Rice Lake Excess Nutrient TMDL

Wenck

Prepared for

North Fork Crow River

Watershed District

April 2012

wq-iw8-35e

Rice Lake Nutrient TMDL Report

Wenck File #1878-03

Prepared for:

NORTH FORK CROW RIVER WATERSHED DISTRICT

Prepared by:

WENCK ASSOCIATES, INC.
1800 Pioneer Creek Center
P.O. Box 249
Maple Plain, Minnesota 55359-0249
(763) 479-4200

November 2011

Wenck

Table of Contents

Table of Contents

Table of Contents

TABLES

FIGURES

Table of Contents

APPENDICES

Table of Contents

TMDL Summary

<table>
<tr><th colspan="5">TMDL Summary Table</th></tr>
<tr><th>EPA/MPCA Required Elements</th><th colspan="3">Summary</th><th>TMDL Section</th></tr>
<tr><td>Location</td><td colspan="3">Rice Lake is a 1,509 acre lake located in the south central portion of Stearns County about 10 miles southeast of the town of Paynesville. The North Fork Crow River flows in and out of Rice Lake through the southwest basin of the lake. Rice Lake is located in the Upper Mississippi River basin.</td><td>2.1</td></tr>
<tr><td>303(d) Listing Information</td><td colspan="3">Segment: Rice Lake (DNR #73-0196)
Impaired Beneficial Use(s): Aquatic life and recreation
Indicator: Nutrient/Eutrophication Biological Indicators
Target start/completion date: 2009/2013
Original Listing year: 2008</td><td>1.2</td></tr>
<tr><td>Applicable Water Quality Standards/ Numeric Targets</td><td colspan="3">Criteria set forth in Minn. R. 7050.0150 (3) and (5). The numeric criteria for a deep lake located within the North Central Hardwood Forest (NCHF) Ecoregion are:

Total Phosphorus (TP) (µg/L): TP < 40
Chlorophyll-a (chl-a) (µg/L): chl-a < 14
Secchi Depth (SD) (m): SD > 1.4

TP, chl-a and SD values are averaged over the summer season (June 1 through September 30).</td><td>1.3</td></tr>
<tr><td>Loading Capacity (expressed as daily load)</td><td colspan="3">The loading capacity is the total maximum daily load for each of these conditions. The critical condition for these lakes is the summer growing season. The total maximum daily phosphorus loading capacity for Rice Lake is 81.2 pounds per day (lbs/day)</td><td>4.1.1</td></tr>
<tr><td rowspan="4">Wasteload Allocation</td><td colspan="3">Portion of the loading capacity allocated to existing and future permitted sources.</td><td rowspan="4">4.1.3</td></tr>
<tr><th>Source</th><th>Total Permits</th><th>Gross WLA (lbs/day)</th></tr>
<tr><td>Construction Stormwater</td><td>6</td><td>0.8</td></tr>
<tr><td>Industrial Stormwater</td><td>1</td><td>0.4</td></tr>
</table>

TMDL Summary

TMDL Summary Table					
EPA/MPCA Required Elements	**Summary**				**TMDL Section**
	NPDES Point Sources	3		8.6	
Load Allocation	The portion of the loading capacity allocated to existing and future non-permitted sources.				4.1.2
	Source		**Allocation (lbs/day)**		
	Atmospheric		1.1		
	Rice Lake Direct Watershed		1.0		
	North Fork Crow River Watershed		64.0		
	Internal Load		1.2		
Margin of Safety	An explicit margin of safety of 5% of the total load (4.1 lbs/day) was used in the Rice Lake TMDL.				4.1.4
Seasonal Variation	Seasonal variation is accounted for by developing targets for the summer critical period (6/1 through 9/30) where the frequency and severity of nuisance algal growth is greatest. Although the critical period is the summer, lakes are not sensitive to short-term changes but rather respond to long-term changes in annual load.				4.4
Reasonable Assurance	Reasonable assurance is provided by implementing the TMDL through the Stearns County Water Plan and the North Fork Crow River Watershed District (NFCRWD) and CROW Watershed Management Plan.				7
Monitoring	The NFCRWD plans to continue monitoring Rice Lake on a monthly basis in the summer for total phosphorus, chlorophyll-a, and Secchi depth.				7
Implementation	This TMDL sets forth an implementation framework and general load reduction strategies that will be expanded and refined through the development of an Implementation Plan.				6
Public Participation	Stakeholder and Public participation was accomplished through a series of stakeholder meetings. Feedback garnered from these meetings was incorporated into the TMDL Report.				5

Executive Summary

This Total Maximum Daily Load (TMDL) study addresses nutrient impairments for Rice Lake (DNR #73-0196) located in the North Fork Crow River (NFCR) watershed, HUC-8 (# 07010204), Upper Mississippi River Basin in Stearns County, Minnesota. The goal of this TMDL is to quantify the pollutant reductions needed to meet the Minnesota water quality standards for deep lakes in the North Central Hardwood Forests (NCHF) ecoregion. The numeric water quality standards for Rice Lake are summer average values of a total phosphorus concentration less than 40 µg/L, summer average values less than 14 µg/L for chlorophyll-a, and summer average values greater than 1.4 meters for Secchi depth. Water quality in Rice Lake does not currently meet state nutrient concentration standards for deep lakes in the North Central Hardwood Forest ecoregion.

Rice Lake has a direct watershed that is approximately 10,730 acres in size. The North Fork Crow River watershed drains approximately 162,122 acres above Rice Lake and flows in and out of the lake through the southwest basin. Land use in the North Fork Crow River and Rice Lake direct watersheds is predominantly agriculture (>50%); including row crops (corn soybean rotation) and animal agriculture. Rice Lake has four major basins; three of which have an average depth greater than 10 feet (L1, L2 and L4) while one basin, L3, has an average depth of 7 feet. Rice Lake has a history of carp and curly-leaf pondweed infestation.

A nutrient budget was developed for Rice Lake along with a lake response model to set Load and Wasteload Allocations. Phosphorus sources to Rice Lake include direct watershed runoff (approximately 2%), North Fork Crow River watershed runoff (approx. 93%), internal sediment release of phosphorus (approx. 4%), with the remaining phosphorus source loads coming from atmospheric deposition (approx. 1%). The TMDL allocation for Rice Lake to meet state water quality standards necessitates a phosphorus load of 29,848 pounds per year. The TMDL allocation represents a 50% reduction from current loading to Rice Lake.

One of the primary nonpoint sources of phosphorus for Rice Lake is runoff from agricultural areas, containing both row crops and animal agriculture. Based on the Unit Area Load (UAL) model and agricultural animal counts through the watershed, one of the primary nonpoint sources of nutrients from agricultural areas is from animal manure. There are over 55,000 animal units in the North Fork Crow River watershed above Rice Lake and Rice Lake direct watershed. These animals produce over 5.3 million pounds of phosphorus per year. A large portion of the phosphorus input to Rice Lake is via land applied manure practices. Nutrient management in the Rice Lake watershed will need to focus on manure management. Sediment phosphorus release rates in the deep basins of Rice Lake were high compared to typical release rates in healthy mesotrophic lake ecosystems. So while the internal nutrient load (4%) may appear small compared to the total watershed load, sediment loading should be addressed through internal load controls.

1.0 Introduction

1.1 PURPOSE

This Total Maximum Daily Load (TMDL) study addresses a nutrient impairment in Rice Lake (DNR Lake #73-0196). The goal of this TMDL is to quantify the pollutant reductions needed to meet state water quality standards for nutrients in Rice Lake. The Rice Lake nutrient TMDL is being established in accordance with section 303(d) of the Clean Water Act, because the Minnesota Pollution Control Agency (MPCA) has determined waters in Rice Lake did not meet water quality standards for nutrients. This TMDL provides wasteload allocations (WLAs) and load allocations (LAs) for Rice Lake to attain water quality standards for the NCHF ecoregion...

1.2 PROBLEM IDENTIFICATION

Rice Lake, located primarily in Eden Lake Township, Stearns County, Minnesota, was placed on the 2008 State of Minnesota's 303(d) list of impaired waters. Rice Lake's aquatic life and recreation designated use was identified as being impaired by excessive nutrients/algal blooms. Water quality in Rice Lake does not meet state eutrophication water quality standards for deep lakes in the North Central Hardwood Forest ecoregion.

The primary recreation activities supported by the lake include boating and fishing. The lake has two public access points and is a well-known recreational and summer vacation water body within Stearns County. It has a very active Lake Association comprised of lake shore property owners who are active in the management of the lake. Members of the Lake Association are excited and willing to take on the challenges of this TMDL study.

Water quality in Rice Lake has been periodically monitored over the past 30 years with the most intensive monitoring occurring in 2009 and 2010 as a part of this TMDL and various lake management planning efforts. During this monitoring period, the average summer values (June 1 through September 30) for total phosphorus at the long-term monitoring site ranged from 32 µg/L to 78 µg/L and averaged 59 µg/L. Chlorophyll-a concentrations ranged from 11 µg/L to 54 µg/L and averaged 31 µg/L. Finally, Secchi depth transparencies averaged about 1.5 m with a range over the monitoring years of 0.8 m to 2.3 m. Values for total phosphorus and chlorophyll-a exceeded the state standards for deep lakes in the North Central Hardwood Forest ecoregion.

The Rice Lake watershed was given a priority ranking for TMDL development due to: the impairment impacts on public health and aquatic life, the public value of the impaired water resource, the likelihood of completing the TMDL in an expedient manner, the inclusion of a strong base of existing data and the restorability of the water body, the technical capability and the willingness of local partners to assist with the TMDL, and the appropriate sequencing of TMDLs within a watershed or basin. Areas within the Rice Lake watershed are popular locations for aquatic recreation. Water quality degradation has led to efforts to improve the overall water quality within the Rice Lake watershed, and to the development of a TMDL.

1.3 IMPAIRED WATERS AND MINNESOTA WATER QUALITY STANDARDS

1.3.1 State of Minnesota Water Quality Standards and Designated Uses

Rice Lake is located in the North Central Hardwood Forest ecoregion and is designated as a class 2B water. The Class 2B designation specifies aquatic life and aquatic recreation as the protected beneficial use of the water body.

Minnesota's standards for nutrients limit the quantity of nutrients which may enter surface waters. Minnesota's standards at the time of listing (Minnesota Rules 7050.0150(3)) stated that in all Class 2 waters of the state, "…there shall be no material increase in undesirable slime growths or aquatic plants including algae." In accordance with Minnesota Rules 7050.0150(5), to evaluate whether a water body is in an impaired condition the MPCA developed "numeric translators" for the narrative standard for purposes of determining which lakes should be included in the section 303(d) list as being impaired for nutrients. The numeric translators established numeric thresholds for phosphorus, chlorophyll-a, and clarity as measured by Secchi depth.

The numeric target used to list this lake was the phosphorus standard for Class 2B waters in the North Central Hardwood Forest ecoregion (40 µg/L); this TMDL presents load and wasteload allocations and estimated load reductions for the 40 µg/L target. Although the TMDL is set for the total phosphorus standard, the other lake eutrophication standards (chlorophyll-a and Secchi depth) must also be met (Table 1-1). All three of these parameters were assessed in this TMDL to assure that the TMDL will result in compliance with state water quality standards. Numeric standards applicable to Rice Lake for chlorophyll-a and Secchi depth are 14 µg/L and 1.4 meters, respectively. All values are growing season means.

Table 1-1. Numeric targets for deep lakes in the North Central Hardwood Forest ecoregion.

Parameters	North Central Hardwood Forest (Deep Lakes)[1]
Phosphorus Concentration (µg/L)	40
Chlorophyll-a Concentration (µg/L)	14
Secchi disk transparency (meters)	>1.4

[1] Deep lakes are defined as lakes with a maximum depth of more than 15 feet, and with less than 80% of the lake area shallow enough to support emergent and submerged rooted aquatic plants (littoral zone).

2.0 Watershed and Lake Characterization

2.1 LAKE AND WATERSHED DESCRIPTION

Rice Lake is a 1,509 acre lake located in the south central portion of Stearns County about 10 miles southeast of the town of Paynesville in the North Central Hardwood Forest Ecoregion (Figure 2-1). Due to Rice Lake's size and complex morphometry, the lake was divided in to four separate basins for this TMDL study (Figure 2-2). Thus, much of the calculations, modeling and analysis for this report were performed individually for each basin prior to calculating lake totals. Public access areas are located in the southwest corner of the lake, south of the Crow River outlet (basin L1), and in the northwest portion of the lake (basin L4).

Minnesota Rules define "deep lakes" as enclosed basins filled or partially filled with standing fresh water with a maximum depth greater than 15 feet. A "shallow lake" is defined as a freshwater basin with a maximum depth of 15 feet or less or with 80% or more of the lake area shallow enough to support emergent and submerged rooted aquatic plants (littoral zone). With a maximum depth of 41 feet and 59% littoral zone, Rice Lake is considered a deep lake by Minnesota rules. However it should be pointed out that Basin L3, commonly referred to as Schaumann's Bay, displays characteristics more common of shallow lakes (Table 2-1). Typically, the greater the percentage of the lake that is littoral, the greater the influences of biological processes (fish, zooplankton, and plants) on water quality. Rice Lake likely will respond to both watershed inputs as well as changes in the lake's biological system.

Table 2-1. Rice Lake morphometric and watershed characteristics.

Parameter	Entire Lake	Basin L1	Basin L2	Basin L3	Basin L4
Surface Area (acres)	1,509	194	533	399	383
Average Depth (ft.)	15	12	21	7	18
Maximum Depth (ft.)	41	18	36	12	41
Volume (acre-ft.)	25,027	3,493	11,053	3,522	6,959
Residence Time (years)	0.24	0.03	6.63	3.97	10.47
Littoral Area (acres)	958	81	196	511	170
Littoral Area (%)	59%	42%	37%	100%	44%
Direct Watershed (acres)	10,730	592	1,434	5,247	3,457
Total Watershed (acres)	172,852	NA	NA	NA	NA
Watershed: Lake Area ratio	107:1	NA	NA	NA	NA

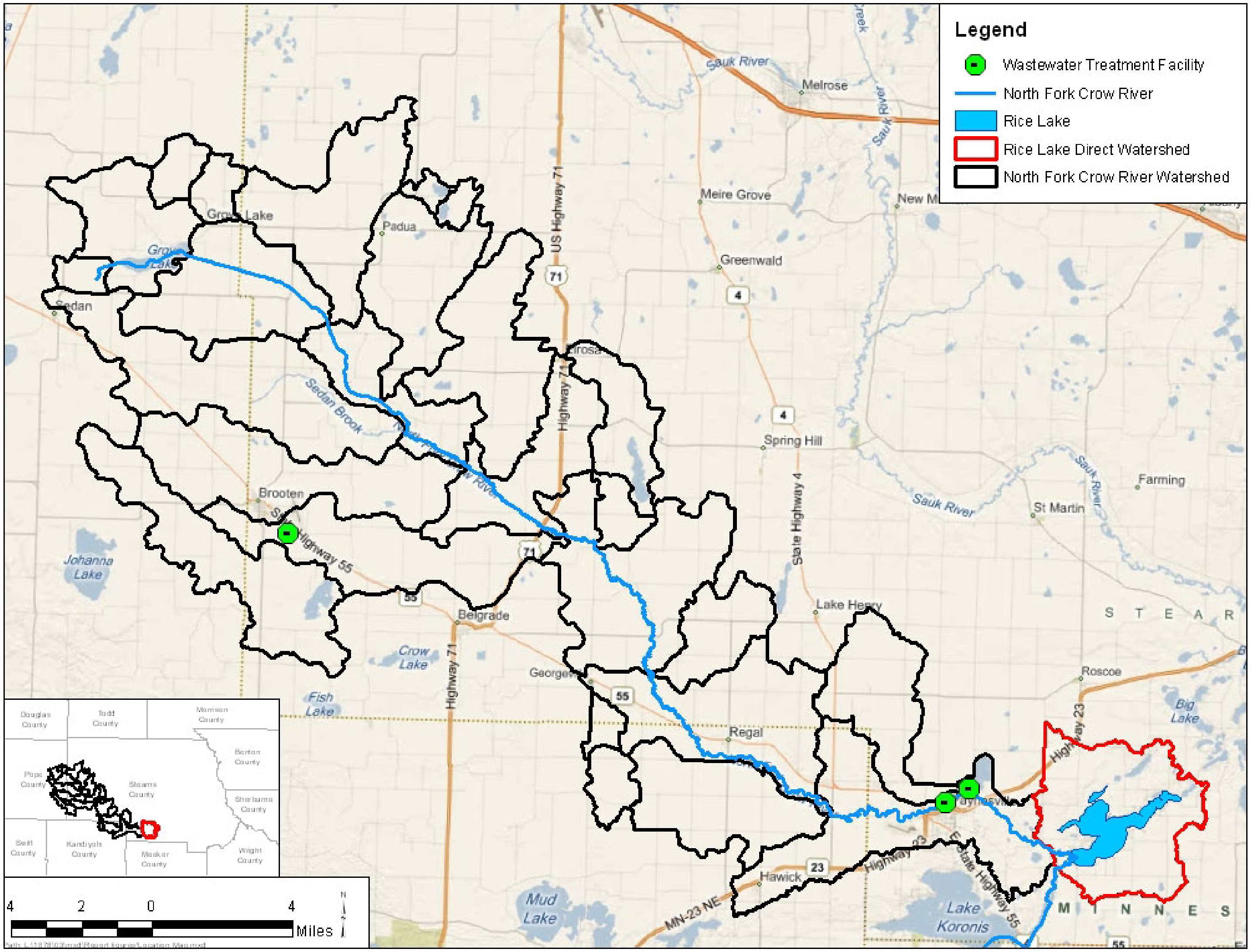


Figure 2-1. Rice Lake watershed location map.

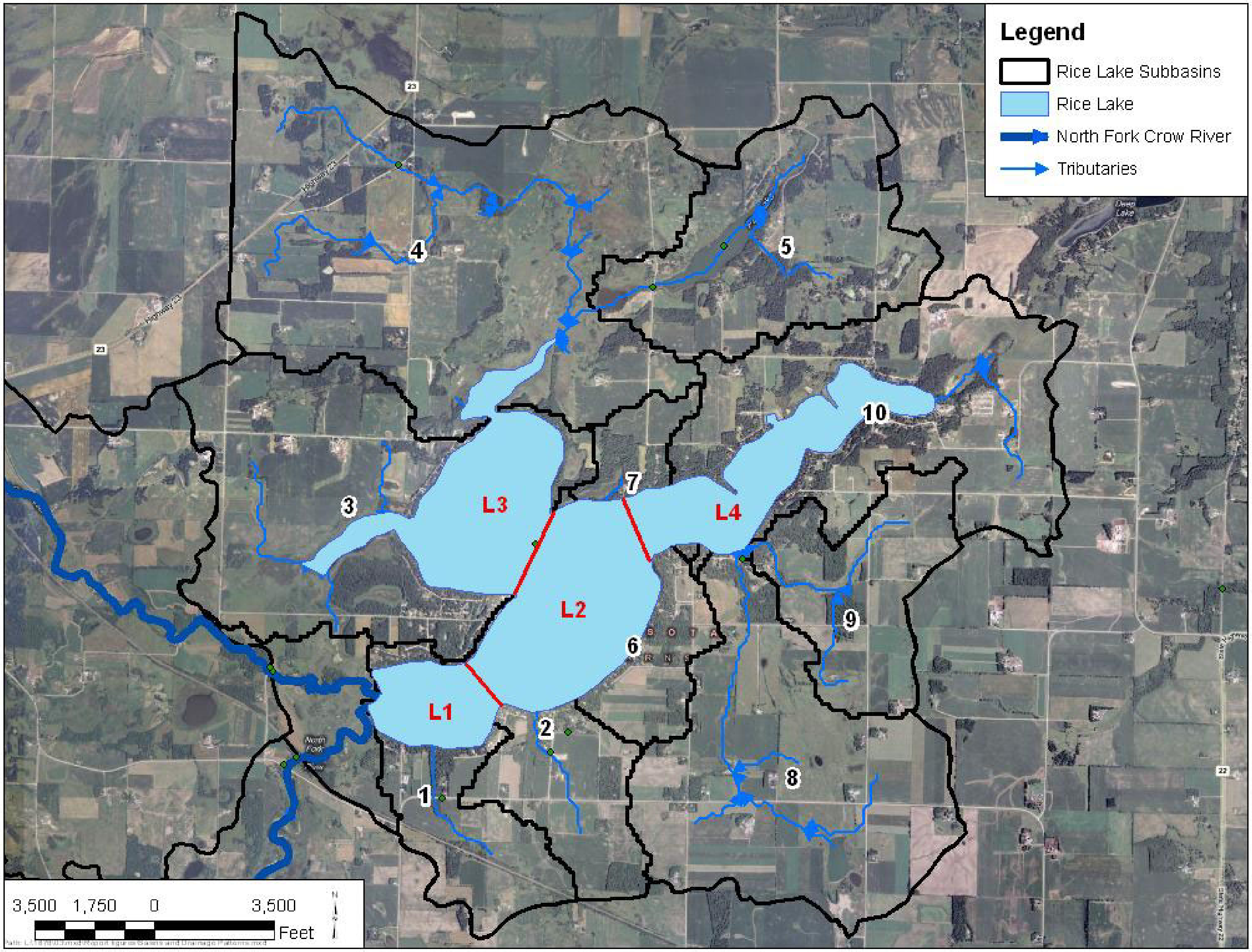


Figure 2-2. Rice Lake direct watershed drainage patterns.

2.2 DRAINAGE PATTERNS

Rice Lake has a large drainage area, most of which includes the North Fork Crow River watershed. The lake's watershed-to-lake area ratio is 107:1, which indicates that the lake will be extremely sensitive to watershed nutrient inputs. The North Fork Crow River watershed above Rice Lake is approximately 162,000 acres and accounts for a majority (94%) of the lake's total watershed. The river enters the lake in the northwest portion of Basin L1 and discharges in the southwest portion of the same basin (Figure 2-3). The unique inflow/outflow characteristics of the river to Rice Lake play an important role in the hydrology and water quality of Rice Lake.

The Rice Lake direct watershed is approximately 10,730 acres in size and was subdivided into 10 subwatersheds (Figure 2-2). Each subwatershed represents a major tributary or lake watershed that flows directly to one of the four lake basins.

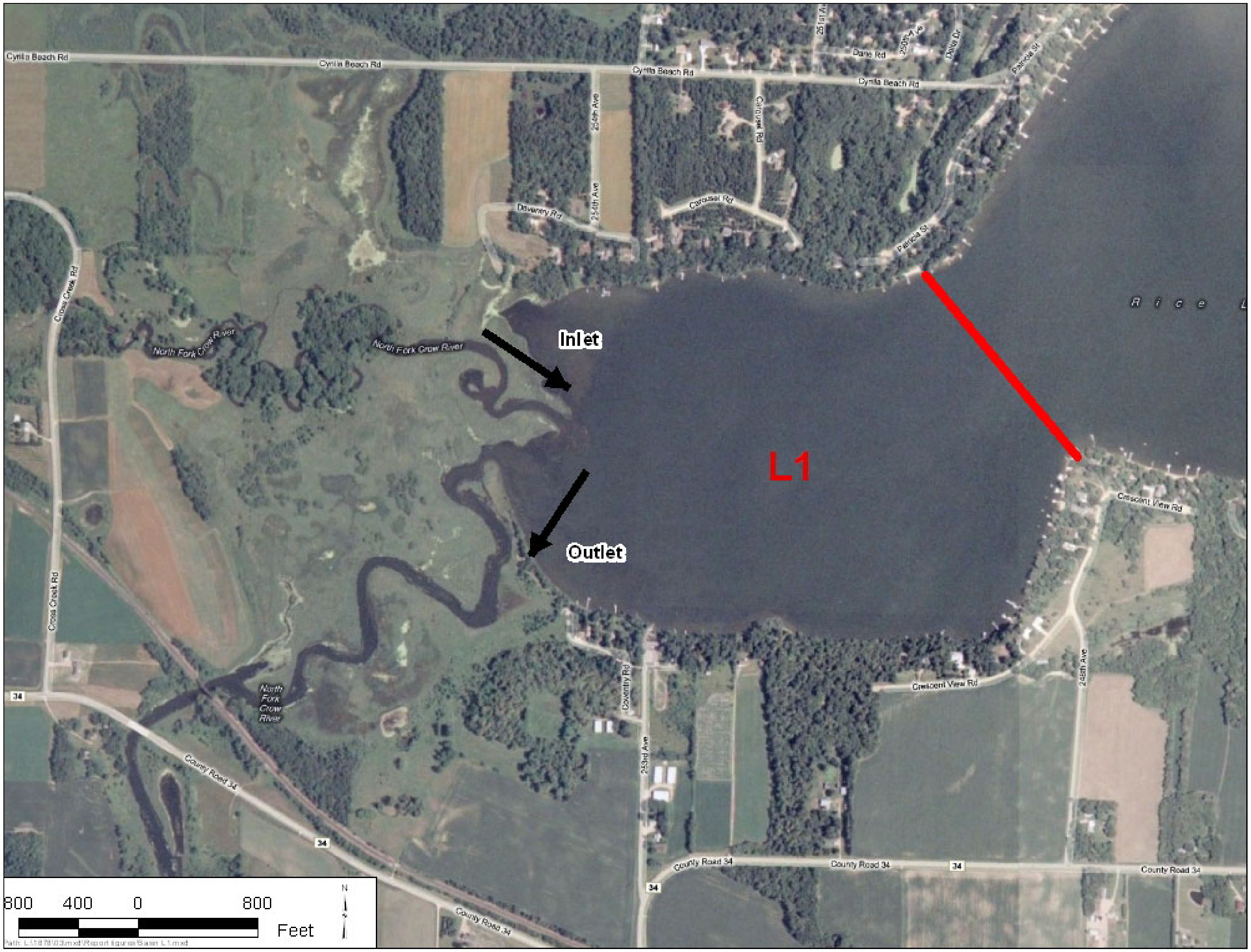


Figure 2-3. North Fork Crow River inlet/outlet.

2.3 LAND USE

Land use data for Rice Lake's direct watershed and the North Fork Crow River watershed above Rice Lake are presented in Tables 2-2 and 2-3, respectively. Figure 2-4 shows land use for both the direct and North Fork Crow River watershed. Land use in both watersheds is dominated by row crops and pasture.

Table 2-2. Land use in the Rice Lake direct watershed.

Land Use*	Acres	Percent
Pasture/Hay	3,304	31%
Corn/Soybean	2,697	25%
Open Water	1,673	16%
Forest	1,577	14%
Roads/Transportation	692	6%
Wetland	529	5%
Alfalfa	206	2%
Other Agriculture	40	<1%
Low Intensity Development	11	<1%
Medium Intensity Development	1	<1%
TOTAL	10,730	100%

*Source: 2009 National Agricultural Statistics Services (NASS) Land Cover.

Table 2-3. Land use in the North Fork Crow River watershed above Rice Lake.

Land Use*	Acres	Percent
Corn/Soybean	62,447	39%
Pasture/Hay	61,701	38%
Roads/Transportation	9,333	6%
Forest	8,984	6%
Other Agriculture	7,206	4%
Wetland	6,385	4%
Alfalfa	2,981	2%
Open Water	2,010	1%
Low Intensity Development	857	<1%
Medium Intensity Development	150	<1%
High Intensity Development	68	<1%
TOTAL	162,122	100%

*Source: 2009 National Agricultural Statistics Services (NASS) Land Cover

2.4 LAKE RECREATIONAL USES

Rice Lake supports a variety of recreational uses, including open water and ice fishing, swimming, and boating. The lake is highly developed with approximately 288 homes and cabins. There is one small resort (located at the East end of Rice Lake) and a large RV campground (northeast end). A Girl Scout camp is located along the southeast shore.

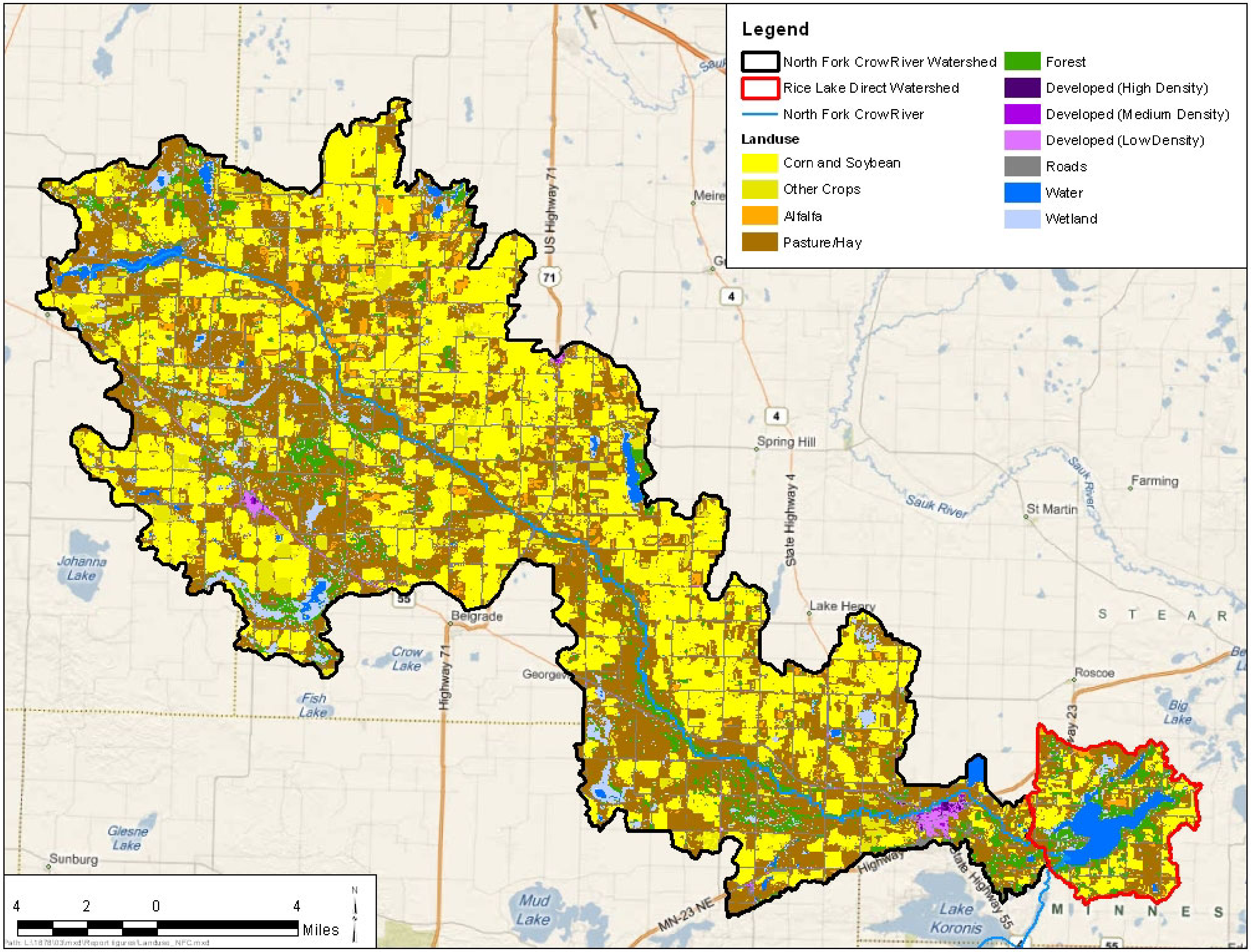


Figure 2-4. North Fork Crow River inlet/outlet. Rice Lake watershed 2009 National Agricultural Statistics Services land cover.

2.5 LAKE WATER QUALITY

Water quality in Minnesota lakes is often evaluated using three associated parameters: total phosphorus, chlorophyll-a, and Secchi depth. Total phosphorus is typically the limiting nutrient in Minnesota's lakes meaning that algal growth will increase with increases in phosphorus. However, there are cases where phosphorus is widely abundant and the lake becomes limited by nitrogen or light availability. Chlorophyll-a is the primary pigment in aquatic algae and has been shown to have a direct correlation with algal biomass. Since chlorophyll-a is a simple measurement, it is often used to evaluate algal abundance rather than expensive cell counts. Secchi depth is a physical measurement of water clarity made by lowering a black and white disk until it can no longer be seen from the surface. Higher Secchi depths indicate less light refracting particulates in the water column and better water quality. Conversely, high total phosphorus and chlorophyll-a concentrations point to poorer water quality and thus lower water clarity. Measurements of these three parameters are interrelated and can be combined into an index that describes water quality.

2.5.1 Rice Lake Monitoring Efforts

Water quality monitoring has been conducted at several locations on Rice Lake under a variety of efforts. The main sampling stations (L2 and L4) on Rice Lake are located near the deepest parts of basins L2 and L4 (see Figure 2-5). Samples have been taken periodically at these locations since the early 1980's; however, only data collected in the most recent 15 years are presented in this report (Appendix B). Basins L1 and L3 were sampled in 2009 and 2010, along with samples collected at L2 and L4, in order to compare water quality across all 4 basins for the purpose of this study. Sampling in 2009-2010 was conducted bi-weekly from April/May through October for the following lake water quality parameters: Secchi depth, total phosphorus (TP), chlorophyll-a, ortho-phosphorus, nitrate+nitrite, total Kjeldahl nitrogen (TKN), total suspended solids (TSS), volatile suspended solids (VSS), and temperature and dissolved oxygen measurements. Collection efforts were coordinated and carried out by the North Fork Crow River Watershed District (NFCRWD) and the MPCA.

NFCRWD and MPCA staff also collected TP, ortho-phosphorus, TSS and flow measurements from the North Fork Crow River inlet and outlet (S001-510 and S002-357, respectively) and one tributary to basin L4 (S002-734, referred to in this report as the Fishers Resort station in subwatershed 8) in 2009 and 2010. MPCA measured continuous flow at each of these stations and water quality grab samples were collected approximately once every two weeks. All stream and lake water quality sampling locations are shown in Figure 2-5.

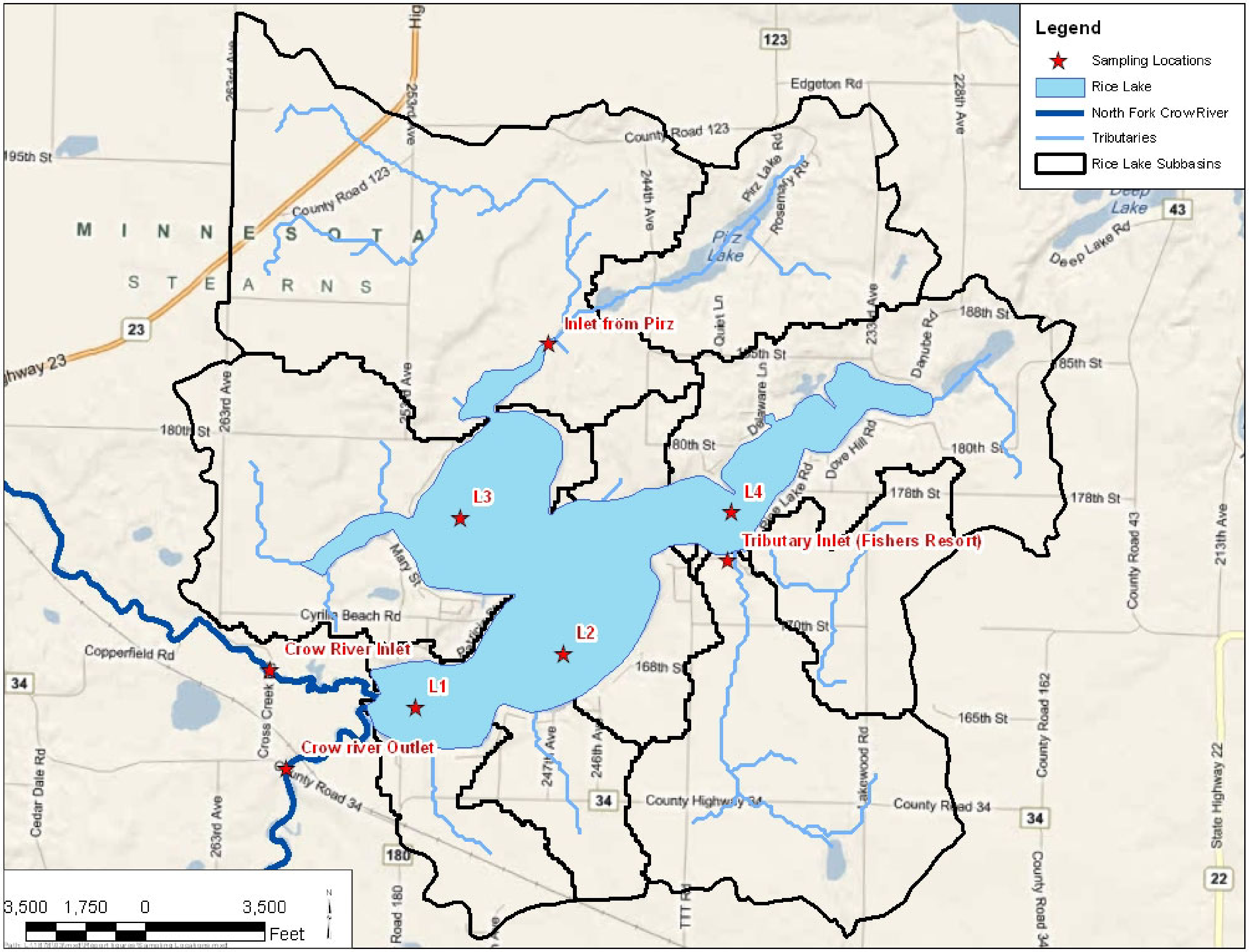


Figure 2-5. Rice Lake and North Fork Crow River 2009-2010 sampling locations.

