Goose Lake (North Bay), 2006.

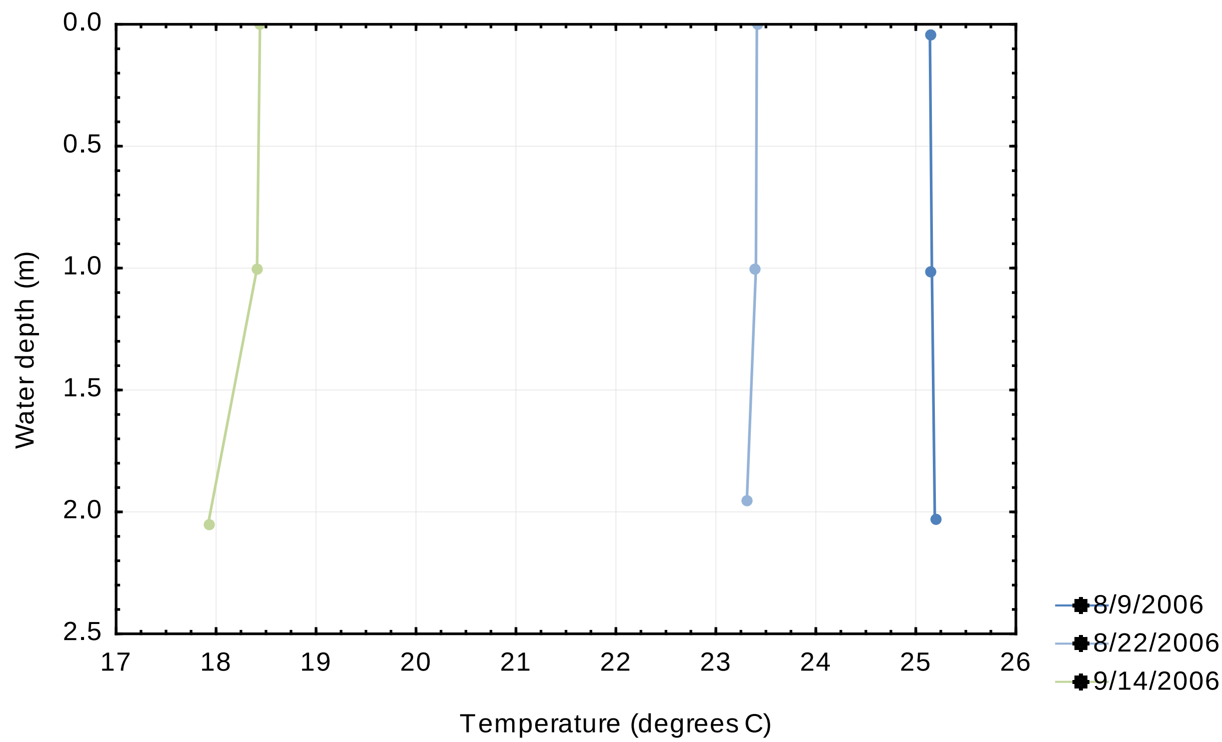

Figure 22: Temperature profiles for Goose Lake (North), 2006

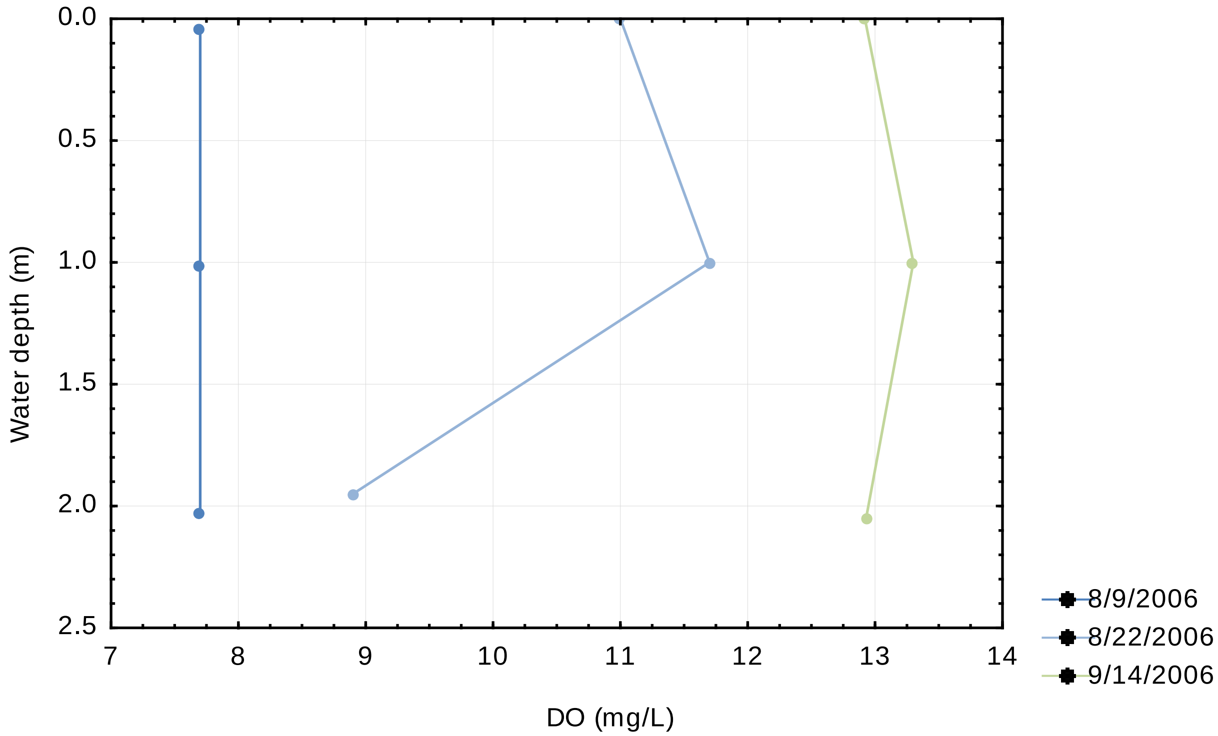

Figure 23: Dissolved oxygen profiles for Goose Lake (North), 2006

14.1.3 Macrophytes

The most recent plant survey on North Goose was done in 2012 (not 2008). 13 submerged, three floatingleaf, and one emergent species were found, although this was a point intercept survey that did not target emergent or shoreline species. Curlyleaf pondweed, or evidence of turions, was found at 44% of sample points on North Goose; coontail and Canada waterweed were also common. (I can provide a copy of the survey if you are interested) The 16 emergent and 20 submerged and floating leaf species that is quoted is a list of all species that had been found in all plant surveys on Goose Lake, north and south basins combined, as of 2008. As of 2012 the numbers were 15 emergent and 24 submerged and floating leaf species (One species, needlerush, was reclassified from emergent to submerged). The Minnesota County Biological Survey surveyed Goose Lake in 2014; an additional four emergent and two submerged species were documented.

14.1.4 Fish

Goose Lake is comprised of a north and south basin that are connected by a shallow channel. The north basin is significantly shallower than the south and causes differences in water quality. The most recent fish survey was conducted in 2012 by the DNR but differences between the two basins were not recorded. There are special regulations in place for size of walleye caught and a bag limit for black crappie. Walleye numbers were below the lake's historic mean but met the management goal. Northern pike numbers were a historic high with good size structure. Yellow perch and black crappie numbers were near historic means.

14.2 Goose Lake (South Bay)

14.2.1 Physical Characteristics

Goose Lake (South Bay) (DNR Lake ID 13-0083-02) and its entire watershed are located in Chisago County. The watershed is located in the western portion of the Goose Creek watershed. The lake is upstream of the northern basin and is much deeper. It is also connected to two smaller upstream lakes, Mandall and Rabour. Table 77 summarizes the physical characteristics of the lake, illustrates the available bathymetry and Figure 25 shows the 2011 aerial photograph.

Table 77. Goose Lake (South Bay) physical characteristics

Characteristic	Value	Source
Lake total surface area (acre)	447	0 m depth contour digitized from 2010 aerial photography
Percent lake littoral surface area (%)	45%	Calculated from DNR bathymetry using 2010 surface (aerial photo) and 1991-92 depth contours
Lake volume (acre-feet)	6,409	
Mean depth (feet)	14.3	Lake volume ÷ surface area
Maximum depth (feet)	55	DNR Lake Finder
Watershed area, including lake area (acre)	7,696	DNR Catchments
Watershed area: Lake area	17:1	Calculated

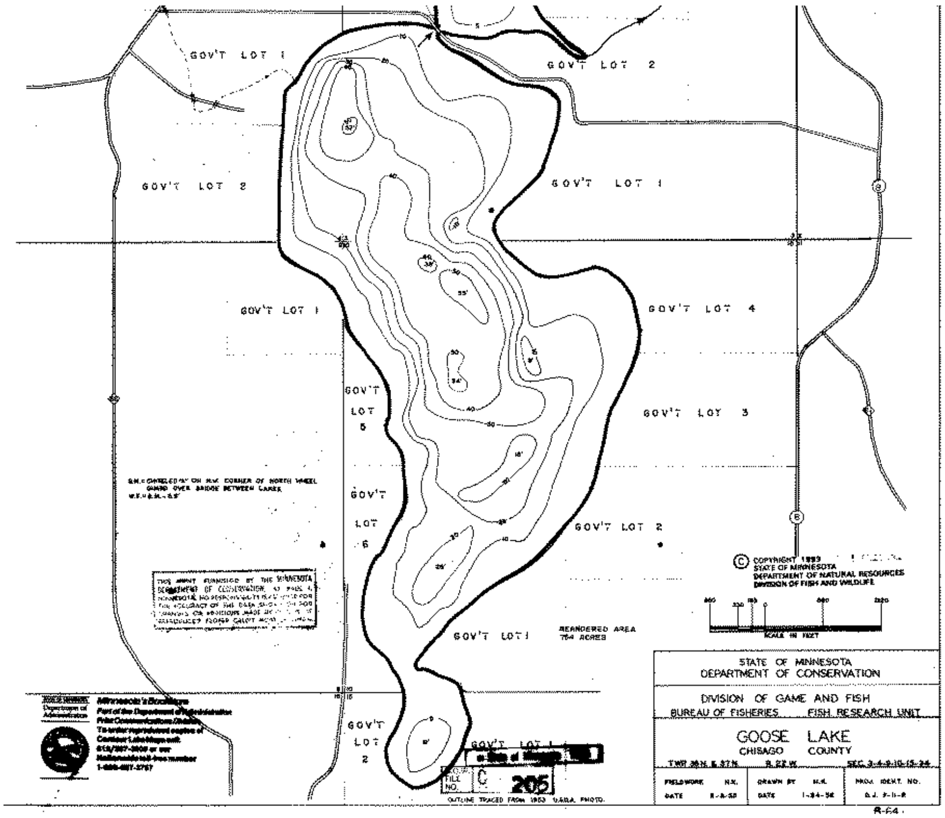

Figure 24. Goose Lake (South Bay) Bathymetry (DNR)

14.2.2 Water Quality

Table 78. 15-year Growing Season Mean TP, Chl-a, and Secchi, Goose Lake (South Bay), 1998-2012

Parameter	Growing Season Mean (June – September)	Growing Season CV (June – September)	NCHF Lake Standard
Total phosphorus (µg/L)	55.4	41%	< 40
Chlorophyll-*a* (µg/L)	15.5	13%	< 14
Secchi transparency (m)	1.9	3%	> 1.4

*CV, coefficient of variation, defined in BATHTUB as the standard error divided by the mean.

Figure 25. Aerial photograph of Goose Lake (South Bay) (Google Earth, August 2011)

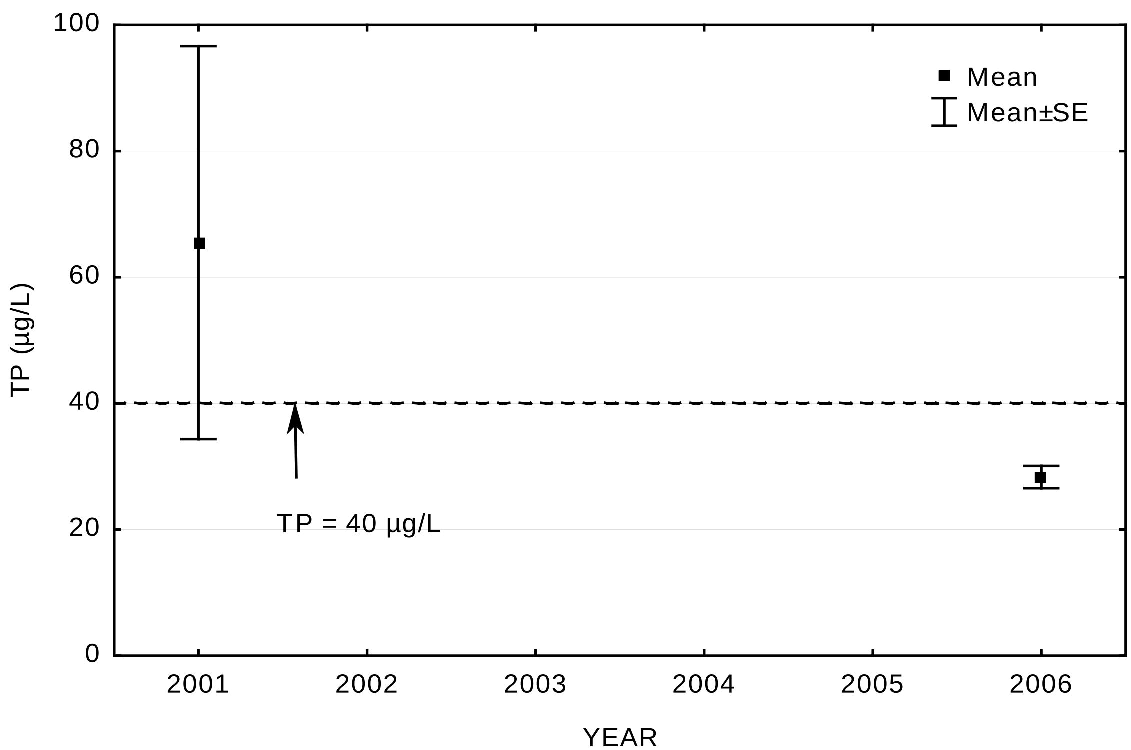

Figure 26. Growing Season Means ± SE of Total Phosphorus for Goose Lake (South Bay) by Year
The dashed line represents the water quality standard for TP (40 µg/L).

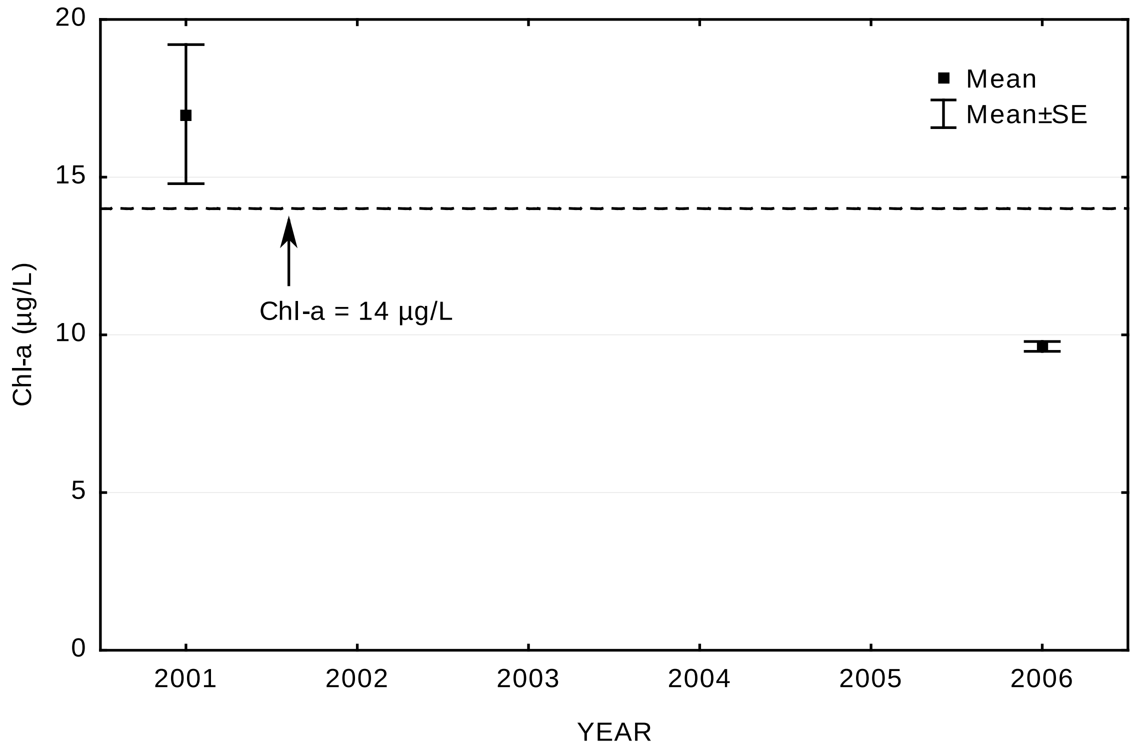

Figure 27. Growing Season Means ± SE of Chlorophyll-a for Goose Lake (South Bay) by Year
The dashed line represents the water quality standard for Chl-a (14 µg/L).