2.5.2 Temperature and Dissolved Oxygen

Temperature and dissolved oxygen measurements from all four lake monitoring locations were collected bi-weekly in each basin in 2009 and 2010 (see Appendix A). Temperature profiles suggest reasonably stable stratification during the summer in basins L1, L2 and L4 where maximum depth is greater than 5 meters (16.4 ft.) (Appendix A). Basin L3, with a maximum depth of approximately 2 meters (6.6 ft.), did not display stable stratification during the summer months. Dissolved oxygen (DO) concentrations in basins L1, L2 and L4 also demonstrate stratification with hypoxia (DO less than 2 mg/L) measured as shallow as 3 meters (9.8 ft). DO concentrations in basin L3 did not demonstrate hypoxia during the growing season. Temperature and dissolved oxygen conditions in Rice Lake demonstrate the potential for internal loading of phosphorus.

2.5.3 Total Phosphorus

Summer average total phosphorus concentrations in Rice Lake consistently exceeded the state water quality standard of 40 µg/L for TP at all monitoring stations (Figures 2-6 and Appendix B). The highest summer average concentration for TP was 78 µg/L in basin L4 in 2002. Based on water quality information collected in 2009 and 2010, data collected in each lake basin suggests minimal spatial variability in average annual total phosphorus between the 4 basins in any one year and no consistent pattern from year to year.

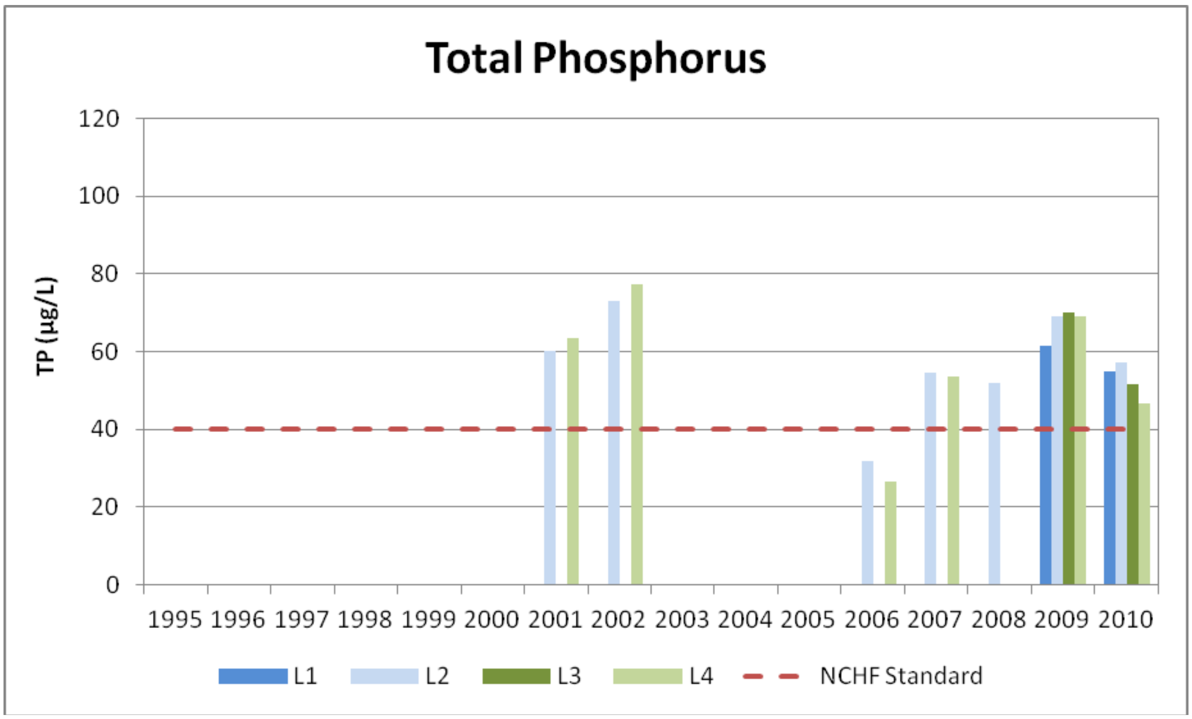


Figure 2-6. Summer (June 1 –September 30) mean total phosphorus concentrations for all four Rice Lake basins. The dotted red line indicates the current State standard for the Northern Central Hardwood Forest ecoregion. Only sampling seasons with four or more measurements are displayed.

2.5.4 Chlorophyll-a

From 1995 to 2010, chlorophyll-a concentrations in Rice Lake basins L2 and L4 ranged from 9 µg/L to as high as 65 µg/L in years with four samples or more during the summer season. Chlorophyll-a concentrations over 14 µg/L are in violation of the state water quality standards and indicate a high incidence of nuisance algae blooms. Based on water quality information collected in 2009 and 2010, chlorophyll-a concentrations demonstrated little variation between the four basins in 2009 and 2010 (Figure 2-7).

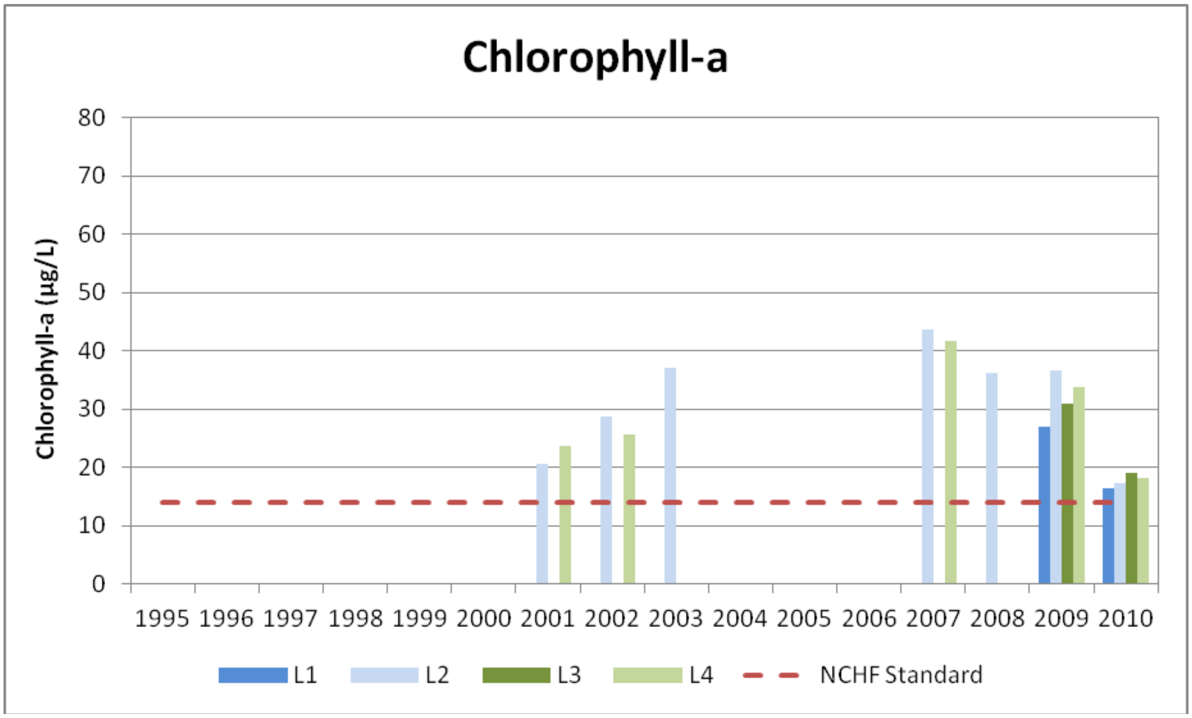


Figure 2-7. Summer (June 1 –September 30) mean chlorophyll-a concentrations for all four Rice Lake basins. The dotted red line indicates the current State standard for the Northern Central Hardwood Forest ecoregion. Only sampling seasons with four or more measurements are displayed.

2.5.5 Secchi Depth

Water clarity (Secchi depth) in general follows the same trend as TP and chlorophyll-a. Mean summer Secchi depths have been below the state standard of 1.4 meters (4.6 ft.) in multiple years for basins L1, L2 and L4 (Figure 2-8). Data for 2009, 2010 and long-term suggest basins L1-L3 have similar water clarity while L4 exhibits slightly higher clarity during certain years. There are no apparent temporal trends in the Secchi depth data suggesting that the lake has demonstrated similar water quality over the past 15 years.

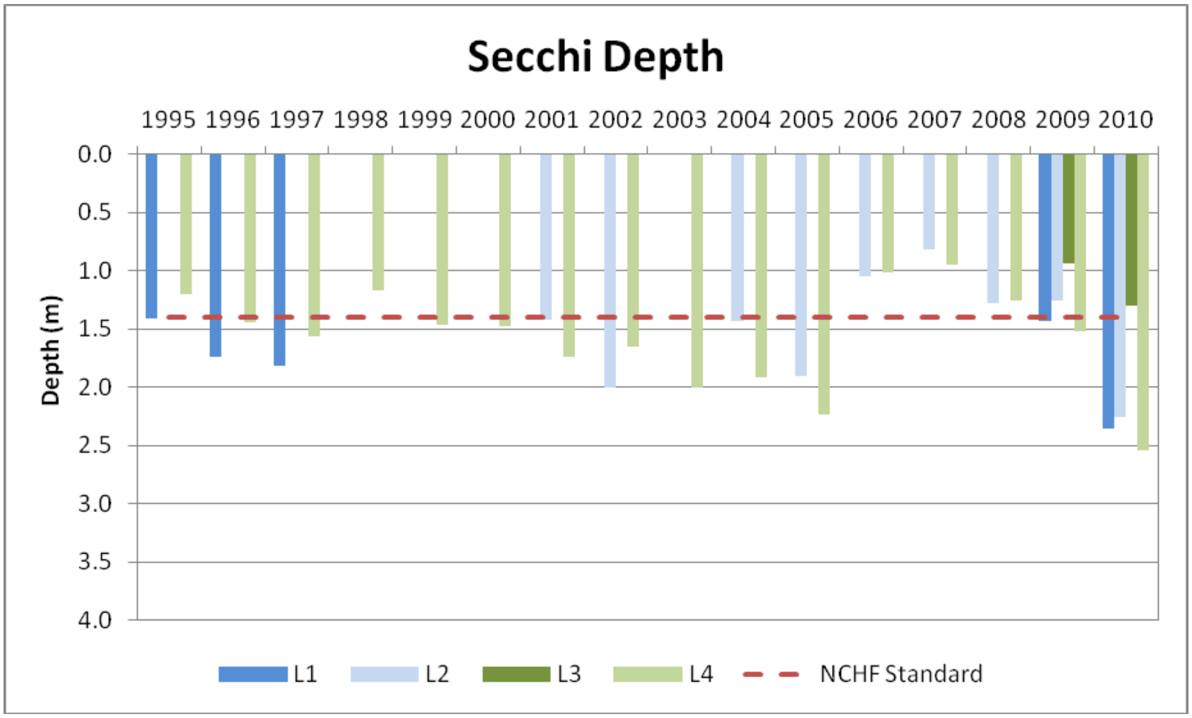


Figure 2-8. Summer (June 1 –September 30) mean Secchi depth for all four Rice Lake basins. The dotted red line indicates the current State standard for the Northern Central Hardwood Forest ecoregion. Only sampling seasons with four or more measurements are displayed.

2.5.6 Conclusions

Overall, Rice Lake has not met current Minnesota lake water quality standards for deep lakes in the NCHF ecoregion since consistent data collection began. While there is some variability in the monitoring data from year to year, trends over that time show that the water quality is relatively stable in its current state. There has not been a significant decline or improvement in the water quality of Rice Lake over this time period. However, it is important to note that a rigorous trend analysis has not been conducted on the data set.

2.6 FISH POPULATIONS AND FISH HEALTH

2.6.1 Fish Populations

The fisheries lake management plan and fish survey reports for Rice Lake were provided by the DNR Area Fisheries Office in Spicer, MN. The first DNR fish survey for Rice Lake was conducted in 1958. There have been eleven additional surveys since that time, with a survey being conducted on average once every three years since 1977. Standard survey methods used by the DNR include gill net and trap nets. These sampling methods do have some sampling bias, including focusing on game management species (i.e., northern pike and walleye), under representing small minnow and darter species presence/abundance, and under representing certain management species such as largemouth bass. The current methods also likely under-represent carp populations in the lakes. However, in our experience, when carp are present in the lakes, the sampling methods do capture some of the population. So, although carp density is likely under-represented, the methods do provide a reasonable year to year comparison.

Rice Lake is managed primarily for walleye and black crappie with northern pike, bluegill, and yellow perch as secondary species. Commercial harvest of carp, black bullhead, bigmouth/smallmouth buffalo and white sucker has occurred in past years, but none since 2001 (9,150 pounds of carp, 40 pounds of bigmouth/smallmouth buffalo, and 860 pounds of white sucker). Current fish management activities on Rice Lake include protecting important aquatic vegetation through the permit process, participating in local watershed projects, stocking various species as needed, and stocking walleye fry or fingerlings as required or needed. There have been 23 species collected during DNR surveys:

- black bullhead
- black crappie
- bluegill
- bowfin
- brown bullhead
- common carp
- channel catfish
- common shiner
- green sunfish
- hybrid sunfish
- largemouth bass
- northern pike
- pumpkinseed
- rock bass
- smallmouth buffalo
- shorthead redhorse
- smallmouth bass
- tulibee cisco
- walleye
- white crappie
- white sucker
- yellow bullhead
- yellow perch

Fish community data was summarized by trophic groups (Figures 2-9 and 2-10). Species within a trophic group serve the same ecological process in the lake (i.e., panfish species feed on zooplankton and invertebrates; may serve as prey for predators). Analyzing all the species as a group is often a more accurate summary of the fish community then analyzing individual species trends. The following conclusions can be drawn from the fish data:

- The North Fork Crow River, a major river inflow to Rice Lake, undoubtedly has a big impact on the lake’s fish population. Certain species, such as smallmouth buffalo and shorthead redhorse are common river species that were captured and documented in numerous Rice Lake fish surveys. Other species, such as smallmouth bass, channel catfish, tulibee Cisco and white Suckers can live and survive in both lake and stream environments. The North Fork Crow River may also aid in the migration and movement of carp and other rough fish in and out of the system.
- Rough fish and forage species have been the most abundant species for a majority of the surveys since 1957. However, pan fish species, including black crappie and bluegill, were the most abundant group for 2 of the 3 most recent DNR surveys.
- The surveys show carp and other rough fish (primarily black bullhead) had the highest biomass per net in 6 of the 12 sampling years. It appears carp and rough fish biomass has shown a slight downward trend since 1994. It should be noted that common carp abundance may not be accurately assessed using DNR surveys. However, the current

methods allow reasonable year-to-year comparisons. A carp specific survey would ultimately assess the actual carp abundance in the lake.

- Top predators and forage species have comprised the largest percentage of the total biomass catch during the past two DNR surveys, with walleye, northern pike, shorthead redhorse and white sucker all well represented. However, their abundance is relatively low suggesting a few large individuals. The low abundance may not be able to adequately control the panfish population.
- The large panfish population in recent years may be able to produce significant grazing pressure on the zooplankton community in the lake. However, since there is no long-term zooplankton record for Rice Lake, it is difficult to determine the impact this trend has had on the current zooplankton community.

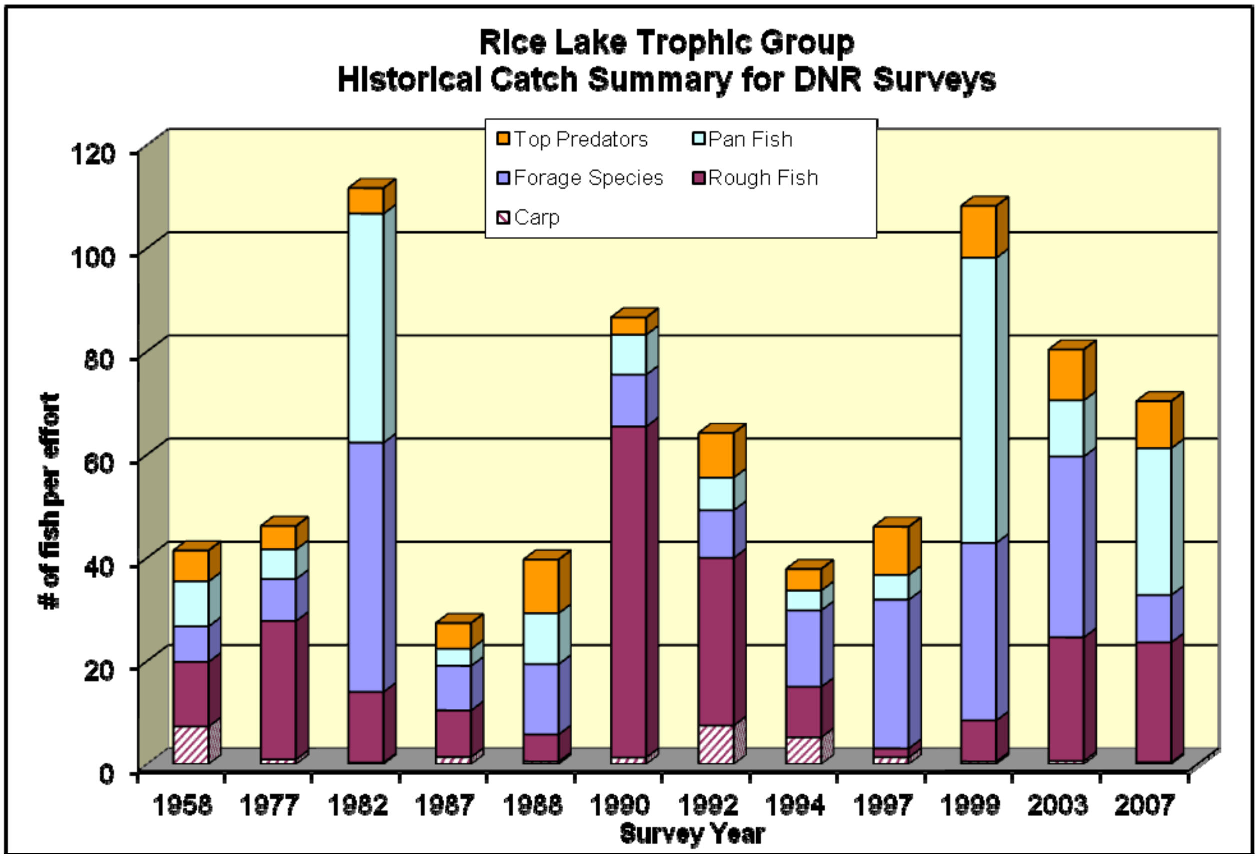


Figure 2-9. Historical fish survey results for trophic group abundance in Rice Lake.

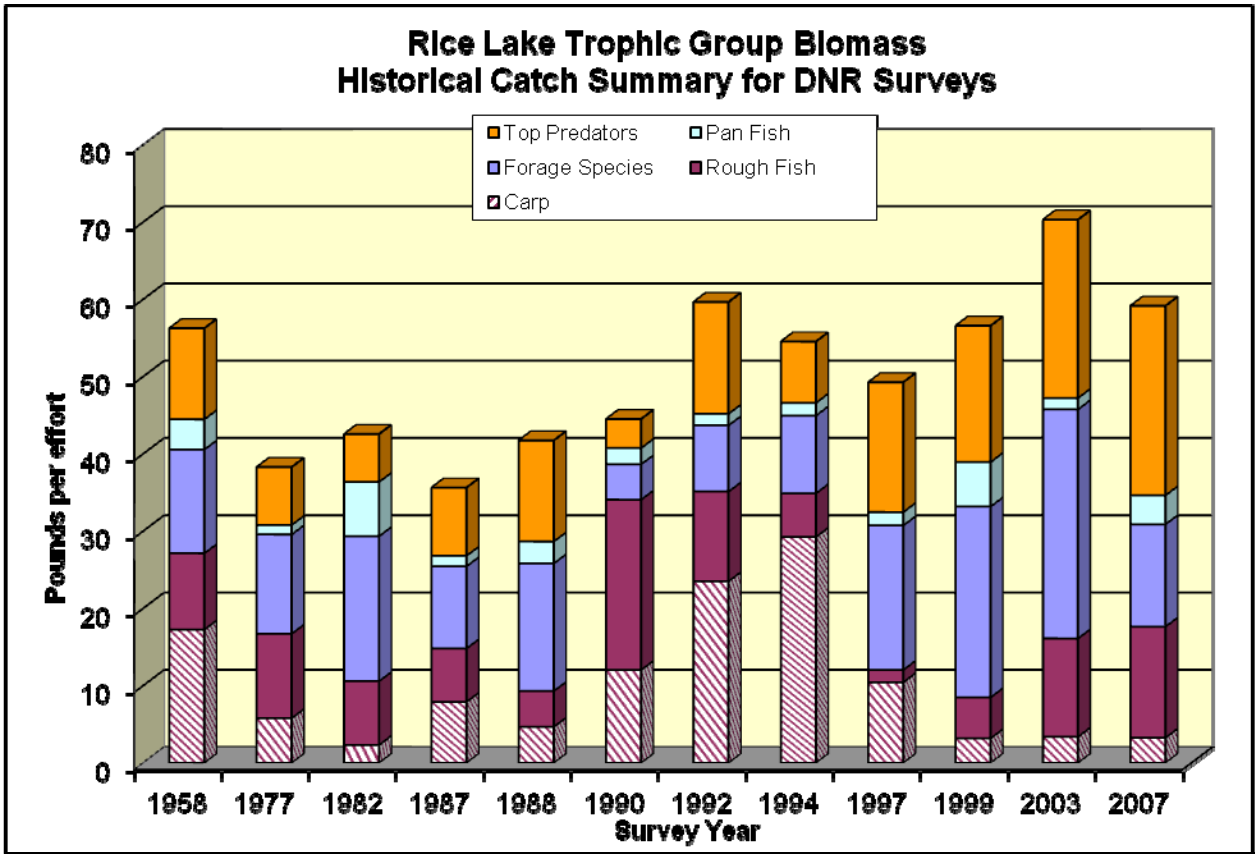


Figure 2-10. Historical fish survey results for trophic group biomass in Rice Lake.

2.6.2 Carp

Common carp have both direct and indirect effects on aquatic environments. Carp uproot aquatic macrophytes during feeding and spawning and re-suspend bottom sediments and nutrients. These activities can lead to increased nutrients in the water column ultimately resulting in increased nuisance algal blooms. Surveys suggest carp and other rough fish are present in Rice Lake, but their exact size and composition is currently unclear. Standard DNR methods are not particularly effective at capturing carp. However, when carp populations are quite large, the DNR methods often do catch some. At least some common carp have been captured in seven out of the eight DNR surveys conducted since the 1950s. Further analysis may be needed to better characterize the carp population in Rice Lake. However, based on year to year comparisons from DNR surveys, current carp populations appear to be relatively small and likely are having little impact on lake water quality. Due to sampling bias in current DNR survey methods, only a targeted assessment of the carp density would verify this assumption.

2.7 PLANKTON SURVEYS

Phytoplankton and zooplankton samples were collected in each basin in July, 2009. Sample results suggest Cyanophyta were the dominate phytoplankton community in each basin during this particular summer sampling event (Table 2-4). Cyanophyta, also referred to as Cyanobacteria or blue-green algae, are commonly found in nutrient enriched eutrophic and hypereutrophic lakes. They are often associated with nuisance algal blooms as their buoyancy allows them to float near the surface, limiting light penetration. Cyanobacteria are typically not eaten by other aquatic organisms and are not an important part of lake food chains. Many species of cyanobacteria produce toxins that, when consumed in large quantities, can affect the liver and nervous systems of humans and other animals.

Table 2-4. Phytoplankton sampling results for each Rice Lake basin. Results are presented in percent total biomass of each phytoplankton division.

Division	L1	L2	L3	L4	Lake Average
Bacillariophyta	0.0%	10.4%	26.6%	0.0%	9.2%
Chlorophyta	0.0%	1.4%	1.4%	0.0%	0.7%
Chrysophyta	0.0%	0.3%	0.7%	0.0%	0.3%
Cryptophyta	0.0%	4.8%	11.5%	0.0%	4.1%
Cyanophyta	100.0%	83.2%	59.7%	100.0%	85.7%
Pyrrhophyta	0.0%	0.0%	0.2%	0.0%	0.0%

Zooplankton are key components in lake food webs and overall ecology. Certain zooplankton, especially large Cladocerans, play a special role in controlling water clarity in shallow lakes. Cladocerans are filter feeders that have the capacity to filter significant amounts of algae and improve water clarity. All four Rice Lake basins displayed a large and healthy Cladocera population in terms of both numbers and biomass during the July 2009 sampling event (Tables 2-5 and 2-6) Basin L3 showed a higher population of smaller zooplankton species (small Cladocera and Copepods) most likely due to the basin's small size, shallow depth and high turbidity. However, all three basins displayed a relatively good balance of Copepods, and large and small Cladocera.

Table 2-5. Zooplankton population estimates for each basin summarized by division.

Division	Measurement	L1	L2	L3	L4	Lake Ave
Large Cladocera	Count (#/L)	10.6	13.6	4.4	9.8	9.6
	% total	34%	32%	10%	31%	26%
Small Cladocera	Count (#/L)	0.2	2.0	2.7	0.2	1.3
	% total	1%	5%	6%	1%	3%
Copepods	Count (#/L)	20.6	26.5	37.1	21.4	26.4
	% total	66%	63%	84%	68%	71%
Total	Count (#/L)	31.4	42.2	44.2	31.4	37.3

Table 2-6. Zooplankton biomass for each basin summarized by division.

Division	Measurement	L1	L2	L3	L4	Lake Ave
Large Cladocera	Biomass (µg/L)	113.3	146.9	77.8	179.6	129.4
	% total	59%	55%	48%	67%	58%
Small Cladocera	Biomass (µg/L)	0.4	8.9	8.3	0.3	4.5
	% total	0%	3%	5%	0%	2%
Copepods	Biomass (µg/L)	77.5	109.9	77.4	88.4	88.3
	% total	41%	41%	47%	33%	40%
Total	Biomass (µg/L)	191.2	265.7	163.5	268.3	222.2

2.8 AQUATIC PLANTS

2.8.1 Introduction

Aquatic plants are beneficial to lake ecosystems, providing spawning and cover for fish, habitat for macroinvertebrates, refuge for prey, and stabilization of sediments. However, in high abundance and density they limit recreation activities, such as boating and swimming, and may reduce aesthetic value. Excess nutrients in lakes can lead to non-native, invasive aquatic plants taking over a lake. Some exotics can lead to special problems in lakes. For example, under the right conditions, Eurasian watermilfoil can reduce plant biodiversity in a lake because it grows in great densities and out-competes all the other plants. Ultimately, this can lead to a shift in the fish community because these high densities favor panfish over larger game fish. Species such as curly-leaf pondweed can cause very specific problems by changing the dynamics of internal phosphorus loading. All in all, there is a delicate balance within the aquatic plant community in any lake ecosystem.

2.8.2 Aquatic Plants in Rice Lake

Plant surveys have been conducted by the DNR on Rice Lake dating back to 1947. Rice Lake possesses a moderately diverse aquatic plant community with 28 different species observed across the various surveys, with a mix of emergent, floating leaf and submerged plant species. There were 13 different submerged and floating leaf species observed during the recent aquatic plant survey in 2007 (Figure 2-11). There was a relatively high abundance of native submergent vegetation species such as water celery, sago pondweed, clasping-leaf pondweed, flat-stem pondweed and coontail. There was also less desirable aquatic vegetation species present in high occurrence and abundance including curly-leaf pondweed, muskgrass and water moss. Curly-leaf pondweed was first noted in the lake during a 1987 survey by DNR. Rice Lake is not on the Minnesota Department of Natural Resources Designated Infested Waters list for Eurasian water milfoil or the other nuisance species included in this list.

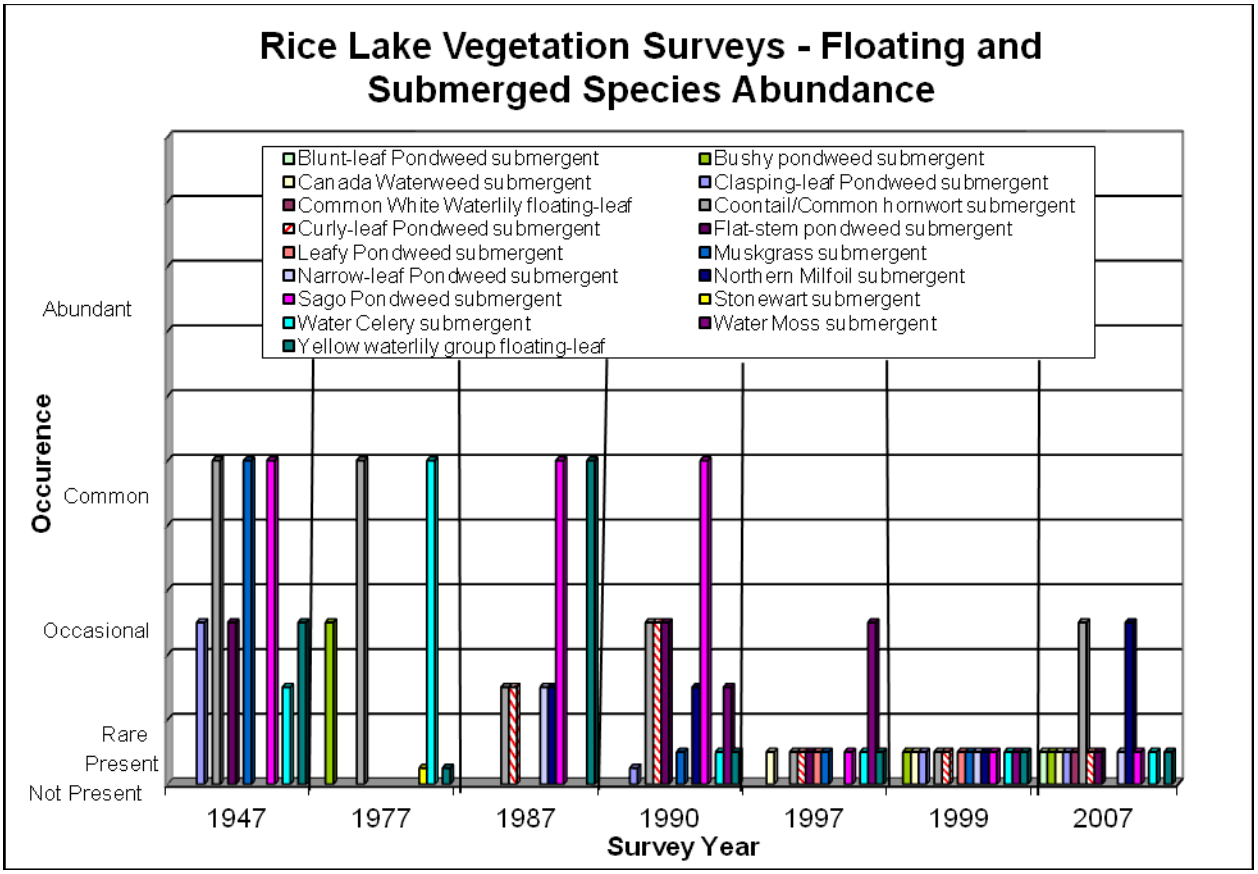


Figure 2-11. Historical vegetation survey data for Rice Lake.

2.8.3 Curly-leaf Pondweed

Curly-leaf pondweed is an invasive plant that, like Eurasian watermilfoil, can easily take over a lake's aquatic macrophyte community. Curly-leaf pondweed presents a unique problem in that it is believed to significantly affect the in-lake availability of phosphorus, contributing to eutrophication problems. Curly-leaf pondweed begins growing in late-fall, continues growing under the ice, and dies back relatively early in summer, releasing nutrients into the water column as it decomposes, possibly contributing to algal blooms. Curly-leaf pondweed can also out-compete more desirable native plant species.

Curly-leaf pondweed was first observed during a 1987 DNR survey and was found to be common in the lake during that time even though the survey was conducted in August, well after the typical seasonal peak in biomass for the plant had passed. Recent surveys (1997, 1999 and 2007) indicate curly-leaf pondweed is still present in the lake. However, it should be pointed out all these surveys were performed in July. More early-season surveys should be conducted to target curly-leaf pondweed abundance and determine its potential for nutrient release.

2.9 SHORELINE HABITAT AND CONDITIONS

The shoreline areas are defined as the areas adjacent to the lake's edge, with hydrophytic vegetation and water up to 1.5 feet deep or a water table within 1.5 feet from the surface. Natural shorelines provide water quality treatment, wildlife habitat, and increased biodiversity of plants and aquatic organisms. Natural shoreline areas also provide important habitat to fisheries including spawning areas and refugia as well as aesthetic values. In addition to the ecological benefits, natural shorelines can stabilize sediments, and protect lake edges from wave-induced erosion. Natural shoreland exists around Rice Lake; however, no quantitative data have been collected to date. Much of the shoreline area has been impacted by development and agricultural practices. Naturalization of the shorelines could have a positive effect on Rice Lake and water quality.

2.10 RIVER AND STREAM MONITORING

In 2009 and 2010, NFCRWD and MPCA staff collected total phosphorus , ortho-phosphorus, total suspended solids and flow data from the North Fork Crow River inlet and outlet (S001-510 and S002-357, respectively) and one tributary to basin L4 (S002-734, referred to in this report as the Fishers Resort station in subwatershed 8). Flow was measured continuously at each station from June to December in 2009 and from March to November in 2010. Water quality grab samples were collected approximately once every two weeks from March through October in 2009 and 2010.

Water quality results show the Fishers Resort station TP concentrations were consistently high and often higher than main-stem North Fork Crow concentrations (Figure 2-12). Fishers Resort TSS concentrations were also significantly higher than the North Fork Crow inlet and outlet, especially during runoff events (Figure 2-13). However, Fishers Resort pollutant loading to Rice Lake is considerably less than the North Fork Crow River since this tributary's flow contribution is significantly less. Pollutant loads to Rice Lake are estimated in the source assessment section (3.3) of this report while the affect and response these loads have on Rice Lake water quality will be discussed in the lake response modeling section.

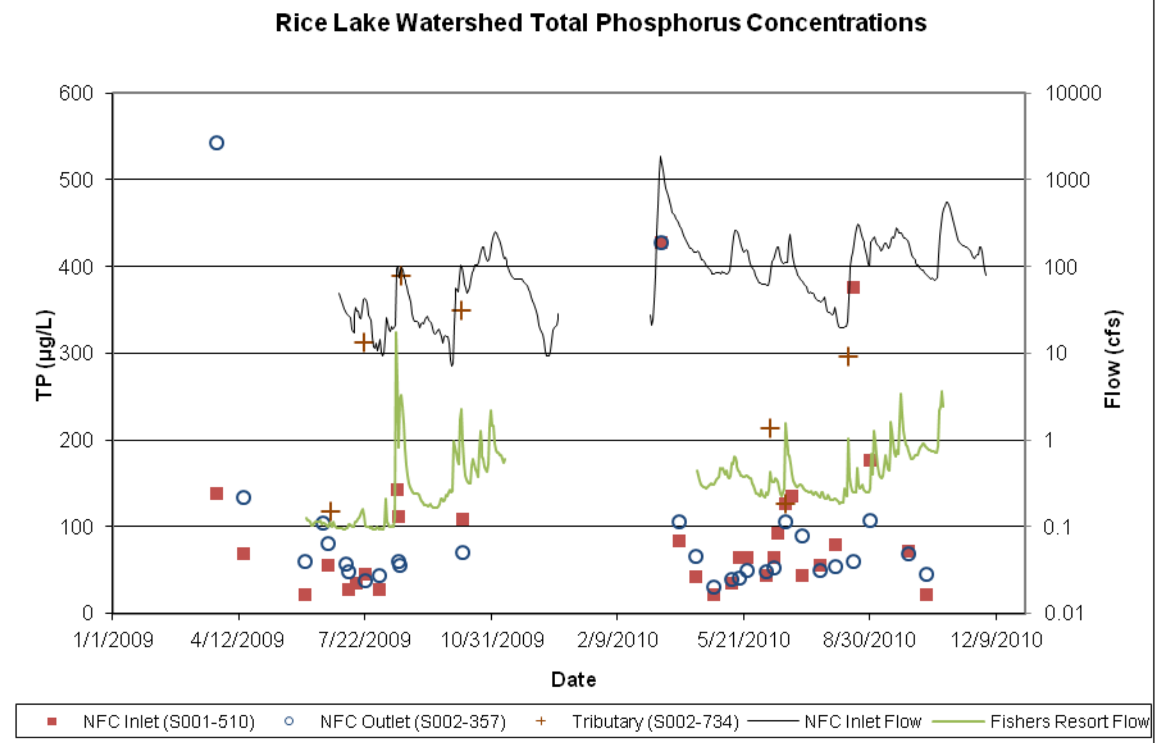


Figure 2-12. 2009 and 2010 flow and total phosphorus concentrations and continuous flow for the Fishers Resort monitoring station and the North Fork Crow inlet and outlet to/from Rice Lake.

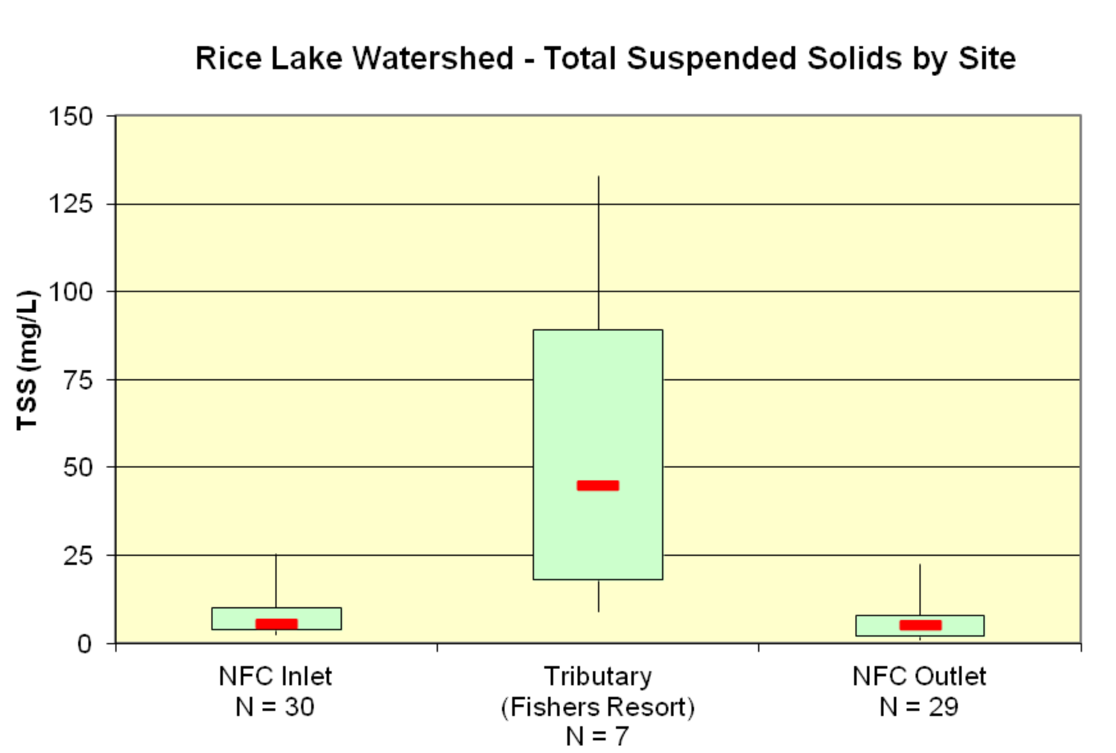


Figure 2-13. 2009 and 2010 watershed monitoring TSS concentration by site.

3.0 Nutrient Sources and Lake Response

3.1 INTRODUCTION TO NUTRIENT SOURCES

Phosphorus may enter lakes from the atmosphere, watershed and chemical processes within the lake itself. The following is a brief description of the major sources of phosphorus to surface water and how they are typically transported to lakes and other freshwater systems.

Atmospheric deposition: Phosphorus may be added via particulate deposition. Particles from the atmosphere may fall onto surface waters throughout the watershed. Phosphorus is often bound to these particles which may add to the phosphorus inputs to surface water environments.

Forest Sources (watershed): Phosphorus may be added to surface waters via runoff from forested areas within the watershed. Runoff from forested areas may include debris from decomposing vegetation and organic soil particles.

Wetland Sources (watershed): Phosphorus may be added to surface waters by stormwater flows through wetland areas in the Rice Lake watershed. Storm events may mobilize phosphorus through the transport of suspended solids and other organic debris.

Agricultural Sources (watershed): Phosphorus may be added via surface runoff from upland areas which are being used for Conservation Reserve Program (CRP) lands, grasslands, cropland and land used for growing hay. Phosphorus on these lands may originate naturally in the soils and/or plant material or may have been added from wildlife and livestock grazing or manure spreading. It is important to point out that phosphorus delivery and incorporation into surface waters is more rapid and efficient in agricultural land that has a significant amount of drain tile.

Livestock Sources (watershed): Animal feeding operations which fall beneath the animal threshold limits to be given an NPDES permit, may transport phosphorus to surface waters during storm events (via stormwater runoff). Animal feeding operations may transport phosphorus laden materials from feeding, holding and manure storage areas to surface waters.

Inadequate Subsurface Sewage Treatment Systems (SSTS) (watershed): Phosphorus may be added to surface waters from failing septic systems. Age, construction and use of SSTS can vary throughout a watershed and influence the nutrient contribution from these systems. It is likely that those systems that are sited along the lake shore or near streams/rivers are more likely to contribute nutrients than those systems sited further away from the lake or streams. Failing SSTS can discharge nutrients directly into surface waters by straight pipe connections (considered point sources) or by effluents leaching into groundwater or ponding at the surface where they can be washed into surface waters via stormwater runoff.

Urban/Residential Sources (watershed): Nutrients may be added via runoff from homes and urban areas near Rice Lake. Runoff from residential properties can include phosphorus derived from fertilizers, leaf and grass litter, pet wastes, and other sources of anthropogenic derived nutrients.

National Pollution Discharge Elimination Systems (NPDES) Facilities (watershed): NPDES facilities (typically wastewater treatment plants) are facilities that are permitted by the MPCA and EPA to discharge wastewater effluent to surface waters. Effluent from these facilities often contain phosphorus, however their permits require frequent monitoring of phosphorus concentrations and limit the total phosphorus load they are allowed to discharge.

Shoreline Erosion (in-lake): Phosphorus may be added to Rice Lake by erosional processes impacting lake shoreline areas. Phosphorus may be attached to eroded shoreline materials and may be mobilized through the transport of sediment and suspended solids.

Internal loading (in-lake): Internal loading includes the release of phosphorus from sediment, the release of phosphorus via physical disturbance from benthic fish (rough fish, ex. carp), the release of phosphorus from wind mixing the water column, and the release of phosphorus from decaying plant material. Phosphorus may build up in the bottom waters of the lake and then resuspended or mixed into the water column during strong winds or when the thermocline decreases and the lake water mixes.

3.2 MODELING APPROACH

Understanding each source of phosphorus to a lake is a key component in developing an excess nutrient TMDL for lakes. To that end, a phosphorus budget that sets forth the current phosphorus load contributions from each potential source was developed using the modeling and collected data described below. Additionally, lake response models can be developed to understand how different lake variables respond to changes in nutrient loads.

3.2.1 Direct Watershed Loading

To estimate direct watershed loading, a hydrologic budget was calculated and a Unit Area Load (UAL) model was developed for the Fishers Resort subwatershed (sub-basin #8 in Figure 2-2). The runoff for this subwatershed was calculated by multiplying annual water yields from the 2009-2010 continuous flow data, measured at the Fishers Resort flow gage (S002-734), by the flow weighted mean total phosphorus concentration for each sampling season.

A water budget for the Fishers Resort subwatershed was calculated using the Rational Method and calibrated to monitored monthly water yields. The Rational Method is commonly used to estimate discharge from small drainage areas and is calculated using the following equation (MPCA 2008):

$$Q = CIA$$

Where:
Q = peak runoff rate (in cfs)
C = runoff coefficient
I = rainfall (inches per hour)
A = area (acres)

Rainfall data was taken from a nearby National Weather Service weather station in New London, MN which was downloaded from the Minnesota Climatology Working Group website (http://climate.umn.edu). Watershed landuse was separated into categories using GIS and assigned typical runoff coefficients. It should be noted that this equation represents the *peak* runoff rate for each individual landuse in the subwatershed. Thus, runoff coefficients had to be lowered globally in order to estimate average runoff values and meet monitored water yields (Appendix E). Once runoff coefficients were adjusted, this equation was applied to the non-monitored subwatersheds to estimate annual water yields for the entire Rice Lake direct watershed.

The Hydrologic Response Unit (HRU) approach was used to develop a robust Unit Area Load Model for each subwatershed in Rice Lake's direct watershed. HRUs were developed in GIS by overlaying the watershed's soil types (from the Soil Survey Geographic (SSURGO) Database), slope and land use. HRUs helped define the landscape and phosphorus loading potential in the direct watershed which allowed for more reliable UAL model predictions/calibrations.

Land use information, which was utilized in setting the HRUs for the Rice Lake watershed, was defined in GIS using the 2008 National Agricultural Statistics Service Land Cover (NASS) file. Before incorporation in to the model, the US Fish and Wildlife Service National Wetland Inventory shapefile was burned in to the 2008 NASS shapefile to more accurately define all wetland boundaries. Any 2008 NASS wetland land-cover not delineated in the USFWS NWI layer was assigned a different land-use classification based on the 2007 NASS land cover file.

Soil erodibility and saturated infiltration were used to develop a soil delivery potential (Appendix F) which was another variable incorporated into the development of the HRU approach. Land slope was calculated from 30 meter resolution Digital Elevation Models (DEM; Appendix G). A range of loading rates was selected to represent loading from each of the HRUs (Appendix H). Data were selected based on literature review for land uses in Minnesota (Reckhow et al. 1980).

The UAL model was run for the Fishers Resort subwatershed using the aforementioned literature value loading rates. The rates were then adjusted globally to match Fishers Resort average observed total phosphorus loading in 2009-2010. Below average snowfall combined with extremely dry and below average rainfall from 2006 through 2008 likely contributed to the low water yields observed in 2009-2010 (runoff was approximately 6% of total precipitation). As a result, loading rates had to be lowered approximately 80% from their original values to match observed estimates (Appendix I). The loading rates were subsequently applied to HRUs in the remaining, unmonitored subwatersheds to calculate total phosphorus loading for Rice Lake's direct watershed.

3.2.2 North Fork Crow River Loading

Main-stem North Fork Crow River inflow and phosphorus loads to basin L1 were calculated using the continuous average daily flows from the North Fork Crow River inlet station (S001-510). Data gaps were filled using a regression equation with an upstream flow monitoring station (S002-027) near Georgeville, MN (Appendix J). Winter flow was estimated based on late fall/early spring data and typical winter measurements at the Georgeville station. In analyzing the average daily flow and phosphorus concentration data together, it was evident phosphorus concentrations were heavily influenced by flow condition. Thus, the flow and phosphorus data were separated into two categories: low-flow conditions (<100 cfs) and high-flow conditions (>100 cfs). Annual flow-weighted mean phosphorus concentrations (total and ortho-P) were then calculated for each flow category (Table 3-1). Phosphorus loads to basin L1 were calculated by multiplying the total annual flow in each category by the appropriate flow-weighted mean phosphorus concentration.

Table 3-1. Flow weighted mean phosphorus concentrations used to estimate North Fork Crow River phosphorus loads to Rice Lake.

Year	Total Phosphorus (µg/L)		Ortho-Phosphorus (µg/L)	
	<100 cfs	>100 cfs	<100 cfs	>100 cfs
2009	70	134	33	33
2010	39	255	20	191

3.2.3 Internal Loading

The next step in developing an understanding of nutrient loading to Rice Lake is to estimate internal nutrient loads. Internal phosphorus loading from lake sediments has been demonstrated to be an important aspect of the phosphorus budgets of lakes. However, measuring or estimating internal loads can be difficult, especially in shallow lakes that may mix many times throughout the year.

To estimate internal loading, an anoxic factor (Nürnberg 2004), which estimates the period where anoxic conditions exist over the sediments, is estimated from the dissolved oxygen profile data. The anoxic factor is expressed in days but is normalized over the area of the lake. The anoxic factor is then used along with a sediment release rate to estimate the total phosphorus load from the sediments. Phosphorus release rates were estimated individually for basins L1-L4 by collecting sediment cores from each basin and incubating them in the lab under anoxic conditions (ACOE-ERD 2008; Appendix K).

3.2.4 Atmospheric Load

The atmospheric load refers to the load applied directly to the surface of the lake through atmospheric deposition. Atmospheric inputs of phosphorus from wet and dry deposition are estimated using rates set forth in the MPCA report "Detailed Assessment of Phosphorus Sources to Minnesota Watersheds" (Barr Engineering, 2004), and are based on annual precipitation. The values used for dry (< 25 inches), average, and wet precipitation years (>38 inches) for atmospheric deposition are 24.9, 26.8, and 29.0 kg/km^2-year, respectively. These values are equivalent to 0.22, 0.24, and 0.26 pounds/acre-year for dry, average, and wet years in English units, respectively.

3.2.5 BATHTUB Model (Lake Response)

Once the nutrient budget for a lake has been developed, the response of the lake to those nutrient loads must be established. The focus of the lake response modeling is on total phosphorus, chlorophyll-a and Secchi depth. For this TMDL, the BATHTUB model 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). BATHTUB 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 – September) mean surface water quality. BATHTUB's time-scales are appropriate because watershed P 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 P model that accounts for water and P inputs from tributaries, watershed runoff, the atmosphere, sources internal to the lake, and (if appropriate) groundwater; and outputs through the lake outlet, groundwater (if appropriate), water loss via evaporation, and P sedimentation and retention in the lake sediments. BATHTUB allows choice among several different mass-balance P models. For deep lakes in Minnesota, the option of the Canfield-Bachmann lake formulation has proven to be appropriate in most cases. For shallow Minnesota lakes, other options have often been more useful. BATHTUB's in-lake water quality predictions include two response variables, chlorophyll-a concentration and Secchi depth, in addition to total phosphorus concentration. Empirical relationships between in-lake total phosphorus, chlorophyll-a, and Secchi depth form the basis for predicting the two response variables. Among the key empirical model parameters is the ratio of the inverse of Secchi depth (the inverse being proportional to the light extinction coefficient) to the chlorophyll-a concentration. The ratio's default value in the model is 0.025 meters squared per milligram (m^2/mg); however, the experience of Minnesota Pollution Control Agency staff supports a lower value, as low as 0.015 m^2/mg, as typical of Minnesota lakes in general.

A BATHTUB lake response model was constructed using the nutrient budget developed according to the methods previously described in this section. Two years (2009 and 2010) were modeled to validate the assumptions of the model. Several models (subroutines) are available for use within the BATHTUB model. The selection of the subroutines is based on past experience in modeling lakes in Minnesota and is focused on subroutines that were developed based on data from natural lakes. The Canfield-Bachmann natural lake model was chosen for the phosphorus model. Longitudinal exchange between the four basins was calculated in BATHTUB using option 1 from the BATHTUB longitudinal dispersion model package. For more information on these model equations, see the BATHTUB model documentation (Walker 1999). Model coefficients are also available in the model for calibration or adjustment based on known cycling characteristics.

3.3 ESTIMATION OF SOURCE LOADS

3.3.1 Atmospheric Load

The atmospheric load (pounds/year) for Rice Lake was calculated by multiplying the lake area (acres) by the atmospheric deposition rate (pounds/acre-year). For example, in an average precipitation year the atmospheric load to Rice Lake would be 0.256 pounds/acre-year times the lake surface area (1,509 acres), which is 387 pounds/year. Rice Lake's direct watershed is small enough that it is unlikely that there are significant geographic differences in rainfall intensity and amounts across the watershed.

3.3.2 Direct Watershed Nutrient Loading

Table 3-2 summarizes the results of the Rice Lake direct watershed flows and UAL phosphorus models. Figure 3-1 shows estimated phosphorus loading hotspots for the Rice Lake watershed.

Table 3-2. Annual water yield, total phosphorus load and total phosphorus concentration for each Rice Lake subwatershed. Values were estimated using the flow and UAL models described in section 3.2.1.

Subwatershed	Basin	Acres	Water Yield (acre-ft.)		Modeled Phosphorus Load (lbs/year)		Modeled Concentration (µg/L)	
			2009	2010	2009	2010	2009	2010
1	L1	592	70	118	76	89	398	279
L1 Totals		592	70	118	76	89	398	279
2	L2	660	72	122	92	91	470	275
6	L2	501	38	64	32	38	306	221
7	L2	273	18	30	10	11	196	132
L2 Totals		1,434	128	216	134	140	383	239
3	L3	1,722	187	314	188	205	370	240
4	L3	2,507	351	590	47*	79*	49*	49*
5	L3	1,018	134	225	9*	16*	26*	26*
L3 Totals		5,247	672	1,129	244	300	332	217
8	L4	1,390	214	361	216	214	371	218
9	L4	596	91	153	111	113	449	273
10	L4	1,471	179	302	169	213	347	260
L4 Totals		3,457	484	816	496	540	377	244
Lake Totals		10,731	1,354	2,279	950	1,069	356	232

***Concentration values based on surface water monitoring samples collected in 2009-2010 from lake/marsh near outlet of subwatershed.**

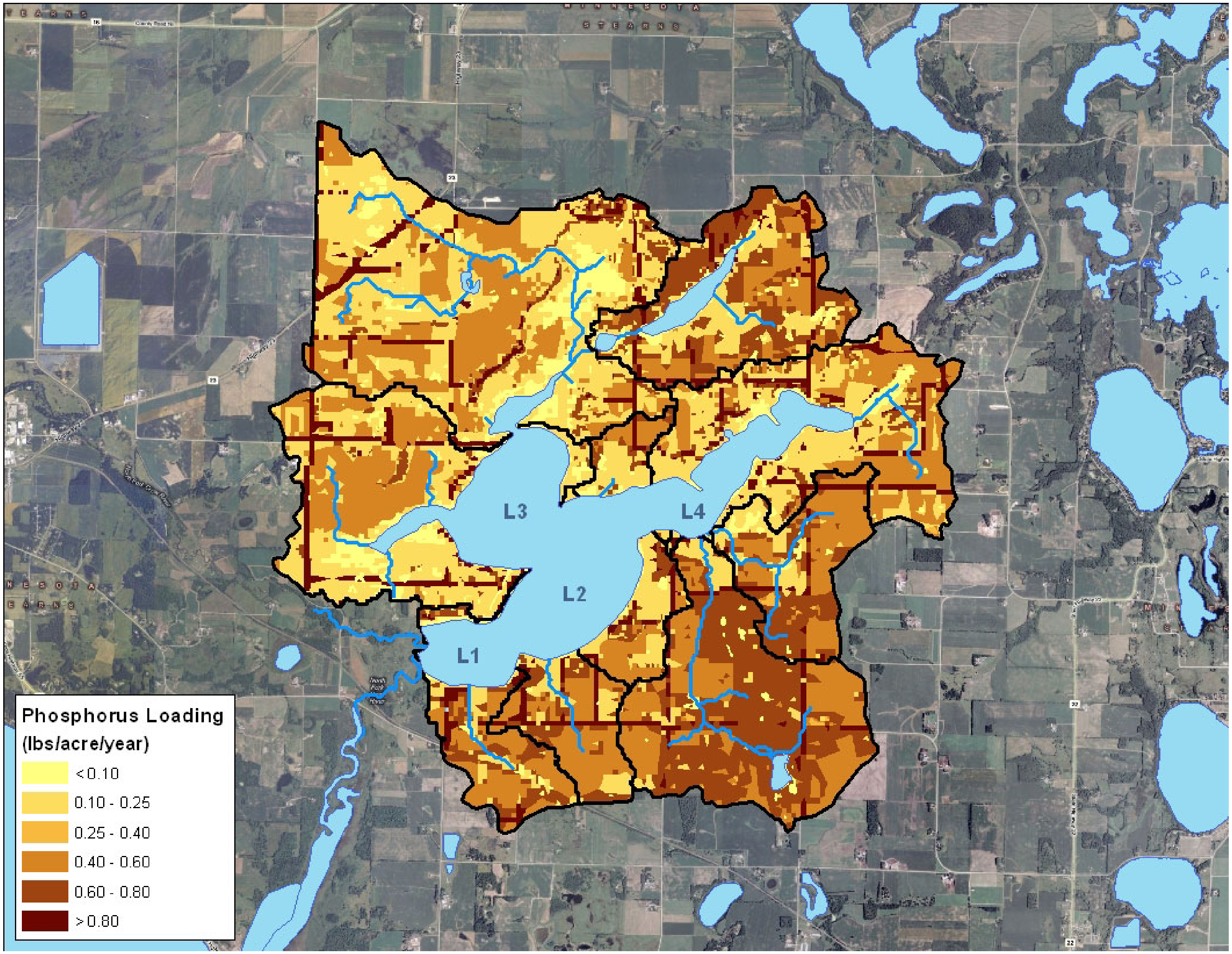


Figure 3-1. Phosphorus loading for the Rice Lake Direct watershed estimated using the Unit Area Load Model.

3.3.3 Schaumann's Bay Watershed

Two of the primary features of drainage to Schaumann's Bay (basin L3) are Pirz Lake (subwatershed 5) and the shallow marsh connected to the bay at the north end of the basin (outlet of sub 4). Total phosphorus samples were collected in Pirz Lake in 2009 and 2010 and in the shallow marsh in 2010. Results show Pirz Lake surface TP averaged 26 µg/L for the two years while average concentrations in the shallow marsh were 49 µg/L in 2010. Both monitored values are significantly less than the modeled TP concentrations for subwatersheds 4 and 5. This suggests both systems may act as a nutrient sink and help filter watershed runoff entering Rice Lake through Schaumann's Bay.

3.3.4 North Fork Crow River

Phosphorus loading from the North Fork Crow River to basin L1 is summarized in Table 3-3. The data shows 2009 and 2010 water yields were nearly identical. However, daily hydrographs indicate spring runoff from snowmelt was greater in 2009 while 2010 had more storm events from April through October which created higher summer water yields (Figure 2-12). As a result, phosphorus loads were more than two times greater in 2010 compared to 2009. It is also important to note that North Fork Crow River suspended solids are relatively low as a significant portion of the phosphorus appears to be dissolved rather than particulate. This is especially true during summer runoff events as noted in 2010 when ortho-phosphorus accounted for approximately 74% of the total phosphorus load.

Table 3-3. Estimated North Fork Crow River phosphorus loading to Rice Lake.

Year	Water Yield (acre-ft.)	TP Load		Ortho-P Load	
		kg	lbs	kg	lbs
2009	100,464	14,535	32,043	4,089	9,015
2010	108,695	30,109	66,380	22,339	49,250
Average	104,579	22,322	49,212	13,214	29,133

3.3.5 Animal Agriculture

Animal agriculture is a prominent use in both the North Fork Crow River watershed and the Rice Lake direct watershed. Manure produced by the animals in both watersheds is applied to fields and pastures for fertilizer as well as general manure management. Manure that is applied beyond the nutrient uptake ability of the crops/vegetation causes the field to become saturated with phosphorus. As a result, the phosphorus can dissolve easily in water and be transported through overland surface flow and runoff from tile drainage.

To assess the role of manure management on surface water nutrient concentrations and loads, an inventory of all the animals in both watersheds was conducted. The MPCA maintains a statewide database of registered feedlots. These data are then linked in GIS to evaluate the spatial distribution of animals in the watershed (Figure 3-2).

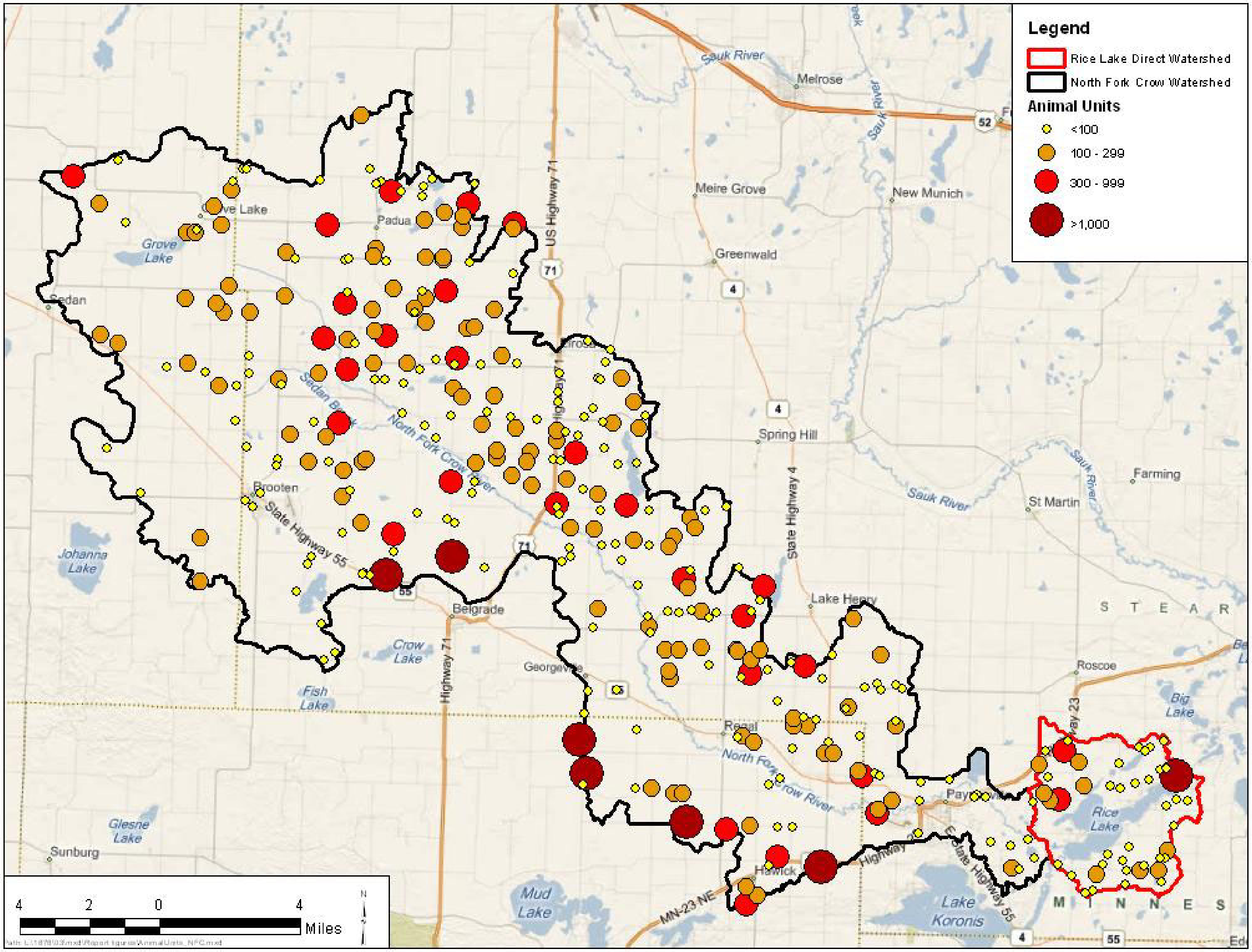


Figure 3-2. Minnesota Pollution Control Agency registered feedlots in the North Fork Crow and Rice Lake direct watersheds.

There are 44 separate animal operations and more than 5,800 total animal units in the Rice Lake direct watershed. The North Fork Crow River Watershed that drains to Rice Lake has 321 animal operations and over 49,000 total animal units (Table 3-4 and 3-5). Dairy and beef cattle operations together account for well over 50% of the animal units in both watersheds. Owners of an animal feedlot or manure storage area with 50 or more animal units (10 animal units in shoreland areas) are required to register with the MPCA. Owners with fewer than 300 animal units are not required to have a permit for the construction of a new facility or expansion of an existing facility as long as construction is in accordance with the technical standards. For owners with 300 animal units or more, and less than 1,000 animal units, a streamlined short-form permit is required for construction/expansion activities. Feedlots greater than 1,000 animal units are considered large confined animal feedlot operations (CAFOs) and are required to apply for a National Pollutant Discharge Elimination System (NPDES) or State Disposal System (SDS) permit. These operations, by law, are not allowed to discharge to waters of the state (Minn. R. 7020.2003). There are currently two feedlots in the Rice Lake direct watershed with 300-999 animal units (permit #s 145-74908 and 145-75958) and one large CAFO with over 1,000 animal units (permit # 145-75594).

The total mass of phosphorus produced by each animal unit category can be estimated using literature values (Evans, et al 2008). Based on these estimates, over 4.8 million pounds of phosphorus are potentially applied to land in the form of manure in the North Fork Crow River watershed and over 0.4 million pounds of phosphorus are potentially applied within Rice Lake direct watershed. To put this in perspective, total loading to Rice Lake is typically around 52,656 pounds or approximately 1% of the phosphorus applied to the land throughout both watersheds. Only a small proportion of this phosphorus need make its way into Rice Lake to cause serious eutrophication issues. Furthermore, much of the phosphorus loading in the watershed is in a dissolved form, further indicating that manure is a primary contributing source of phosphorus to surface waters in the Rice Lake watershed.

Table 3-4. 2010 MPCA registered animal units in the Rice Lake direct watershed.

Animal Type	Animal Units	TP Produced per Animal Unit (lbs/day)	Daily TP Production (lbs/day)	Annual TP Production (lbs/year)
Dairy Cows	3,510	0.15	527	192,173
Beef Cows	1,033	0.20	207	75,555
Swine	587	0.33	194	70,810
Horses	51	0.13	7	2,555
Sheep	17	0.22	4	1,460
Chickens	624	0.66	412	150,380
Turkeys	-	0.44	-	-
Totals	5,822		1,351	492,933

Table 3-5. 2010 MPCA registered animal units in the North Fork Crow watershed upstream of Rice Lake.

Animal Type	Animal Units	TP Produced per Animal Unit (lbs/day)	Daily TP Production (lbs/day)	Annual TP Production (lbs/year)
Dairy Cows	18,123	0.15	2,718	992,070
Beef Cows	10,733	0.20	2,147	783,655
Swine	9,305	0.33	3,071	1,120,915
Horses	356	0.13	46	16,790
Sheep	41	0.22	9	3,285
Chickens	1,594	0.66	1,052	383,980
Turkeys	9,719	0.44	4,276	1,560,740
Totals	49,871		13,319	4,861,435

The Rice Lake watershed UAL model does not explicitly model phosphorus contributions from manure spreading. The model does, however, implicitly account for animal contributions by calibrating to the Fishers Resort subwatershed monitoring data (2009-2010). The Fishers Resort subwatershed has 10 feedlot operations, 590 total animal units and a wide range of agricultural animal types. This subwatershed should be representative of the surrounding subwatersheds assuming manure practices are similar and spreading occurs close to where the animals are contained.

3.3.6 Permitted Point Sources

There are no NPDES permitted point source discharges located in the Rice Lake direct watershed. There are three active point sources in the North Fork Crow River watershed upstream of Rice Lake: Associated Milk Producers Inc. (AMPI) of Paynesville, Brooten WWTP and Paynesville WWTP. Appendix L summarizes each facility and their permitted effluent total phosphorus limits. Discharge Monitoring Reports (DMRs) show the facilities rarely exceed their current TP concentration limit (1,000 µg/L) and have never exceeded their daily loading limits. The MPCA estimates the facilities currently discharge only 509 pounds of phosphorus per year but are permitted to discharge up to 3,144 lbs/year (MPCA, 2010).

3.3.7 Septic Systems

Septic systems in the Rice Lake watershed have received attention historically as a possible source of nutrients to the lake. In 2005, the NFCRWD established a $50,000 per year, 5-year ad valorem levy to fund a watershed-wide Septic Certification Project. A septic inspector was hired in 2006 to inspect all systems in the North Fork Crow River Watershed through a Joint Powers agreement between NFCRWD, Pope, Meeker, Kandiyohi and Stearns Counties. Systems that were found to be non-compliant were required to upgrade within 10 months of notice. Through 2010, there were approximately 400 systems left to be inspected. To-date inspection results are summarized below:

Inspections Complete: 1,142
Compliant Systems: 823 (72%)
Non-Compliant Systems: 319 (28%)

Septics in the riparian zone of Rice Lake were considered priority and inspected first in 2007. All of these systems were in compliance and do not appear to be a significant nutrient source to the lake. By law, septic systems cannot discharge to surface waters and are assigned an allowable load of zero pounds per year. Current loading is assumed to be a part of the Rice Lake direct and North Fork Crow River watershed loads as no effort was made to separate the septic portion from the total.

3.3.8 Internal Phosphorus Loading

Rice Lake basins L1, L2 and L4 demonstrate significant anoxia over the bottom sediments throughout the summer with peak anoxic areas occurring in mid to late summer. Anoxic conditions in lakes are often expressed as the number of days anoxia occurs over the entire lake or basin; this term is referred to as the anoxic factor. The anoxic factor ranged from 26 to 53 in 2009 and 2010 for the three Rice Lake basins experiencing anoxic conditions during the summer months.

Once anoxia is quantified, the next step is to identify the rate at which sediments release phosphorus under anoxic conditions. The measured rates of phosphorus release from anoxic sediments in Rice Lake are 8.1, 2.9, 0.0, and 5.2 mg/m^2/day for basins L1, L2, L3 and L4, respectively (see Appendix K). This rate can then be used to estimate the gross internal loading based on the anoxic factor for the lake (Nürnburg 2004). The estimated gross loads for Rice Lake are presented in Table 3-6. Gross internal loading for Rice Lake ranges from 1,803 to 2,281 pounds per year. These estimates were used in the lake response model to estimate the role of internal loading on current lake water quality.

Table 3-6. Estimated gross internal loading from anoxic phosphorous release in Rice Lake.

Year	Basin	Release Rate (mg/m^2/day)	Anoxic Factor (days)	Gross Load (kg)	Gross Load (lbs)
2009	L1	8.1	26	169	371
	L2	2.9	46	290	638
	L3	0	0	0	0
	L4	5.2	45	361	794
	Lake Total			820	1,803
2010	L1	8.1	46	290	638
	L2	2.9	53	329	724
	L3	0	0	0	0
	L4	5.2	52	418	919
	Lake Total			1,037	2,281

3.4 SOURCE SUMMARY AND CURRENT PHOSPHORUS BUDGET

Phosphorus and water budgets were developed for 2009 and 2010. The average phosphorus budget for model years 2009 and 2010 is presented in Figure 3-3. Nutrient loading to Rice Lake is dominated by inputs from the North Fork Crow River. Secondary sources are split evenly between internal loading from the sediments and direct watershed runoff. While direct watershed runoff loading only accounts for approximately 2% of the Rice Lake phosphorus budget, monitored and modeled stream TP concentrations are high (117 µg/L - 401 µg/L) and are consistently above the proposed TP stream standard of 100 µg/L. North Fork Crow River TP concentrations were slightly lower (21 µg/L - 428 µg/L) but the river represents a significantly larger portion of the lake's water budget.

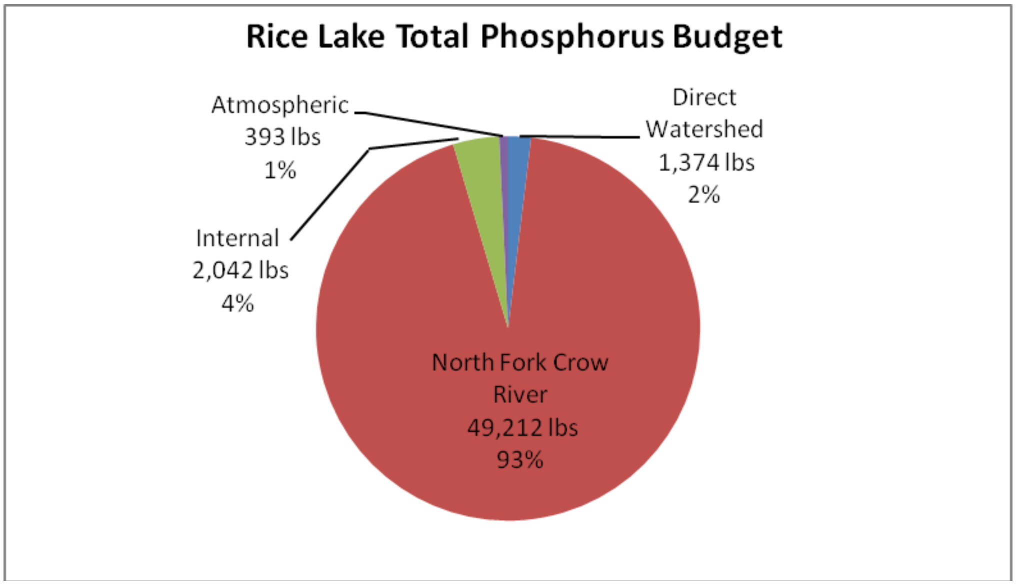


Figure 3-3. Average (2009 and 2010) total phosphorus budget for Rice Lake.

3.5 LINKING WATER QUALITY TARGETS AND SOURCES

The final step in understanding lake response to nutrient loads is to link the previously described nutrient budgets to lake water quality. This step is accomplished through the use of BATHTUB lake response models previously described in Section 3.2.5. The BATHTUB lake response model was applied using default model values and the water and nutrient budgets previously described in this section. Physical lake attributes such as volume, average depth, and surface area were derived from GIS and DNR contour maps.

3.6 FIT OF THE BATHTUB MODEL

Two years (2009 and 2010) were modeled for total phosphorus to evaluate the performance of the lake response model. A third iteration was setup by averaging the 2009 and 2010 nutrient and water budget model inputs. A Calibration factor of 1.7 was applied to basin L1 and 0.8 for basins L2, L3 and L4 to adjust the model to properly meet observed conditions. A TP calibration factor greater than one essentially increases the phosphorus sedimentation rate in the lake response model. This relatively large calibration factor is likely the result of North Fork Crow River particulate phosphorus settling and burial in the L1 basin of Rice Lake and direct bypass of TP river load from the North Fork Crow inflow to its outflow. The BATHTUB model performed reasonably well for both years and the 2009-2010 average (typically within 15% of measured values, Figure 3-4). The 2009-2010 average period total phosphorus lake response model was used to develop the TMDL allocations described in the next section. A complete water and nutrient mass balance for the 2009-2010 TMDL average BATHTUB model is presented in Appendix M.

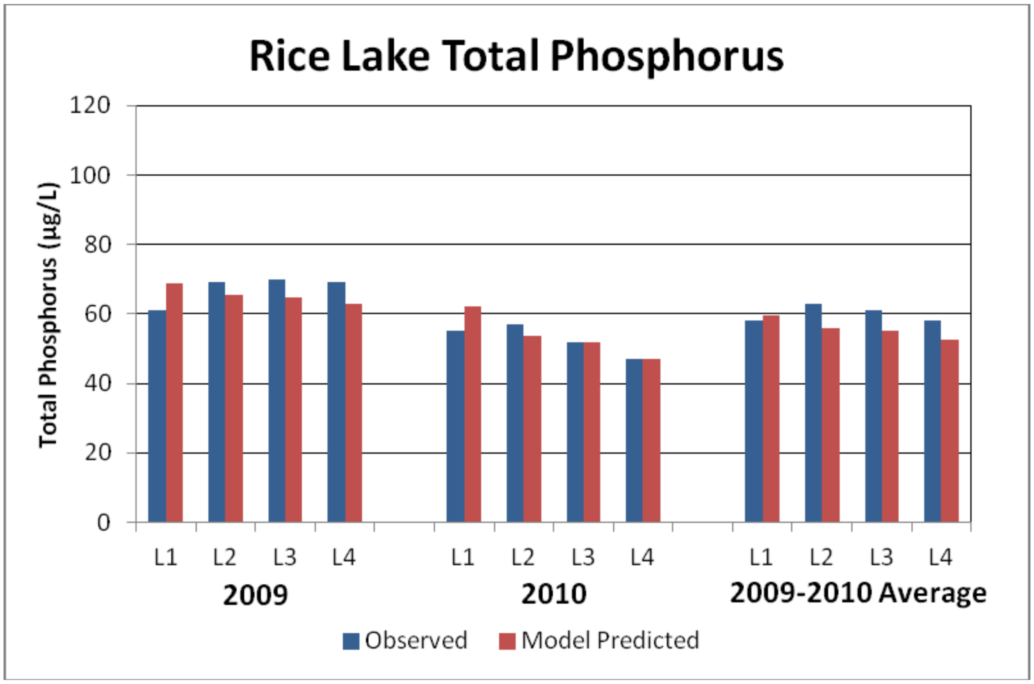


Figure 3-4. BATHTUB predicted and observed total phosphorus concentrations for each Rice Lake basin. The average of 2009 and 2010 was used to set the TMDL allocations described in section 4.0.