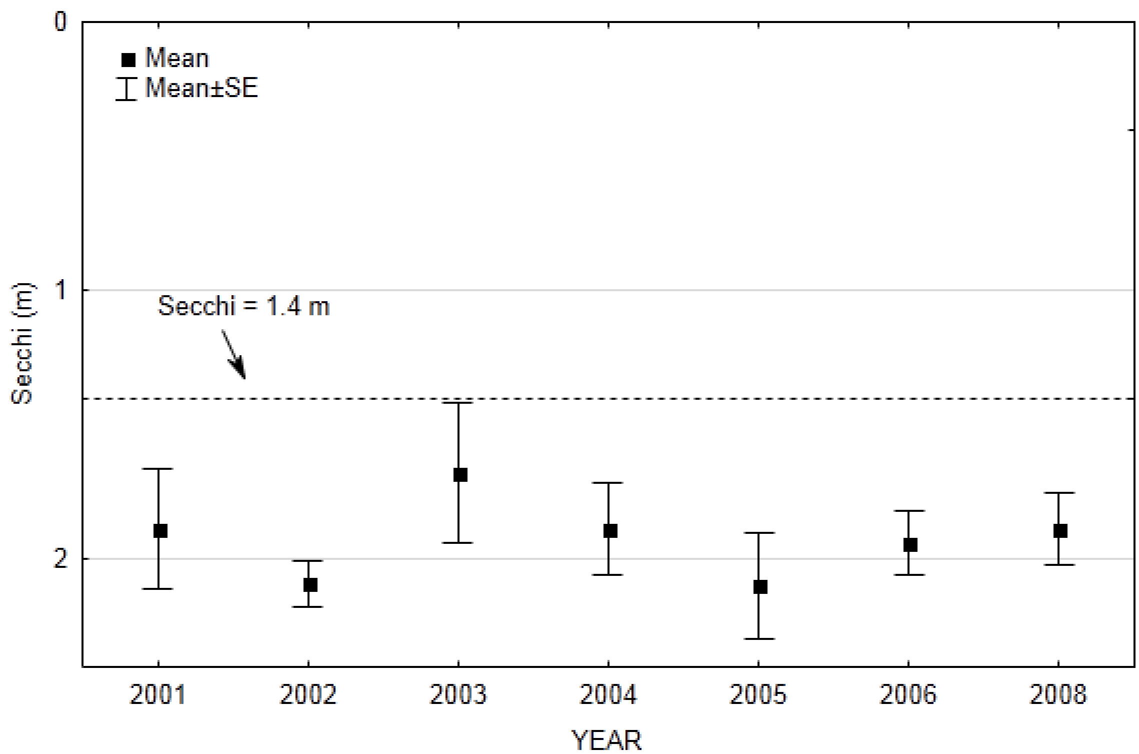

Figure 28. Growing Season Means ± SE of Secchi transparency for Goose Lake (South Bay) by Year
The dashed line represents the lake water quality standard for transparency (1.4 m).

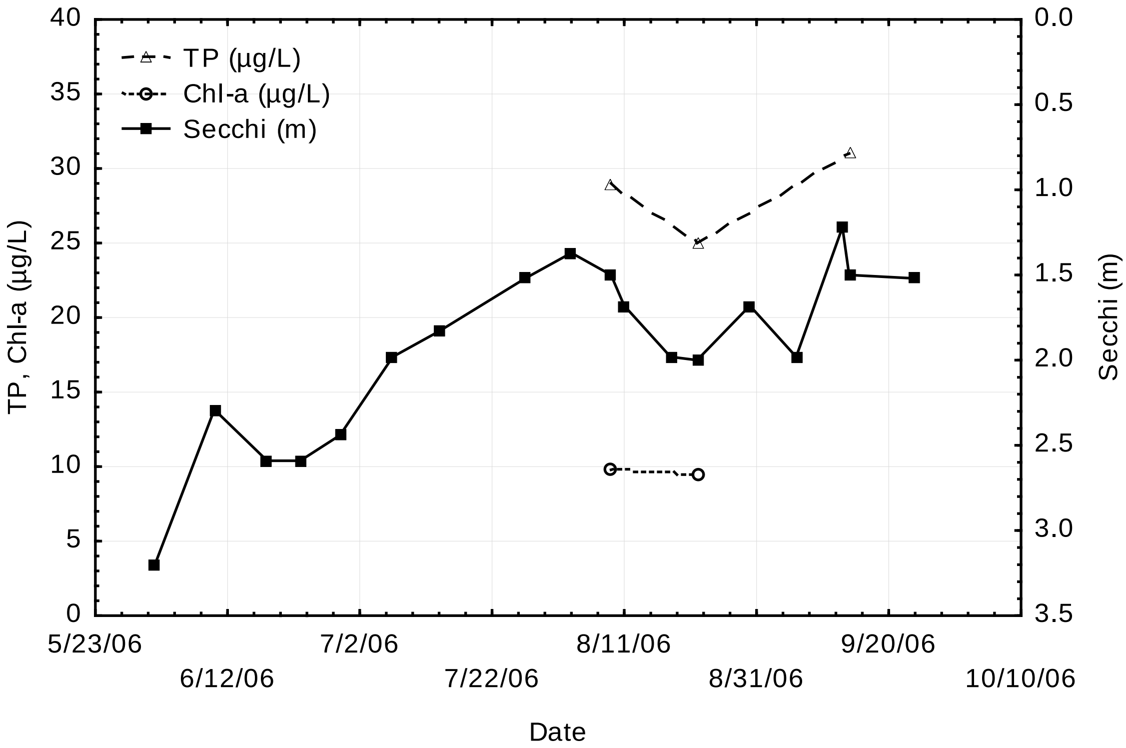

Figure 29. Growing Season Trends of Chl-a, TP, and Secchi depth for Goose Lake (South Bay), 2006

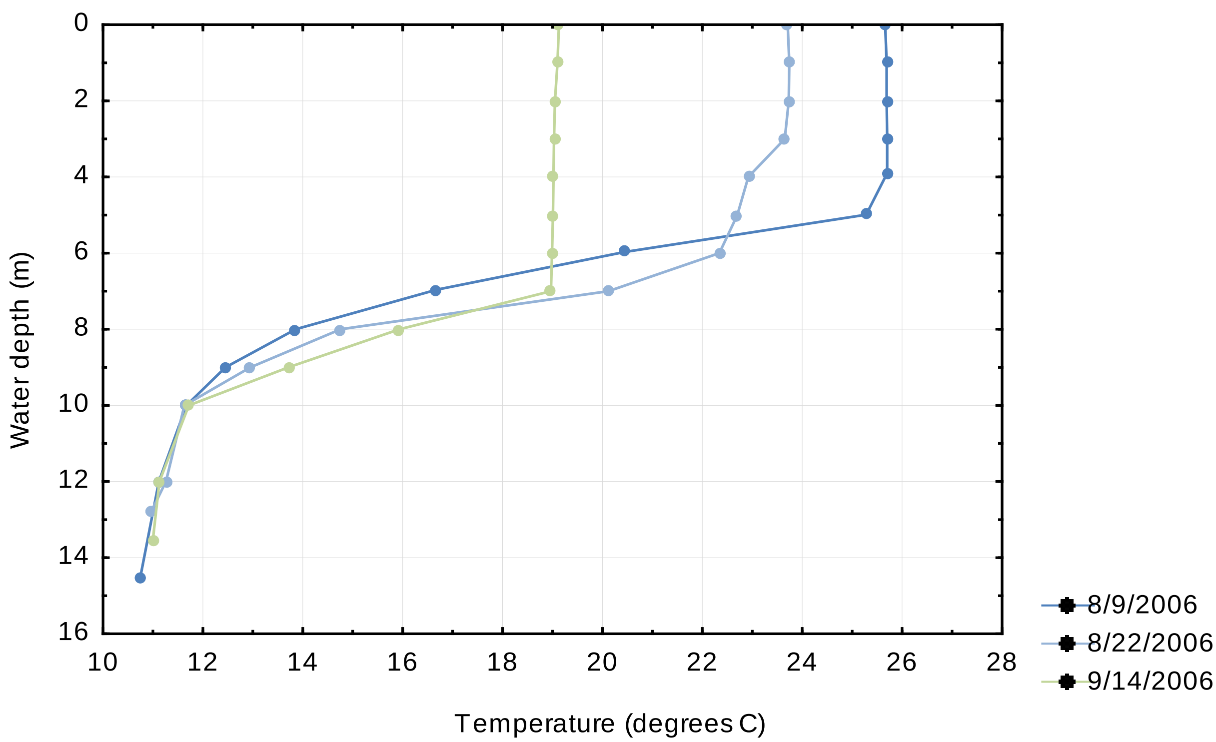

Figure 30: Temperature profiles for Goose Lake (South), 2006

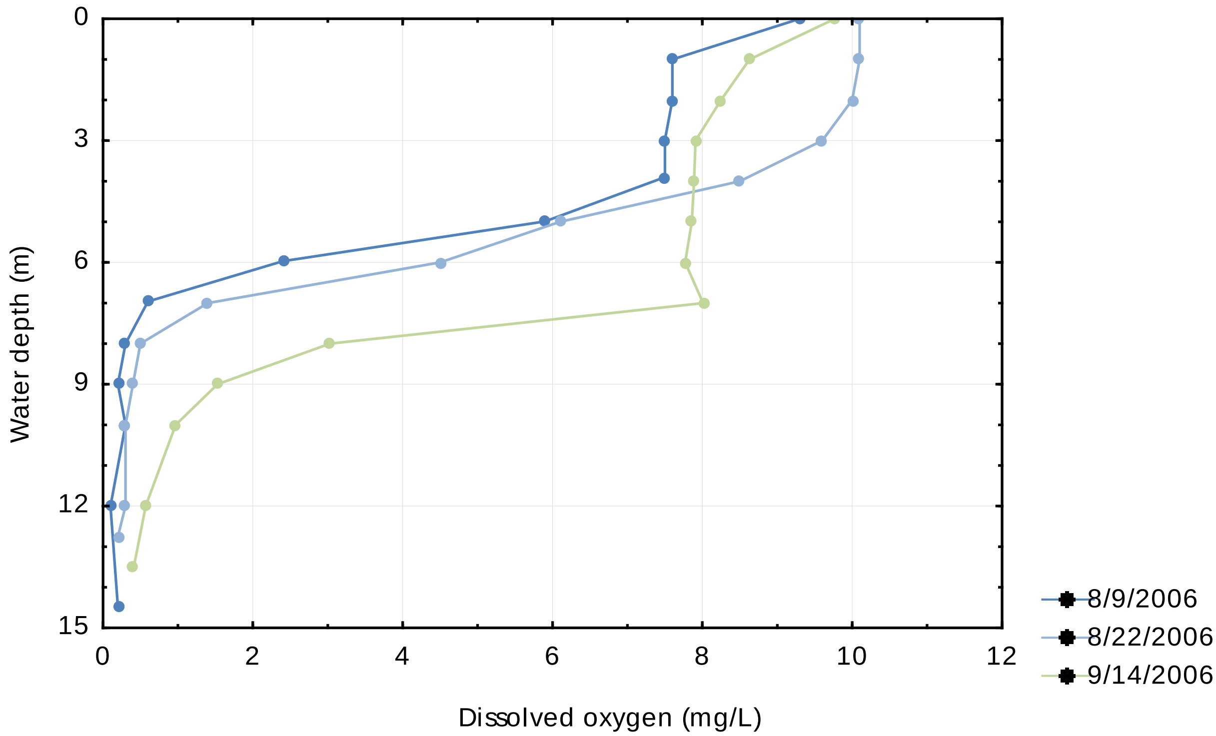

Figure 31: Dissolved oxygen profiles for Goose Lake (South), 2006

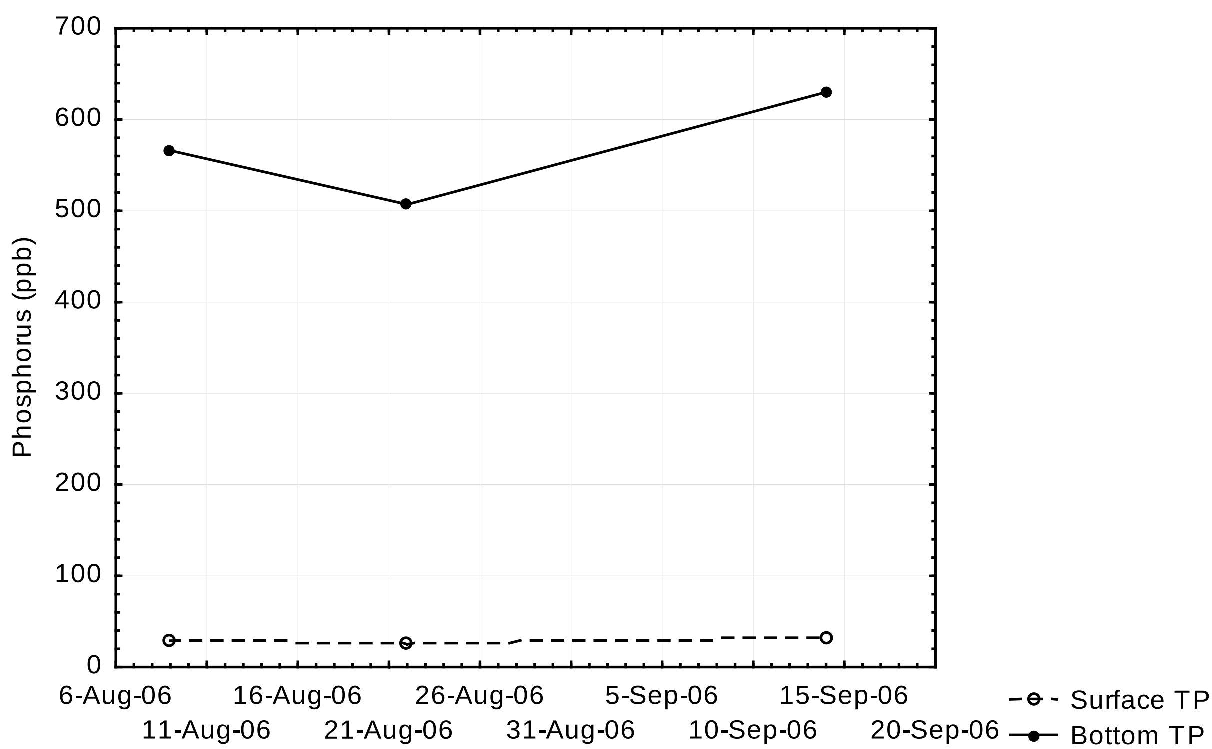

Figure 32: Surface and bottom total phosphorus concentrations for Goose Lake (South), 2006

14.2.3 Macrophytes

The most recent plant survey was conducted in 2012 by the DNR. Sixteen emergent species and 20 submerged and floating leaf species were identified. Curlyleaf pondweed has been present in Goose Lake since at least 1971. Curlyleaf pondweed is an invasive species to Minnesota lakes and can have adverse effects on water quality and native plant species. The south bay had mostly native plant species with coontail and flatstem pondweed being the most abundant. Curlyleaf pondweed was only found in 14% of the points surveyed.