4.0 TMDL Allocation

4.1 TOTAL MAXIMUM DAILY LOAD CALCULATIONS

The numerical TMDL for Rice Lake was calculated as the sum of the Wasteload Allocation, Load Allocation and the Margin of Safety (MOS) expressed as phosphorus mass per unit time (lbs/day and lbs/year). The TMDL allocations for Rice Lake are set for phosphorus, since this is typically the limiting nutrient for nuisance aquatic algae. However, it will be demonstrated that both chlorophyll-a and Secchi response will also meet state standards once total phosphorus allocations are set to meet the state standard. The wasteload allocations and load allocations for this TMDL were calculated so that Rice Lake would meet its water quality standards for TP, chlorophyll-a and Secchi depth over the summer growing season.

The North Fork Crow River watershed makes up a majority of the watershed which lies upstream of the Rice Lake direct watershed. It was decided that the North Fork Crow River watershed above Rice Lake would serve as an upstream boundary condition for the source assessment modeling portion of this TMDL study. However, Wasteload and Load Allocations were calculated for the North Fork Crow River watershed above Rice Lake (Table 3-3). Section 4.1.2 defines phosphorus load reductions for the North Fork Crow River watershed and Rice Lake direct watershed that were estimated using the BATHTUB lake response model.

4.1.1 Total Loading Capacity

The first step in developing an excess nutrient TMDL for lakes was to determine the total nutrient loading capacity for Rice Lake. To determine the total loading capacity, the current nutrient budget and the BATHTUB lake response modeling (average of 2009 and 2010), presented in Section 3, were used as the starting point. Nutrient inputs were systematically reduced in the BATHTUB modeling exercise until the water quality values for TP in all four Rice Lake basins were below the total phosphorus standard of 40 µg/L as a growing season mean. The reductions were applied first to internal load and then the watershed sources. Once the total phosphorus water quality standard was met via BATHTUB modeling efforts, both the chlorophyll-a and Secchi depth were predicted external of the BATHTUB model using regression equations established by the Minnesota Pollution Control Agency (MPCA 2005). The regression equations were developed to determine the relationship between chlorophyll-a and total phosphorus in Minnesota lakes as a part of developing the State water quality standards. The regressions also describe the relationship between Secchi depth and chlorophyll-a. Further details of how this was applied are included in the following sections.

4.1.2 Load Allocations

The Load Allocation includes all nonpermitted sources including stormwater runoff not covered by a state or federal permit, atmospheric deposition and internal loading. No changes were expected for atmospheric deposition because this source is impossible to control.

One of the first steps in determining the allowable phosphorus loads to Rice Lake is setting the appropriate internal load release rate. There are two methods for determining the appropriate allowable internal load including looking at similar reference lakes and determining the achievable release rates based on available technology. Measured anoxic release rates in Rice Lake (anoxic release ranges from 0 to 8.1 mg/m^2/day) were compared to expected release rates for lakes with similar features to Rice Lake but are not impaired. In its current state, Rice Lake is considered a highly productive (eutrophic) lake based on its Secchi depth, chlorophyll-a and phosphorus measurements. Ideally, Rice Lake should be moderately productive (mesotrophic) given the lake's size, maximum depth and watershed area. Mesotrophic lakes demonstrate internal phosphorus release rates ranging from 0 to 12 mg/m^2/day with a median release rate around 4 mg/m^2/day (Figure 4-1; Nurnberg 1997). Although the median is 4 mg/m^2/day, there is a broad range of internal loads in mesotrophic lakes which makes selecting an appropriate number difficult. Furthermore, 42% of Rice Lake is littoral and can be expected to release little or no phosphorus when maintained in a healthy state.

An internal release rate of 1 mg/m^2/day was determined to be reasonable for Rice Lake based on the release rates demonstrated in similar lakes. It is also important to note that the selected Canfield-Bachmann lake response model implicitly accounts for some internal loading because lake water quality response is predicted from external loads from a lake database that includes lakes with internal loading. Therefore, the assigned internal load in the BATHTUB model is above and beyond the implicitly included internal load. Therefore, the lake can likely have an internal load greater than what is explicitly identified in the TMDL and still meet state water quality standards.

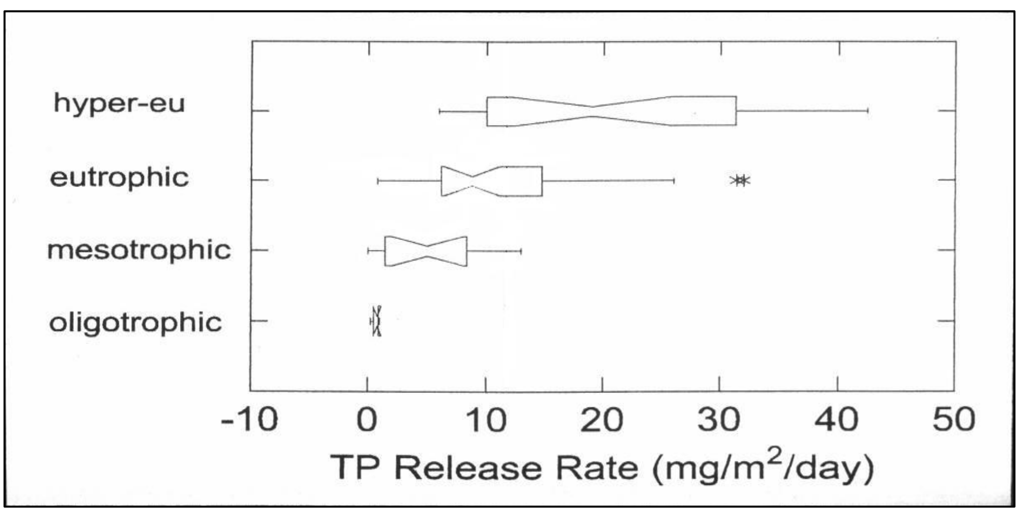


Figure 4-1. Sediment phosphorus release rates by eutrophic condition. (Nürnberg 1997).

After internal release rates were adjusted, the North Fork Crow River watershed and Rice Lake direct watershed phosphorus loads were systematically reduced within the lake response model until all four Rice Lake basins met the total phosphorus NCHF deep lake water quality standard. The BATHTUB modeling calculated that in order to meet the TP 40 µg/L water quality standard, the North Fork Crow River average total phosphorus concentration must be lowered from 173 µg/L to 100 µg/L and the Rice Lake direct watershed tributaries must be lowered from 278 µg/L to 150 µg/L. In November, 2010 The Minnesota Pollution Control Agency proposed nutrient criteria for Minnesota rivers that establishes a eutrophication numeric target of 100 µg/L for central region Minnesota rivers and streams (MPCA 2010). To be consistent with North Fork Crow requirements and the newly proposed river/stream state nutrient standards, this TMDL will also require Rice Lake's direct watershed runoff to meet an average TP concentration numerical target of 100 µg/L.

4.1.3 Wasteload Allocations

The wasteload allocation includes municipal, construction and industrial stormwater, confined animal feedlot operations (CAFOs) and permitted discharges such as waste-water treatment facilities. There are currently no permitted Municipal Separate Storm Sewer Systems (MS4s) in the Rice Lake direct watershed or the North Fork Crow River watershed that drains to Rice Lake.

4.1.3.1 Construction and Industrial Stormwater

There are six active construction stormwater permits in the Rice Lake watershed (Appendix N). A review of construction permits for the entire North Fork Crow River watershed showed minimal construction activities (<1% of the watershed area). The construction stormwater wasteload allocation was determined based on estimated percentage of land in the watershed that is currently under construction. However, to account for future growth (reserve capacity), allocations in the TMDL were rounded to one percent. The TMDL allocation for construction stormwater was calculated to be 297 lbs/year (0.8 lbs/day).

There is currently one industrial stormwater permit in the Rice Lake watershed (Appendix N). To account for future growth (reserve capacity), allocations for industrial stormwater in this TMDL are set at a half percent. The TMDL allocation for industrial stormwater was calculated to be 148 lbs/year (0.4 lbs/day).

4.1.3.2 Feedlots

There are currently 365 permitted animal feedlot operations in the Rice Lake watershed (Appendix O), 7 of which have more than 1,000 animal units and are considered a Confined Animal Feedlot Operation (CAFO). By rule, CAFOs and other feedlots are not allowed to discharge to waters of the state (Minn. R. 7020.2003). Furthermore, feedlots are assigned an allocation of zero based on state rules. Manure from these lots is spread on nearby fields and can be an important source phosphorus found in watershed runoff. However, manure on fields is unregulated and included in the watershed runoff portion of the load allocation.

4.1.3.3 NPDES Permitted Point Sources

There are three NPDES permitted point source dischargers upstream of Rice Lake: City of Brooten WWTP, City of Paynesville WWTP and AMPI Paynesville. All three facilities are located in the North Fork Crow River watershed and have 1,000 µg/L TP concentration limits (Figure 2-1, Table 4-1). The facilities have a collective actual (current) load of approximately 509 lbs/year and a permitted load of 3,144 lbs/year (MPCA, 2010). The Rice Lake TMDL does not include a reserve capacity for permitted sources. The three NPDES permitted facilities currently discharge well below their permitted TP load. The NPDES permitted loads allow each facility flexibility in terms of expanding their current nutrient loading.

Table 4-1. Total phosphorus permit limits for the Rice Lake watershed NPDES permitted point sources.

Facility	Permit ID	Concentration Limit (µg/L)	Permitted Load (lbs/year)
AMPI Paynesville	MN0044326	1,000	35
Brooten WWTP	MN0025909	1,000	406
Paynesville WWTP	MN0020168	1,000	2,703
Total Permitted Load			3,144

4.1.4 Margin of Safety

The margin of safety (MOS) is established to account for variability and lack of knowledge in the relationship between load and wasteload allocations and water quality. The MOS can be established through explicit quantification of the data/results or through implicit conservative assumptions in the analysis. An explicit MOS sets aside a portion of the total loading capacity by acknowledging uncertainties in the modeling and datasets used to calculate the TMDL. If the MOS is implicit, no load is set aside however the conservative assumptions in the modeling or analysis used to calculate the TMDL must be described. This TMDL study set aside 5% of the total load to represent an explicit MOS. It was determined a higher MOS was not necessary since there were a number of conservative assumptions that were included the modeling and analysis for this TMDL. Some of these assumptions include:

1. Achieving runoff total P load reductions would require greater percentage reductions in soluble reactive P (likely from animal waste, fertilizer or septic discharge), which has a greater impact on lake algal productivity, as compared with other forms of phosphorus that are less biologically available (Walker, 1985).

2. Best Management Practices for reducing phosphorus loads from agriculture (Sharpley et al., 2006) and other sources could be conservatively designed in the process of implementation.

3. The selected Canfield-Bachmann lake response model implicitly accounts for some internal loading because the response is predicted from external loads from a database that includes lakes with internal loading. Therefore, the assigned internal load in these models is included above and beyond the implicitly included internal load. Therefore, the

lake can likely demonstrate an internal load greater than what is explicitly identified in the TMDL and still meet state water quality standards.

4. This TMDL requires the Rice Lake direct watershed tributaries to achieve a 100 µg/L average TP concentration in order to meet the newly proposed Minnesota stream and river nutrient concentration standard. However, the lake response model suggests direct watershed runoff could be as high as 150 µg/L and Rice Lake would still meet NCHF deep lake standards. Thus, requiring the Rice Lake direct watershed to meet the proposed stream and river nutrient standard is a conservative assumption in the Rice Lake TMDL.

4.1.5 Summary of TMDL Allocations

Table 4-2 summarizes the TMDL allocations for Rice Lake. A total nutrient reduction of 53% from all sources is required for Rice Lake to meet state TP, Chlorophyll-a and transparency standards.

Table 4-2. TMDL total phosphorus daily loads partitioned among the major sources for Rice Lake assuming the lake standard of 40 µg/L.

Allocation	Source	Existing TP Load[1]		TP Load Allocations		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/day)[2]	(lbs/year)	Percent
Waste Load	Const. Stormwater	--	--	297	0.8	--	--
	Indust. Stormwater	--	--	148	0.4	--	--
	CAFO(s)	--	--	0	0.0	--	--
	NPDES point sources	509	1.4	3,144	8.6	--	--
Load	Atmospheric	392	1.1	392	1.1	--	0%
	Direct watershed	1,010	2.8	381	1.0	629	62%
	NFC River watershed	49,212	134.7	23,393	64.0	25,819	52%
	Internal Load	2,042	5.6	445	1.2	1,597	78%
Margin of Safety		--	--	1,484	4.1	--	--
Total		53,165	145.6	29,684	81.2	28,045	53%

[1] Existing load is the average for the years 2009-2010.
[2] Annual loads converted to daily by dividing by 365.25 days per year accounting for leap years

4.2 LAKE RESPONSE VARIABLES

The TMDL presented here is developed to be protective of the aquatic recreation beneficial use in Rice Lake. However there is no loading capacity *per se* for nuisance algae. Consequently, to understand the impacts of the phosphorus loads to the lake, a water quality response model was used to predict the water quality after load reductions are implemented. Utilization of this approach allows for a better understanding of potential lake conditions under numerous load scenarios. The following sections describe the results from the water quality response modeling.

Using the regression equations developed by the MPCA to establish Minnesota state water quality standards, Secchi depth and chlorophyll-a concentrations were predicted for load reductions in 5% increments using the 2009-2010 average lake response model run TP predictions. These predicted responses can be used to develop goals for load reductions with an understanding of the overall water quality benefits.

4.2.1 Total Phosphorus

Modeled total phosphorus concentrations expected at various phosphorus loads were calculated using BATHTUB and are presented in Figure 4-2. The lake response model predicts that all four Rice Lake basins will meet the NCHF deep lake water quality standard of 40 µg/L total phosphorus as a growing season mean at the TMDL designated load (29,684 pounds/year).

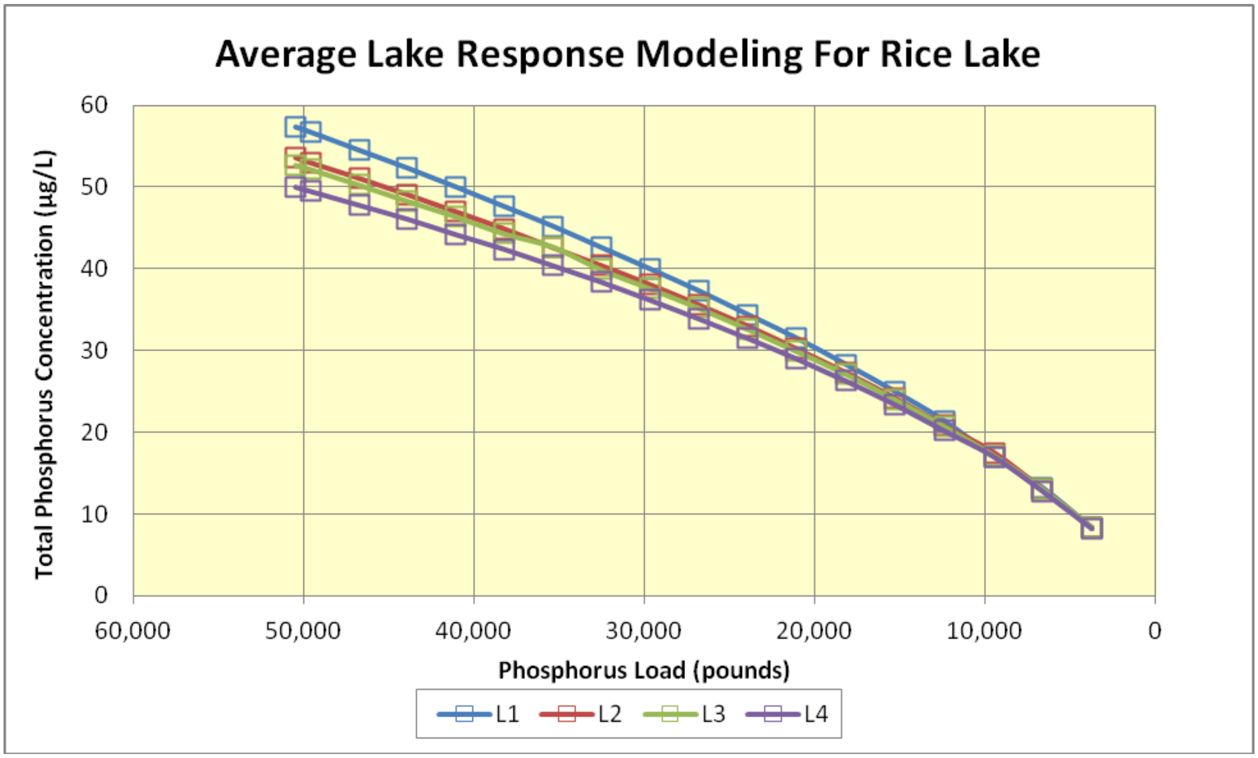


Figure 4-2. In-lake total phosphorus concentrations predicted for total phosphorus load reductions applied to all sources.

4.2.2 Chlorophyll-a

Rice Lake chlorophyll-a concentrations were predicted outside of the BATHTUB TP model using the Chlorophyll-TP MPCA regression equation (MPCA, 2005) under various phosphorus loading conditions (Figure 4-3). The MPCA Chlorophyll-TP regression equation ensures that the summer growing season mean chlorophyll-a target of 14 µg/L would be met at the TMDL designated load (29,684 pounds/year).

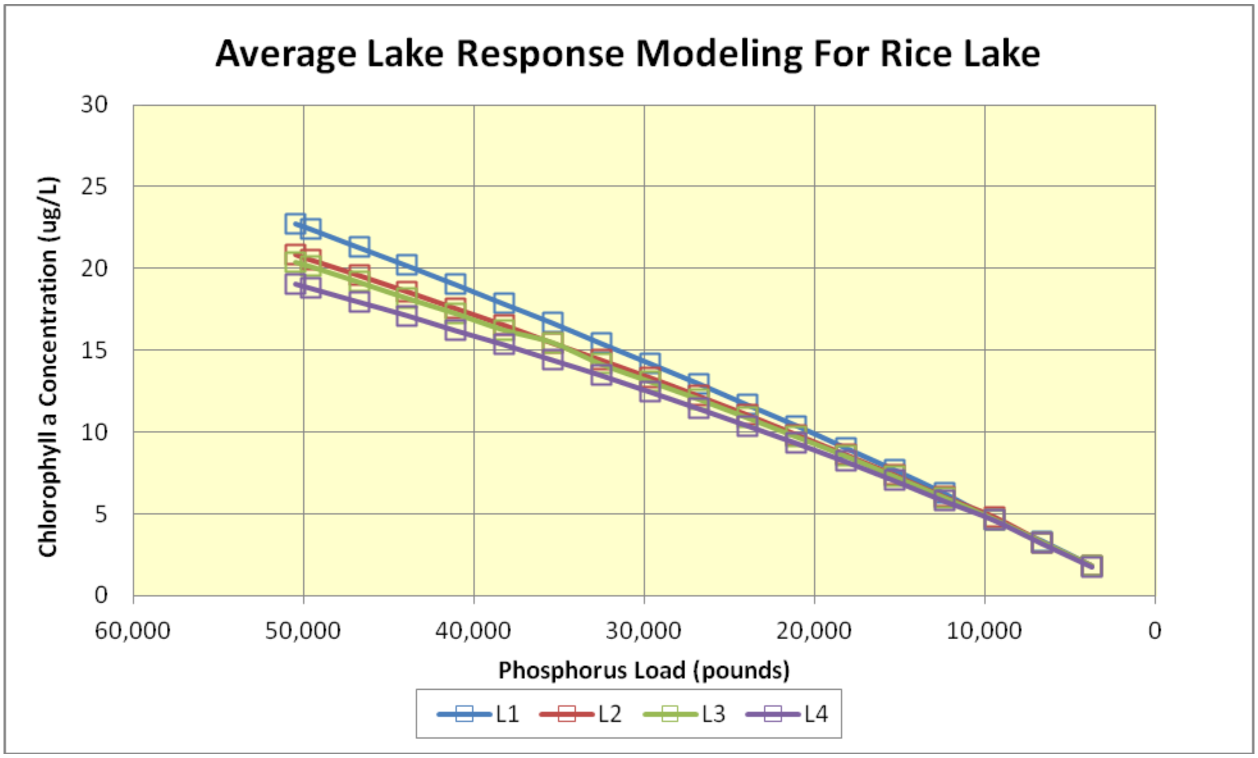


Figure 4-3. In-lake chlorophyll-a concentrations predicted for total phosphorus load reductions applied to all sources.

4.2.3 Secchi Depth

Rice Lake transparency was predicted outside of BATHTUB using the Secchi-TP regression equation developed by the MPCA (2005) under various TP loading conditions (Figure 4-4). These predictions suggest the Secchi depth target of >1.4 meters as a summer growing season mean would be exceeded in all four basins at the TMDL designated load (29,684 pounds/year).

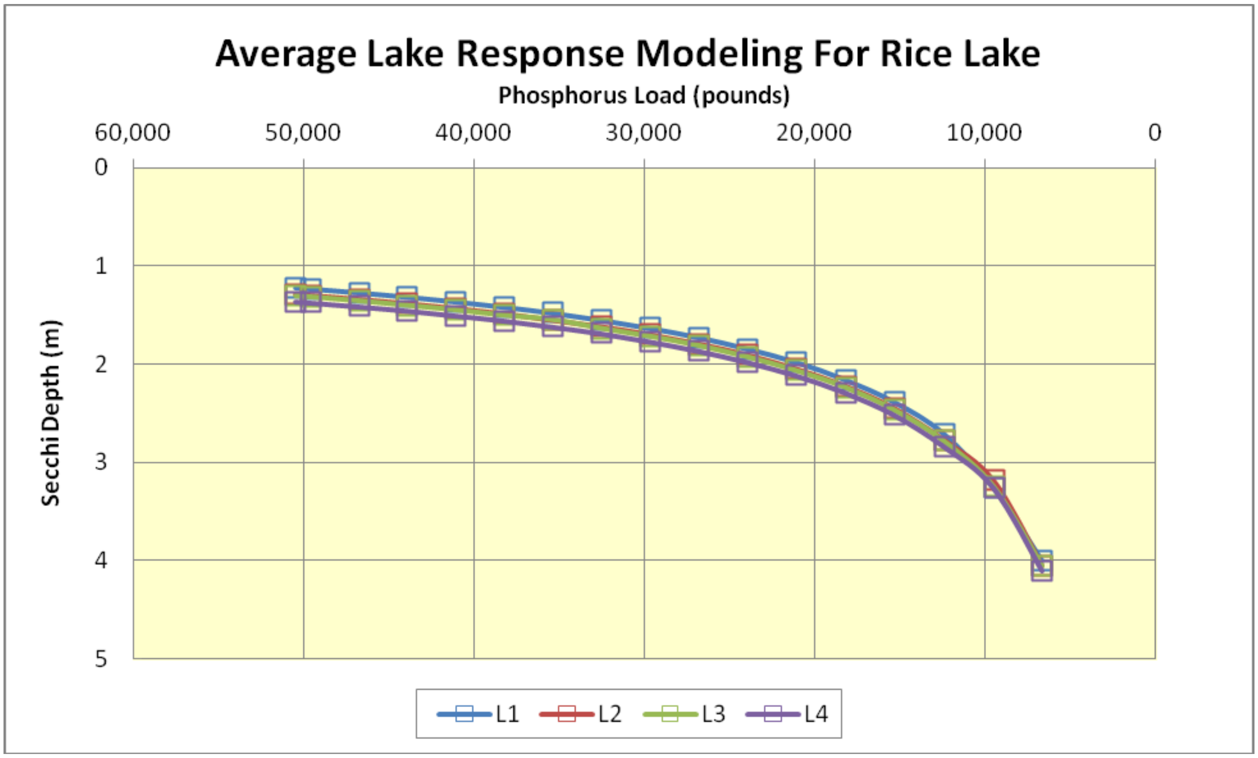


Figure 4-4. Secchi depth predicted for total phosphorus load reductions applied to all sources.

4.3 RESERVE CAPACITY AND FUTURE DEVELOPMENT

This TMDL does not explicitly define or set aside any reserve capacity for permitted or unpermitted sources. The three NPDES permitted point sources currently discharge well below their permitted TP load. Thus, the NPDES permit loads should allow each facility flexibility for moderate growth and expansion. The amount of land in agricultural use in the Rice Lake watershed is likely to remain fairly constant over the next several decades. The watershed is comprised mainly of row crops (corn and soybeans) and land used for pasture and hay. While the majority of the landscape is likely to remain in an agricultural land use, it is possible a modest shift between pasture/hay and row crops may occur. Any such shift would likely not affect the loading capacity of the lake, since that capacity is driven by a large river system that already varies year to year. Furthermore, the North Fork Crow River Watershed District, under Minnesota Statute 103D, maintains a set of rules meant to govern land development and re-development for urban use. These rules require developers and municipalities to provide water quality treatment for any new impervious surface, and in some cases, for alterations to existing impervious surface.

4.4 SEASONAL AND ANNUAL VARIATION

The daily load reduction targets in this TMDL are calculated from the current phosphorus budget for Rice Lake using two years of monitoring data. BMPs designed to address excess loads to the lake will be designed for these average conditions; however, the performance will be protective of all conditions. For example, a stormwater pond designed for average conditions may not perform at design standards for wet years; however the assimilative capacity of the lake will increase due to increased flushing. Additionally, in dry years the watershed load will be naturally down allowing for a larger proportion of the load to come from internal loading. Consequently, averaging across a few modeled years addresses annual variability in in-lake loading.

Seasonal variation is accounted for through the use of annual loads and developing targets for the summer period where the frequency and severity of nuisance algal growth will be the greatest. Although the critical period is the summer, lakes are not sensitive to short term changes in water quality - rather lakes respond to long-term changes such as changes in the annual load. Therefore, seasonal variation is accounted for in the annual loads. Additionally, by setting the TMDL to meet targets established for the most critical period (summer), the TMDL will inherently be protective of water quality during all the other seasons.

5.0 Public Participation

5.1 INTRODUCTION

TMDL development should be a stakeholder-driven process that develops an understanding of the issues and the processes driving the impairments. To that end, a detailed stakeholder process was employed that included working with the members of the Rice Lake Association and North Fork Crow River Watershed board members. These groups represent the stakeholders ultimately responsible for implementation of the TMDLs who need to be fully engaged in the applied science. It is our goal for this TMDL to result in a science based, implementable TMDL with a full understanding of the scientific tools developed to make informed, science based decisions.

5.2 STAKEHOLDER MEETINGS

Below is a to-date list of stakeholder meetings conducted for this TMDL study:

- Stakeholder Kickoff Meeting, July, 2009
  Attendees: Rice Lake Association, NFCRWD
  Objectives: Project overview and timeline

- Rice Lake Association Meeting, August, 2009
  Attendees: Rice Lake Association members
  Objectives: Project introduction

- 1st Season Review, December, 2009
  Attendees: Rice Lake Association, NFCRWD
  Objectives: Review of 2009 monitoring data – water quality, plankton surveys, sediment coring

- Project Update, May, 2010
  Attendees: Rice Lake Association, residents
  Objectives: Review 2009 monitoring data and objectives for 2010 monitoring

- Project Update, March, 2011
  Attendees: Rice Lake Association, NFCRWD
  Objectives: Update on 2010 monitoring results, presentation of modeling and TMDL allocations, final TMDL timeline

6.0 Implementation

6.1 INTRODUCTION

The purpose of the implementation section of the TMDL is to develop an implementation strategy for meeting the load and wasteload allocations set forth in this TMDL. This section is not meant to be a comprehensive implementation plan; rather it is the identification of a strategy that will be further developed in an implementation plan separate from this document.

6.2 REDUCTION STRATEGIES

Restoration options for lakes are numerous with varying rates of success. Consequently, each technology must be evaluated in light of our current understanding of physical and biological processes in that lake. Following is a description of potential actions for controlling nutrients in the Rice Lake watershed that will be further developed in the Rice Lake Implementation Plan.

6.3 IMPLEMENTATION FRAMEWORK

6.3.1 Watershed and Local Plans

Numerous governing units have water quality responsibilities in the watershed, including the North Fork Crow River Watershed District, the Crow River Organization of Water and the Stearns County SWCD. Each of these organizations maintains water plans aimed at improving water quality in their respective jurisdictions. These plans set the framework for implementing the TMDLs. A TMDL implementation plan will be developed separate from this TMDL document and the implementation plan will guide the governing units in the implementation of BMPs focused on achieving the TMDL.

6.3.2 Adaptive Management

The load allocations in the TMDL represent aggressive goals for nutrient reductions. Consequently, implementation will be conducted using adaptive management principles (Figure 6.1). Adaptive management is appropriate because it is difficult to predict the lake response that will occur from implementing strategies with the paucity of information available to demonstrate expected reductions. Future technological advances may alter the course of actions detailed here. Continued monitoring and "course corrections" responding to monitoring results are the most appropriate strategy for attaining the water quality goals established in this TMDL.

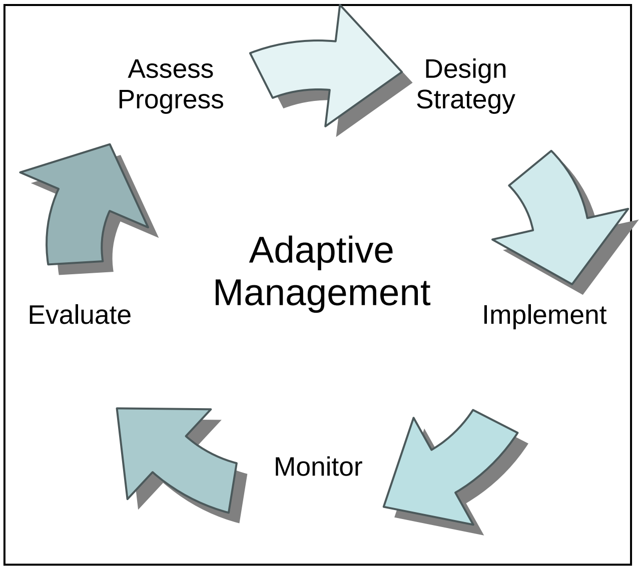


Figure 6-1. Adaptive management.

6.4 NUTRIENT REDUCTION STRATEGIES

Following is a description of potential actions for controlling nutrients in the Rice Lake watershed that will be further developed in the Implementation Plan.

6.4.1 External Nutrient Load Reductions

The Rice Lake TMDL requires a 62% and 52% total phosphorus reduction for Rice Lake direct watershed and the North Fork Crow River watershed, respectively. To meet the required load reduction, various watershed management activities will be implemented on an opportunistic basis, including the following:

Protect and restore high-value wetlands to prevent phosphorus export. Numerous high-value wetlands are present in the watershed. As development or redevelopment occurs, there is the potential to discharge stormwater and additional nutrients and sediment to the wetlands, altering the hydroperiod and natural assimilative characteristics and converting the wetlands from nutrient sinks to nutrient sources. Protecting the wetlands from these impacts will ensure they don't increase nutrient loading to the lake. Furthermore, fixing wetlands that are discharging phosphorus will decrease nutrient loads.

Increase infiltration and filtration in the watershed. One method for reducing phosphorus loading to Rice Lake is to increase infiltration and filtration in the watersheds. This can be accomplished through large scale infiltration areas, removing tile lines, adding buffers, or adding vegetated swales.

Manure Management. Minnesota feedlot rules (Minn. R. ch. 7020) now require manure management plans for feedlots greater than 300 animal units that do not employ a certified manure applicator. These plans require manure accounting and record-keeping as well as manure application risk assessment based on method, time and place of application and soil and manure testing. The following BMPs will be considered in all manure management plans to reduce potential nutrient delivery to surface waters:

- Immediate incorporation of manure into topsoil
- Reduction of winter spreading, especially on slopes
- Eliminate spreading near open inlets and sensitive areas
- Erosion control through conservation tillage and vegetated buffers
- Consider changing from N to P based manure management plan (MMP)

Pasture Management. Overgrazed pastures, reduction of pastureland and direct access of livestock to streams may contribute a significant amount of nutrients to surface waters throughout all flow conditions. The following livestock grazing practices are for the most part economically feasible and are extremely effective measures in reducing nutrient runoff from pastures:

- Livestock exclusion from public waters through setback enforcement and fencing
- Limited stabilized animal access
- Creating alternate livestock watering systems
- Rotational grazing
- Vegetated buffer strips between grazing land and surface water bodies

Feedlot and Manure Stockpile Runoff Controls. There are a variety of options for controlling manure stockpile runoff that reduce nonpoint source nutrient loading, including:

- Move fences or altering layout of feedlot
- Eliminate open tile intakes and/or feedlot runoff to direct intakes
- Install clean water diversions and rain gutters
- Install grass buffers
- Maintain buffer areas
- Construct solid settling area(s)
- Prevent manure accumulations
- Manage feed storage
- Manage watering devices
- Total runoff control and storage
- Install roofs
- Runoff containment with irrigation onto cropland/grassland
- Vegetated infiltration areas or tile-drained vegetated infiltration area with secondary filter strips

Septic Systems. While septics are not believed to be a major source of nutrients to Rice Lake, failing or nonconforming septic systems should be addressed. The counties throughout the Rice Lake watershed shall continue to identify and address systems that are not meeting adopted septic ordinances. Special attention shall be given to systems with high nutrient loading potential based on proximity to the lake, streams and systems that may discharge directly to surface water.

Soil and Manure Phosphorus Testing. Because the amount of manure applied in the Rice Lake watershed is so high, soil and manure testing would help manage where manure can be applied with little or no loss to surface waters. A soil and manure phosphorus testing program will allow managers to make better decisions about where P from manure is needed and where it may be applied in excess.

Stormwater Management. Municipal stormwater throughout the Rice Lake watershed is not believed to be a major source of phosphorus to Rice Lake. However, urban contributions may be addressed through better site design and BMPs such as infiltration basins and bioretention structures.

Encourage shoreline restoration. Many property owners maintain a turfed edge to the shoreline. Property owners should be encouraged to restore their shoreline with native plants to reduce erosion and capture direct runoff. Shoreline restoration can cost $30-50 per linear foot, depending on the width of the buffer installed. The NFCRWD will develop some demonstration projects as well as work with all willing landowners to naturalize their shorelines. Residents will be encouraged to apply to the NFCRWD’s Water Quality Cost-Share program.

6.4.2 Internal Nutrient Load Reductions

Internal nutrient loads will need to be reduced to meet the TMDL allocations presented in this document. There are numerous options for reducing internal nutrient loads ranging from simple chemical inactivation of sediment phosphorus to complex infrastructure techniques including hypolimnetic aeration.

Internal load reduction technical review. Prior to implementation of any strategy to reduce internal loading in Rice Lake, a technical review needs to be completed to evaluate the cost and feasibility of the lake management techniques available to reduce or eliminate internal loading. Several options could be considered to manage internal sources of nutrients including hypolimnetic withdrawal, alum treatment, vegetation management and hypolimnetic aeration. A technical review will be completed to provide recommendations for controlling internal loading in Rice Lake. Following is a brief description of some of the techniques that could be considered for controlling internal loading in Rice Lake.

1. Alum Addition. One of the most common methods for controlling internal nutrient loading in lakes is the addition of aluminum sulfate to permanently bind phosphorus in the sediments. When aluminum sulfate reacts with sediment phosphorus, the aluminum permanently binds phosphorus eliminating anoxic phosphorus release. Although alum can be quite effective and is relatively inexpensive, the floc blanket must remain relatively undisturbed to ensure long term effectiveness.

2. Hypolimnetic Withdrawal. Another option that may be considered is the removal of phosphorus rich water from the bottom, or hypolimnion, of a lake and discharging or treating that water. Hypolimnetic withdrawal can be fairly expensive and often has a long lag period before positive results are realized in the lake. However, hypolimnetic withdrawal does eliminate the need to add chemicals the lake.

3. Hypolimnetic Aeration. Sediment phosphorus release from sediments is primarily controlled by anoxia over the sediments. Consequently, one solution is to aerate the hypolimnion to prevent anoxic conditions from occurring over the sediments. To maintain oxygenated conditions in the hypolimnion, or bottom water, aerators are placed at the bottom of the lake, but are covered so that artificial mixing of the lake does not occur. Hypolimnetic aeration is a relatively costly approach and is dependent on a large amount of infrastructure that must be maintained.

4. Other Options. There are also other sources of internal loading to consider. One area that may need to be addressed is the resuspension of sediments in shallow areas of the lake as a result of recreational boating activities. Curlyleaf pondweed and carp can both add to internal loading and should be considered. The presence of invasive species and recreational activities will need to be considered when selecting the appropriate approach for controlling internal nutrient loads.

6.4.3 Studies and Biological Management Plans

Following are recommended studies needed to further refine management actions in Rice Lake and other Lakes in the North Fork Crow River watershed:

Vegetation management. Curly-leaf pondweed is present in many lakes in the North Fork Crow River watershed, and is at nuisance levels in some. Senescence of the curly-leaf pondweed in summer can be a significant source of internal phosphorus load that often results in a late summer nuisance algal bloom. Vegetation management, such as several successive years of chemical treatment, will be required to keep this exotic invasive species at non-nuisance levels.

Conduct periodic aquatic plant surveys and prepare and implement vegetation management plans. As BMPs are implemented and water clarity improves, the aquatic vegetation community will change. Surveys should be updated periodically and vegetation management plans amended to take into account appropriate management activities for that changing community.

Manage fish populations. One activity should be to partner with the DNR to monitor and manage the fish population to maintain a beneficial community. As the aquatic vegetation changes to a more desirable mix of species, it may be possible to restore a more balanced fish community that includes both panfish and top predators. Options to reduce rough fish populations should be evaluated, and the possibility of fish barriers explored to reduce rough fish access to spawning areas and to minimize rough fish migration between lakes.

6.4.4 Education

Conduct education and outreach awareness programs. Provide educational and outreach opportunities to property owners throughout the watershed about proper manure practices, feedlot management, fertilizer use, low-impact lawn care practices, and other topics to increase awareness of sources of pollutant loadings to the lakes and encourage the adoption of good individual property management practices. Opportunities to better understand aquatic vegetation management practices and how they relate to beneficial biological communities and water quality should also be developed.

Because Rice Lake is a highly used recreational lake, there is a potential for the recreation activities to have an impact on the water quality in the lake. To address these potential impacts, educational materials will be developed for lake users to make them aware of the potential impacts to the lake. The educational materials will also identify sensitive areas of the lake.

6.4.5 Lake and Watershed Monitoring

Monitoring water quality to assess progress in achieving the TMDL is a critical element in the adaptive management approach. Water quality monitoring will be conducted on Rice Lake annually including dissolved oxygen, temperature, total phosphorus, chlorophyll-a, secchi depth and total Kjeldahl nitrogen. The North Fork Crow River inflow to Rice Lake accounts for approximately 93% of the Rice Lake phosphorus budget. Monitoring the North Fork Crow River inflow will be critical in understanding watershed loading to the lake as well as evaluating the effects of management in the watershed. The MPCA currently maintains a monitoring station on the North Fork Crow River near the inlet to Rice Lake and collects data for nutrients and flow. This station will be continued in the future as part of the Rice Lake implementation plan.

7.0 Reasonable Assurance

7.1 INTRODUCTION

When establishing a TMDL, reasonable assurances must be provided demonstrating the ability to reach and maintain water quality endpoints. Several factors control reasonable assurance, including a thorough knowledge of the ability to implement BMPs as well as the overall effectiveness of the BMPs. This TMDL establishes aggressive goals for the reduction of nutrients to Rice Lake.

The goals outlined in this TMDL study are consistent with objectives outlined in the Stearns County and North Fork Crow River Watershed District Water Plans. This plan has the same objective of developing and implementing strategies to bring impaired waters into compliance with appropriate water quality standards and thereby establish the basis for removing those impaired waters from the 303(d) Impaired Waters List. The plan provides the watershed management framework for addressing water quality issues. In addition, the stakeholder process associated with this TMDL effort as well as the broader planning efforts mentioned previously have generated commitment and support from the local government units affected by this TMDL and will help ensure that this TMDL project is carried successfully through implementation.

Various technical and funding sources will be used to execute measures that will be detailed in the implementation plan that will be developed within one year of approval of this TMDL. Funding resources include a mixture of state and federal programs, including (but not limited to) the following:

- Federal Section 319 Grants for watershed improvements
- Funds ear-marked to support TMDL implementation from the Clean Water, Land, and Legacy constitutional amendment, approved by the state's citizens in November 2008.
- Local government cost-share funds
- Soil and Water Conservation Districts cost-share funds
- NRCS cost-share funds
- NFCRWD and CROW cost-share funds

It is a reasonable expectation that existing regulatory programs such as those under NDPES will continue to be administered to control discharges from industrial, municipal, and construction sources as well as large animal feedlots that meet the thresholds identified in those regulations.

7.2 REGULATORY APPROACHES

Industrial stormwater activities are considered in compliance with provisions of the TMDL if they obtain an industrial stormwater general permit or General Sand and Gravel general permit

(MNG49) under the NPDES program and properly select, install and maintain all BMPs required under the permit. There are not currently any industrial dischargers in the watershed, but these regulations would apply to future dischargers.

Construction storm water activities are considered in compliance with provisions of the TMDL if they obtain a 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. Industrial storm water activities areconsidered in compliance with provisions of the TMDL if they obtain an industrial stormwater general permit or General Sand and Gravel general permit (MNG49) under the NPDES program and properly select, install and maintain all BMPs required under the permit.

7.3 LOCAL MANAGEMENT

7.3.1 North Fork Crow River Watershed District

The North Fork Crow River Watershed District is governed by a board of five managers appointed by the Pope, Kandiyohi, Stearns and Meeker Counties Board of Commissioners. The District's primary purpose is the conservation of the quality and quantity of water within the Watershed District Boundary. The NFCRWD has drainage authority of all county and judicial ditch systems located within the boundaries of the Watershed District. A major goal of the NFCRWD Comprehensive Water Management Plan is to minimize or reduce priority pollutants to sustainable levels. Some strategies for achieving this goal include:

- Supporting efforts by local units of government in the District to develop, adopt and administer performance standards that protect water resources
- Working to minimize pollution from key areas, such as from wastewater plants, industrial sites, and similar easily recognizable sources commonly referred to as "point source pollution"
- Assisting district residents with implementing Best Management Practices
- Reducing erosion and controlling sediment where possible
- Assisting with identifying priority areas for implementation activities
- Continued surface water quality monitoring efforts within the District

7.3.2 Crow River Organization of Waters

Portions of ten counties in Central Minnesota make up the Crow River Watershed. From the perspective of the Upper Mississippi River Basin, the Crow River is one of its major tributaries. The effects of rapid urban growth, new and expanding wastewater facilities and erosion from agricultural lands have been common concerns of many citizens, local, state and regional governments in Central Minnesota. As a result, many groups began meeting in 1998 to discuss management of the Crow River basin consisting of the North Fork and South Fork. The Crow River Organization of Water (CROW) was formed in 1999 as a result of heightened interest in the Crow River. A Joint Powers Agreement has been signed between all ten of the Counties with land in the Crow River Watershed. The CROW Joint Powers Board is made up of one representative from each of the County Boards who signed the agreement. The Counties involved in the CROW Joint Powers include Carver, Hennepin, Kandiyohi, McLeod, Meeker, Pope, Renville, Sibley, Stearns and Wright. The CROW currently focuses on identifying and promoting the following:

- Protecting water quality and quantity
- Protect and enhance fish and wildlife habitat and water recreation facilities
- Public education & awareness
- BMP implementation

7.3.3 County Soil and Water Conservation Districts

The Rice Lake watershed is primarily situated in Stearns County, with smaller portions in Kandiyohi and Pope Counties. The County Soil and Water Conservation Districts (SWCD) for these three counties manage and direct natural resource management programs at the local level. Their mission is to provide local leadership in the conservation of soil, water, and related natural resources through programs and partnerships with individuals, businesses, organizations and the government. They are particularly concerned with erosion of soil due to wind and water. The SWCDs are heavily involved in the implementation of practices that effectively reduce or prevent erosion, sedimentation, siltation, and agricultural-related pollution in order to preserve water and soil as resources. The Districts frequently act as local sponsors for many types of projects, including grassed waterways, on-farm terracing, erosion control structures, and flow control structures. The NFCRWD has established close working relationships with the SWCDs on a variety of projects.

7.3.4 Local Comprehensive Water Management Plans

Addressing impaired waters by improving water bodies within the county that do not support their designated use was identified as one of the top three priority concerns in the Stearns County Local Water Management Plan. In addition, the Implementation Program section of the plan focuses on a number of areas important in restoring impaired waters to a non-impaired status, including;

- Annually review the sampling data and determine continuing monitoring needs.
- Coordinate and implement monitoring and analysis.
- Provide assistance to County landowners in implementing agricultural Best Management Practices on working lands to reduce soil erosion, protect stream banks and improve water resources.
- Educate landowners about proper land application of nutrients and pesticides.
- Develop/support workshops for volunteer monitors.
- Establish and maintain vegetative buffers in the shore and bluff impact zones.

7.3.5 Rice Lake Association

The Rice Lake Association will play a crucial role in educating stakeholders and carrying out the implementation plan for this TMDL study. The Rice Lake Association was organized in 1975 to address the following goals and objectives:

- Improve the water and recreational quality of Rice Lake through promotion of sound lake management practices
- Educate members regarding issues that affect lakeshore
- Advocate members' interests before governmental bodies in matters involving Rice Lake
- Promote research and appropriate standards for proper management of Rice Lake, the North Fork Crow River, and surrounding tributaries
- Seek enforcement of laws that affect Minnesota lakes and watersheds

8.0 Literature Cited

Army Corps of Engineers – Engineer Research and Development Center. 2009. Internal Phosphorus Loading and Sediment Phosphorus Fractionation Analysis for Rice Lake, Minnesota. Prepared for North Fork Crow River Watershed District.

Barr Engineering. 2004. Detailed Assessment of Phosphorus Sources to Minnesota Watersheds. Prepared for the Minnesota Pollution Control Agency, St. Paul, MN.

Evans, B.M., Lehning, D.W., and K.J Corradini. 2008. AVGWLF User's Guide. Version 7.1. Penn State Institutes of Energy and the Environment. The Pennsylvania State University.

Minnesota Pollution Control Agency. 2005. Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria. 3rd Edition.

Minnesota Pollution Control Agency. 2008. Minnesota Stormwater Manual. Version 2, January 2008.

Minnesota Pollution Control Agency. 2010. Statement of Basis: Associated Milk Producers – Paynesville.

Nürnberg, G. 1997. Coping with water quality problems due to hypolimnetic anoxia in central Ontario lakes. Water Quality Research Journal of Canada. 32 (2) pp 391-405.

Nürnberg, G. K. 2004. "Quantified Hypoxia and Anoxia in Lakes and Reservoirs." The Scientific World Journal 4: 42-54.

Reckhow, K.H., M.N. Beaulac, and J.T. Simpson. 1980. Modeling Phosphorus Loading and Lake Response Under Uncertainty: A Manual and Compilation of Export Coefficients. Report No. EPA/440/5-80-011. US EPA, Office of Water Regulations and Standards, Washington, D.C. USEPA (U.S. Environmental Protection Agency). 2007. Options for Expressing Daily Loads in TMDLs (Draft). USEPA, Washington, D.C.

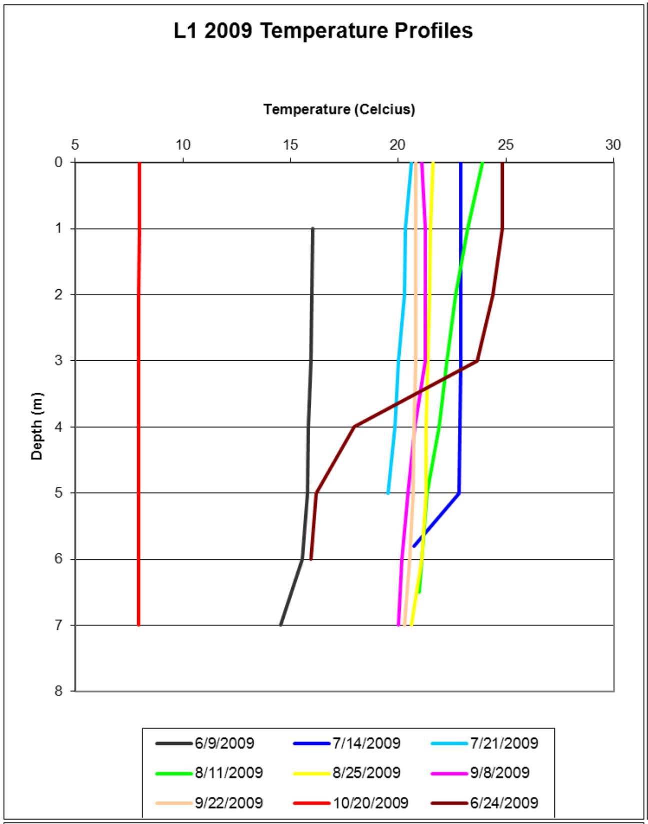
Walker, William W. 1999. Simplified Procedures for Eutrophication Assessment and Prediction: User Manual. USACE Report w-96-2.

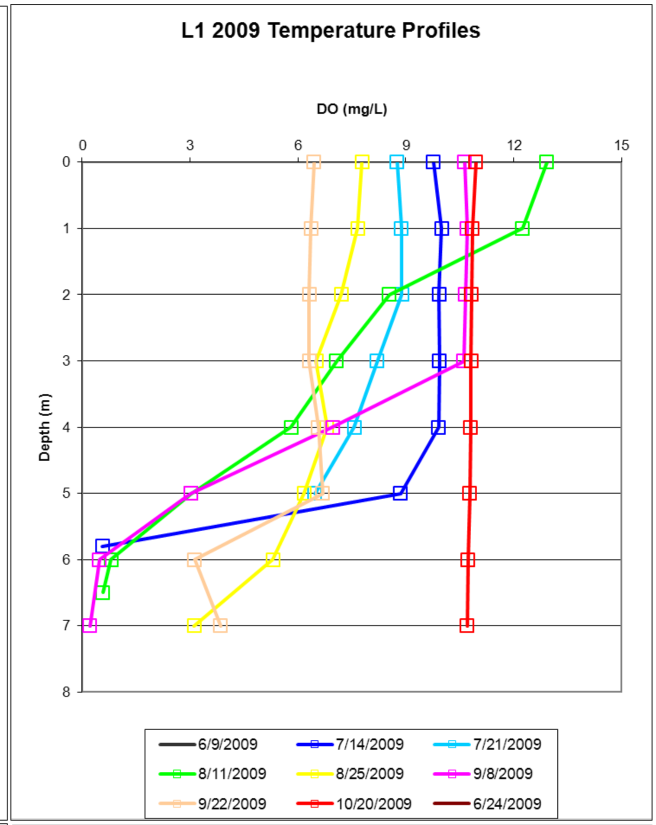
Walker, William W. 2003. Consideration of Variability and Uncertainty in Phosphorus Total Maximum Daily Loads for Lakes. J. Water Resour. Plng. and Mgmt., Volume 129, Issue 4, pp. 337-344 (July/August 2003).

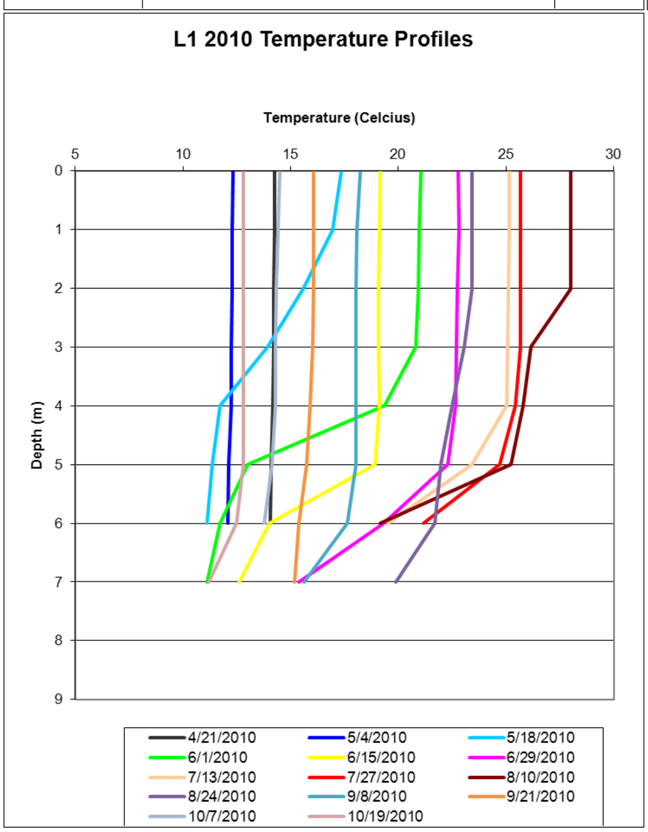
Appendix A

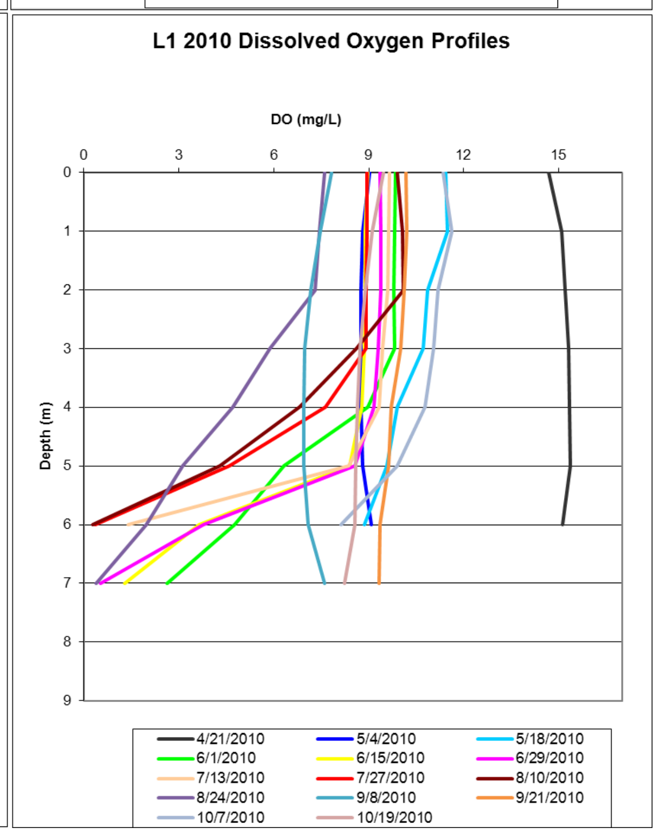
Temperature and Dissolved Oxygen Profiles

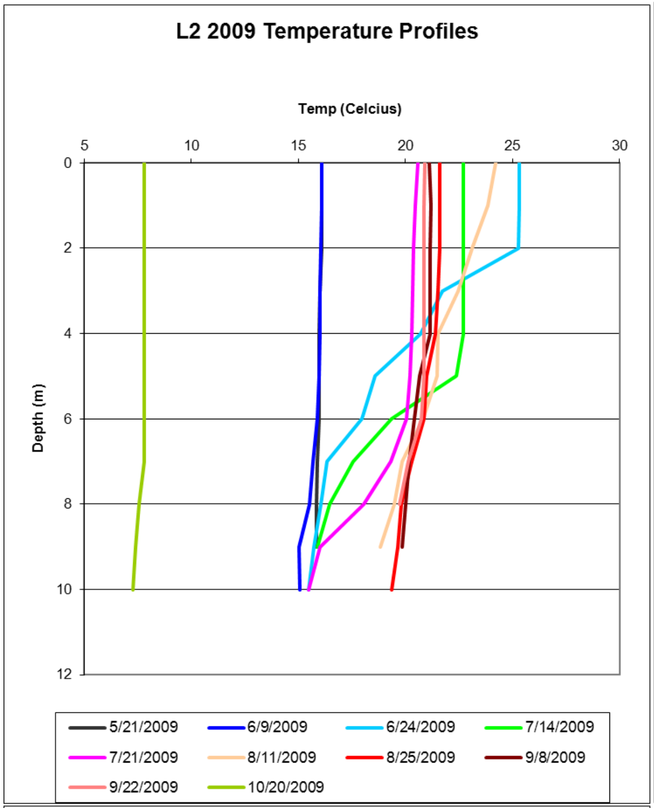
Appendix A: Temperature and Dissolved Oxygen Profiles

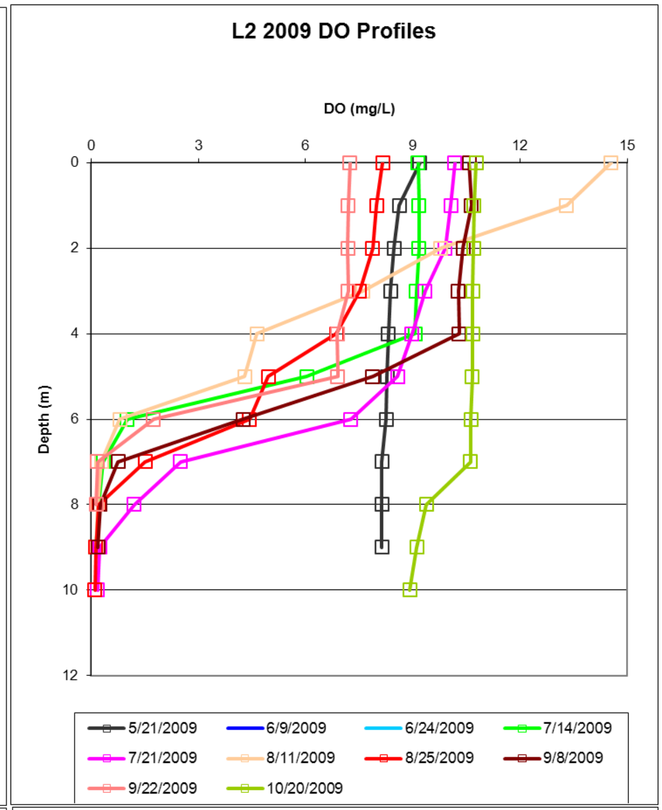


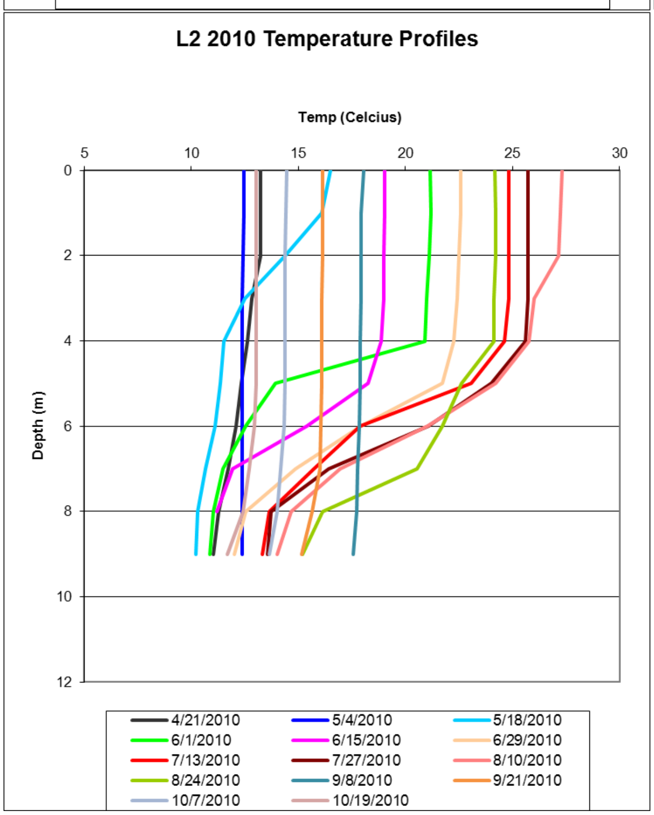


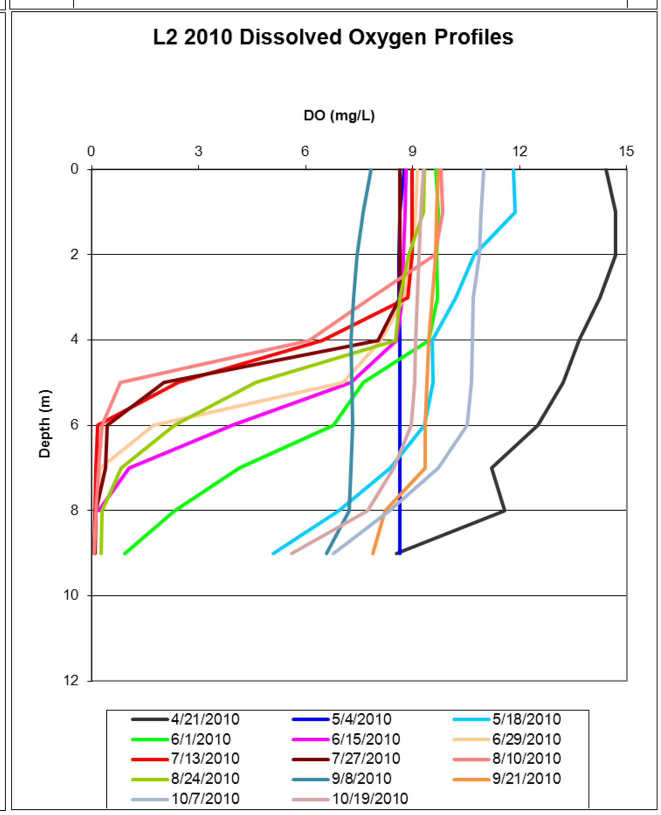


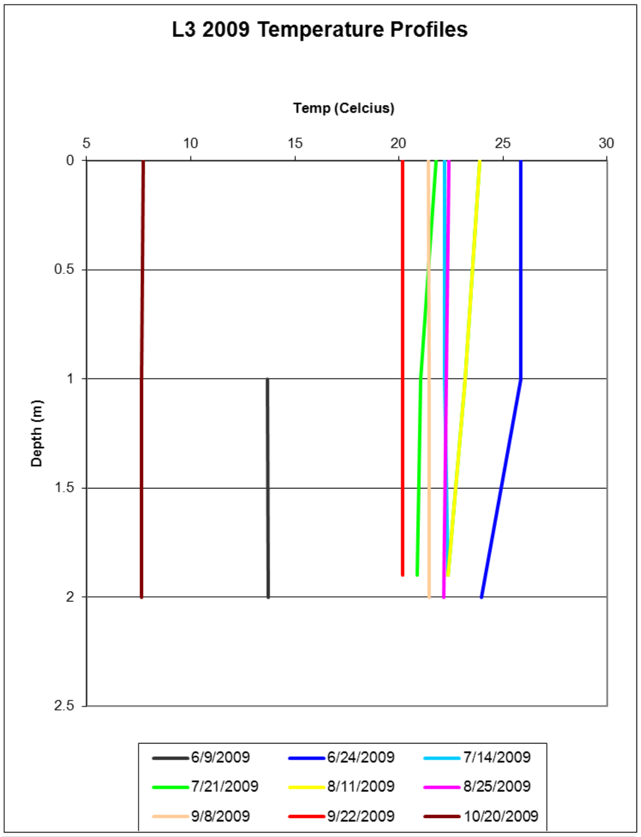


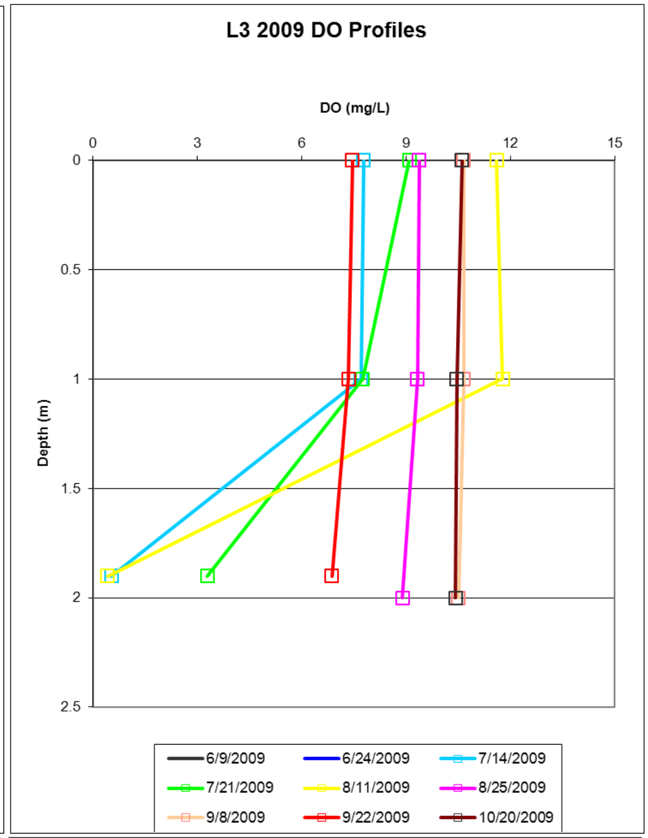

L2 2009 Temperature Profiles
Temp (Celcius)
Depth (m)
5/21/2009
6/9/2009
6/24/2009
7/14/2009
7/21/2009
8/11/2009
8/25/2009
9/8/2009
9/22/2009
10/20/2009

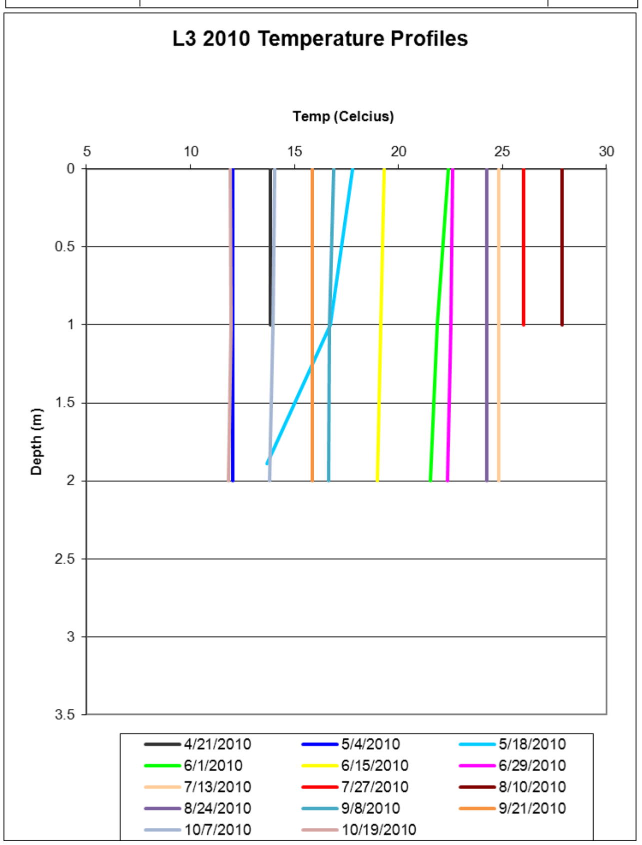

L2 2009 DO Profiles
DO (mg/L)
Depth (m)
5/21/2009
6/9/2009
6/24/2009
7/14/2009
7/21/2009
8/11/2009
8/25/2009
9/8/2009
9/22/2009
10/20/2009

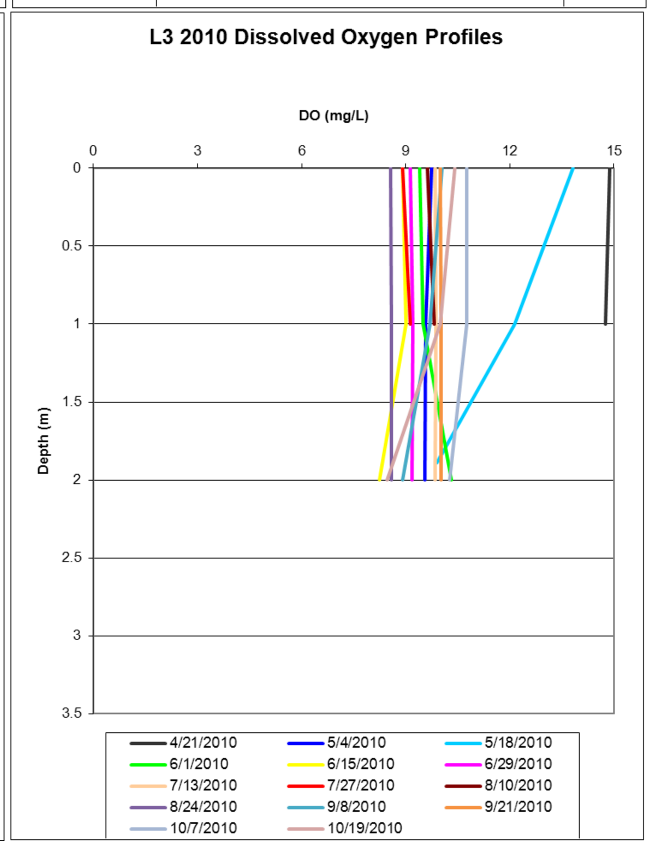

L2 2010 Temperature Profiles
Temp (Celcius)
Depth (m)
4/21/2010
5/4/2010
5/18/2010
6/1/2010
6/15/2010
6/29/2010
7/13/2010
7/27/2010
8/10/2010
8/24/2010
9/8/2010
9/21/2010
10/7/2010
10/19/2010

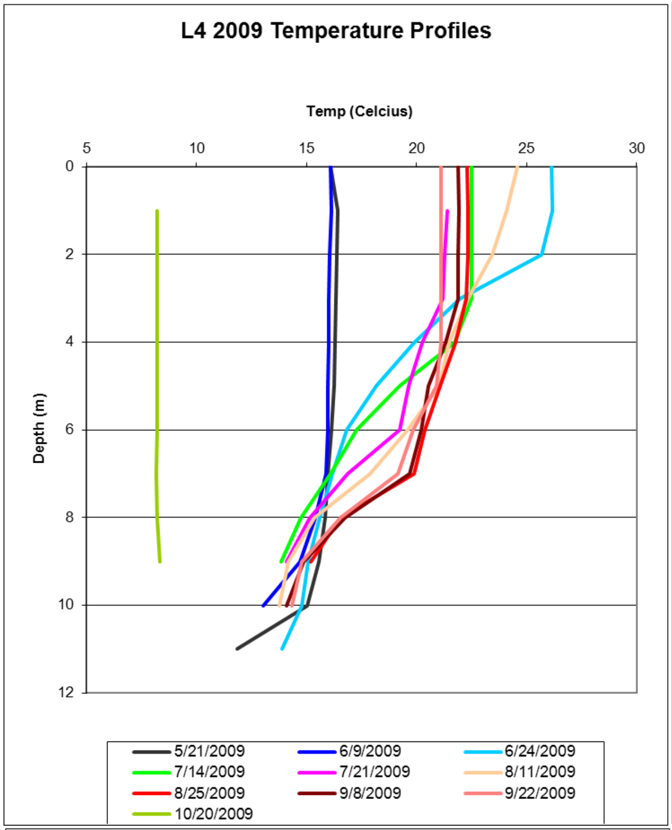

L2 2010 Dissolved Oxygen Profiles
DO (mg/L)
Depth (m)
4/21/2010
5/4/2010
5/18/2010
6/1/2010
6/15/2010
6/29/2010
7/13/2010
7/27/2010
8/10/2010
8/24/2010
9/8/2010
9/21/2010
10/7/2010
10/19/2010

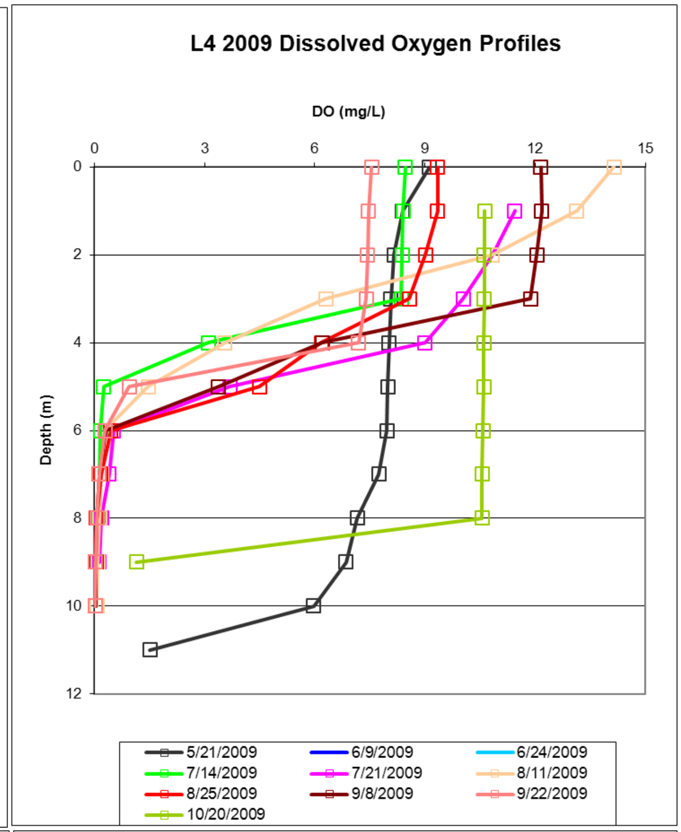

L3 2009 Temperature Profiles
Temp (Celcius)
5
10
15
20
25
30
Depth (m)
0
0.5
1
1.5
2
2.5
6/9/2009
6/24/2009
7/14/2009
7/21/2009
8/11/2009
8/25/2009
9/8/2009
9/22/2009
10/20/2009

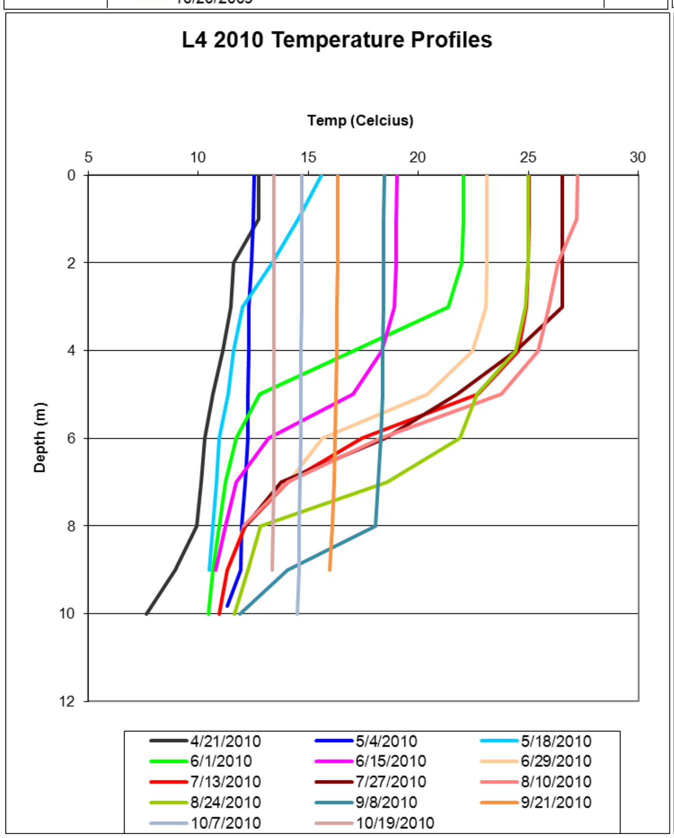

L3 2009 DO Profiles
DO (mg/L)
0
3
6
9
12
15
Depth (m)
0
0.5
1
1.5
2
2.5
6/9/2009
6/24/2009
7/14/2009
7/21/2009
8/11/2009
8/25/2009
9/8/2009
9/22/2009
10/20/2009

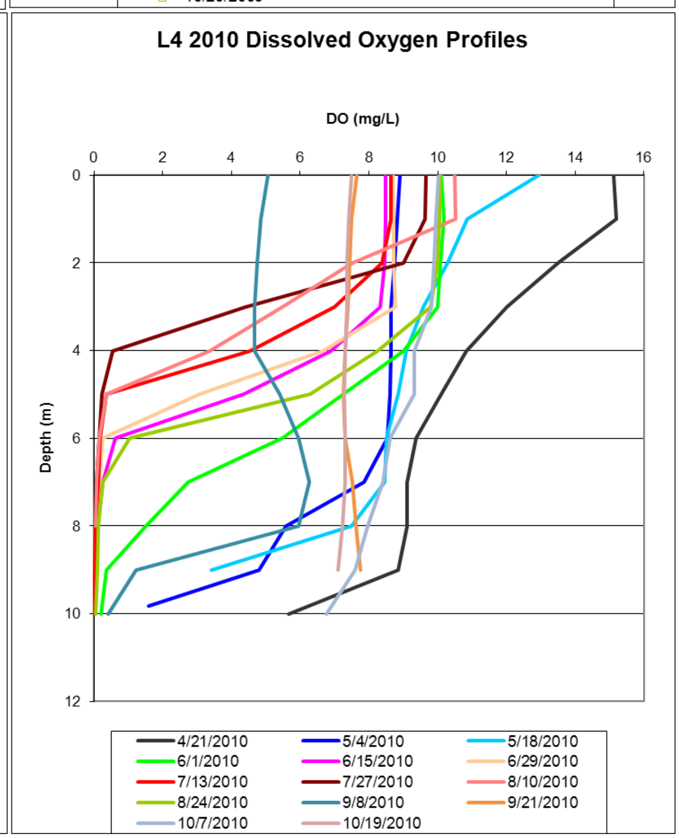

L3 2010 Temperature Profiles
Temp (Celcius)
5
10
15
20
25
30
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
4/21/2010
5/4/2010
5/18/2010
6/1/2010
6/15/2010
6/29/2010
7/13/2010
7/27/2010
8/10/2010
8/24/2010
9/8/2010
9/21/2010
10/7/2010
10/19/2010


L3 2010 Dissolved Oxygen Profiles
DO (mg/L)
0
3
6
9
12
15
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
4/21/2010
5/4/2010
5/18/2010
6/1/2010
6/15/2010
6/29/2010
7/13/2010
7/27/2010
8/10/2010
8/24/2010
9/8/2010
9/21/2010
10/7/2010
10/19/2010


L4 2009 Temperature Profiles
Temp (Celcius)
5 10 15 20 25 30
Depth (m)
0 2 4 6 8 10 12
5/21/2009
6/9/2009
6/24/2009
7/14/2009
7/21/2009
8/11/2009
8/25/2009
9/8/2009
9/22/2009
10/20/2009


L4 2009 Dissolved Oxygen Profiles
DO (mg/L)
0 3 6 9 12 15
Depth (m)
0 2 4 6 8 10 12
5/21/2009
6/9/2009
6/24/2009
7/14/2009
7/21/2009
8/11/2009
8/25/2009
9/8/2009
9/22/2009
10/20/2009


L4 2010 Temperature Profiles
Temp (Celcius)
5 10 15 20 25 30
Depth (m)
0 2 4 6 8 10 12
4/21/2010
5/4/2010
5/18/2010
6/1/2010
6/15/2010
6/29/2010
7/13/2010
7/27/2010
8/10/2010
8/24/2010
9/8/2010
9/21/2010
10/7/2010
10/19/2010


L4 2010 Dissolved Oxygen Profiles
DO (mg/L)
0 2 4 6 8 10 12 14 16
Depth (m)
0 2 4 6 8 10 12
4/21/2010
5/4/2010
5/18/2010
6/1/2010
6/15/2010
6/29/2010
7/13/2010
7/27/2010
8/10/2010
8/24/2010
9/8/2010
9/21/2010
10/7/2010
10/19/2010

Appendix B

Historic Lake Water Quality Sampling Methods and Tables

Appendix B: Historic Lake Water Quality Sampling Methods and Tables

General Methods

All water quality data used in the TMDL study was downloaded from STORET through MPCA's Environmental Data Access system. Consistent with MPCA impairment listing methodology, only state 'approved' water quality data available in STORET was used in this TMDL study. Data collected or available through RMB Laboratories or other agencies that is not available in STORET was not presented in the TMDL. Below is a summary of the methods used to process the Rice Lake STORET data for the TMDL report.