14.2.4 Fish

Goose Lake is comprised of a north and south basin that are connected by a shallow channel. The north basin is significantly shallower than the south and causes differences in water quality. The most recent fish survey was conducted in 2012 by the DNR but differences between the two basins were not recorded. There are special regulations in place for size of walleye caught and a bag limit for black crappie. Walleye numbers were below the lake's historic mean but met the management goal. Northern pike numbers were a historic high with good size structure. Yellow perch and black crappie numbers were near historic means.

14.3 Horseshoe Lake

14.3.1 Physical Characteristics

Horseshoe Lake (DNR Lake ID 13-0073-00) and its entire watershed are located in Chisago County. The watershed is located in the southwestern portion of the Goose Creek watershed. It is downstream of Little Horseshoe Lake. Table 79 summarizes the physical characteristics of the lake, Figure 33 illustrates the available bathymetry for the lake and Figure 34 shows the 2011 aerial photograph.

Table 79. Horseshoe Lake physical characteristics

Characteristic	Value	Source
Lake total surface area (acre)	224	0 m depth contour digitized from 2010 aerial photography
Percent lake littoral surface area (%)	59%	Calculated from DNR bathymetry using 2010 surface (aerial photo) and 1991-92 depth contours
Lake volume (acre-feet)	2,917	
Mean depth (feet)	13	Lake volume ÷ surface area
Maximum depth (feet)	53	DNR Lake Finder
Watershed area, including lake area (acre)	4,055	DNR Catchments
Watershed area: Lake area	18:1	Calculated

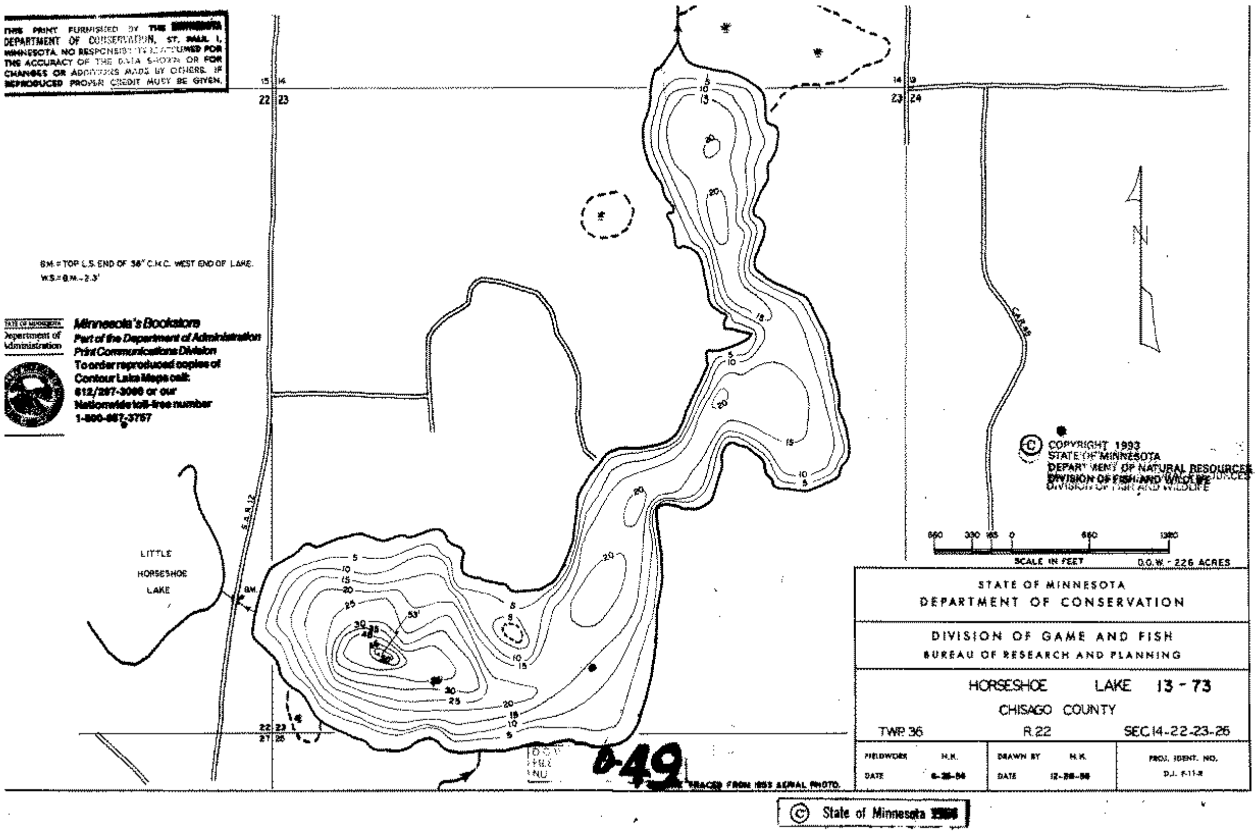

Figure 33. Horseshoe Lake bathymetry (DNR)

14.3.2 Water Quality

Table 80. 15-year Growing Season Mean TP, Chl-a, and Secchi, Horseshoe Lake, 1998-2012

Parameter	Growing Season Mean (June – September)	Growing Season CV (June – September)	NCHF Lake Standard
Total phosphorus (µg/L)	52.6	7%	< 40
Chlorophyll-*a* (µg/L)	26.3	20%	< 14
Secchi transparency (m)	1.3	21%	> 1.4

*CV, coefficient of variation, defined in BATHTUB as the standard error divided by the mean.

Figure 34. Aerial photograph of Horseshoe Lake (Google Earth, August 2011)

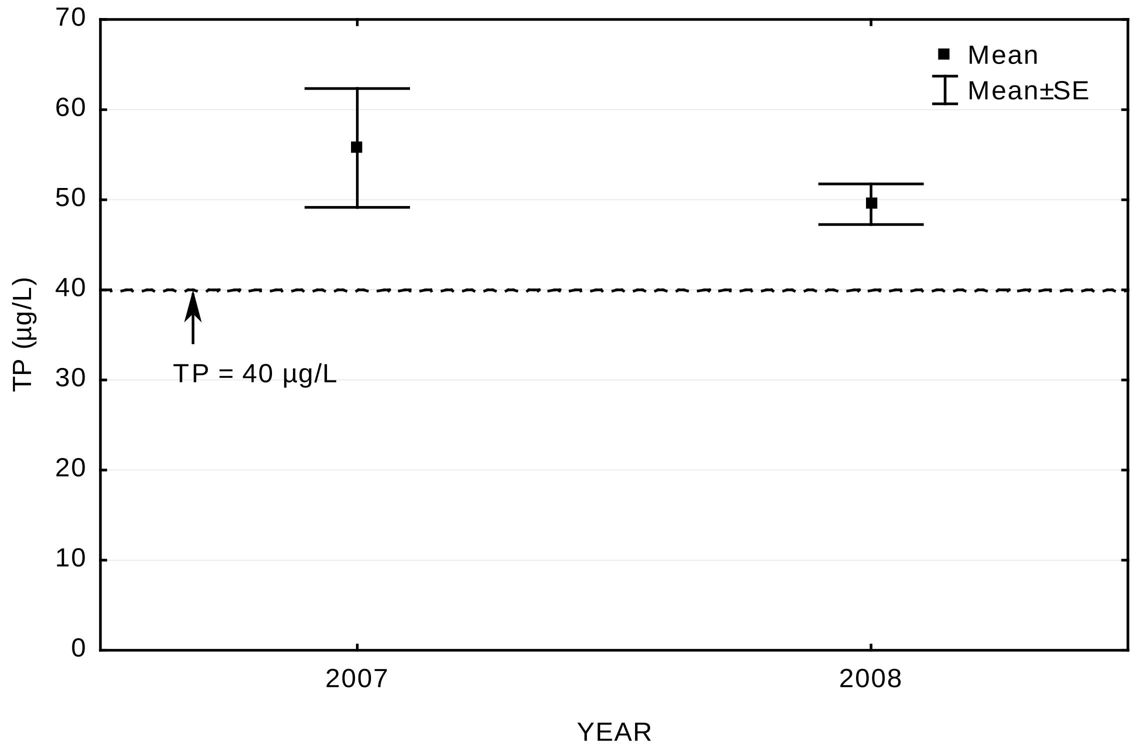

Figure 35. Growing Season Means ± SE of Total Phosphorus for Horseshoe Lake by Year
The dashed line represents the water quality standard for TP (40 µg/L).

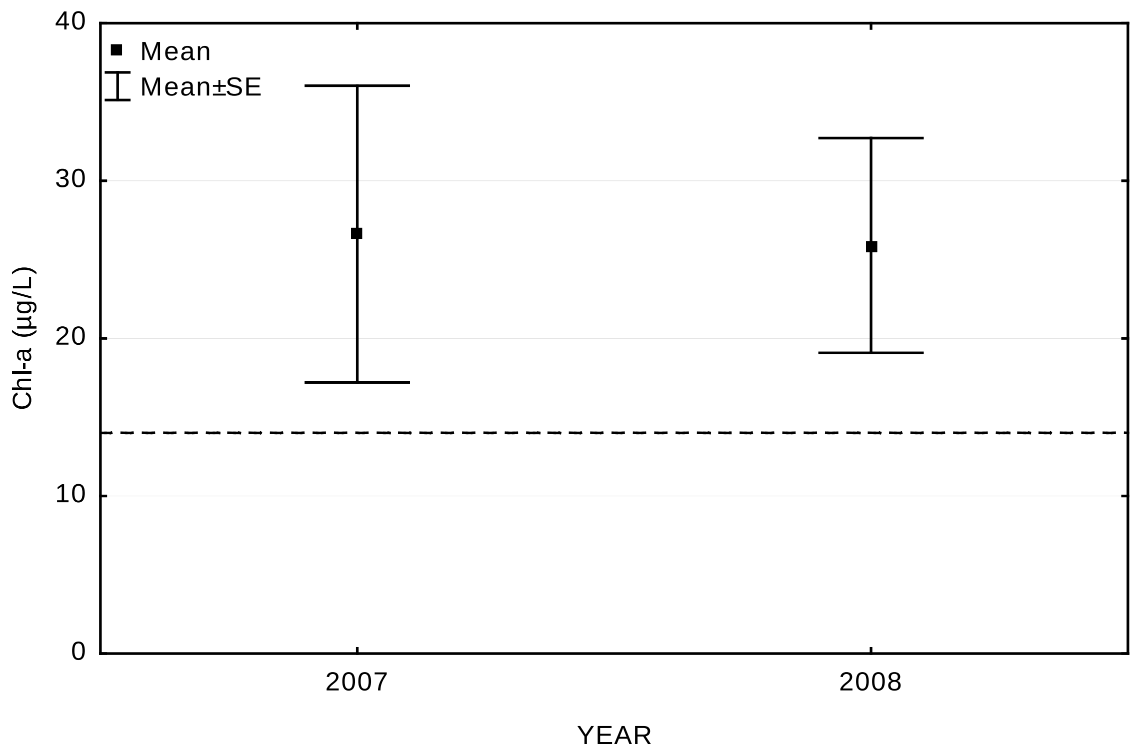

Figure 36. Growing Season Means ± SE of Chlorophyll-a for Horseshoe Lake by Year
The dashed line represents the water quality standard for Chl-a (14 µg/L).

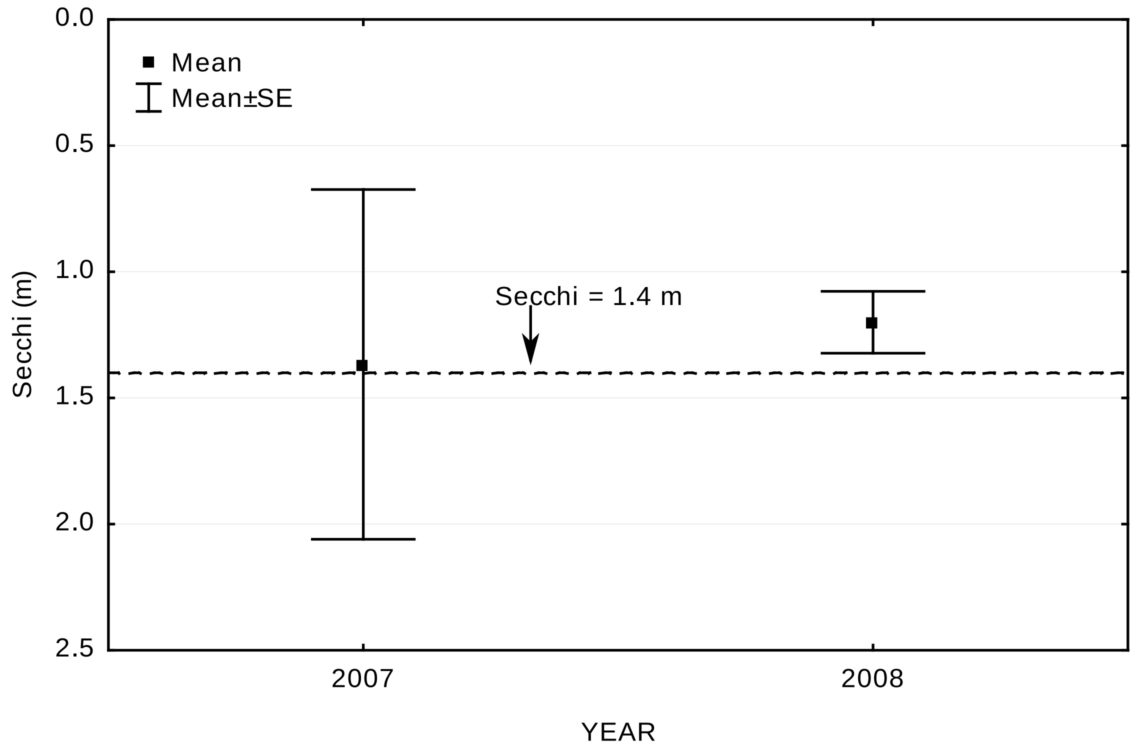

Figure 37. Growing Season Means ± SE of Secchi transparency for Horseshoe Lake by Year
The dashed line represents the lake water quality standard for transparency (1.4 m).