Site Location

In-lake water quality data was grouped and presented by lake basin. There were 19 different station locations identified in STORET. Each station was placed into one of the four Rice Lake basins based on information supplied by RMB Laboratories and discussion with NFCRWD. Stations 201, 202 and 208 were dropped from analysis because it was determined they were located near shore and/or in a shallower portion of the basin (not representative). Stations 6501 and 6502 were not included in the analysis as no location information was supplied.

L1	L2	L3	L4
207 (RMB map)	202 (RMB map)	213 (NFCRWD discussion)	100 (NFCRWD discussion)
	205 (RMB map)		201 (RMB map)
	206 (RMB map)		203 (RMB map)
	209 (RMB map)		204 (RMB map)
	210 (RMB map)		208 (RMB map)
	212 (RMB map)		211 (RMB map)

Date/Depth processing

Lake water quality listing criteria is based on summer mean surface sample measurements. The summer index period is June 1st through September 30th. Only surface samples (0 meters) and surface composite (0-2 meters) samples recorded June 1 – September 30 were included in the TMDL report. Data from multiple stations were grouped to create a single dataset for each basin. All stations were used that appeared to be near the basin's deep hole. Samples were consolidated and averaged by day as some basins and stations had multiple surface measurements on the same day.

Secchi Depth

Year	Samples (N)				Average (meters)			
	L1	L2	L3	L4	L1	L2	L3	L4
1995	11	--	--	12	1.4	--	--	1.2
1996	12	--	--	13	1.7	--	--	1.4
1997	10	--	--	10	1.8	--	--	1.6
1998	--	--	--	12	--	--	--	1.2
1999	--	--	--	11	--	--	--	1.5
2000	--	--	--	11	--	--	--	1.5
2001	3	6	--	16	--	--	--	1.7
2002	--	6	--	17	--	--	--	1.7
2003	--	--	--	12	--	--	--	2.0
2004	--	5	--	9	--	1.4	--	1.9
2005	--	16	--	10	--	1.9	--	2.2
2006	--	12	--	16	--	1.0	--	1.0
2007	--	13	--	17	--	0.8	--	0.9
2008	--	8	--	16	--	1.3	--	1.3
2009	7	7	7	18	1.4	1.3	0.9	1.5
2010	--	9	9	9	2.4	2.3	1.3	2.5

Chlorophyll a

Year	Samples (N)				Average (µg/L)			
	L1	L2	L3	L4	L1	L2	L3	L4
1995	--	--	--	--	--	--	--	--
1996	--	--	--	--	--	--	--	--
1997	--	--	--	--	--	--	--	--
1998	--	--	--	--	--	--	--	--
1999	--	--	--	--	--	--	--	--
2000	--	--	--	--	--	--	--	--
2001	--	6	--	6	--	21	--	24
2002	--	7	--	7	--	29	--	26
2003	--	1	--	3	--	37	--	22
2004	--	3	--	2	--	57	--	65
2005	--	3	--	3	--	19	--	29
2006	--	3	--	3	--	14	--	12
2007	--	6	--	6	--	44	--	42
2008	--	4	--	3	--	36	--	28
2009	7	9	7	9	27	37	31	34
2010	9	9	9	9	16	17	19	18

Total Phosphorus

Year	Samples (N)				Average (µg/L)			
	L1	L2	L3	L4	L1	L2	L3	L4
1995	--	--	--	--	--	--	--	--
1996	--	--	--	--	--	--	--	--
1997	--	--	--	--	--	--	--	--
1998	--	--	--	--	--	--	--	--
1999	--	--	--	--	--	--	--	--
2000	--	--	--	--	--	--	--	--
2001	--	6	--	6	--	60	--	63
2002	--	7	--	7	--	73	--	77
2003	--	1	--	3	--	78	--	50
2004	--	3	--	2	--	64	--	66
2005	--	3	--	3	--	54	--	94
2006	--	4	--	4	--	32	--	27
2007	--	6	--	6	--	55	--	54
2008	--	4	--	3	--	52	--	52
2009	7.00	9	7	9	61	69	70	69
2010	9.00	9	9	9	55	57	52	47

TKN

Year	Samples (N)				Average (mg/L)			
	L1	L2	L3	L4	L1	L2	L3	L4
1995	--	--	--	--	--	--	--	--
1996	--	--	--	--	--	--	--	--
1997	--	--	--	--	--	--	--	--
1998	--	--	--	--	--	--	--	--
1999	--	--	--	--	--	--	--	--
2000	--	--	--	--	--	--	--	--
2001	--	--	--	--	--	--	--	--
2002	--	--	--	--	--	--	--	--
2003	--	--	--	--	--	--	--	--
2004	--	--	--	--	--	--	--	--
2005	--	--	--	--	--	--	--	--
2006	--	--	--	--	--	--	--	--
2007	--	--	--	--	--	--	--	--
2008	--	--	--	--	--	--	--	--
2009	7	8	7	8	1.31	1.24	1.35	1.28
2010	9	9	9	9	0.99	1.08	1.09	1.11

Appendix C

Algae Analysis with Biovolume Estimates

PhycoTech, Inc.
620 Broad Street - Suite 100 - St. Joseph - MI 49085 - Phone: 269-983-3654 - Fax: 269-983-3653
info@phycotech.com - www.phycotech.com

Algae Analysis with Biovolume Estimates

Report and Data Set

Customer ID: 137

Tracking Code: 090001-137 | **Sample ID:** RL 209 | **Replicate:** 1

Customer ID: 137 | **Sample Date:** 7/21/2009 | **Sample Level:** .

Job ID: 1 | **Station:** . | **Sample Depth:** 9.45

System Name: Rice Lake | **Site:** . | **Preservative:** Glutaraldehyde

Report Notes: 10:25

Division: Cyanophyta

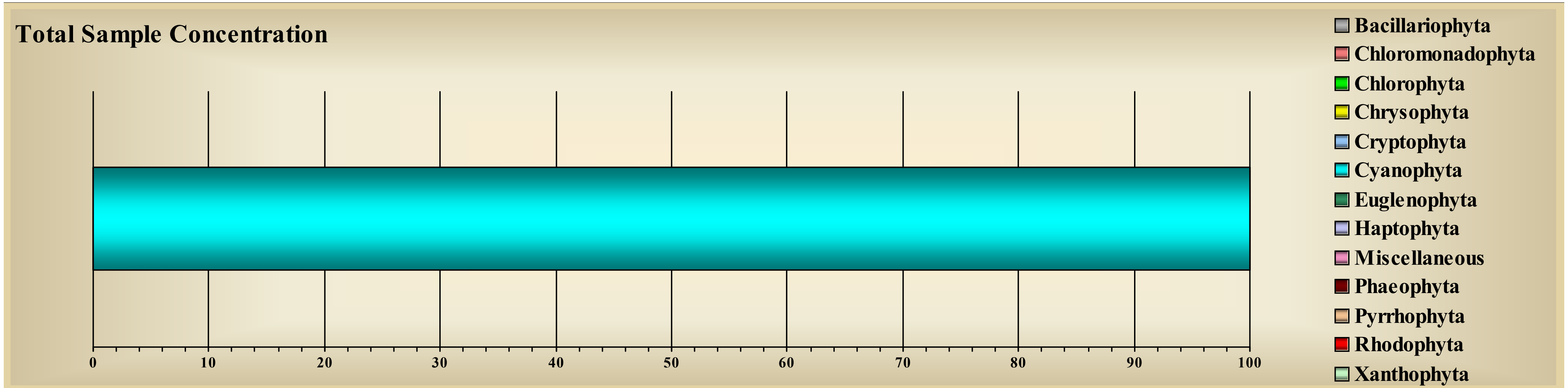
Taxa ID	Genus	Species	Subspecies	Variety	Form	Morph	Structure	GALD µm	Count NU/ml	Relative Count	Total Biovolume µm^3 /ml	Relative Total Biovolume
4282	**Chroococcaceae*	*spp*	.	.	.	<1 um spherical	Vegetative	0.80	32,851.452	2.68	8,807.474	0.00
4010	*Anabaena*	*spp*	.	.	.	.	Vegetative	55.00	18,175.390	1.48	33,624,143.018	3.66
4040	*Aphanizomenon*	*spp*	.	.	.	.	Vegetative	175.00	256,273.003	20.87	563,573,778.826	61.37
4094	*Coelosphaerium*	*spp*	.	.	.	.	Vegetative	5.00	55,434.940	4.51	1,306,152.520	0.14
4090	*Coelosphaerium*	*spp*	.	.	.	.	Vegetative	150.00	908.770	0.07	4,282,475.458	0.47
4267	*Microcystis*	*spp*	.	.	.	.	Vegetative	3.70	616,145.730	50.18	17,066,250.889	1.86
4260	*Microcystis*	*spp*	.	.	.	.	Vegetative	97.75	69,066.483	5.62	292,253,994.067	31.82
4170	*Oscillatoria*	*spp*	.	.	.	.	Vegetative	59.50	49,073.554	4.00	5,159,848.621	0.56
4190	*Phormidium*	*spp*	.	.	.	.	Vegetative	16.50	78,154.178	6.36	1,012,807.810	0.11
4323	*Synechococcus*	*sp. 1*	.	.	.	< 1um ovoid	Vegetative	1.20	16,425.726	1.34	6,604.785	0.00
4285	*Synechocystis*	*spp*	.	.	.	>1 um spherical	Vegetative	1.50	35,442.011	2.89	62,629.578	0.01

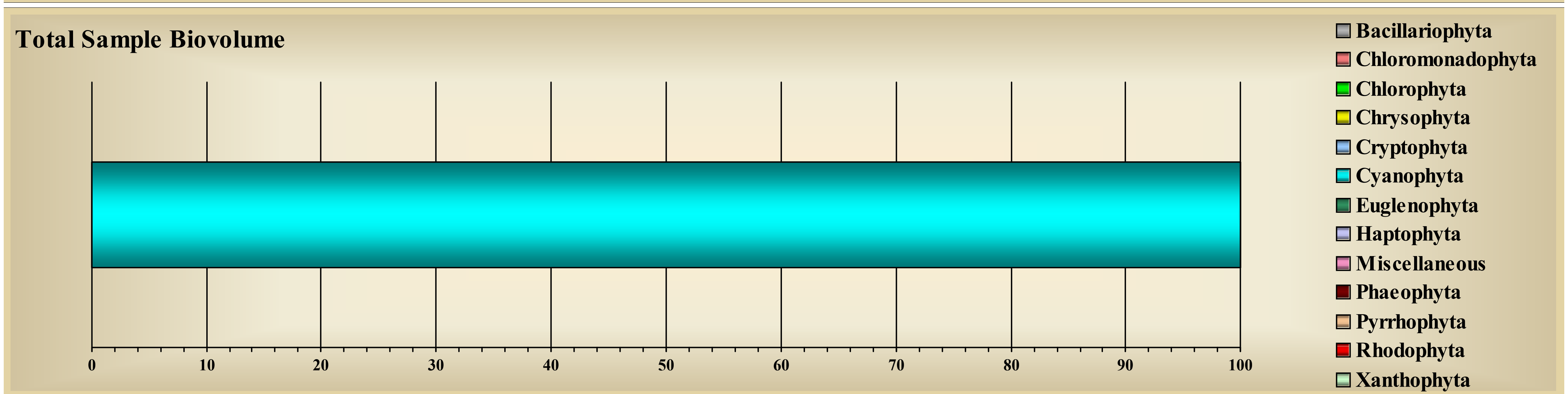
Summary for Division ~ Cyanophyta (11 detail records)

Sum Total Cyanophyta 1,227,951.237 | 100.00 | 918,357,493.045 | 100.00

Total Sample Concentration	Total Sample Biovolume
1,227,951.237	918,357,493.045
NU/ml	µm^3 /ml

SUMMARY GRAPHICS





Tracking Code: 090002-137 | **Sample ID:** RL 203 | **Replicate:** 1

Customer ID: 137 | **Sample Date:** 7/21/2009 | **Sample Level:** .

Job ID: 1 | **Station:** . | **Sample Depth:** 9.14

System Name: Rice Lake | **Site:** . | **Preservative:** Glutaraldehyde

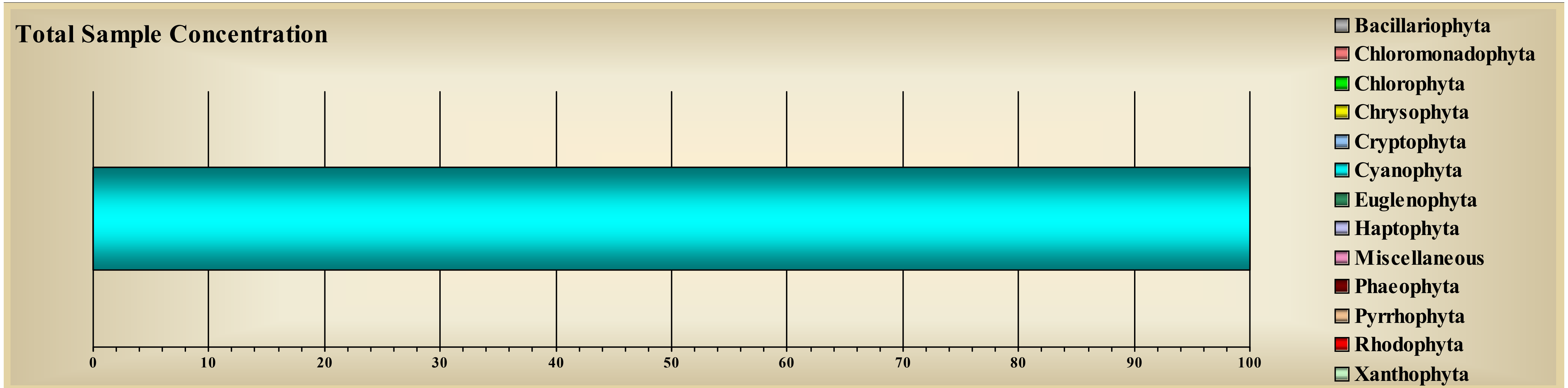
Report Notes: 11:40

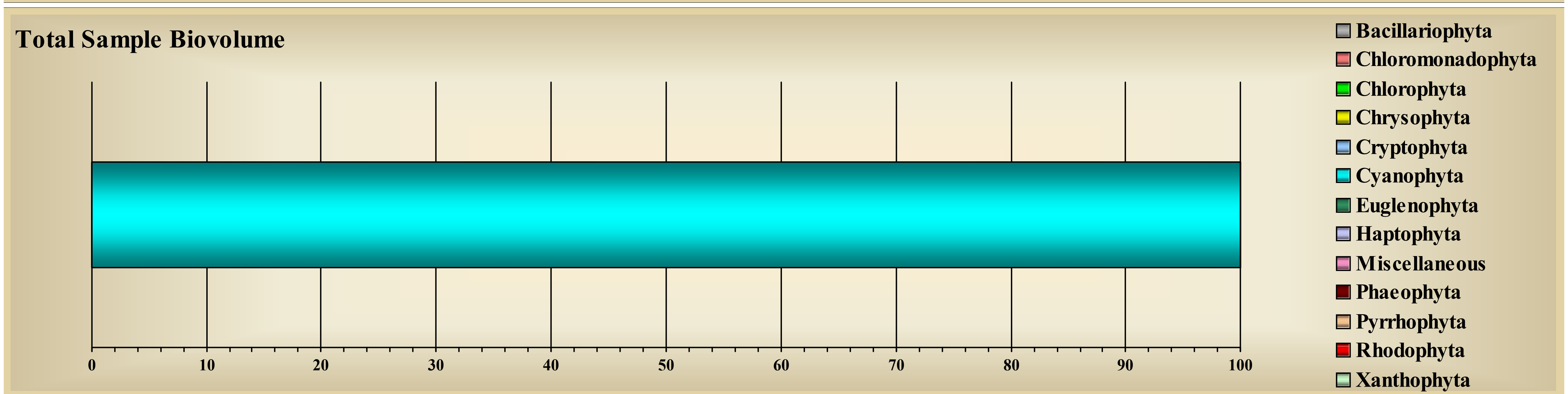
Division: Cyanophyta

Taxa ID	Genus	Species	Subspecies	Variety	Form	Morph	Structure	GALD µm	Count NU/ml	Relative Count	Total Biovolume µm^3 /ml	Relative Total Biovolume
4282	**Chroococcaceae*	*spp*	.	.	.	<1 um spherical	Vegetative	0.80	114,980.083	12.70	30,826.160	0.01
4010	*Anabaena*	*spp*	.	.	.	.	Vegetative	90.40	24,082.392	2.66	94,889,092.169	16.54
4040	*Aphanizomenon*	*spp*	.	.	.	.	Vegetative	178.53	171,757.438	18.96	385,340,560.309	67.18
4094	*Coelosphaerium*	*spp*	.	.	.	.	Vegetative	5.00	10,905.234	1.20	256,948.037	0.04
4090	*Coelosphaerium*	*spp*	.	.	.	.	Vegetative	160.00	454.385	0.05	3,211,856.594	0.56
4260	*Microcystis*	*spp*	.	.	.	.	Vegetative	46.36	72,247.176	7.98	76,616,533.813	13.36
4267	*Microcystis*	*spp*	.	.	.	.	Vegetative	3.60	291,715.014	32.21	7,514,899.641	1.31
4170	*Oscillatoria*	*spp*	.	.	.	.	Vegetative	69.33	42,257.782	4.67	5,177,512.237	0.90
4190	*Phormidium*	*spp*	.	.	.	.	Vegetative	14.00	41,803.398	4.62	459,653.439	0.08
4323	*Synechococcus*	*sp. 1*	.	.	.	< 1um ovoid	Vegetative	1.20	123,192.946	13.60	49,535.884	0.01
4285	*Synechocystis*	*spp*	.	.	.	>1 um spherical	Vegetative	1.50	12,268.388	1.35	21,679.469	0.00
Summary for Division ~ Cyanophyta (11 detail records)							**Sum Total Cyanophyta**		905,664.237	100.00	573,569,097.751	100.00

Total Sample Concentration	Total Sample Biovolume
905,664.237	573,569,097.751
NU/ml	µm^3 /ml

SUMMARY GRAPHICS





Tracking Code: 090003-137 | **Sample ID:** L3 Rice Lk | **Replicate:** 1

Customer ID: 137 | **Sample Date:** 8/25/2009 | **Sample Level:** .

Job ID: 1 | **Station:** . | **Sample Depth:** 0

System Name: Rice Lake | **Site:** . | **Preservative:** Glutaraldehyde

Report Notes: 12:20

Division: Bacillariophyta

Taxa ID	Genus	Species	Subspecies	Variety	Form	Morph	Structure	GALD µm	Count NU/ml	Relative Count	Total Biovolume µm^3 /ml	Relative Total Biovolume
1430	*Aulacoseira*	*spp*	.	.	.	.	Vegetative	154.67	454.385	0.08	2,067,008.163	18.99
1220	*Nitzschia*	*spp*	.	.	.	.	Vegetative	80.00	151.462	0.03	685,196.067	6.29
1000404	*Stephanodiscus*	*sp. 2*	.	.	.	<= 8 um	Vegetative	7.00	302.923	0.05	43,300.595	0.40
1310	*Synedra*	*spp*	.	.	.	.	Vegetative	52.00	302.923	0.05	96,783.953	0.89
Summary for Division ~ Bacillariophyta (4 detail records)							**Sum Total Bacillariophyta**		1,211.693	0.21	2,892,288.779	26.57

Division: Chlorophyta

Taxa ID	Genus	Species	Subspecies	Variety	Form	Morph	Structure	GALD µm	Count NU/ml	Relative Count	Total Biovolume µm^3 /ml	Relative Total Biovolume
2080	*Chlamydomonas*	*spp*	.	.	.	.	Vegetative	6.00	151.462	0.03	11,895.763	0.11
2330	*Micractinium*	*spp*	.	.	.	.	Vegetative	40.00	151.462	0.03	81,208.416	0.75
8044	*Monoraphidium*	*spp*	.	.	.	.	Vegetative	4.00	605.846	0.11	4,732.145	0.04
2380	*Pediastrum*	*spp*	.	.	.	.	Vegetative	40.00	151.462	0.03	38,893.109	0.36
2490	*Schroederia*	*spp*	.	.	.	.	Vegetative	23.00	757.308	0.13	12,847.426	0.12
Summary for Division ~ Chlorophyta (5 detail records)							**Sum Total Chlorophyta**		1,817.539	0.32	149,576.858	1.37

Division: Chrysophyta

Taxa ID	Genus	Species	Subspecies	Variety	Form	Morph	Structure	GALD µm	Count NU/ml	Relative Count	Total Biovolume µm^3 /ml	Relative Total Biovolume
1120	*Dinobryon*	*spp*	.	.	.	.	Vegetative	30.00	151.462	0.03	11,895.763	0.11
☑ 1730	*Erkenia*	*spp*	.	.	.	.	Vegetative	4.00	2,120.462	0.37	64,129.350	0.59

Summary for Division ~ Chrysophyta (2 detail records) **Sum Total Chrysophyta** 2,271.924 0.40 76,025.113 0.70

Division: Cryptophyta

Taxa ID	Genus	Species	Subspecies	Variety	Form	Morph	Structure	GALD µm	Count NU/ml	Relative Count	Total Biovolume µm^3 /ml	Relative Total Biovolume
3010	*Cryptomonas*	*spp*	.	.	.	.	Vegetative	15.09	3,029.232	0.53	1,060,092.966	9.74
3043	*Rhodomonas*	*minuta*	.	nannoplanctica	.	.	Vegetative	6.67	5,907.002	1.04	189,698.048	1.74

Summary for Division ~ Cryptophyta (2 detail records) **Sum Total Cryptophyta** 8,936.234 1.58 1,249,791.014 11.48

Division: Cyanophyta

Taxa ID	Genus	Species	Subspecies	Variety	Form	Morph	Structure	GALD µm	Count NU/ml	Relative Count	Total Biovolume µm^3 /ml	Relative Total Biovolume
4282	**Chroococcaceae*	*spp*	.	.	.	<1 um spherical	Vegetative	0.80	287,450.208	50.72	77,065.401	0.71
4010	*Anabaena*	*spp*	.	.	.	.	Vegetative	120.00	151.462	0.03	494,863.835	4.55
4040	*Aphanizomenon*	*spp*	.	.	.	.	Vegetative	193.33	757.308	0.13	1,839,878.323	16.90
4056	*Aphanocapsa*	*spp*	.	.	.	<1 um spherical	Vegetative	30.00	1,817.539	0.32	57,099.624	0.52
4060	*Aphanothece*	*spp*	.	.	.	.	Vegetative	30.00	454.385	0.08	6,185.812	0.06
4094	*Coelosphaerium*	*spp*	.	.	.	.	Vegetative	5.00	2,044.731	0.36	48,177.757	0.44
4090	*Coelosphaerium*	*spp*	.	.	.	.	Vegetative	60.00	21.945	0.00	27,921.198	0.26
10650	*Cyanogranis*	*spp*	.	.	.	.	Vegetative	5.60	18,068.299	3.19	43,593.384	0.40
4160	*Merismopedia*	*spp*	.	.	.	.	Vegetative	17.33	1,817.539	0.32	6,344.484	0.06
4260	*Microcystis*	*spp*	.	.	.	.	Vegetative	100.29	1,060.231	0.19	2,567,740.513	23.59

4267	*Microcystis*	*spp*	.	.	.	.	Vegetative	4.00	34,078.857	6.01	1,141,992.713	10.49
4170	*Oscillatoria*	*spp*	.	.	.	.	Vegetative	100.00	151.462	0.03	26,765.474	0.25
4190	*Phormidium*	*spp*	.	.	.	.	Vegetative	15.20	4,695.309	0.83	56,053.070	0.51
4320	*Synechococcus*	*spp*	.	.	.	.	Vegetative	3.00	15,676.274	2.77	24,624.291	0.23
4323	*Synechococcus*	*sp. 1*	.	.	.	< 1um ovoid	Vegetative	1.20	180,682.988	31.88	72,652.629	0.67
☑ 4285	*Synechocystis*	*spp*	.	.	.	>1 um spherical	Vegetative	1.50	3,407.886	0.60	6,022.075	0.06

Summary for Division ~ Cyanophyta (16 detail records) **Sum Total Cyanophyta** 552,336.421 97.46 6,496,980.584 59.69

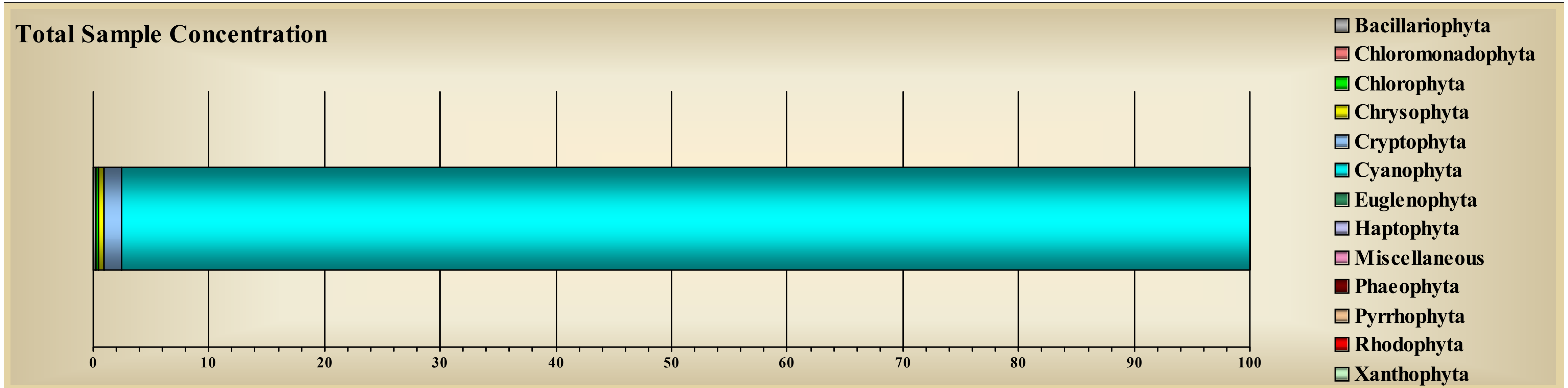
Division: Pyrrhophyta

Taxa ID	Genus	Species	Subspecies	Variety	Form	Morph	Structure	GALD µm	Count NU/ml	Relative Count	Total Biovolume µm^3 /ml	Relative Total Biovolume
6033	*Gymnodinium*	*sp. 2*	.	.	.	.	Vegetative	16.00	21.945	0.00	9,192.164	0.08
6034	*Gymnodinium*	*sp. 3*	.	.	.	.	Vegetative	8.00	151.462	0.03	11,419.931	0.10

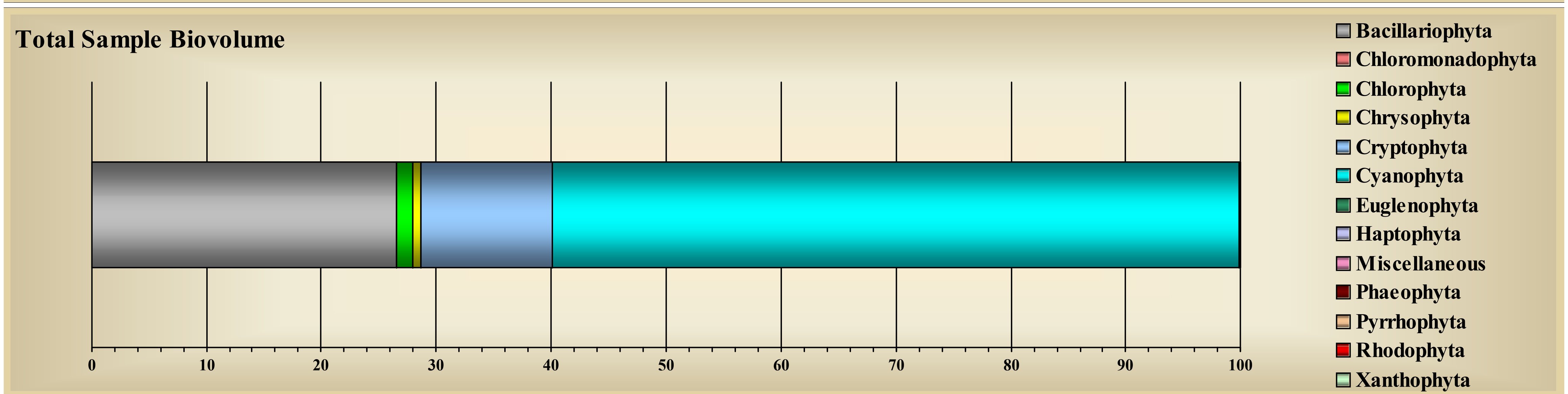
Summary for Division ~ Pyrrhophyta (2 detail records) **Sum Total Pyrrhophyta** 173.406 0.03 20,612.095 0.19

Total Sample Concentration	Total Sample Biovolume
566,747.216	10,885,274.442
NU/ml	µm^3 /ml

S U M M A R Y



G R A P H I C S



Tracking Code:	090004-137	**Sample ID:**	L2 Rice Lk	**Replicate:**	1
Customer ID:	137	**Sample Date:**	8/25/2009	**Sample Level:**	.
Job ID:	1	**Station:**	.	**Sample Depth:**	0
System Name:	Rice Lake	**Site:**	.	**Preservative:**	Glutaraldehyde
Report Notes:	11:00				

Division: Bacillariophyta

Taxa ID	Genus	Species	Subspecies	Variety	Form	Morph	Structure	GALD µm	Count NU/ml	Relative Count	Total Biovolume µm^3 /ml	Relative Total Biovolume
1430	*Aulacoseira*	*spp*	.	.	.	.	Vegetative	200.00	60.585	0.03	342,598.037	9.17
1220	*Nitzschia*	*spp*	.	.	.	.	Vegetative	60.00	60.585	0.03	8,564.953	0.23
1000404	*Stephanodiscus*	*sp. 2*	.	.	.	<= 8 um	Vegetative	8.00	181.754	0.10	36,543.785	0.98
Summary for Division ~ Bacillariophyta (3 detail records)							**Sum Total Bacillariophyta**		302.923	0.16	387,706.774	10.38

Division: Chlorophyta

Taxa ID	Genus	Species	Subspecies	Variety	Form	Morph	Structure	GALD µm	Count NU/ml	Relative Count	Total Biovolume µm^3 /ml	Relative Total Biovolume
2080	*Chlamydomonas*	*spp*	.	.	.	.	Vegetative	6.00	60.585	0.03	6,402.778	0.17
2250	*Eudorina*	*spp*	.	.	.	.	Vegetative	40.00	8.778	0.00	16,990.061	0.45
2330	*Micractinium*	*spp*	.	.	.	.	Vegetative	20.00	60.585	0.03	8,120.843	0.22
8044	*Monoraphidium*	*spp*	.	.	.	.	Vegetative	4.00	302.923	0.16	2,366.072	0.06
2490	*Schroederia*	*spp*	.	.	.	.	Vegetative	17.33	302.923	0.16	3,616.327	0.10
2640	*Sphaerocystis*	*spp*	.	.	.	.	Vegetative	10.00	60.585	0.03	13,703.923	0.37
Summary for Division ~ Chlorophyta (6 detail records)							**Sum Total Chlorophyta**		796.378	0.43	51,200.005	1.37

Division: Chrysophyta

Taxa ID	Genus	Species	Subspecies	Variety	Form	Morph	Structure	GALD µm	Count NU/ml	Relative Count	Total Biovolume µm^3 /ml	Relative Total Biovolume
1120	*Dinobryon*	*spp*	.	.	.	.	Vegetative	40.00	60.585	0.03	6,344.411	0.17
☑ 1730	*Erkenia*	*spp*	.	.	.	.	Vegetative	4.00	181.754	0.10	5,496.802	0.15

Summary for Division ~ Chrysophyta (2 detail records) **Sum Total Chrysophyta** 242.339 0.13 11,841.212 0.32

Division: Cryptophyta

Taxa ID	Genus	Species	Subspecies	Variety	Form	Morph	Structure	GALD µm	Count NU/ml	Relative Count	Total Biovolume µm^3 /ml	Relative Total Biovolume
3010	*Cryptomonas*	*spp*	.	.	.	.	Vegetative	17.33	242.339	0.13	138,054.327	3.69
3043	*Rhodomonas*	*minuta*	.	nannoplanctica	.	.	Vegetative	8.50	1,211.693	0.65	40,604.185	1.09

Summary for Division ~ Cryptophyta (2 detail records) **Sum Total Cryptophyta** 1,454.031 0.78 178,658.513 4.78

Division: Cyanophyta

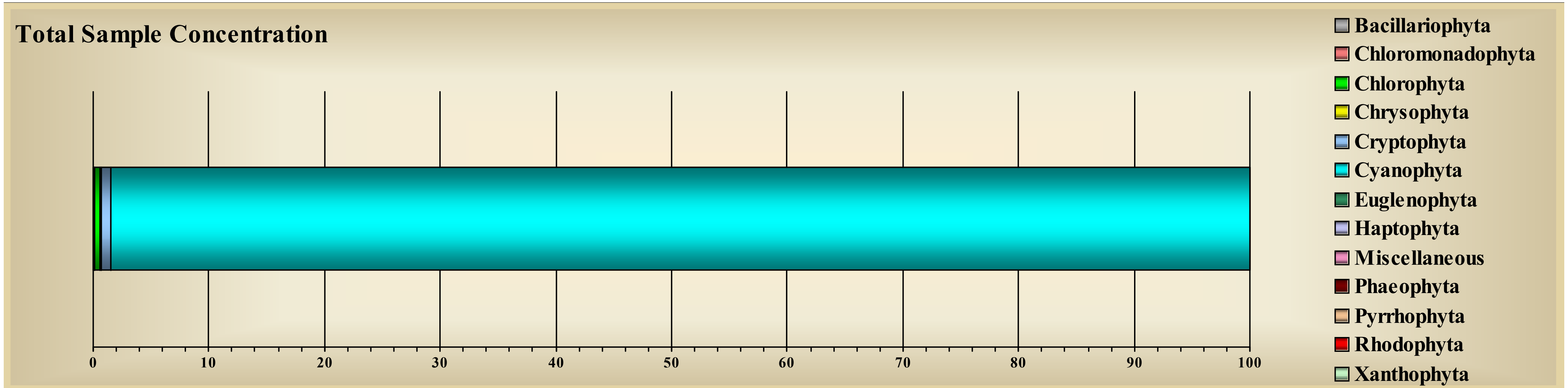
Taxa ID	Genus	Species	Subspecies	Variety	Form	Morph	Structure	GALD µm	Count NU/ml	Relative Count	Total Biovolume µm^3 /ml	Relative Total Biovolume
4282	**Chroococcaceae*	*spp*	.	.	.	<1 um spherical	Vegetative	0.80	91,984.066	49.53	24,660.928	0.66
4010	*Anabaena*	*spp*	.	.	.	.	Vegetative	92.00	60.585	0.03	229,153.358	6.13
4040	*Aphanizomenon*	*spp*	.	.	.	.	Vegetative	165.82	545.262	0.29	1,136,179.651	30.41
4056	*Aphanocapsa*	*spp*	.	.	.	<1 um spherical	Vegetative	30.00	181.754	0.10	4,758.299	0.13
4060	*Aphanothece*	*spp*	.	.	.	.	Vegetative	30.00	60.585	0.03	380.665	0.01
4094	*Coelosphaerium*	*spp*	.	.	.	.	Vegetative	5.00	545.262	0.29	12,847.402	0.34
4090	*Coelosphaerium*	*spp*	.	.	.	.	Vegetative	110.00	60.585	0.03	235,536.149	6.30
10650	*Cyanogranis*	*spp*	.	.	.	.	Vegetative	6.00	8,760.387	4.72	23,017.918	0.62
4160	*Merismopedia*	*spp*	.	.	.	.	Vegetative	20.40	363.508	0.20	1,598.780	0.04
4267	*Microcystis*	*spp*	.	.	.	.	Vegetative	4.20	16,176.097	8.71	645,397.167	17.27

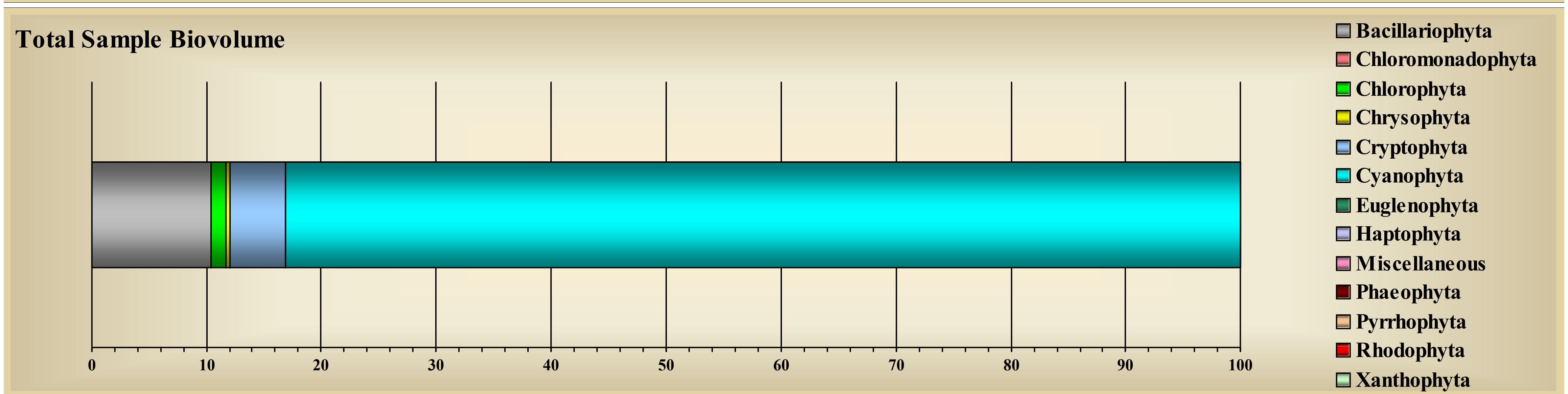
4260	*Microcystis*	*spp*	.	.	.	.	Vegetative	43.00	363.508	0.20	708,606.921	18.96
4190	*Phormidium*	*spp*	.	.	.	.	Vegetative	10.00	5,997.879	3.23	47,107.340	1.26
4320	*Synechococcus*	*spp*	.	.	.	.	Vegetative	3.00	7,270.156	3.91	11,419.961	0.31
4323	*Synechococcus*	*sp. 1*	.	.	.	< 1um ovoid	Vegetative	1.20	45,992.033	24.77	18,493.397	0.49
4285	*Synechocystis*	*spp*	.	.	.	>1 um spherical	Vegetative	1.50	4,543.848	2.45	8,029.433	0.21

Summary for Division ~ Cyanophyta (15 detail records) **Sum Total Cyanophyta** 182,905.513 98.49 3,107,187.368 83.16

Total Sample Concentration	Total Sample Biovolume
185,701.184	3,736,593.872
NU/ml	µm^3 /ml

SUMMARY GRAPHICS





Species List

Division: Bacillariophyta

Taxa ID	Genus	Species	Subspecies	Variety	Form	Morph	Structure	Authority
1430	Aulacoseira	spp	.	.	.	.	Vegetative	Thwaites
1220	Nitzschia	spp	.	.	.	.	Vegetative	Hassall
1000404	Stephanodiscus	sp. 2	.	.	.	<= 8 um	Vegetative	Ehrenberg
1310	Synedra	spp	.	.	.	.	Vegetative	Ehrenberg

Division: Chlorophyta

Taxa ID	Genus	Species	Subspecies	Variety	Form	Morph	Structure	Authority
2080	Chlamydomonas	spp	.	.	.	.	Vegetative	Ehrenberg
2250	Eudorina	spp	.	.	.	.	Vegetative	(Shaw) Goldstein
2330	Micractinium	spp	.	.	.	.	Vegetative	Tiffany and Ahlstrom
8044	Monoraphidium	spp	.	.	.	.	Vegetative	(Thurs.) Kom.
2380	Pediastrum	spp	.	.	.	.	Vegetative	(Ehrenberg) Meneg.
2490	Schroederia	spp	.	.	.	.	Vegetative	G. M. Smith
2640	Sphaerocystis	spp	.	.	.	.	Vegetative	Chodat

Division: Chrysophyta

Taxa ID	Genus	Species	Subspecies	Variety	Form	Morph	Structure	Authority
1120	Dinobryon	spp	.	.	.	.	Vegetative	Ehrenberg
1730	Erkenia	spp	.	.	.	.	Vegetative	Skuja

Division: Cryptophyta

Taxa ID	Genus	Species	Subspecies	Variety	Form	Morph	Structure	Authority
3010	Cryptomonas	spp	.	.	.	.	Vegetative	Ehrenberg .
3043	Rhodomonas	minuta	.	nannoplanctica	.	.	Vegetative	Skuja

Division: Cyanophyta

Taxa ID	Genus	Species	Subspecies	Variety	Form	Morph	Structure	Authority
4282	*Chroococcaceae	spp	.	.	.	<1 um spherical	Vegetative	N/A
4010	Anabaena	spp	.	.	.	.	Vegetative	Bory
4040	Aphanizomenon	spp	.	.	.	.	Vegetative	J. Ralfs Ex Bornet and Flah.
4056	Aphanocapsa	spp	.	.	.	<1 um spherical	Vegetative	West & West
4060	Aphanothece	spp	.	.	.	.	Vegetative	West and West 1912
4090	Coelosphaerium	spp	.	.	.	.	Vegetative	Lemmermann
4094	Coelosphaerium	spp	.	.	.	.	Vegetative	Lemmermann
10650	Cyanogranis	spp	.	.	.	.	Vegetative	Hindak
4160	Merismopedia	spp	.	.	.	.	Vegetative	Thompson
4260	Microcystis	spp	.	.	.	.	Vegetative	(Kutzing) Lemmermann
4267	Microcystis	spp	.	.	.	.	Vegetative	(Kutzing) Lemmermann
4170	Oscillatoria	spp	.	.	.	.	Vegetative	Gomont
4190	Phormidium	spp	.	.	.	.	Vegetative	Lemmermann
4320	Synechococcus	spp	.	.	.	.	Vegetative	(Nageli) Elenkin .
4323	Synechococcus	sp. 1	.	.	.	< 1um ovoid	Vegetative	Nageli
4285	Synechocystis	spp	.	.	.	>1 um spherical	Vegetative	N/A

Division: Pyrrhophyta

Taxa ID	Genus	Species	Subspecies	Variety	Form	Morph	Structure	Authority
6033	Gymnodinium	sp. 2	.	.	.	.	Vegetative	Stein
6034	Gymnodinium	sp. 3	.	.	.	.	Vegetative	Stein

Appendix D

Zooplankton Sample Results

Rice Lake Zooplankton Site L2 8/25/2009

SAMPLE	ri89l2
DEVICE	VHAUL
MOUTH DIAM (cm)	12
MESH SIZE (um)	80
HAUL DEPTH (m)	7
SUBSAMP VOL (ml)	5
TOT VOL (ml)	100

SPECIES	**DENSITY**	**BIOMASS**	**NUMBER**	**WEIGHT**	**MEAN WEIGHT**	**MEAN LENGTH**	**COUNT**
Copepods	**#/L**	**ug/L**	**%**	**%**	**ug**	**mm**	
nauplii	8.34	1.45	19.76	0.54	0.17	0.19	33
copepodites	5.05	8.49	11.98	3.20	1.68	0.55	20
calanoids	10.11	74.58	23.95	28.07	7.38	1.09	40
cyclopoids	3.03	25.40	7.19	9.56	8.38	1.08	12
Total copepods	26.53	109.92	62.88	41.37			105
Cladocerans							
Daphnia galeata mendotae	6.32	59.12	14.97	22.25	9.36	1.15	25
Daphnia retrocurva	0.76	3.80	1.80	1.43	5.01	1.11	3
Daphnia pulicaria	6.57	84.01	15.57	31.61	12.79	1.22	26
Chydorus sphaericus	0.25	0.23	0.60	0.09	0.91	0.25	1
Diaphanosoma birgei	1.77	8.65	4.19	3.26	4.89	0.97	7
Total cladocerans	15.66	155.81	37.13	58.64			62
Grand Total	**42.19**	**265.72**	**100.01**	**100.01**			**167**

Rice Lake Zooplankton Site L3 8/25/2009

SAMPLE	ri89l3
DEVICE	VHAUL
MOUTH DIAM (cm)	12
MESH SIZE (um)	80
HAUL DEPTH (m)	2
SUBSAMP VOL (ml)	5
TOT VOL (ml)	100

SPECIES	**DENSITY**	**BIOMASS**	**NUMBER**	**WEIGHT**	**MEAN WEIGHT**	**MEAN LENGTH**	**COUNT**
Copepods	**#/L**	**ug/L**	**%**	**%**	**ug**	**mm**	
nauplii	20.34	3.21	46.00	1.96	0.16	0.18	23
copepodites	5.31	5.54	12.00	3.39	1.04	0.42	6
calanoids	5.31	40.24	12.00	24.62	7.59	1.11	6
cyclopoids	6.19	28.41	14.00	17.38	4.59	0.88	7
Total copepods	37.14	77.40	84.00	47.35			42
Cladocerans							
Daphnia galeata mendotae	2.65	41.50	6.00	25.38	15.64	1.60	3
Daphnia pulicaria	1.77	36.28	4.00	22.19	20.51	1.46	2
Chydorus sphaericus	0.88	0.70	2.00	0.43	0.79	0.23	1
Diaphanosoma birgei	1.77	7.62	4.00	4.66	4.31	0.86	2
Total cladocerans	7.07	86.09	16.00	52.66			8
Grand Total	**44.21**	**163.49**	**100.00**	**100.01**			**50**

Rice Lake Zooplankton Site 203 7/21/2009

SAMPLE	ri79203
DEVICE	VHAUL
MOUTH DIAM (cm)	12
MESH SIZE (um)	80
HAUL DEPTH (m)	9
SUBSAMP VOL (ml)	5
TOT VOL (ml)	100

SPECIES	**DENSITY**	**BIOMASS**	**NUMBER**	**WEIGHT**	**MEAN WEIGHT**	**MEAN LENGTH**	**COUNT**
Copepods	**#/L**	**ug/L**	**%**	**%**	**ug**	**mm**	
nauplii	10.02	1.95	31.88	0.73	0.19	0.20	51
copepodites	3.54	4.78	11.25	1.78	1.35	0.49	18
calanoids	6.09	68.73	19.38	25.62	11.28	1.36	31
cyclopoids	1.77	12.97	5.63	4.84	7.34	1.03	9
Total copepods	21.42	88.43	68.14	32.97			109
Cladocerans							
Daphnia galeata mendotae	2.95	29.48	9.38	10.99	10.00	1.20	15
Daphnia retrocurva	0.20	0.89	0.63	0.33	4.55	1.07	1
Daphnia pulicaria	6.68	149.19	21.25	55.61	22.33	1.50	34
Chydorus sphaericus	0.20	0.29	0.63	0.11	1.50	0.32	1
Total cladocerans	10.02	179.86	31.89	67.04			51
Grand Total	**31.44**	**268.29**	**100.03**	**100.01**			**160**

Rice Lake Zooplankton Site 209 7/21/2009

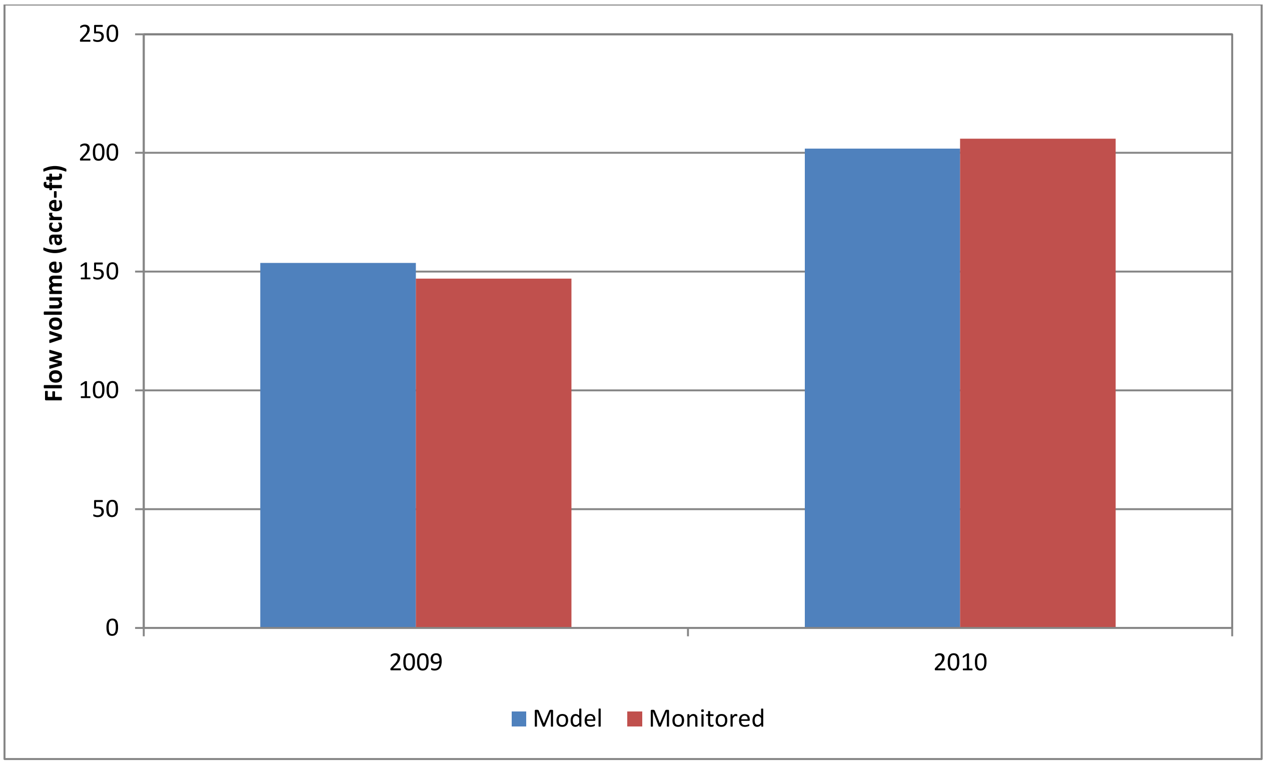
SAMPLE	ri79209
DEVICE	VHAUL
MOUTH DIAM (cm)	12
MESH SIZE (um)	80
HAUL DEPTH (m)	9
SUBSAMP VOL (ml)	5
TOT VOL (ml)	100

SPECIES	**DENSITY**	**BIOMASS**	**NUMBER**	**WEIGHT**	**MEAN WEIGHT**	**MEAN LENGTH**	**COUNT**
Copepods	**#/L**	**ug/L**	**%**	**%**	**ug**	**mm**	
nauplii	9.04	2.06	28.75	1.07	0.23	0.22	46
copepodites	3.54	5.27	11.25	2.76	1.49	0.52	18
calanoids	6.88	66.22	21.88	34.63	9.63	1.25	35
cyclopoids	1.18	3.91	3.75	2.05	3.32	0.79	6
Total copepods	20.63	77.46	65.63	40.51			105
Cladocerans							
Daphnia galeata mendotae	4.13	34.09	13.13	17.83	8.26	1.06	21
Daphnia retrocurva	0.39	0.78	1.25	0.41	1.99	0.79	2
Daphnia pulicaria	6.09	78.44	19.38	41.02	12.88	1.22	31
Diaphanosoma birgei	0.20	0.45	0.63	0.24	2.29	0.47	1
Total cladocerans	10.81	113.76	34.39	59.50			55
Grand Total	**31.44**	**191.22**	**100.02**	**100.01**			**160**

Appendix E

Fisher’s Resort Watershed Hydrologic Model Calibration

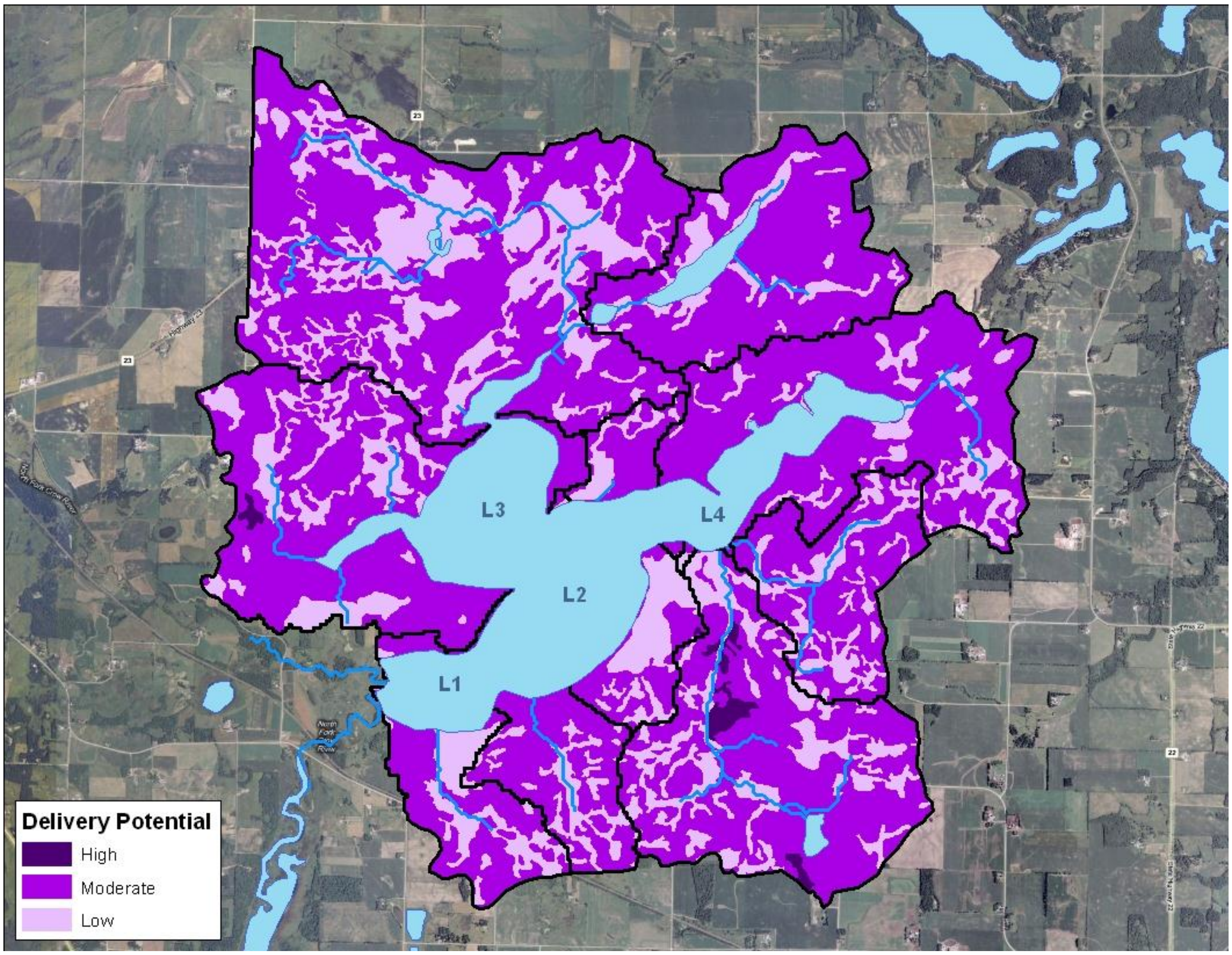
Appendix E: Fisher's Resort Watershed Hydrologic Model Calibration



Appendix F

Rice Lake Direct Watershed Soil Delivery Potential

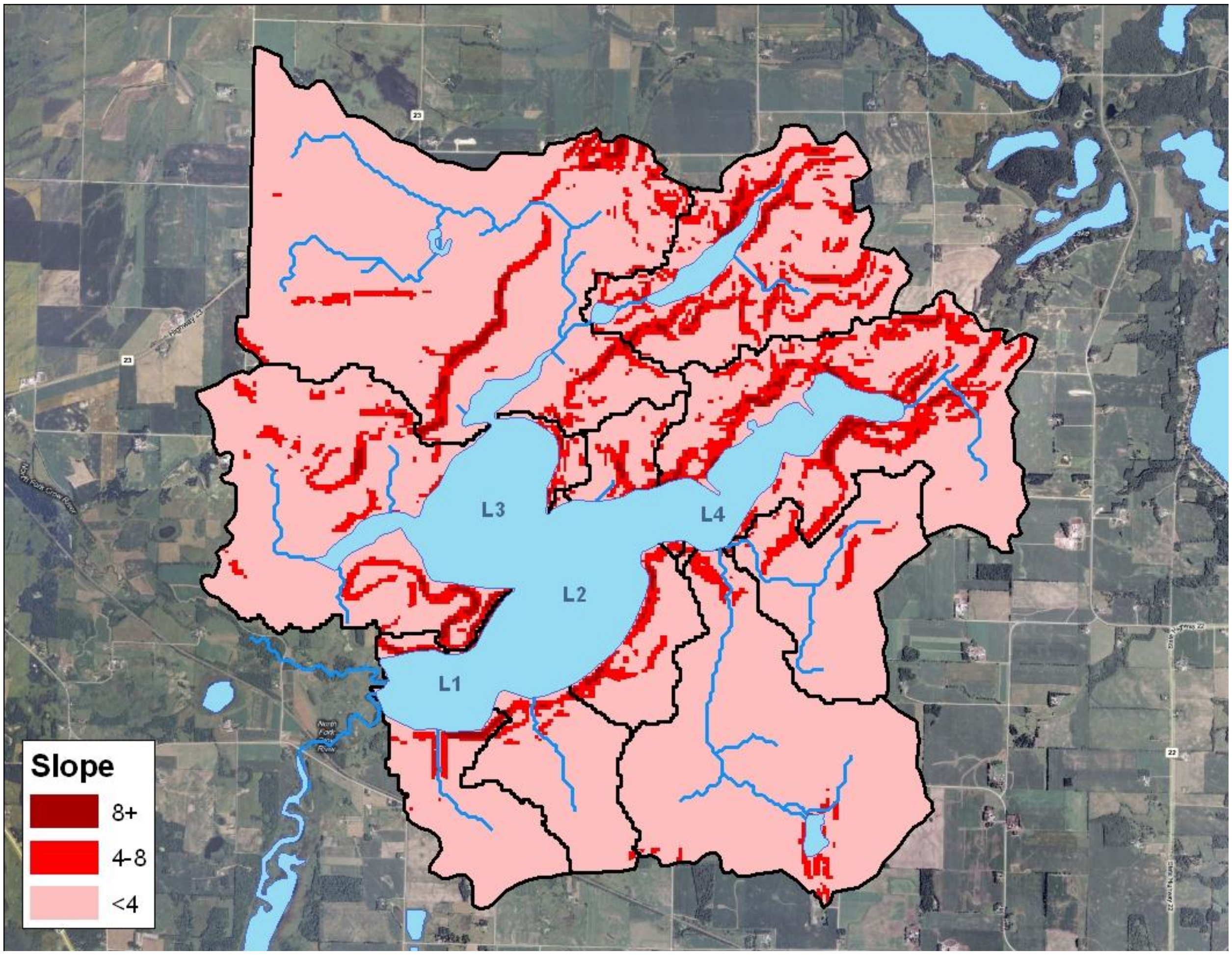
Appendix F: Rice Lake Direct Watershed Soil Delivery Potential



Appendix G

Rice Lake Direct Watershed Land Slope

Appendix G: Rice Lake Direct Watershed Land Slope



Appendix H

Phosphorus Loading Rates Used for Unit Area Load Model

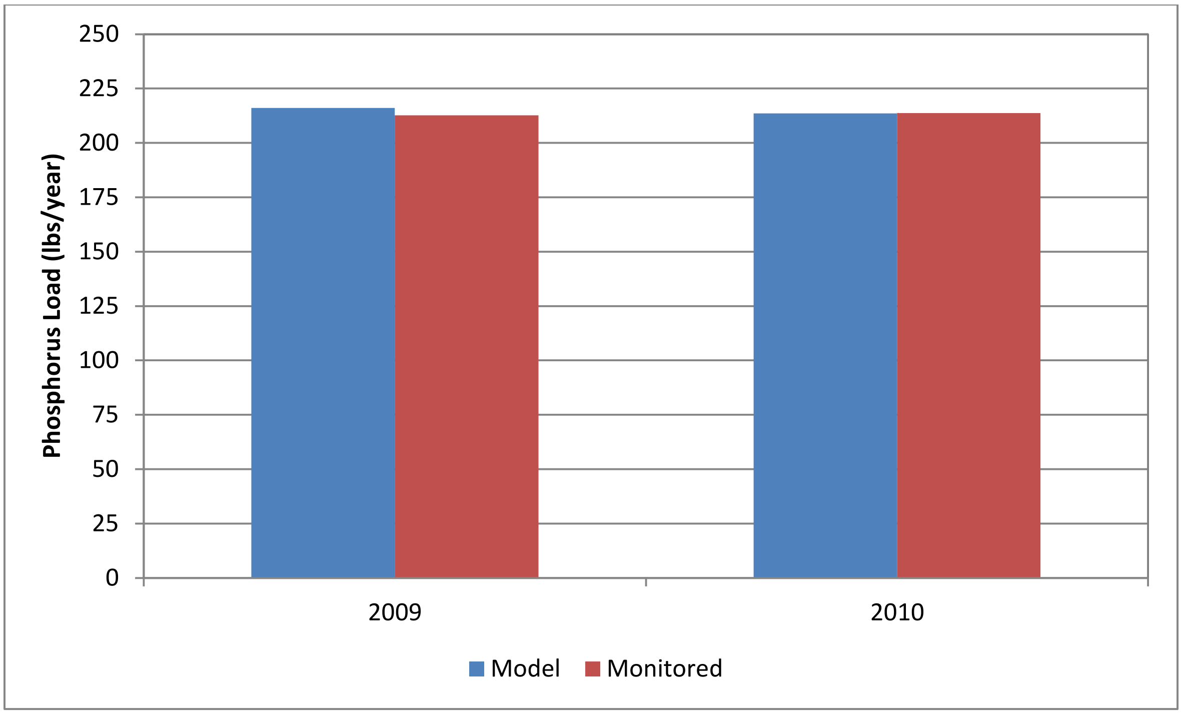
Appendix H: Phosphorus Loading Rates used for Unit Area Load Model

Land Use	Slope	Delivery	Phosphorus load (lbs/acre/year)
General Agriculture	<4	High	0.22
	4-8	High	0.34
	8+	High	0.34
	<4	Low	0.11
	4-8	Low	0.11
	8+	Low	0.22
	<4	Medium	0.22
	4-8	Medium	0.34
	8+	Medium	0.34
Alfalfa	<4	High	0.13
	4-8	High	0.21
	8+	High	0.21
	<4	Low	0.11
	4-8	Low	0.11
	8+	Low	0.13
	<4	Medium	0.13
	4-8	Medium	0.21
	8+	Medium	0.21
Grass/Lawn			0.06
Commercial			0.41
Corn/Soybean	<4	High	0.47
	4-8	High	0.65
	8+	High	0.65
	<4	Low	0.19
	4-8	Low	0.47
	8+	Low	0.65
	<4	Medium	0.47
	4-8	Medium	0.65
	8+	Medium	0.65
Forest			0.03
High Intensity Developed			0.41
Industrial			0.41
Low Intensity Developed			0.03
Medium Intensity Developed			0.31
Pasture	<4	High	0.05
	4-8	High	0.19
	8+	High	0.19
	<4	Low	0.03
	4-8	Low	0.05
	8+	Low	0.19
	<4	Medium	0.03
	4-8	Medium	0.05
	8+	Medium	0.19
Transportation/Roads			0.21
Institutional			0.31
Water			0.00
Wetland			0.00

Appendix I

Fisher's Resort Watershed Unit Area Load Calibration

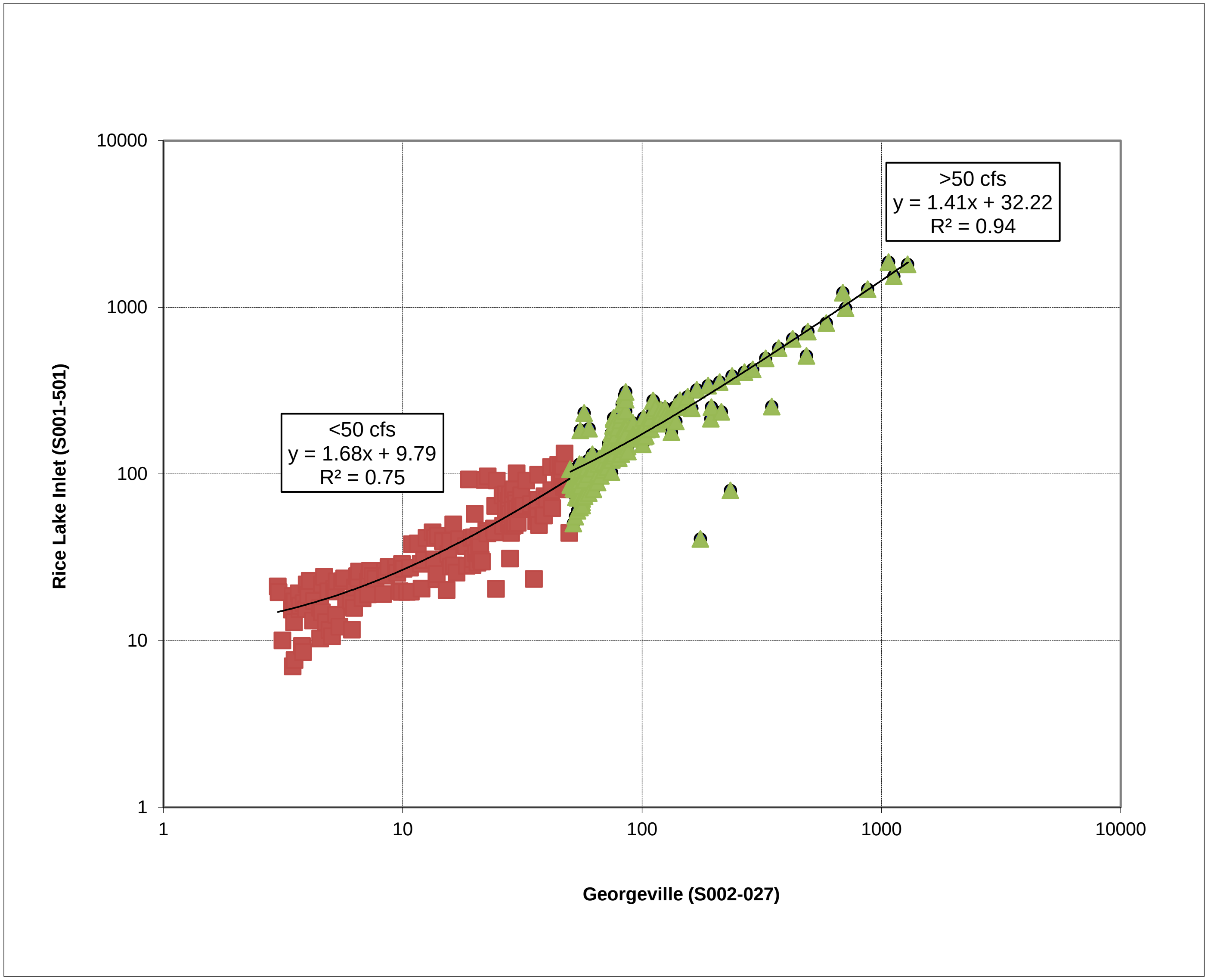
Appendix I: Fisher's Resort Watershed Unit Area Load Calibration



Appendix J

North Fork Crow River Flow Regression

Appendix J: North Fork Crow River Flow Regression



Appendix K

Internal Phosphorus Loading and Sediment Phosphorus Fractionation Analysis for Rice Lake

Internal Phosphorus Loading and Sediment Phosphorus Fractionation Analysis for Rice Lake, Minnesota

4 December, 2009

William F. James
ERDC Eau Galle Aquatic Ecology Laboratory
W. 500 Eau Galle Dam Road
Spring Valley, Wisconsin 54767

OBJECTIVES

The objectives of this investigation were to determine rates of phosphorus (P) release from sediments under laboratory-controlled oxic and anoxic conditions and to quantify mobile and refractory P fractions in sediments of Rice Lake, Minnesota.

APPROACH

Laboratory-derived rates of P release from sediment under oxic and anoxic conditions: Triplicate sediment cores were collected by Wenck Associates from four stations (L1, L2, L3, and L4) in the lake in August, 2009, for determination of rates of P release from sediment. Cores collected from all stations were incubated under anoxic conditions. In addition, triplicate cores collected at station L3 were subjected to an oxic environment. All cores were drained of overlying water and the upper 10 cm of sediment was transferred intact to a smaller acrylic core liner (6.5-cm dia and 20-cm ht) using a core remover tool. Surface water from the lake was filtered through a glass fiber filter (Gelman A-E), with 300 mL then siphoned onto the sediment contained in the small acrylic core liner without causing sediment resuspension. Sediment incubation systems consisted of the upper 10-cm of sediment and filtered overlying water contained in acrylic core liners that were sealed with rubber stoppers. They were placed in a darkened environmental chamber and incubated at a constant temperature (20 ^{o}C). The oxidation-reduction environment in the overlying water was controlled by gently bubbling nitrogen (anoxic) or air (oxic) through an air stone placed just above the sediment surface in each system.

Water samples for soluble reactive P and dissolved iron (Fe) were collected from the center of each system using an acid-washed syringe and filtered through a 0.45 µm membrane syringe filter (Nalge). The water volume removed from each system during sampling was replaced by addition of filtered lake water preadjusted to the proper oxidation-reduction condition. These volumes were accurately measured for determination of dilution effects. Soluble reactive P was measured colorimetrically using the ascorbic acid method (APHA 1998). Dissolved Fe was determined via atomic absorption spectrophotometry (APHA 1998). Rates of P and Fe release from the sediment (mg m^{-2} d^{-1}) were calculated as the linear change in mass in the overlying water divided by time (days) and the area (m^2) of the incubation core liner. Regression analysis was used to estimate rates over the linear portion of the data.

Sediment chemistry: The upper 10 cm from an additional core collected from each station was sectioned for analysis of moisture content (%), sediment density (g/mL), loss on ignition (i.e., organic matter content, %), loosely-bound P, iron-bound P, aluminum-bound P, calcium-bound P, labile and refractory organic P, total nitrogen (N), total P, total iron (Fe), total manganese (Mn), and total calcium (Ca; all expressed at mg/g). A known volume of sediment was dried at 105 ^{o}C for determination of moisture content and sediment density and ashed at 500 ^{o}C for determination of loss-on-ignition organic matter content (Håkanson and Jansson 2002). Additional sediment was dried to a constant weight, ground, and digested for analysis of total Fe and Ca using standard methods (Plumb 1980; APHA 1998). Phosphorus fractionation was conducted according to Hieltjes and Lijklema (1980), Psenner and Puckso (1988), and Nürnberg (1988) for the determination of ammonium-chloride-extractable P (loosely-bound P), bicarbonate-dithionite-extractable P (i.e., iron-bound P), sodium hydroxide-extractable P (i.e., aluminum-bound P), and hydrochloric acid-extractable P (i.e., calcium-bound P). A subsample of the sodium hydroxide extract was digested with potassium persulfate to determine nonreactive sodium hydroxide-extractable P (Psenner and Puckso 1988). Labile organic P was calculated as the difference between reactive and nonreactive sodium hydroxide-extractable P. Refractory organic P was estimated as the difference between total phosphorus and the sum of the other fractions.