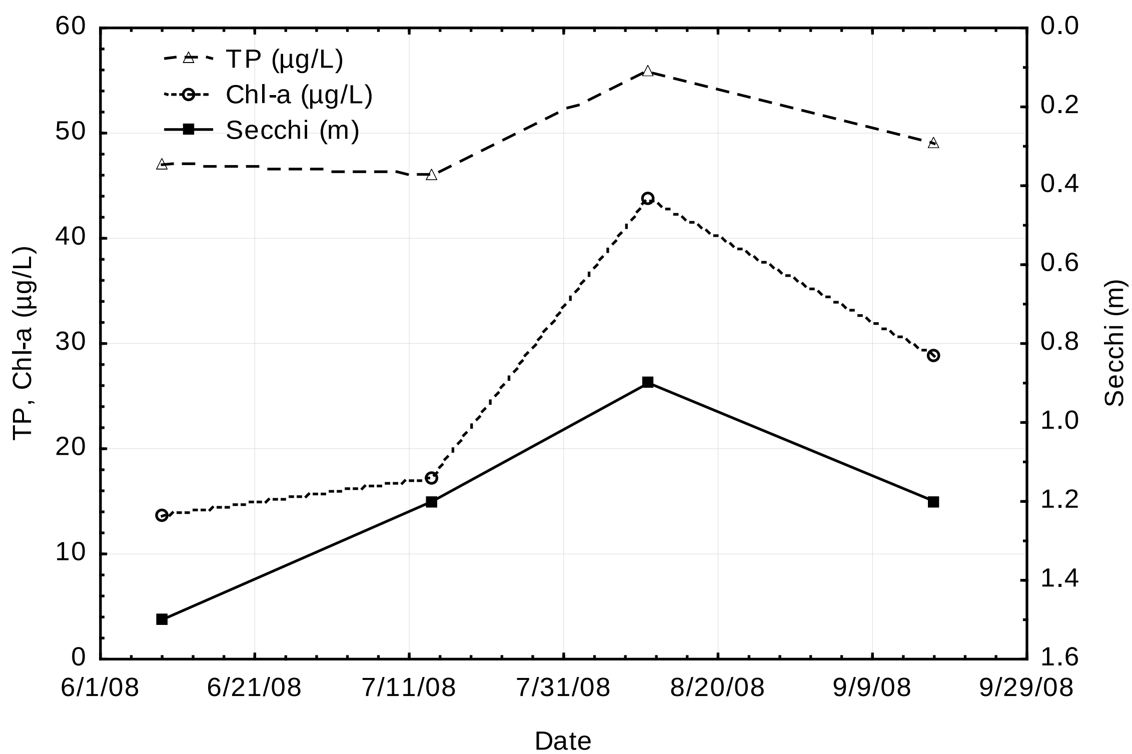

Figure 38. Growing Season Trends of Chl-a, TP, and Secchi depth for Horseshoe Lake, 2008

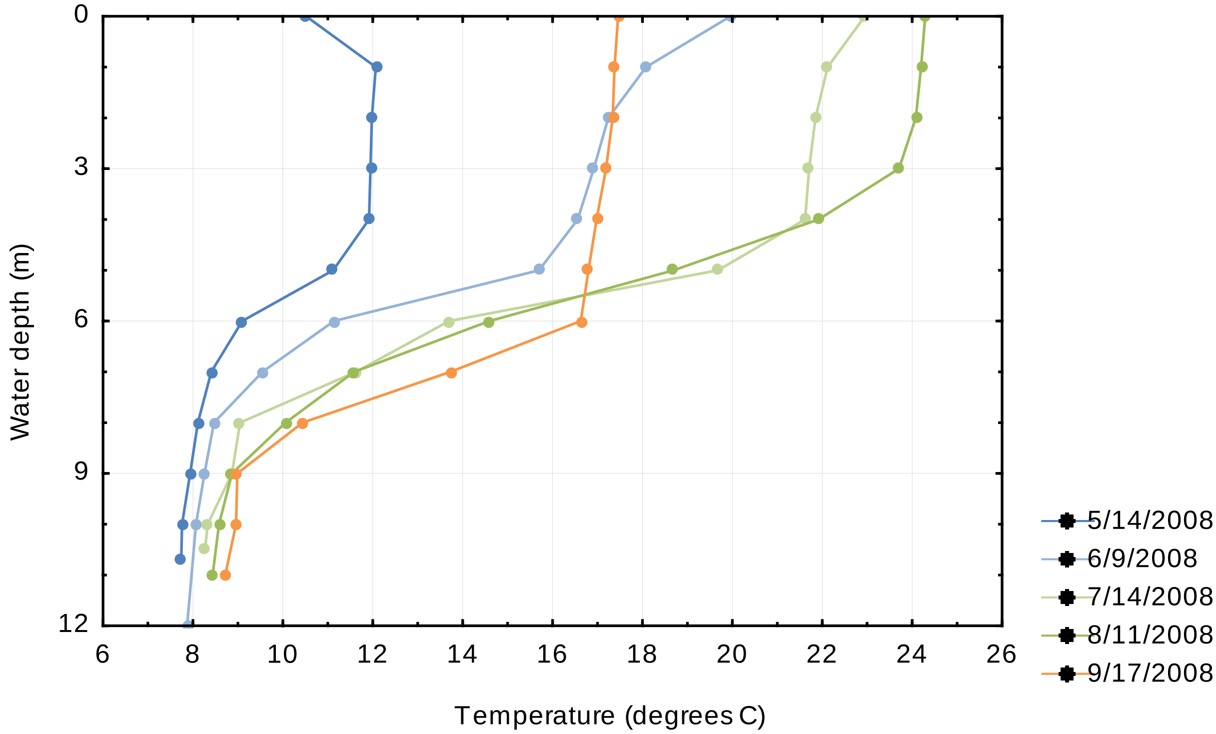

Figure 39: Temperature profiles for Horseshoe Lake, 2008

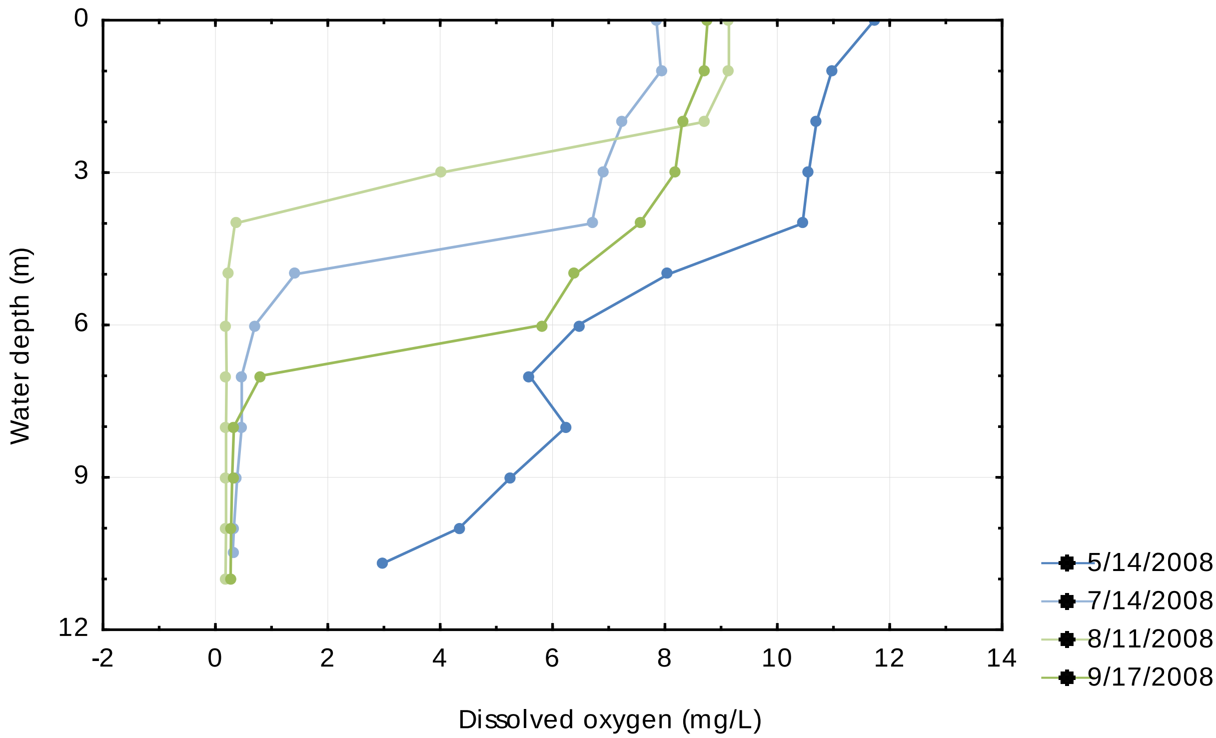

Figure 40: Dissolved oxygen profiles for Horseshoe Lake, 2008

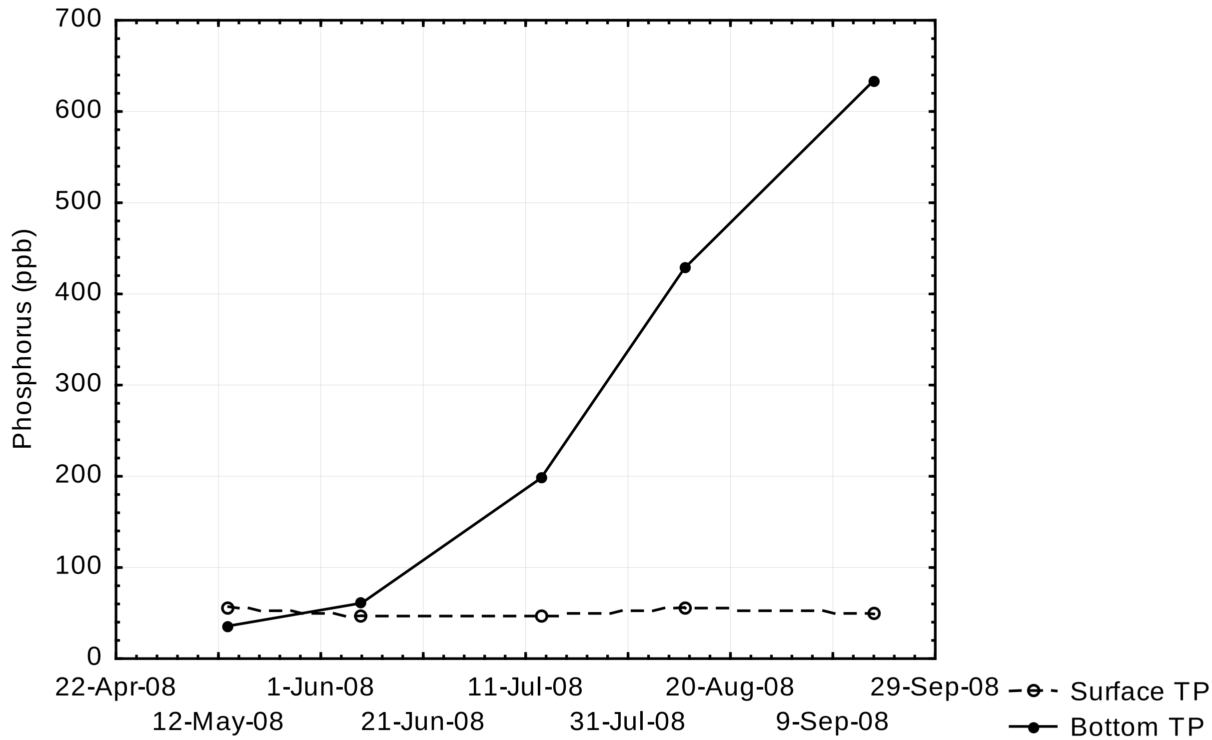

Figure 41: Surface and bottom total phosphorus concentrations for Horseshoe Lake, 2008

14.3.3 Macrophytes

The DNR Section of Fisheries - completed a point intercept vegetation survey in 2014 that included mapping of emergent vegetation beds and observations of shoreline species. 13 emergent, 10 submerged, and 3 floatingleaf species were found. Curlyleaf pondweed was documented; it has been in the lake for an unknown amount of time but probably 10 years or more. Previous vegetation surveys may have been done in late summer when it is not easily found. According to landowners, curlyleaf forms thick mats in some areas in early summer.

14.3.4 Fish

The most recent fish survey was conducted in 2005 by the DNR. The report states that the lake is managed primarily for northern pike and that stocking only took place after a winter kill in 1991-92. Horseshoe lakes experience moderate fishing pressure and anglers can expect a variety of fish species. Fish species observed during the survey include; bowfin, common carp, black bullhead, yellow bullhead, sunfish, pumpkinseed, and white crappie.

14.4 Rock Lake

14.4.1 Physical Characteristics

Rock Lake (DNR Lake ID 58-0117-00) and its entire watershed are located in Pine County south of Pine City. The watershed is located in the northern portion of the Goose Creek watershed. Table 81 summarizes the physical characteristics of the lake, Figure 42 illustrates the available bathymetry and

Figure 43 shows the 2011 aerial photograph. Figure 44 shows the adjacent feedlot and livestock present in the lake.

Table 81. Rock Lake physical characteristics

Characteristic	Value	Source
Lake total surface area (acre)	81	0 m depth contour digitized from 2010 aerial photography
Percent lake littoral surface area (%)	81%	Calculated from DNR bathymetry using 2010 surface (aerial photo) and 1991-92 depth contours
Lake volume (acre-feet)	766	
Mean depth (feet)	9.5	Lake volume ÷ surface area
Maximum depth (feet)	32	DNR Lake Finder
Watershed area, including lake area (acre)	6,264	DNR Catchments
Watershed area: Lake area	77:1	Calculated

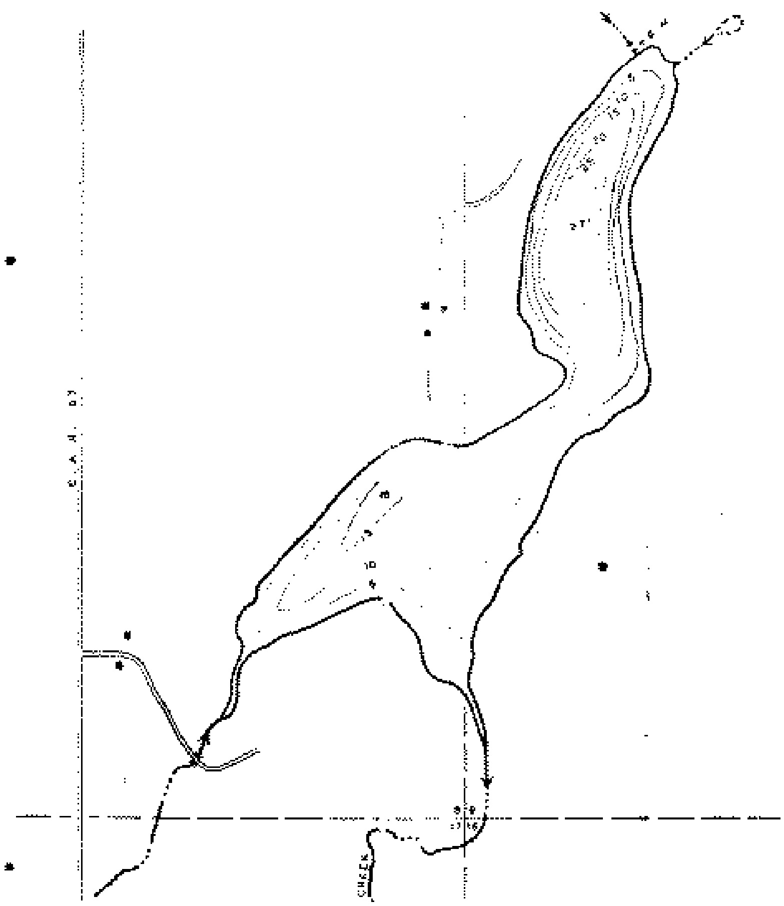

Figure 42. Rock Lake bathymetry (DNR)

14.4.2 Water Quality

Table 82. 15-year Growing Season Mean TP, Chl-a, and Secchi, Rock Lake, 1998-2012

Parameter	Growing Season Mean (June – September)	Growing Season CV (June – September)	NCHF Lake Standard
Total phosphorus (µg/L)	193.3	7%	< 40
Chlorophyll-*a* (µg/L)	28.8	38%	< 14
Secchi transparency (m)	1.1	30%	> 1.4

*CV, coefficient of variation, defined in BATHTUB as the standard error divided by the mean.

Figure 43. Aerial photograph of Rock Lake (Google Earth, August 2011)

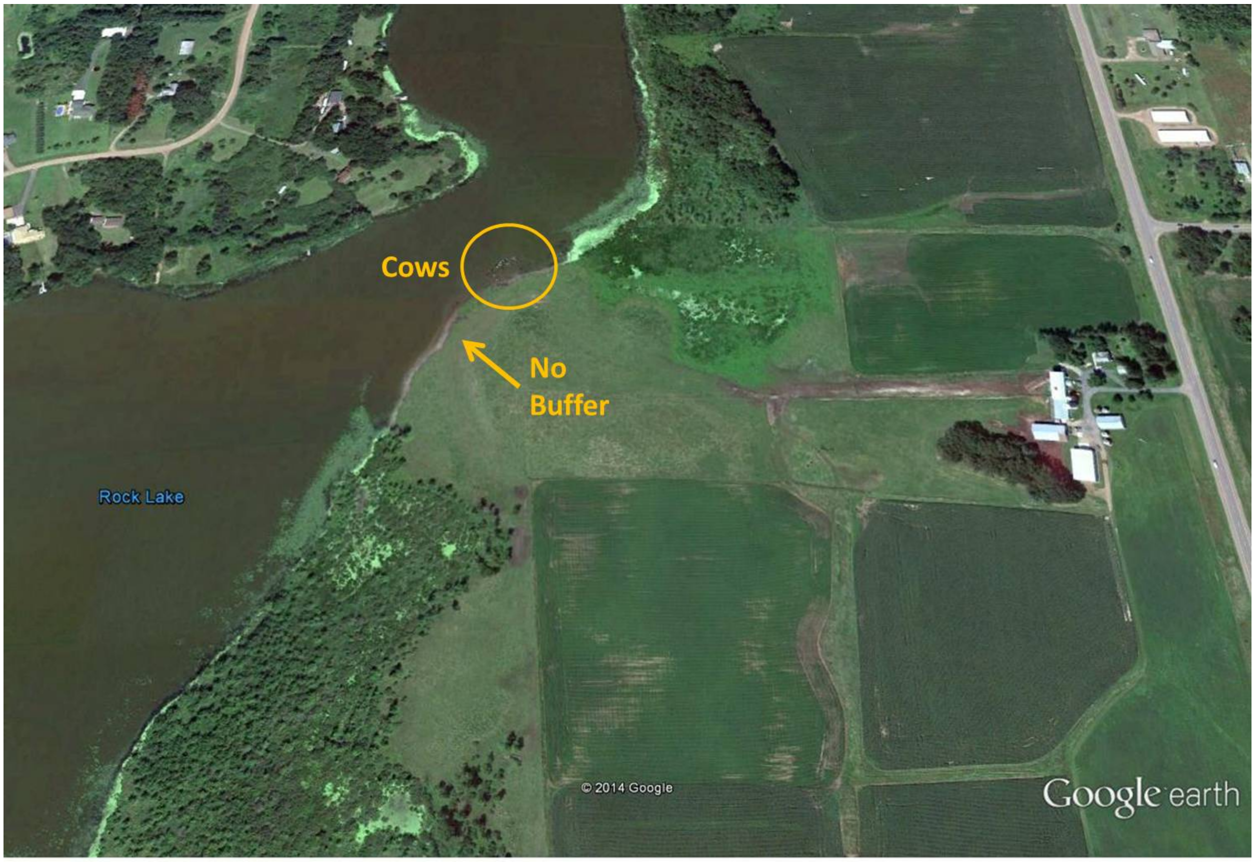

Figure 44: Aerial photograph showing cows in the lake and a pasture that leads up to the water surface with no buffer. (Google Earth, August 2011)

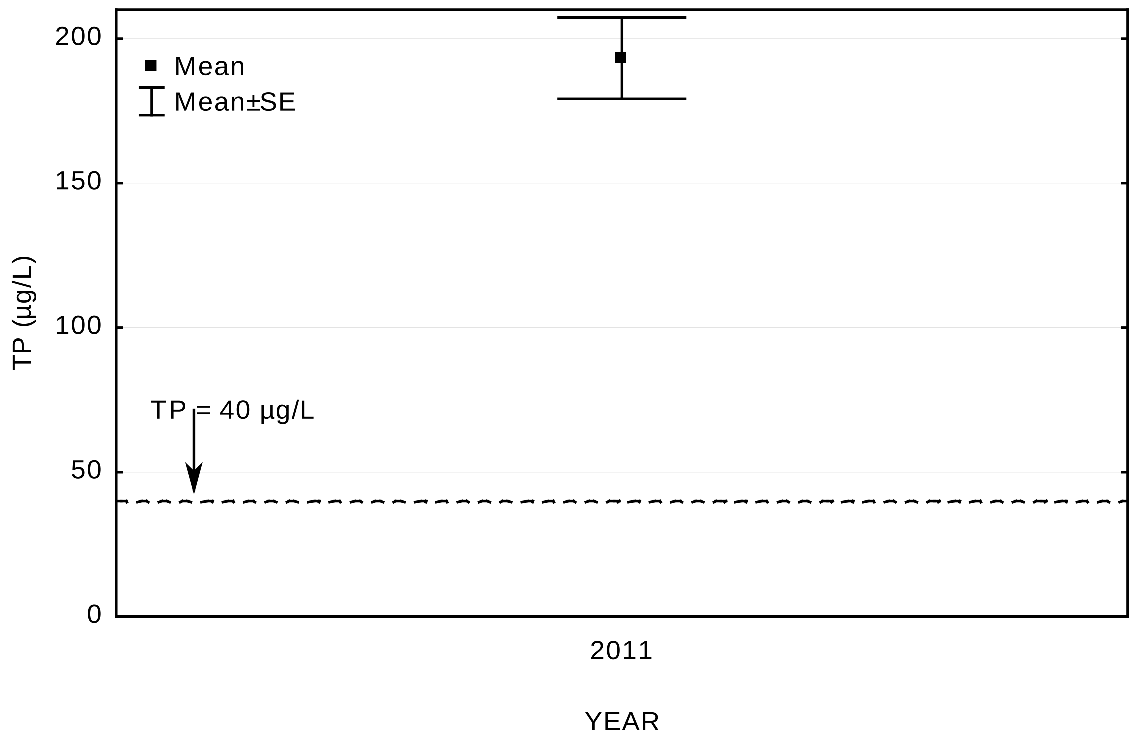

Figure 45. Growing Season Means ± SE of Total Phosphorus for Rock Lake by Year
The dashed line represents the water quality standard for TP (40 µg/L).

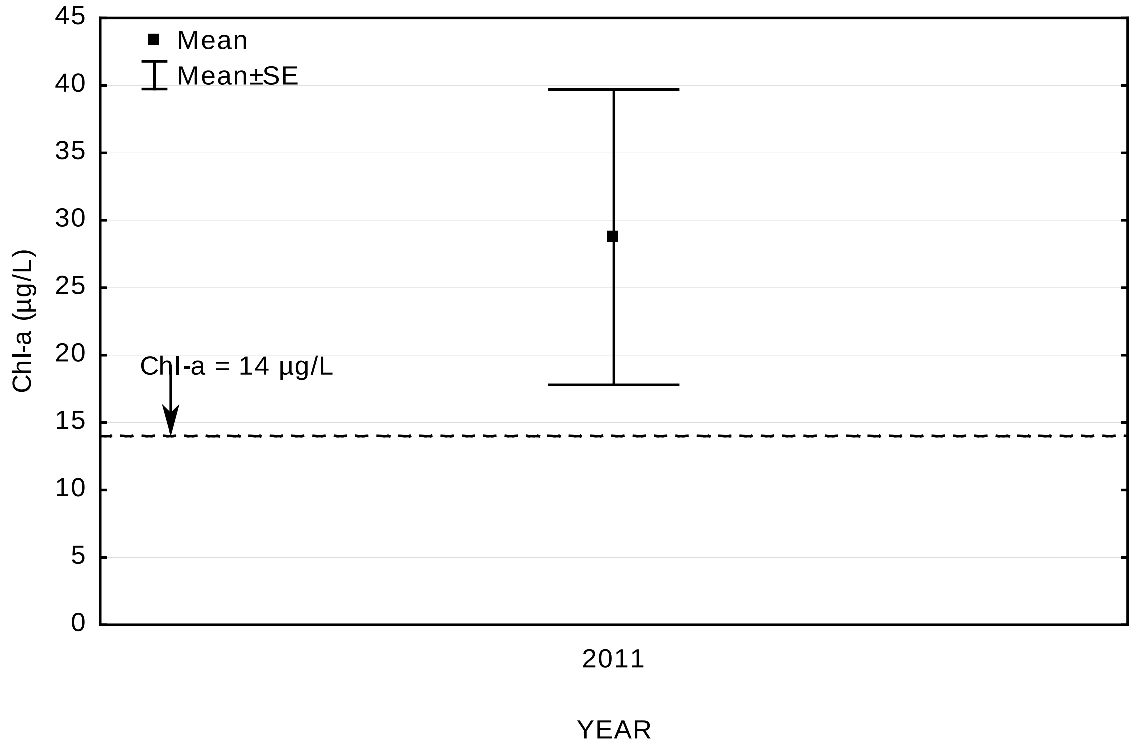

Figure 46. Growing Season Means ± SE of Chlorophyll-a for Rock Lake by Year
The dashed line represents the water quality standard for Chl-a (14 µg/L).

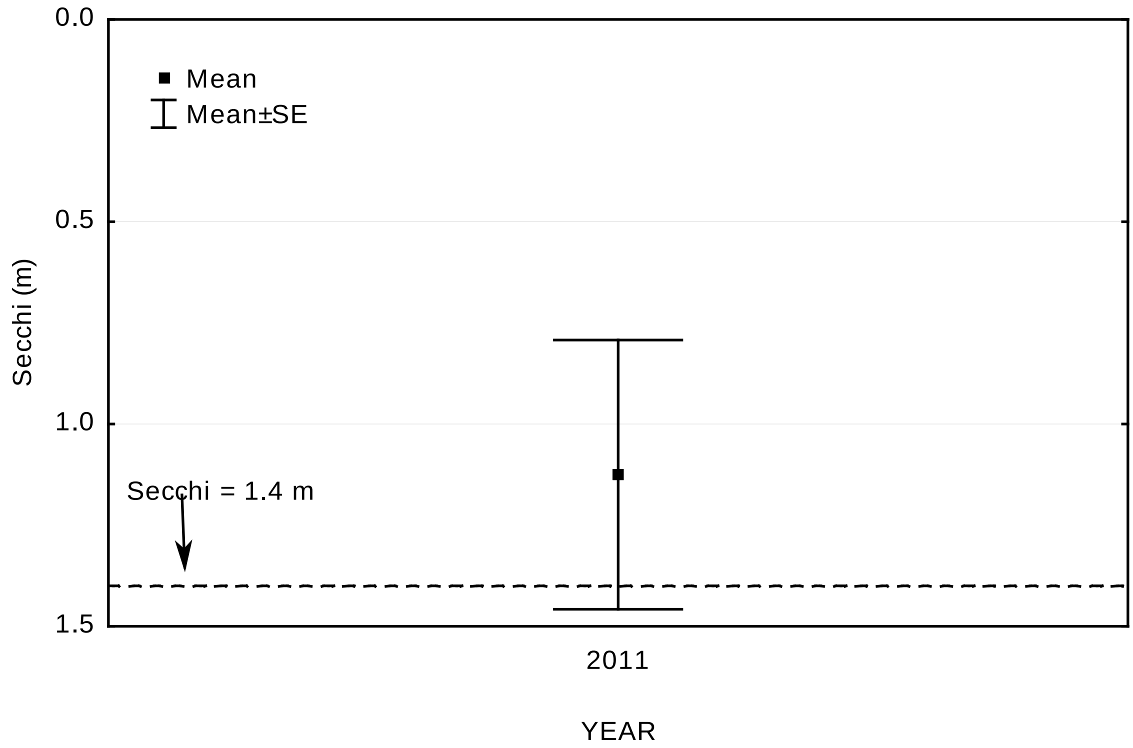

Figure 47. Growing Season Means ± SE of Secchi transparency for Rock Lake by Year
The dashed line represents the lake water quality standard for transparency (1.4 m).

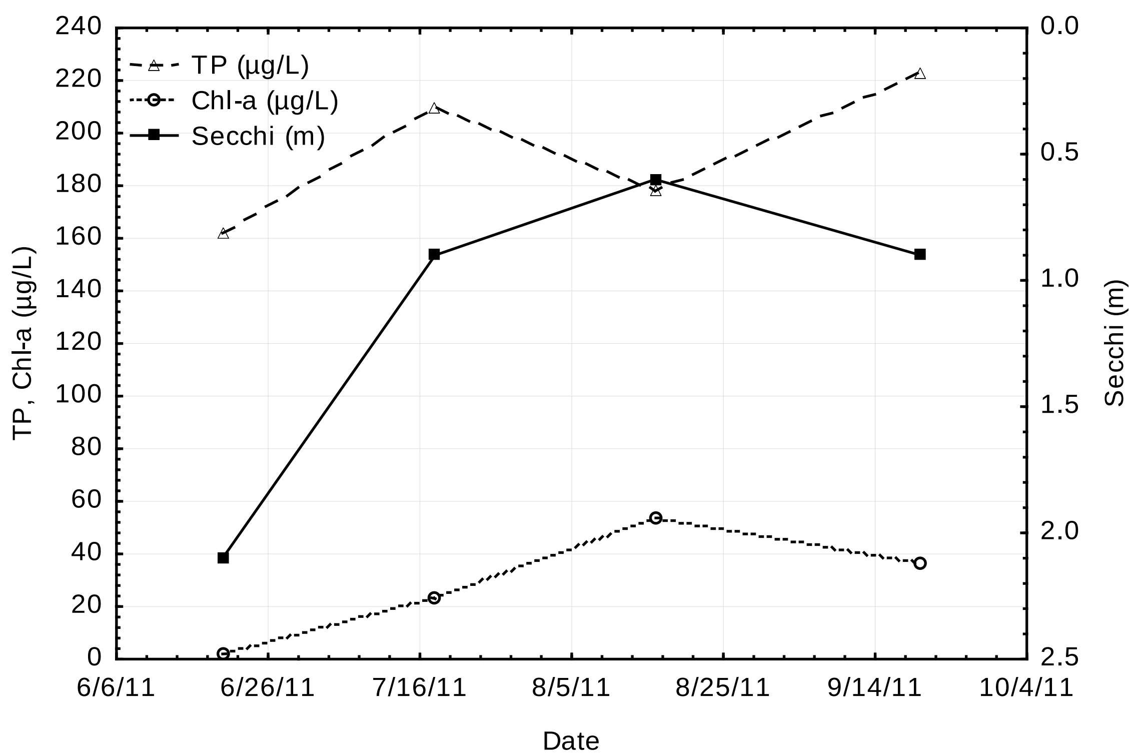

Figure 48. Growing Season Trends of Chl-a, TP, and Secchi depth for Rock Lake, 2011.

14.4.3 Macrophytes

No recent aquatic vegetation surveys have been conducted.

14.4.4 Fish

The most recent fish survey was conducted in 2000. Black bullheads were the most abundant species caught followed by pumpkinseed sunfish and black crappie. Northern pike was present but in small numbers. Winterkills occur in this lake due to low dissolved oxygen (DO) levels caused by high nutrient levels. Due to winterkills and replenishment from Rock Creek, the status of the fishery has been in a constant state of transition for potentially decades.

14.5 Rush Lake (West)

14.5.1 Physical Characteristics

Rush Lake (West) (DNR Lake ID 13-0069-02) is located in Chisago County with portions of its watershed in Chisago County (92%) and Pine County (8%). The watershed is located in the western portion of the Goose Creek watershed. The lake is upstream of Rush Lake (East) and is connected by a narrow channel. Table 83 summarizes the physical characteristics of the lake, Figure 49 illustrates the available bathymetry for the lake and Figure 50 shows the 2011 aerial photograph.

Table 83. Rush Lake (West) physical characteristics

<table>
<tr><th>Characteristic</th><th>Value</th><th>Source</th></tr>
<tr><td>Lake total surface area (acre)</td><td>1,579</td><td>0 m depth contour digitized from 2010 aerial photography</td></tr>
<tr><td>Percent lake littoral surface area (%)</td><td>53%</td><td rowspan="2">Calculated from DNR bathymetry using 2010 surface (aerial photo) and 1991-92 depth contours</td></tr>
<tr><td>Lake volume (acre-feet)</td><td>19,999</td></tr>
<tr><td>Mean depth (feet)</td><td>12.7</td><td>Lake volume ÷ surface area</td></tr>
<tr><td>Maximum depth (feet)</td><td>42</td><td>DNR Lake Finder</td></tr>
<tr><td>Watershed area, including lake area (acre)</td><td>15,509</td><td>DNR Catchments</td></tr>
<tr><td>Watershed area: Lake area</td><td>10:1</td><td>Calculated</td></tr>
</table>

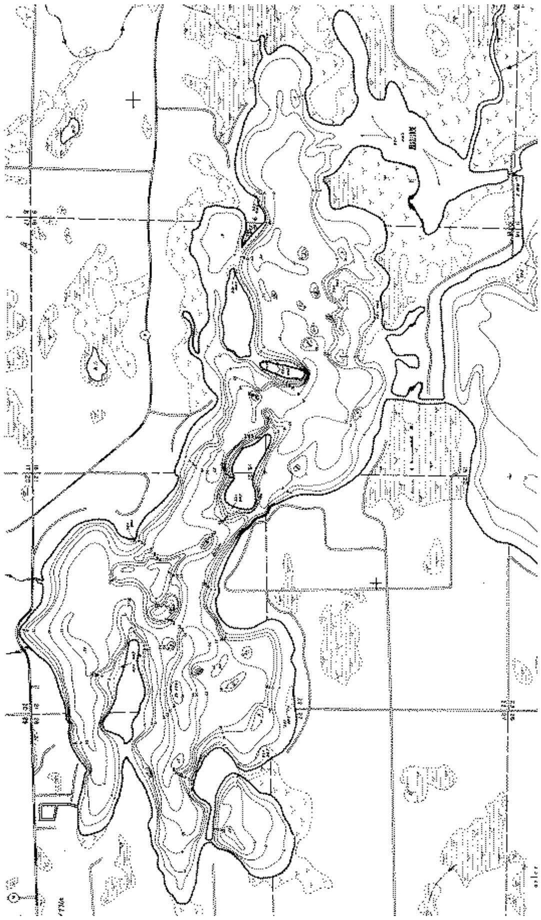

Figure 49. Rush Lake (West) bathymetry (DNR)

14.5.2 Water Quality

Table 84. 15-year Growing Season Mean TP, Chl-a, and Secchi, Rush Lake (West), 1998-2012

Parameter	Growing Season Mean (June – September)	Growing Season CV (June – September)	NCHF Lake Standard
Total phosphorus (µg/L)	64.5	7%	< 40
Chlorophyll-*a* (µg/L)	50.7	19%	< 14
Secchi transparency (m)	1.0	16%	> 1.4

*CV, coefficient of variation, defined in BATHTUB as the standard error divided by the mean.