RESULTS AND INTERPRETATION

For stations L1, L2, and L4, phosphorus mass increased linearly between day 1 and 10 in sediment systems incubated under anoxic conditions (Figure 1). The initial increase in phosphorus mass on the first day of incubation was probably due to an initial equilibrium adjustment between sediment and the overlying water column. In contrast, phosphorus mass either declined or increased very slowly as a function of time for sediment cores collected from station L3 (Figure 1). The mean anoxic P release rate was 8.1 (± 1.9 S.E.), 2.9 (± 1.3 S.E), and 5.2 (± 1.5 S.E.) $mg \cdot m^{-2} \cdot d^{-1}$ for sediment cores collected from station L1, L2, and L4, respectively (Table 1). These rates were relatively high and comparable to anoxic phosphorus release rates measured in other eutrophic systems (Figure 2). Phosphorus mass accumulated in L3 sediment incubation systems that were incubated under oxic conditions (Table 1 & Figure 3). However, the rate of phosphorus release under oxic conditions was only 0.2 $mg \cdot m^{-2} \cdot d^{-1}$. Dissolved iron mass did not increase in sediment systems subjected to anoxia (not shown). This pattern suggested that reaction of Fe with sulfur to form the mineral FeS might have occurred under anoxic conditions (Golterman 1984, 2001; Miltenberg and Golterman 1988).

Sediments exhibited a high moisture content and low sediment density, indicating fine-grained, flocculent sediment (Table 2). Loss-on-ignition organic matter content was approximately 10%. Total phosphorus concentrations in the sediment were moderate at ~ 0.8 to 1.0 $mg \cdot g^{-1}$ compared to other eutrophic lakes (Nürnberg 1988). Loosely-bound P concentrations were relatively high compared to other lake sediments in the region. This fraction was likely associated with calcite and may be related to the high sediment total Ca content of the sediments in Rice Lake (see total Ca; Table 2). Biologically-labile (i.e., subject to recycling; loosely-bound P, iron-bound P, and labile organic P) P accounted for 20% to 56% of the total sediment P (Figure 4). Redox-sensitive P (i.e., loosely-bound and iron-bound P) represented between 15% and 48% of the total sediment P (Table 2). Biologically refractory sediment P (i.e., subject to burial; aluminum-bound P, calcium-bound P, and refractory organic P) accounted for > 50% of the total sediment P.

Refractory organic P dominated refractory forms, particularly for sediment collected at station L3 (Figure 3).

Sediment total Ca was relatively high in concentration, indicating calcareous deposits. The sediment total Fe:P ratio ranged between 3 and 15 (Table 2). Ratios > 10 have been associated with regulation of P release from sediments under oxic conditions (Jensen et al. 1992). Total Mn concentrations were moderate to low (Barko and Smart 1986).

REFERENCES

APHA (American Public Health Association). 1998. Standard Methods for the Examination of Water and Wastewater. 20th ed. American Public Health Association, American Water Works Association, Water Environment Federation.

Barko, J.W., and Smart, R.M. 1986. Sediment-related mechanisms of growth limitation in submersed macrophytes. Ecology 67: 1328-1340.

Golterman, H.L. 1984. Sediments, modifying and equilibrating factors in the chemistry of freshwaters. Verh. int. Ver. Limnol. 22, 23-59.

Golterman, H.L. 2001. Phosphate release from anoxic sediments or ‘what did Mortimer really write? Hydrobiologia 450, 99-106.

Håkanson, L., and Jansson, M. 2002. Principles of lake sedimentology. The Blackburn Press, Caldwell, NJ USA

Hjieltjes, A.H., and Lijklema, L. 1980. Fractionation of inorganic phosphorus in calcareous sediments. J. Environ. Qual. 8, 130-132.

Jensen, H.S., Kristensen, P., Jeppesen, E., and Skytthe, A. 1992. Iron:phosphorus ratio in surface sediment as an indicator of phosphate release from aerobic sediments in shallow lakes. Hydrobiol. 235/236:731-743.

Miltenburg, J.C., and Golterman, H.L. 1988. The energy of the adsorption of o-phosphate onto ferric hydroxide. Hydrobiologia 364, 93-97.

Nürnberg, G.K. 1988. Prediction of phosphorus release rates from total and reductant-soluble phosphorus in anoxic lake sediments. Can. J. Fish. Aquat. Sci. 45:453-462.

Plumb, R.H. 1981. Procedures for handling and chemical analysis of sediment and water samples. Technical Report EPA/CE-81-1. US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Psenner, R., and Puckso, R. 1988. Phosphorus fractionation: Advantages and limits of the method for the study of sediment P origins and interactions. Arch. Hydrobiol. Biel. Erg. Limnol. 30:43-59.

Table 1. Mean (± 1 standard error in parentheses; n=3) rates of phosphorus (P) release and concentrations of biologically labile and refractory P in sediments collected in Rice Lake, MN. DW = dry mass, FW = fresh mass, N.D. = not detected.

Station	Rates of P Release		Redox-sensitive and biologically labile P				Refractory P		
	Oxic (mg m^{-2} d^{-1})	Anoxic (mg m^{-2} d^{-1})	Loosely-bound P (mg/g)	Iron-bound P (mg/g DW)	Iron-bound P (mg/g FW)	Labile organic P (mg/g)	Aluminum-bound P (mg/g)	Calcium-bound P (mg/g)	Refractory organic P (mg/g)
L1		8.1 (0.7)	0.034	0.218	0.062	0.098	0.098	0.186	0.234
L2		2.9 (0.3)	0.244	0.089	0.019	0.063	0.118	0.056	0.248
L3	0.20 (0)	0 (0.2)	0.115	0.039	0.008	0.047	0.084	0.038	0.710
L4		5.2 (0.3)	0.363	0.109	0.018	0.074	0.141	0.038	0.251

Table 2. Mean (± 1 standard error in parentheses; n=3) textural and chemical characteristics of sediments collected Rice Lake. LOI = loss-on-ignition organic matter content; P = phosphorus, Fe = iron, Mn = manganese; Ca = calcium.

Station	Moisture (%)	Density (g/mL)	LOI (%)	Total N (mg/g)	Total P (mg/g)	Redox P (mg/g)	Redox P (%)	Bioavailable P (%)	Refractory P (%)	Total Fe (mg/g)	Total Mn (mg/g)	Total Ca (mg/g)	Fe:P
L1	71.6	0.309	9.2	4.814	0.868	0.000	0.0%	0.0%	100.0%	12.626	0.815	150.5	14.5
L2	78	0.232	9.1	5.294	0.818	0.000	0.0%	0.0%	100.0%	5.848	0.800	198.5	7.1
L3	80	0.234	11.2	6.432	1.033	0.000	0.0%	0.0%	100.0%	3.249	0.722	267.1	3.1
L4	83.3	0.164	9.1	5.308	0.976	0.000	0.0%	0.0%	100.0%	4.410	0.663	174.6	4.5

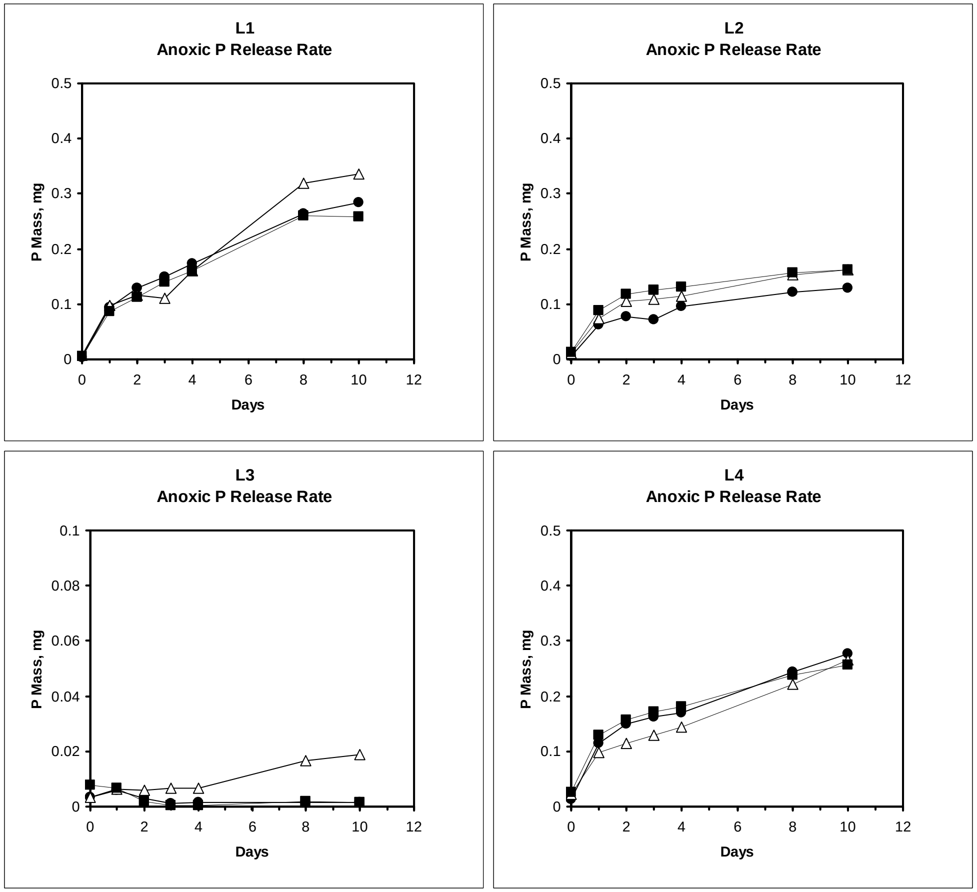


Figure 1. Changes in soluble reactive phosphorus mass in the overlying water column under anoxic conditions versus time for sediment cores collected in Rice Lake.

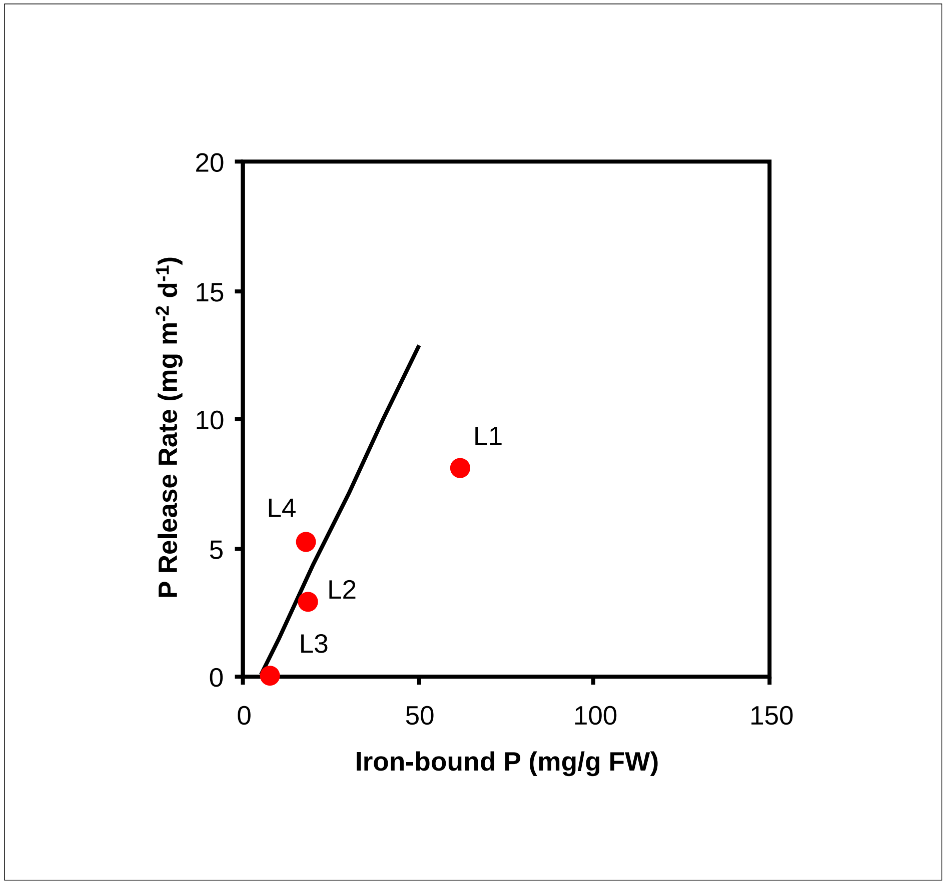


Figure 2. Iron-bound phosphorus (P) versus the anoxic P release rate (regression line) from Nürnburg (1988). The solid red circles represent results for Rice Lake sediment. WW = Fresh or wet weight mass.

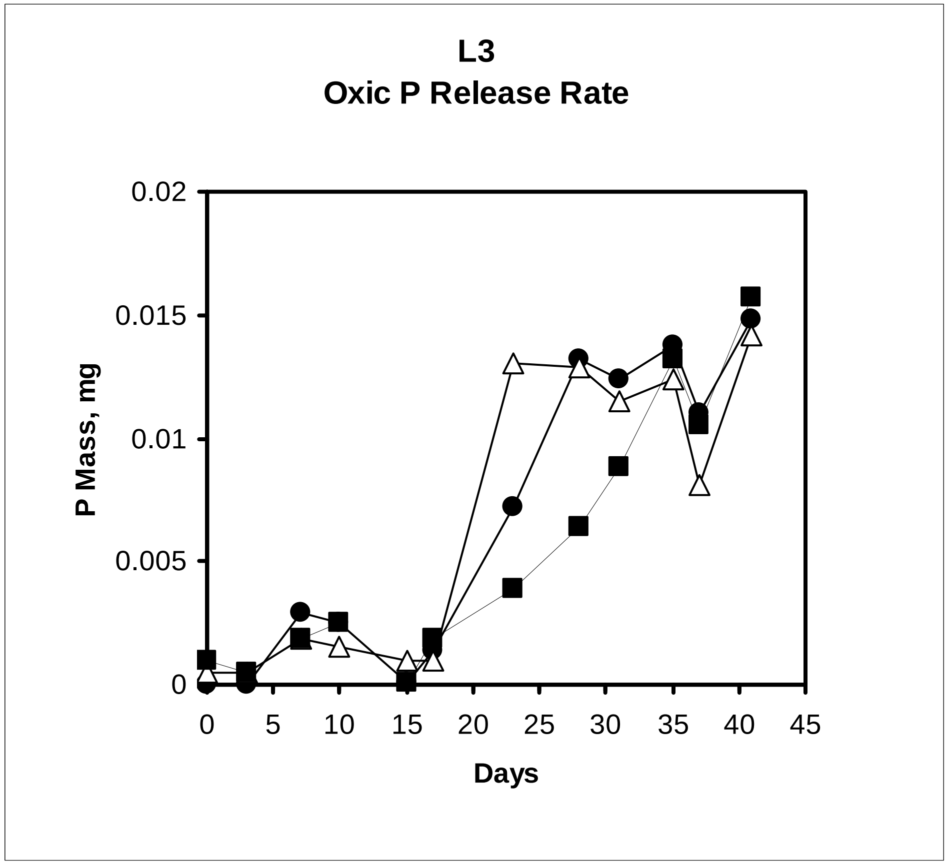


Figure 3. Changes in soluble reactive phosphorus mass in the overlying water column under oxic conditions versus time for sediment cores collected in Rice Lake.

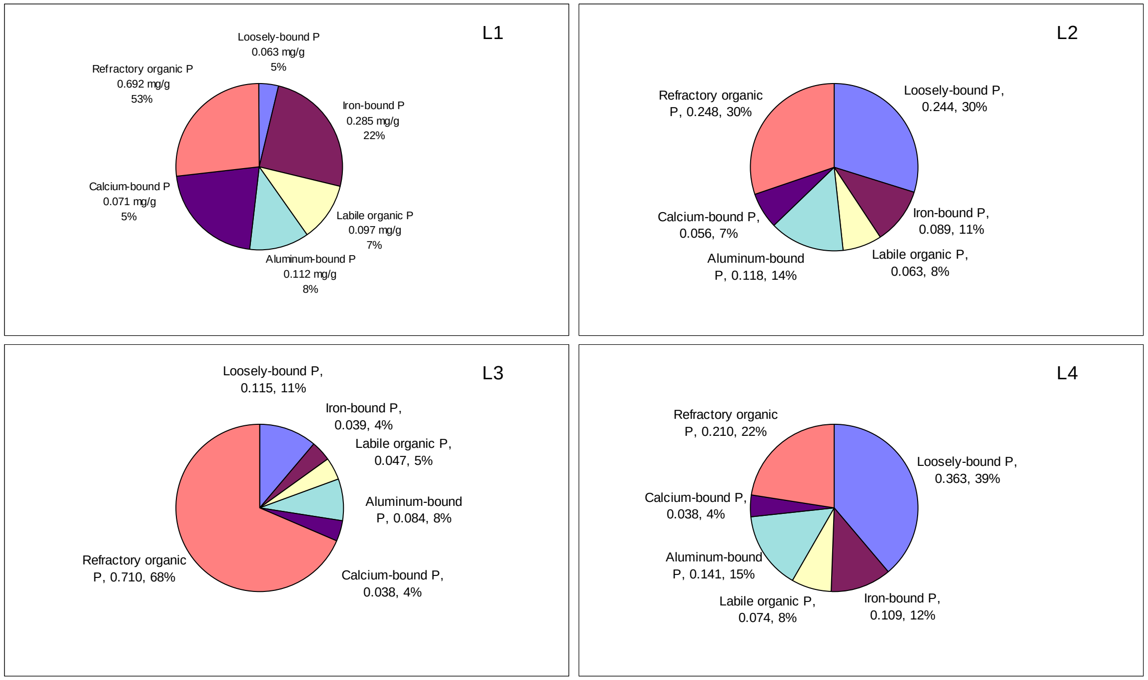


Figure 4. Sediment total phosphorus (P) composition for sediment collected in Rice Lake. Loosely-bound, iron-bound, and labile organic P are biologically reactive (i.e., subject to recycling) while aluminum-bound, calcium-bound, and refractory organic P are more inert to transformation (i.e., subject to burial). Values next to each label represent concentration (mg/g) and percent total P, respectively.

Appendix L

Wastewater Treatment Facility Discharge Monitoring Report Summary

Appendix L: Wastewater Treatment Facility Discharge Monitoring Report Summary

Facility	Permit ID	Permitted Total Phosphorus Effluent		Discharge Monitoring Report - Observed			
		TP Limit	Description	Monitoring	Average	Range	Notes
AMPI - Paynesville	MN0044326-SD-1	1,000 ug/L	Monthly Average concentration	3 samples (2011)	100 ug/L	<1,000 - 1,100 ug/L	TP monitoring did not begin until 2011
		16 kg/year	Annual load	None reported	NA	NA	
Brooten WWTP	MN0025909-SD-1	1,000 ug/L	Monthly Average concentration	7 samples (2008-2011)	704 ug/L	170 - 1,490 ug/L	Only two samples (Oct-2010 and Mar-2011) have exceeded limit
		4.0 kg/day	Daily load	7 samples (2008-2011)	2.22 kg/day	1.28 - 3.75 kg/day	
		184 kg/year	Annual load	None reported	NA	NA	
Paynesville WWTP	MN0020168-SD-1	1,000 ug/L	Monthly Average concentration	75 samples (2000-2011)	115 ug/L	20 - 460 ug/L	42 samples below detection limit. Detection ranged from 60 to 200 ug/L
		6 kg/day	Daily load	75 samples (2000-2011)	1.17 kg/day	0.23 - 5.60 kg/day	26 samples below detection limit. Detection ranged from 0.27 - 2.40 kg/day

Appendix M

Bathtub Lake Response Model Water and Nutrient Mass 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 0	0.6	0.0	0.00E+00	0.00	0.03
2	1	1	NF Crow		129.0	0.00E+00	0.00	
3	1	1	Trib 1	2.4	0.1	0.00E+00	0.00	0.05
4	1	2	Trib 2	2.7	0.1	0.00E+00	0.00	0.04
5	1	3	Trib 3	7.0	0.3	0.00E+00	0.00	0.04
6	1	3	Trib 4	10.1	0.6	0.00E+00	0.00	0.06
7	1	3	Trib 5	4.1	0.2	0.00E+00	0.00	0.05
8	1	2	Trib 6	2.0	0.1	0.00E+00	0.00	0.03
9	1	2	Trib 7	1.1	0.0	0.00E+00	0.00	0.03
10	1	4	Trib 8	5.6	0.4	0.00E+00	0.00	0.06
11	1	4	Trib 9	2.4	0.2	0.00E+00	0.00	0.06
12	1	4	Trib 10	5.9	0.3	0.00E+00	0.00	0.05
TRIBUTARY INFLOW				44.1	131.3	0.00E+00	0.00	2.98
***TOTAL INFLOW				50.7	131.3	0.00E+00	0.00	2.59
ADVECTIVE OUTFLOW				50.7	131.3	0.00E+00	0.00	2.59
***TOTAL OUTFLOW				50.7	131.3	0.00E+00	0.00	2.59

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	Trib 0	6.3	0.0%	0.00E+00		0.00	300.0	10.0
2	1	1	NF Crow	22317.0	93.4%	0.00E+00		0.00	173.0	
3	1	1	Trib 1	37.5	0.2%	0.00E+00		0.00	323.0	15.6
4	1	2	Trib 2	41.8	0.2%	0.00E+00		0.00	348.0	15.6
5	1	3	Trib 3	89.0	0.4%	0.00E+00		0.00	288.0	12.8
6	1	3	Trib 4	28.4	0.1%	0.00E+00		0.00	49.0	2.8
7	1	3	Trib 5	10.8	0.0%	0.00E+00		0.00	49.0	2.6
8	1	2	Trib 6	15.9	0.1%	0.00E+00		0.00	253.0	7.9
9	1	2	Trib 7	4.7	0.0%	0.00E+00		0.00	156.0	4.3
10	1	4	Trib 8	97.6	0.4%	0.00E+00		0.00	275.0	17.3
11	1	4	Trib 9	50.7	0.2%	0.00E+00		0.00	338.0	21.0
12	1	4	Trib 10	87.0	0.4%	0.00E+00		0.00	293.0	14.6
PRECIPITATION				178.2	0.7%	7.94E+03	100.0%	0.50		27.0
INTERNAL LOAD				926.7	3.9%	0.00E+00		0.00		
TRIBUTARY INFLOW				22786.7	95.4%	0.00E+00		0.00	173.6	517.2
***TOTAL INFLOW				23891.7	100.0%	7.94E+03	100.0%	0.00	182.0	471.6
ADVECTIVE OUTFLOW				7815.7	32.7%	4.80E+06		0.28	59.5	154.3
***TOTAL OUTFLOW				7815.7	32.7%	4.80E+06		0.28	59.5	154.3
***RETENTION				16076.0	67.3%	4.80E+06		0.14		

Overflow Rate (m/yr)	19.9	Nutrient Resid. Time (yrs)	0.0726
Hydraulic Resid. Time (yrs)	0.2390	Turnover Ratio	13.8
Reservoir Conc (mg/m3)	55	Retention Coef.	0.673

Appendix N

Rice Lake Watershed Construction and Industrial Stormwater Permits

Appendix N: Rice Lake Watershed Construction and Industrial Stormwater Permits

Name	Permit ID	Type	Watershed	Date Established
2010 Street & Utility Improvements CSW	C00029777	Construction Stormwater Permit	NFC River	5/6/2010
Industrial Drive - 000193-08002-0 - Redwood Falls	C00027958	Construction Stormwater Permit	NFC River	6/23/2009
SP 3408-15 (TH23) Paynesville - CSW	C00029336	Construction Stormwater Permit	NFC River	3/18/2010
SP 7318-36 (TH 71) Bridge 73045 Belgrade- CSW	C00027819	Construction Stormwater Permit	NFC River	6/4/2009
Voss Plumbing - Paynesville - CSW	C00029006	Construction Stormwater Permit	NFC River	11/5/2009
Paynesville Auto Parts & Service - SW	A00002281	Industrial Stormwater Permit	NFC River	7/13/1998
Holly Estates CSW	C00028080	Construction Stormwater Permit	Rice Lake Direct	7/6/2009

Appendix O

Rice Lake Watershed Feedlots

Appendix O: Rice Lake Watershed Feedlots

Permit ID	Watershed	Total Animal Units	Notes
145-102455	Rice Lake Direct	59	
145-106156	Rice Lake Direct	3	
145-106202	Rice Lake Direct	154.3	
145-108025	Rice Lake Direct	9	
145-108027	Rice Lake Direct	3.4	
145-110940	Rice Lake Direct	131.08	
145-113926	Rice Lake Direct	11	
145-114561	Rice Lake Direct	43.02	
145-73761	Rice Lake Direct	14	
145-73859	Rice Lake Direct	89	
145-73908	Rice Lake Direct	1.2	
145-73981	Rice Lake Direct	240	
145-73998	Rice Lake Direct	94	
145-74049	Rice Lake Direct	110	
145-74062	Rice Lake Direct	14	
145-74186	Rice Lake Direct	65.4	
145-74215	Rice Lake Direct	34	
145-74218	Rice Lake Direct	60	
145-74273	Rice Lake Direct	9.6	
145-74303	Rice Lake Direct	29.5	
145-74376	Rice Lake Direct	190	
145-74573	Rice Lake Direct	14	
145-74628	Rice Lake Direct	38	
145-74629	Rice Lake Direct	59.2	
145-74707	Rice Lake Direct	10.6	
145-74840	Rice Lake Direct	23.5	
145-74865	Rice Lake Direct	36	
145-74908	Rice Lake Direct	492.5	
145-74944	Rice Lake Direct	119	
145-74950	Rice Lake Direct	1	
145-75032	Rice Lake Direct	38	
145-75061	Rice Lake Direct	96	
145-75110	Rice Lake Direct	13.2	
145-75114	Rice Lake Direct	41	
145-75145	Rice Lake Direct	13	
145-75378	Rice Lake Direct	120.2	
145-75395	Rice Lake Direct	0	
145-75401	Rice Lake Direct	250.7	
145-75524	Rice Lake Direct	134.3	

Permit ID	Watershed	Total Animal Units	Notes
145-75594	Rice Lake Direct	2540.4	CAFO
145-75897	Rice Lake Direct	60	
145-75953	Rice Lake Direct	0	
145-75958	Rice Lake Direct	486	
067-101060	NFC River	203	
067-101064	NFC River	38	
067-101067	NFC River	142.5	
067-101104	NFC River	79.8	
067-101114	NFC River	246	
067-103660	NFC River	86.2	
067-103682	NFC River	52.4	
067-103684	NFC River	246	
067-103696	NFC River	103	
067-103697	NFC River	142.5	
067-103713	NFC River	295	
067-103761	NFC River	35.4	
067-50005	NFC River	1260	CAFO
067-50006	NFC River	1290	CAFO
067-50007	NFC River	1620	CAFO
067-60152	NFC River	500	
067-61000	NFC River	123	
067-61099	NFC River	107.6	
067-61144	NFC River	35	
067-61152	NFC River	131.5	
067-61159	NFC River	99	
067-61243	NFC River	1215	CAFO
067-61252	NFC River	640	
067-61253	NFC River	820.8	
067-61254	NFC River	135	
067-61278	NFC River	105.5	
067-61279	NFC River	106.2	
067-61289	NFC River	195	
067-61291	NFC River	98.25	
067-61393	NFC River	13	
067-61422	NFC River	62.6	
067-61464	NFC River	165	
067-61470	NFC River	13	
067-61476	NFC River	120	
067-62222	NFC River	402.1	
067-62238	NFC River	87.5	

Permit ID	Watershed	Total Animal Units	Notes
067-80022	NFC River	72.5	
121-100883	NFC River	50	
121-106480	NFC River	874.4	
121-112147	NFC River	874.4	
121-69641	NFC River	142	
121-76411	NFC River	96.9	
121-76430	NFC River	196	
121-76438	NFC River	194	
121-76445	NFC River	50	
121-76476	NFC River	120	
121-76477	NFC River	120	
121-76489	NFC River	280	
121-76508	NFC River	95.3	
121-76522	NFC River	70	
121-76539	NFC River	50	
121-76548	NFC River	17.1	
121-76572	NFC River	47	
121-76586	NFC River	137.7	
121-76589	NFC River	98	
121-76608	NFC River	167	
121-76633	NFC River	270	
121-76644	NFC River	144	
121-76662	NFC River	250	
121-76684	NFC River	74	
121-76688	NFC River	125.5	
121-76712	NFC River	200	
121-76714	NFC River	221	
121-76728	NFC River	105	
121-76735	NFC River	53.4	
121-76765	NFC River	189	
121-82370	NFC River	115	
145-102407	NFC River	6.5	
145-102412	NFC River	30	
145-102415	NFC River	105	
145-102422	NFC River	34	
145-102425	NFC River	10.3	
145-102427	NFC River	10.5	
145-102429	NFC River	20	
145-102431	NFC River	1	
145-102446	NFC River	27.3	

Permit ID	Watershed	Total Animal Units	Notes
145-102447	NFC River	40	
145-102463	NFC River	99	
145-102468	NFC River	250	
145-102476	NFC River	112.2	
145-102480	NFC River	0	
145-102507	NFC River	36	
145-106149	NFC River	30	
145-106182	NFC River	316.25	
145-106186	NFC River	27.3	
145-107558	NFC River	36	
145-107559	NFC River	4	
145-107587	NFC River	4	
145-107588	NFC River	0.3	
145-107610	NFC River	9	
145-107611	NFC River	2	
145-107792	NFC River	8.4	
145-108341	NFC River	3.6	
145-109412	NFC River	4	
145-110936	NFC River	102	
145-110937	NFC River	49	
145-110949	NFC River	22	
145-111094	NFC River	65	
145-112030	NFC River	855	
145-112167	NFC River	9.975	
145-113014	NFC River	125	
145-113947	NFC River	18	
145-114386	NFC River	6	
145-114913	NFC River	61.8	
145-61684	NFC River	0	
145-73587	NFC River	135.1	
145-73589	NFC River	37.5	
145-73595	NFC River	36.6	
145-73614	NFC River	200	
145-73615	NFC River	0	
145-73663	NFC River	115	
145-73671	NFC River	0	
145-73677	NFC River	0	
145-73687	NFC River	5.8	
145-73697	NFC River	15.8	
145-73722	NFC River	118	

Permit ID	Watershed	Total Animal Units	Notes
145-73725	NFC River	112	
145-73772	NFC River	28	
145-73791	NFC River	57	
145-73841	NFC River	60	
145-73856	NFC River	0	
145-73858	NFC River	12.6	
145-73866	NFC River	21	
145-73893	NFC River	92.5	
145-73899	NFC River	18	
145-73925	NFC River	84	
145-73937	NFC River	141.2	
145-73939	NFC River	147.5	
145-73940	NFC River	90	
145-73962	NFC River	127.5	
145-73993	NFC River	0	
145-73994	NFC River	0	
145-74011	NFC River	171.05	
145-74028	NFC River	60	
145-74029	NFC River	271.054	
145-74038	NFC River	165.125	
145-74044	NFC River	96	
145-74071	NFC River	95	
145-74075	NFC River	5.6	
145-74083	NFC River	231.9	
145-74084	NFC River	222	
145-74137	NFC River	77.5	
145-74163	NFC River	31	
145-74164	NFC River	163	
145-74165	NFC River	0	
145-74168	NFC River	25	
145-74197	NFC River	26.1	
145-74204	NFC River	88	
145-74217	NFC River	141	
145-74260	NFC River	74.9	
145-74291	NFC River	13	
145-74305	NFC River	325	
145-74306	NFC River	397.7	
145-74313	NFC River	238.9	
145-74326	NFC River	444	
145-74353	NFC River	44.5	

Permit ID	Watershed	Total Animal Units	Notes
145-74365	NFC River	415	
145-74366	NFC River	73	
145-74396	NFC River	540	
145-74561	NFC River	90	
145-74562	NFC River	44	
145-74575	NFC River	98	
145-74580	NFC River	48.1	
145-74588	NFC River	108	
145-74594	NFC River	99.55	
145-74602	NFC River	62.5	
145-74603	NFC River	0	
145-74604	NFC River	8.4	
145-74608	NFC River	230	
145-74609	NFC River	9	
145-74614	NFC River	305.5	
145-74639	NFC River	20	
145-74642	NFC River	219.8	
145-74646	NFC River	48	
145-74663	NFC River	424	
145-74665	NFC River	95	
145-74680	NFC River	5.2	
145-74681	NFC River	65	
145-74682	NFC River	70	
145-74692	NFC River	327.2	
145-74700	NFC River	71.6	
145-74715	NFC River	73.4	
145-74725	NFC River	139	
145-74727	NFC River	0	
145-74729	NFC River	0	
145-74733	NFC River	88	
145-74738	NFC River	102.1	
145-74747	NFC River	224	
145-74778	NFC River	0	
145-74780	NFC River	184	
145-74792	NFC River	74	
145-74793	NFC River	12	
145-74802	NFC River	0	
145-74804	NFC River	38.2	
145-74805	NFC River	92.5	
145-74814	NFC River	9	

Permit ID	Watershed	Total Animal Units	Notes
145-74881	NFC River	18.2	
145-74882	NFC River	110	
145-74891	NFC River	28	
145-74895	NFC River	180	
145-74898	NFC River	56.7	
145-74917	NFC River	237.4	
145-74919	NFC River	232.5	
145-74920	NFC River	0	
145-74953	NFC River	30.2	
145-75016	NFC River	62.8	
145-75025	NFC River	340	
145-75039	NFC River	9	
145-75069	NFC River	45.1	
145-75070	NFC River	48.24	
145-75116	NFC River	0	
145-75136	NFC River	99.8	
145-75151	NFC River	12	
145-75163	NFC River	261	
145-75166	NFC River	26	
145-75182	NFC River	76.4	
145-75183	NFC River	3	
145-75188	NFC River	900	
145-75190	NFC River	1595.5	CAFO
145-75194	NFC River	40	
145-75198	NFC River	51	
145-75199	NFC River	1065	CAFO
145-75204	NFC River	6	
145-75208	NFC River	40	
145-75222	NFC River	36	
145-75224	NFC River	7	
145-75229	NFC River	23.3	
145-75230	NFC River	24	
145-75243	NFC River	61.5	
145-75265	NFC River	0	
145-75266	NFC River	0	
145-75267	NFC River	116.4	
145-75268	NFC River	110	
145-75288	NFC River	2.4	
145-75293	NFC River	40	
145-75294	NFC River	19.2	

Permit ID	Watershed	Total Animal Units	Notes
145-75295	NFC River	201.6	
145-75305	NFC River	210	
145-75309	NFC River	246.175	
145-75318	NFC River	180	
145-75319	NFC River	60	
145-75331	NFC River	162	
145-75359	NFC River	87.4	
145-75373	NFC River	105.105	
145-75374	NFC River	78.9	
145-75434	NFC River	122.7	
145-75437	NFC River	136.6	
145-75450	NFC River	242	
145-75470	NFC River	72	
145-75486	NFC River	178.896	
145-75495	NFC River	107.6	
145-75500	NFC River	79.6	
145-75501	NFC River	46.1	
145-75533	NFC River	252	
145-75547	NFC River	143	
145-75553	NFC River	113	
145-75570	NFC River	189	
145-75571	NFC River	90.425	
145-75578	NFC River	240.8	
145-75580	NFC River	153	
145-75592	NFC River	462.8	
145-75593	NFC River	245	
145-75597	NFC River	44	
145-75627	NFC River	296	
145-75639	NFC River	116.4	
145-75648	NFC River	111	
145-75670	NFC River	130.9	
145-75671	NFC River	240.5	
145-75674	NFC River	42	
145-75675	NFC River	6	
145-75679	NFC River	143.5	
145-75680	NFC River	162	
145-75703	NFC River	221.2	
145-75704	NFC River	155.9	
145-75726	NFC River	401.4	
145-75735	NFC River	85	

Permit ID	Watershed	Total Animal Units	Notes
145-75747	NFC River	151.6	
145-75751	NFC River	108.5	
145-75753	NFC River	147.4	
145-75754	NFC River	410	
145-75773	NFC River	192	
145-75775	NFC River	128.5	
145-75778	NFC River	226	
145-75780	NFC River	118.5	
145-75790	NFC River	208	
145-75793	NFC River	218	
145-75795	NFC River	128.6	
145-75796	NFC River	64	
145-75805	NFC River	38.4	
145-75806	NFC River	83.7	
145-75815	NFC River	135.4	
145-75833	NFC River	85.7	
145-75841	NFC River	48.5	
145-75851	NFC River	153.8	
145-75872	NFC River	189.5	
145-75912	NFC River	383.5	
145-75916	NFC River	99	
145-75917	NFC River	50	
145-75939	NFC River	415.255	
145-75949	NFC River	161	
145-75955	NFC River	481	
145-75982	NFC River	15	
145-75987	NFC River	200	
145-76020	NFC River	621	
145-76059	NFC River	195.2	
145-76062	NFC River	286	
145-76064	NFC River	344.65	
145-76076	NFC River	222.5	
145-76131	NFC River	281	
145-82392	NFC River	197.5	
145-82395	NFC River	25	
145-82396	NFC River	59.7	
145-82399	NFC River	6.1	
145-82408	NFC River	147.9	
145-82411	NFC River	45	
145-82414	NFC River	210.2	

Permit ID	Watershed	Total Animal Units	Notes
145-82417	NFC River	150	
145-82418	NFC River	364	
145-82420	NFC River	166.5	
145-95020	NFC River	72.8	
145-97140	NFC River	87.5	
145-99401	NFC River	975	