Figure 50. Aerial photograph of Rush Lake (West) (Google Earth August 2011)

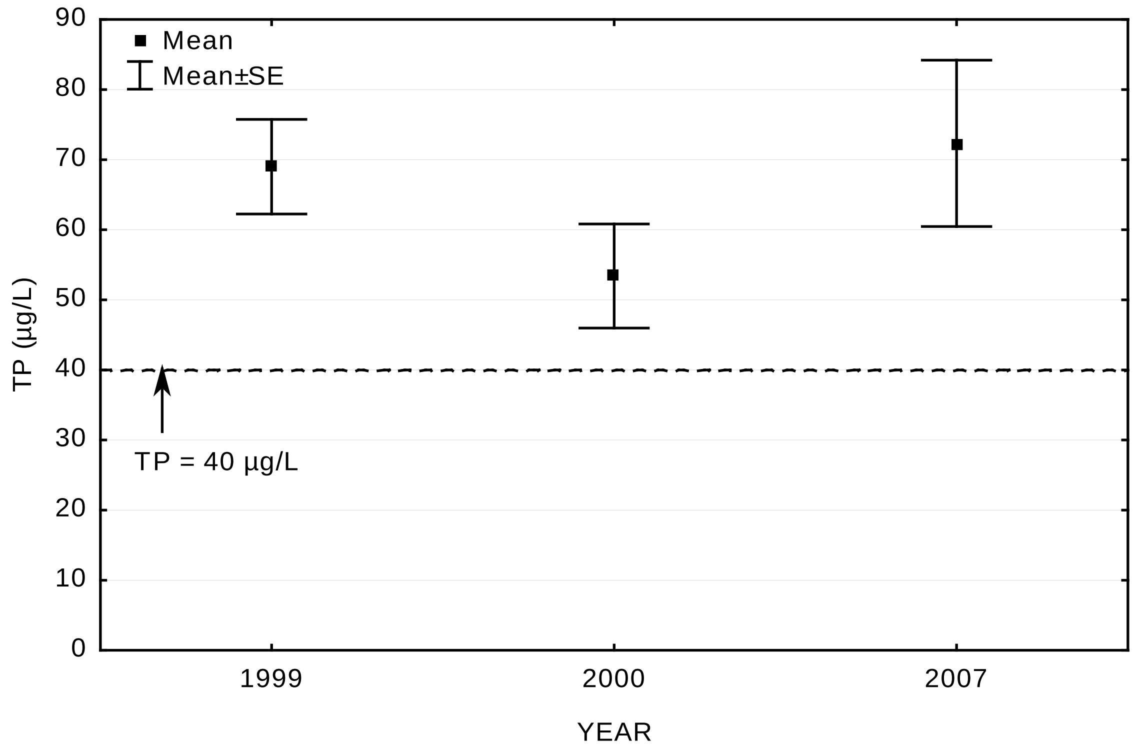

Figure 51. Growing Season Means ± SE of Total Phosphorus for Rush Lake (West) by Year
The dashed line represents the water quality standard for TP (40 µg/L).

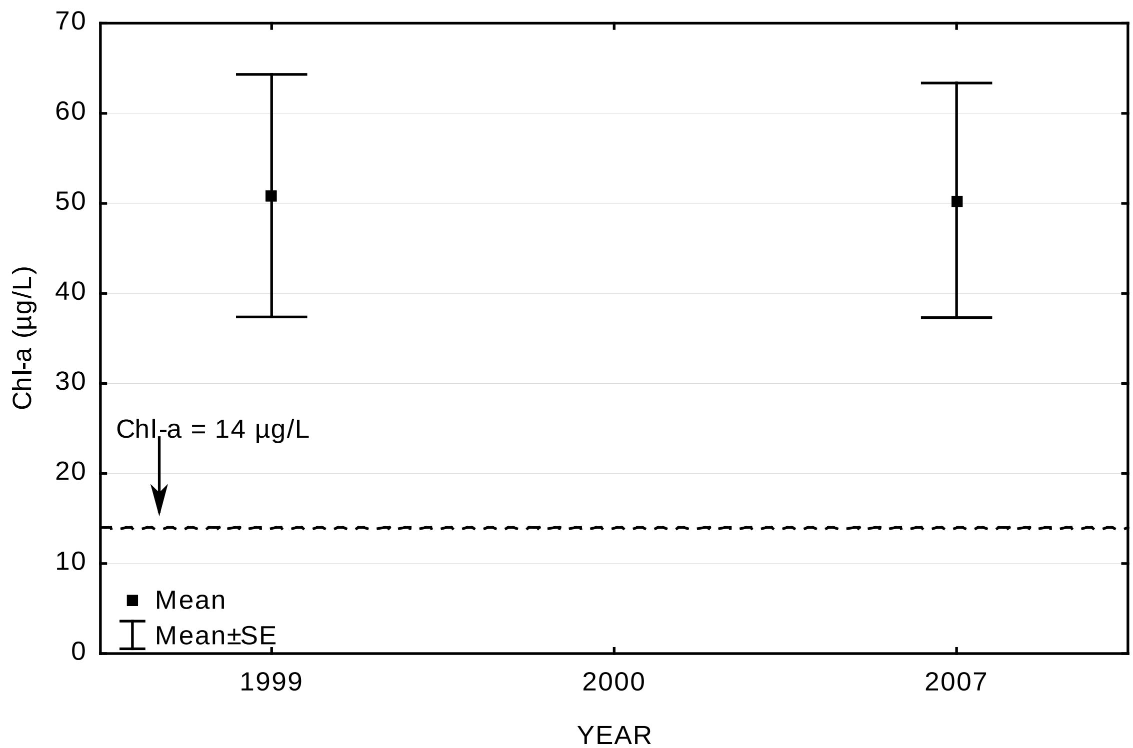

Figure 52. Growing Season Means ± SE of Chlorophyll-a for Rush Lake (West) by Year
The dashed line represents the water quality standard for Chl-a (14 µg/L).

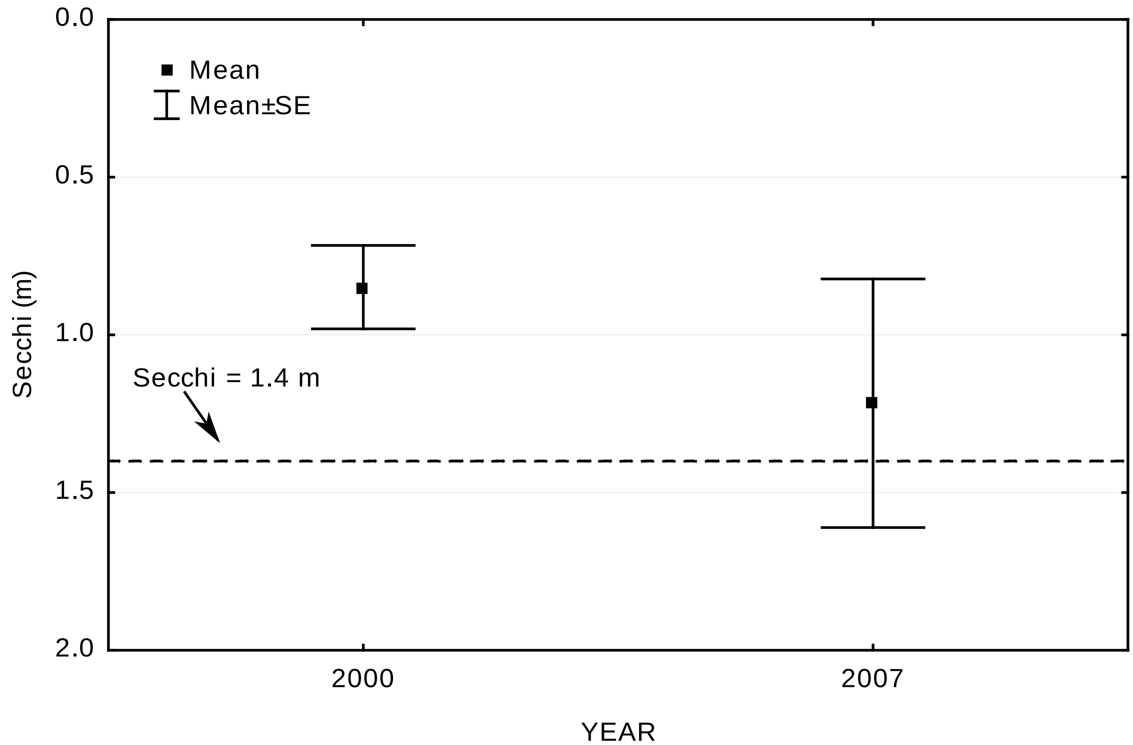

Figure 53. Growing Season Means ± SE of Secchi transparency for Rush Lake (West) by Year
The dashed line represents the lake water quality standard for transparency (1.4 m).

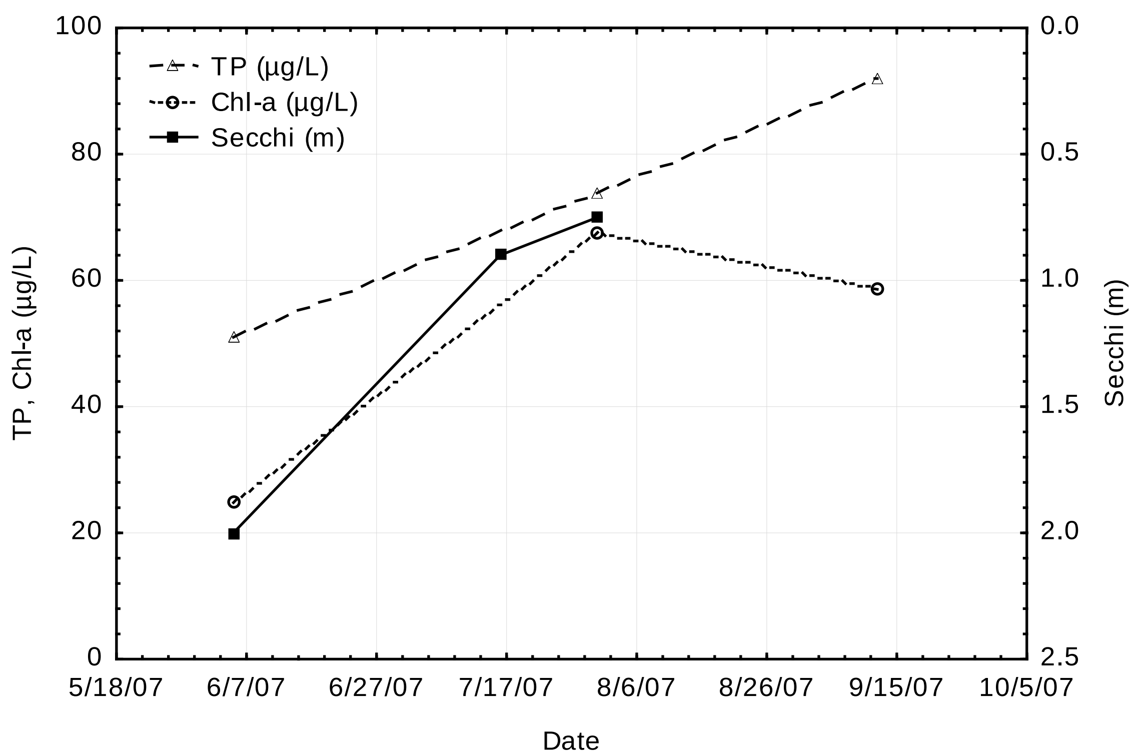

Figure 54. Growing Season Trends of Chl-a, TP, and Secchi depth for Rush Lake (West), 2007

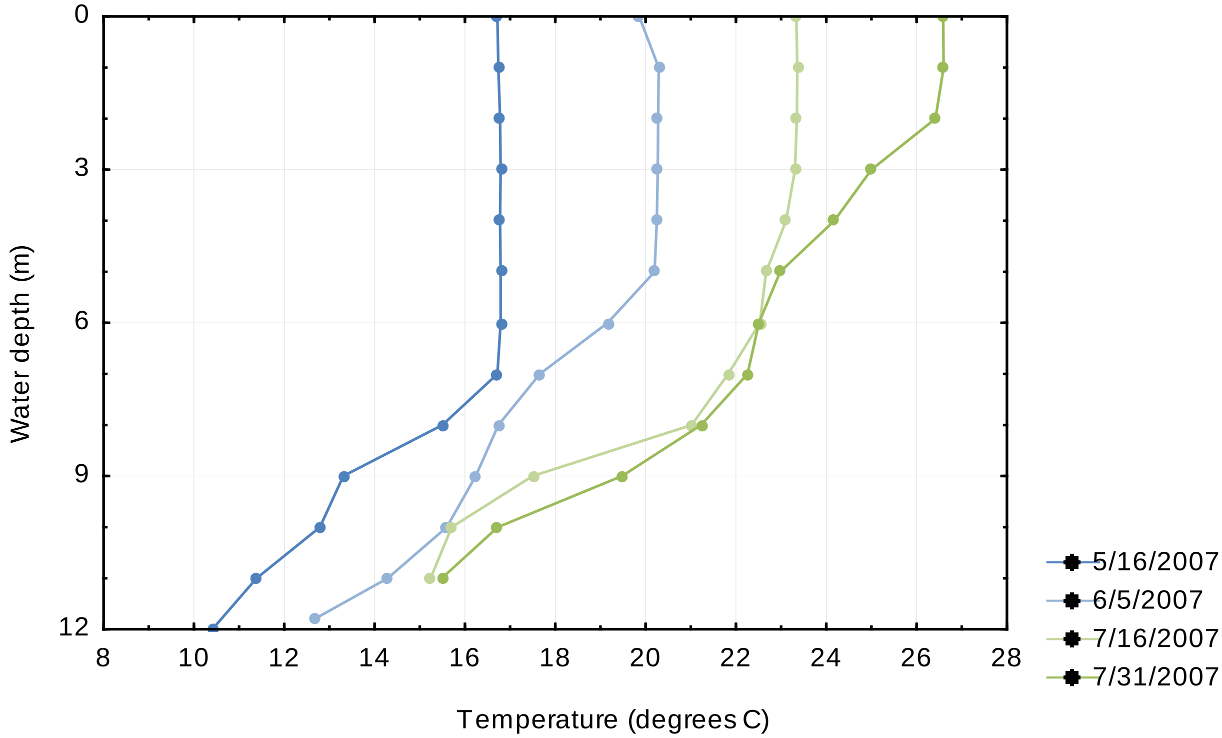

Figure 55: Temperature profiles for Rush Lake (West), 2007

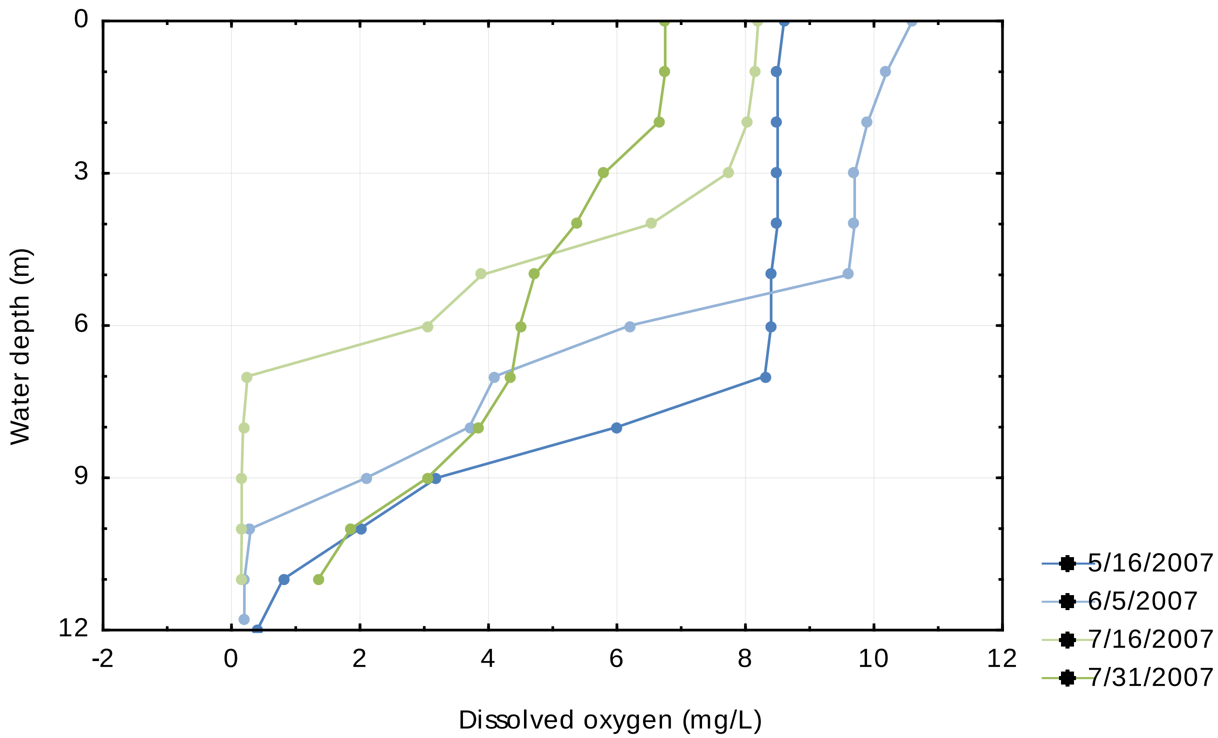

Figure 56: Dissolved oxygen profiles for Rush Lake (West), 2007

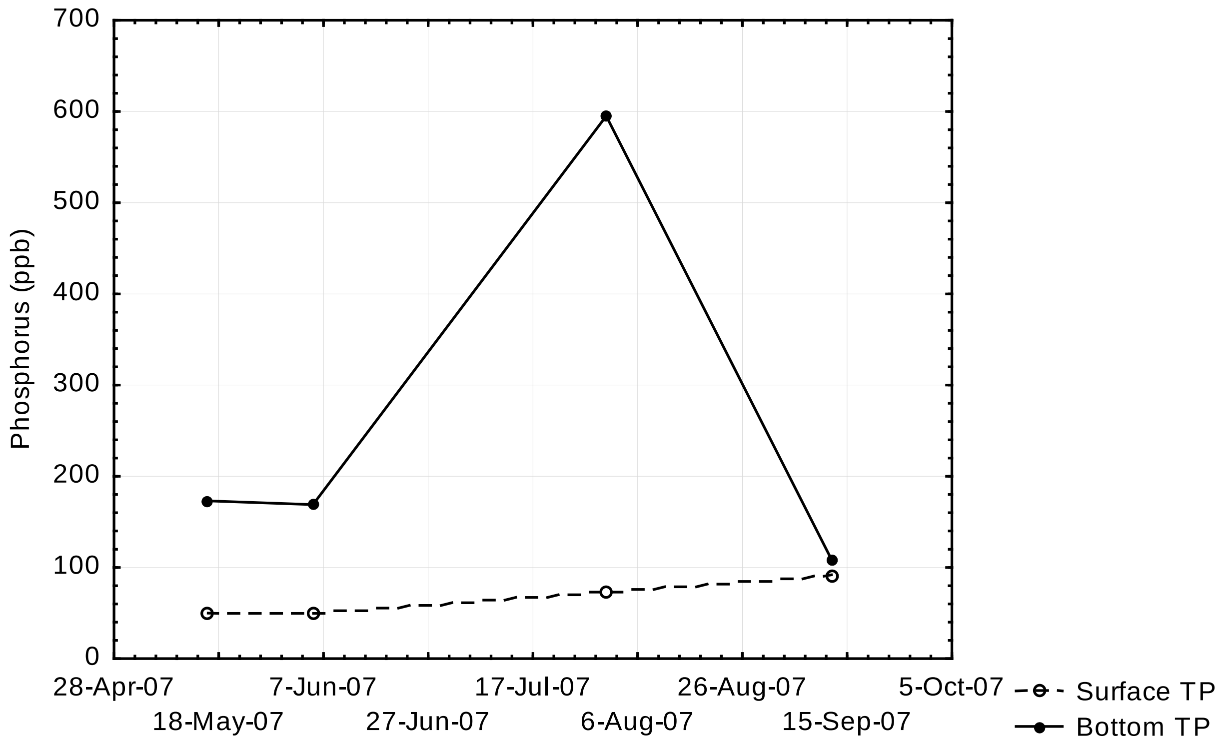

Figure 57: Surface and bottom total phosphorus concentrations for Rush Lake (West), 2007

14.5.3 Macrophytes

The DNR has conducted aquatic vegetation transect surveys in 2000 and 2007, followed by surveys targeting curlyleaf pondweed in 2009 and 2012. Twenty-four plant species were found in East Rush Lake in 2007, including 15 submerged, seven emergent, and two floating leaf species. Muskgrass and Eurasian watermilfoil were the most common submerged plant species. Maximum depth of plant growth was five feet. Twenty-five plant species were found in West Rush Lake in 2007, including 16 submerged, seven emergent, and two floating leaf plant species. Coontail and muskgrass were the most common submerged plant species. Maximum depth of plant growth was 6.8 feet.

Curlyleaf pondweed has been present in Rush Lake since 1972 or earlier. This species becomes abundant in late spring and early summer. A vegetation point intercept survey in late spring 2012 found curlyleaf pondweed at 63% of sample points (applies to both lakes). The Rush Lake Improvement Association has contracted with an herbicide applicator for over 10 years to provide boating channels in selected areas of the lake that have heavy curlyleaf pondweed growth. These treatments are considered nuisance control and are generally not effective at long term control. A map of the treatment area in 2013 is available online (http://www.rlia.net/docs/clp_ver5_2013.pdf).

14.5.4 Fish

The most recent fish survey was conducted in 2013 by the DNR. The lake is primarily managed for walleye, muskellunge, and northern pike. The number of walleyes caught was lower than the long term average and normal range for that lake class. However, anglers have reported fair success fishing walleye over the past 10 years. The number of northern pike caught was identical to the long term average. Yellow perch have been historically highly abundant with no exception during the most recent survey and provide forage for game fish. The black crappie catch was the highest ever recorded and greatly exceed the normal range for the lake class. Other species identified included bigmouth buffalo, bowfin, common carp, freshwater drum, hybrid sunfish, and pumpkinseed.

14.6 Rush Lake (East)

14.6.1 Physical Characteristics

Rush Lake (East) (DNR Lake ID 13-0069-01) is located in Chisago County with portions of its watershed in Chisago County (75%) and Pine County (25%). The watershed is located in the western portion of the Goose Creek watershed. The lake is downstream of Rush Lake (West) and is connected by a narrow channel. Table 85 summarizes the physical characteristics of the lake, Figure 58 illustrates the available bathymetry and Figure 59 shows the 2011 aerial photograph.

Table 85. Rush Lake (East) physical characteristics

Characteristic	Value	Source
Lake total surface area (acre)	1,484	0 m depth contour digitized from 2010 aerial photography
Percent lake littoral surface area (%)	76%	Calculated from DNR bathymetry using 2010 surface (aerial photo) and 1991-92 depth contours
Lake volume (acre-feet)	12,997	
Mean depth (feet)	8.8	Lake volume ÷ surface area
Maximum depth (feet)	24	DNR Lake Finder
Watershed area, including lake area (acre)	22,557	DNR Catchments
Watershed area: Lake area	15:1	Calculated

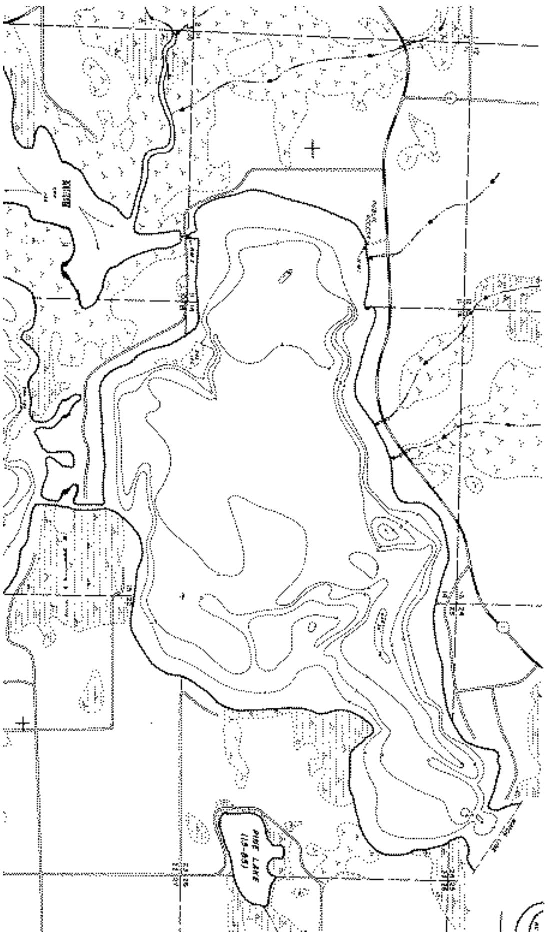

Figure 58. Rush Lake (East) bathymetry (DNR)

14.6.2 Water Quality

Table 86. 15-year Growing Season Mean TP, Chl-a, and Secchi, Rush Lake (East), 1998-2012

Parameter	Growing Season Mean (June – September)	Growing Season CV (June – September)	NCHF Lake Standard
Total phosphorus (µg/L)	61	26%	< 40
Chlorophyll-*a* (µg/L)	33.1	39%	< 14
Secchi transparency (m)	1.0	23%	> 1.4

*CV, coefficient of variation, defined in BATHTUB as the standard error divided by the mean.

Figure 59. Aerial photograph of Rush Lake (East) (Google Earth, August 2011)

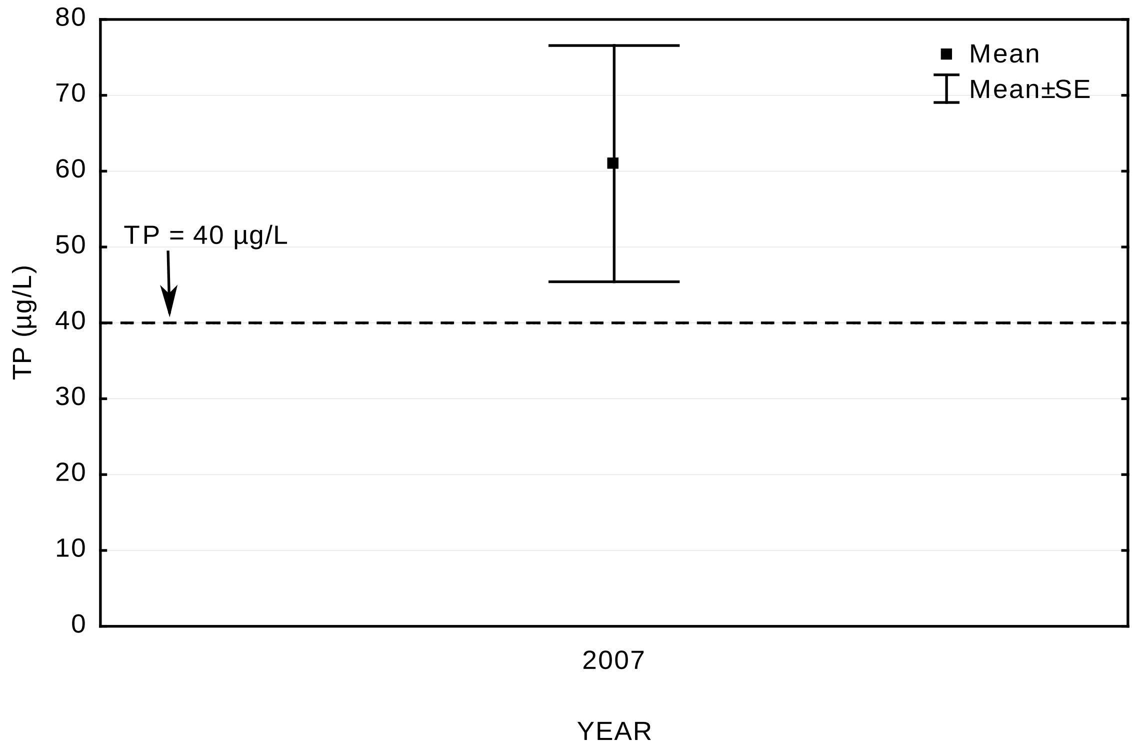

Figure 60. Growing Season Means ± SE of Total Phosphorus for Rush Lake (East) by Year
The dashed line represents the water quality standard for TP (40 µg/L).

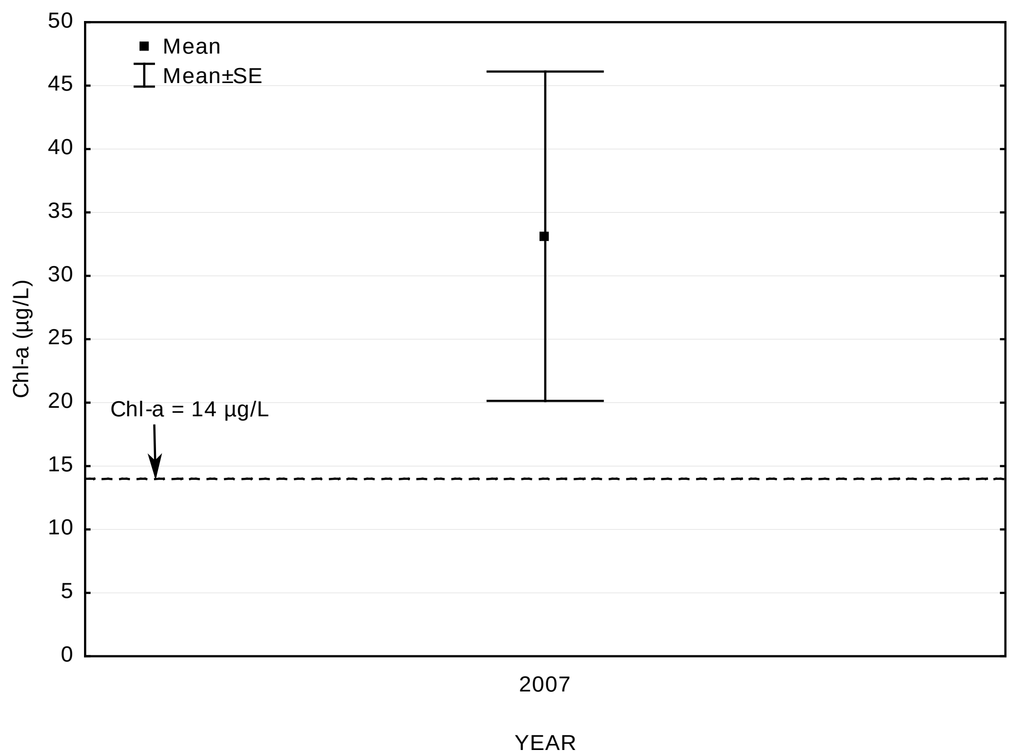

Figure 61. Growing Season Means ± SE of Chlorophyll-a for Rush Lake (East) by Year
The dashed line represents the water quality standard for Chl-a (14 µg/L).

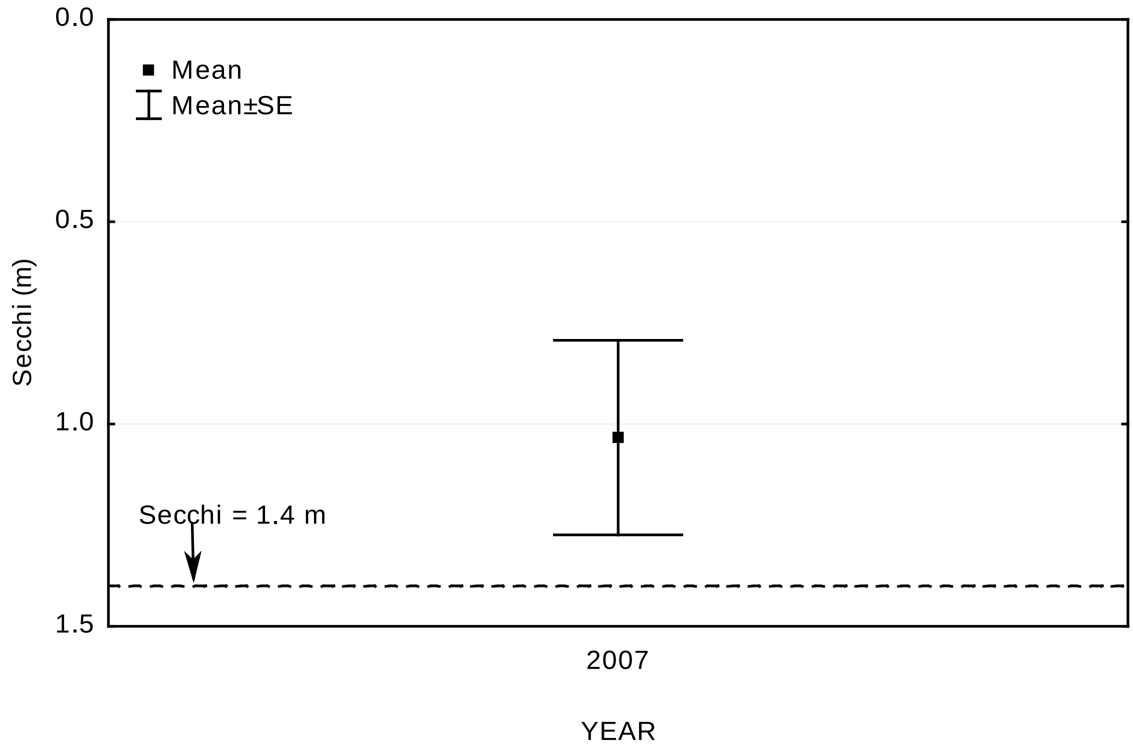

Figure 62. Growing Season Means ± SE of Secchi transparency for Rush Lake (East) by Year
The dashed line represents the lake water quality standard for transparency (1.4 m).

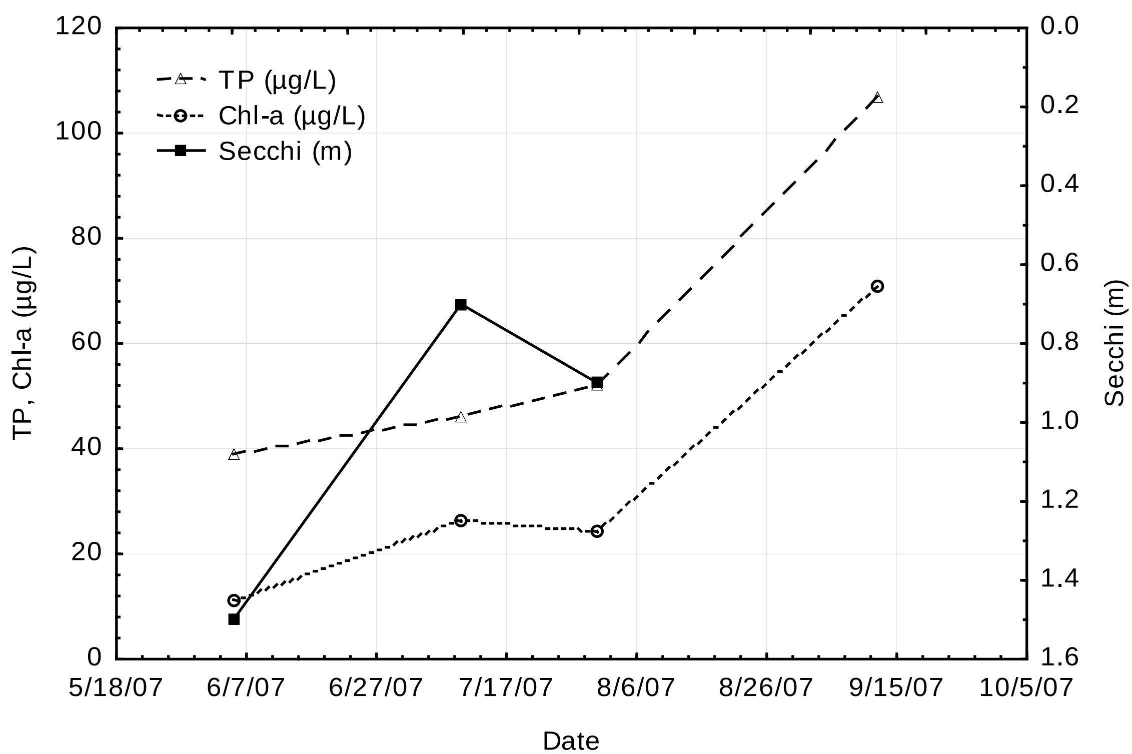

Figure 63. Growing Season Trends of Chl-a, TP, and Secchi depth for Rush Lake (East), 2007

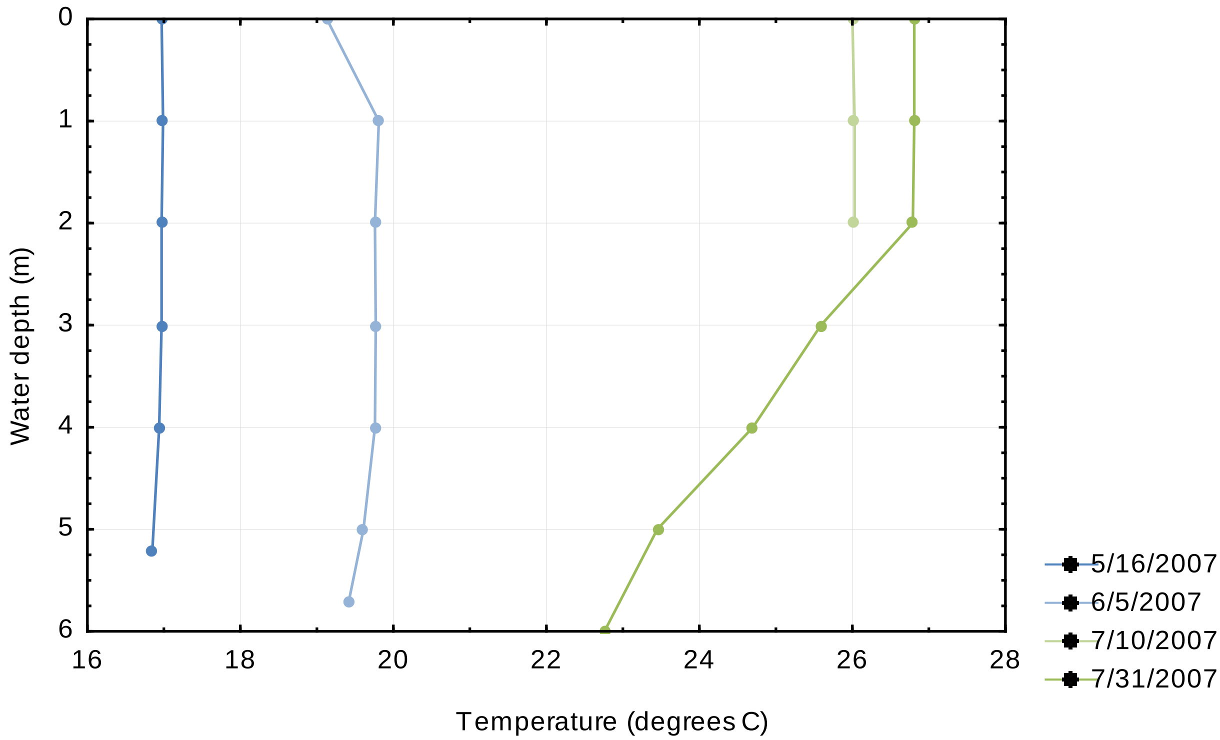

Figure 64: Temperature profiles for Rush Lake (East), 2007

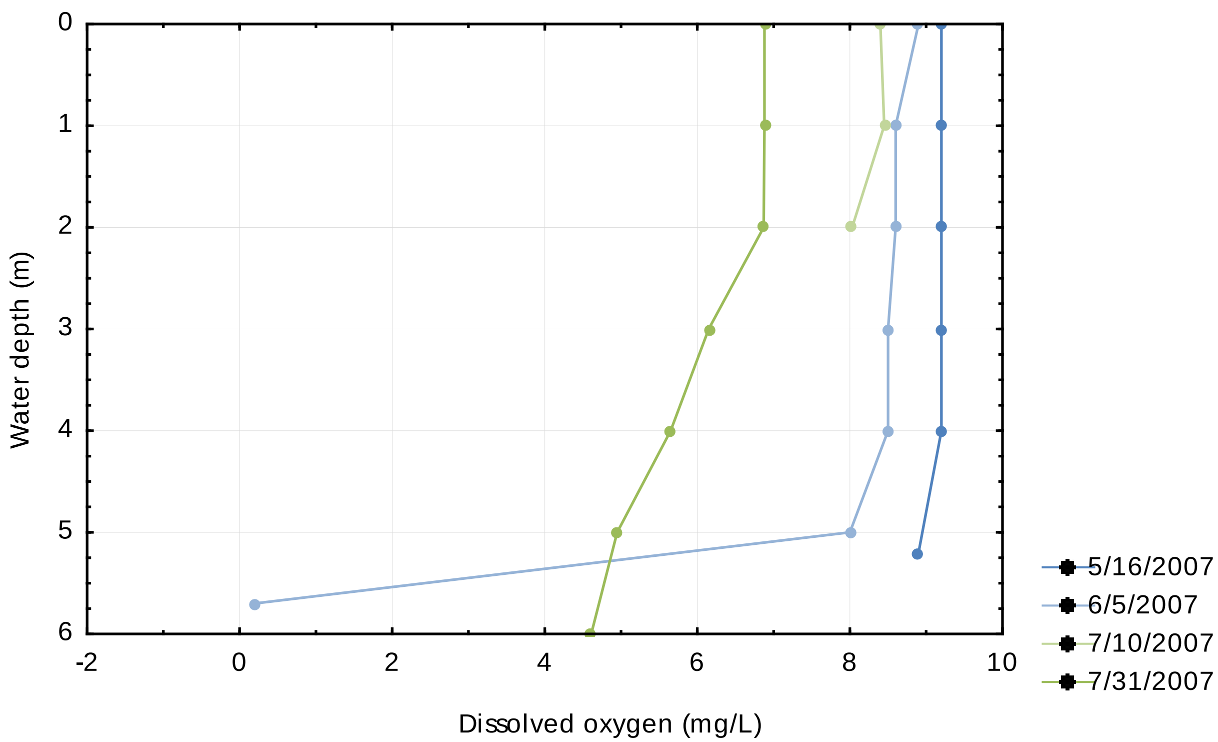

Figure 65: Dissolved oxygen profiles for Rush Lake (East), 2007

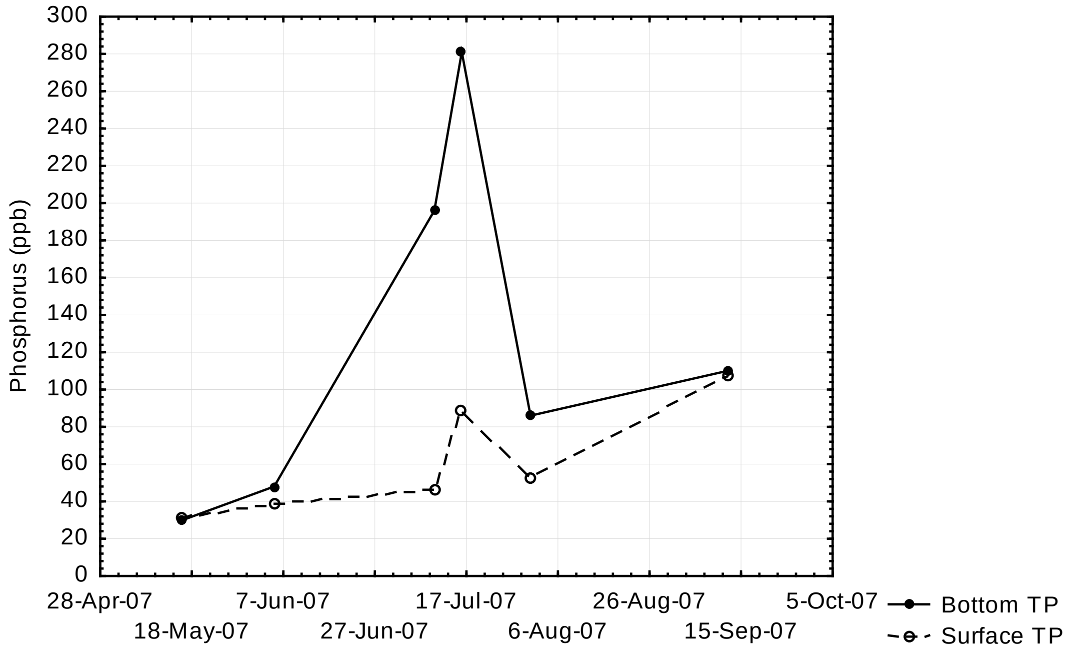

Figure 66: Surface and bottom total phosphorus concentrations for Rush Lake (East), 2007

14.6.3 Macrophytes

The DNR has conducted aquatic vegetation transect surveys in 2000 and 2007, followed by surveys targeting curlyleaf pondweed in 2009 and 2012. Twenty-four plant species were found in East Rush Lake in 2007, including 15 submerged, seven emergent, and two floating leaf species. Muskgrass and Eurasian watermilfoil were the most common submerged plant species. Maximum depth of plant growth was five feet. Twenty-five plant species were found in West Rush Lake in 2007, including 16 submerged, seven emergent, and two floating leaf plant species. Coontail and muskgrass were the most common submerged plant species. Maximum depth of plant growth was 6.8 feet.

Curlyleaf pondweed has been present in Rush Lake since 1972 or earlier. This species becomes abundant in late spring and early summer. A vegetation point intercept survey in late spring 2012 found curlyleaf pondweed at 63% of sample points. (applies to both lakes) The Rush Lake Improvement Association has contracted with an herbicide applicator for over 10 years to provide boating channels in selected areas of the lake that have heavy curlyleaf pondweed growth. These treatments are considered nuisance control and are generally not effective at long term control. A map of the treatment area in 2013 is available online (http://www.rlia.net/docs/clp_ver5_2013.pdf).

14.6.4 Fish

The most recent fish survey was conducted in 2011 by the DNR. The report states that the lake is primarily managed for walleye, muskellunge, and northern pike. There are good numbers of yellow perch, black crappie, bluegill, walleye, largemouth bass, and northern pike based on the most recent sampling. Walleye numbers fell within the normal range for this lake class and the population is maintained primarily through stocking efforts. Minimum length regulations for muskellunge seem to be beneficial for increasing numbers of fish over 40 inches. Black crappie was present in abundant numbers and provides forage for game fish.