Rice Marsh Lake and Lake Riley: Use Attainability Analysis Update

Prepared for

RILEY PURGATORY BLUFF CREEK WATERSHED DISTRICT

January 20, 2016

Rice Marsh Lake

Lake Riley

Rice Marsh Lake and Lake Riley Use Attainability Analysis Update

Prepared for
Riley-Purgatory-Bluff Creek Watershed District

RILEY
PURGATORY
BLUFF CREEK
WATERSHED DISTRICT January 20, 2016

Certifications

I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.

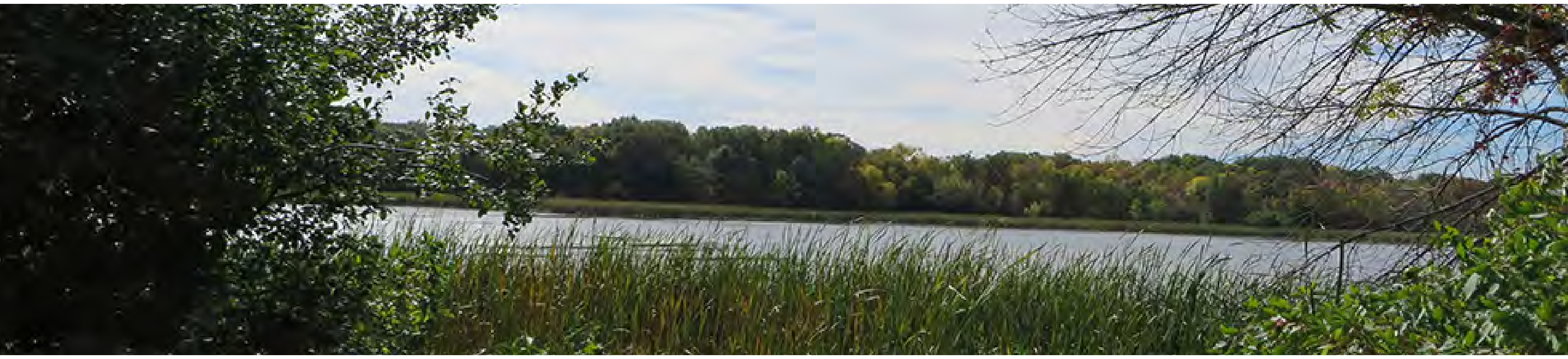
Scott Sobiech
PE #: MN 41338

January 20, 2016
Date

Rice Marsh Lake and Lake Riley: Use Attainability Analysis Update

Executive Summary

Prepared for the Riley-Purgatory-Bluff Creek Watershed District
January 2016



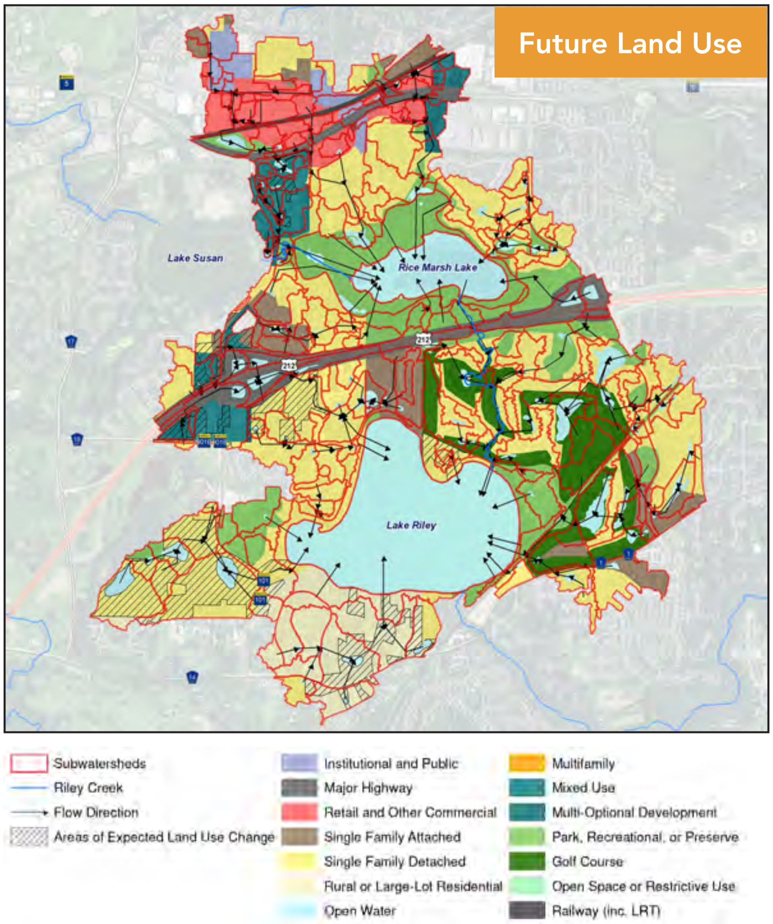
Introduction

A use attainability analysis (UAA) is a scientific assessment that uses an outcome-based evaluation and planning process to obtain or maintain water quality conditions and achieve beneficial uses in a water body, such as swimming, fishing, or wildlife habitat.

The Riley-Purgatory-Bluff Creek Watershed District (RPBCWD) originally developed UAAs for Rice Marsh Lake in 1999 and Lake Riley in 2002. The UAAs include a water quality analysis and prescription of protective measures for the lakes and their respective watersheds, based on historical water quality data, the results of intensive lake water quality monitoring, and computer simulations of land use impacts on water quality. Since the original studies, the RPBCWD has implemented improvement projects in the tributary watersheds and has monitored the water quality of Rice Marsh Lake and Lake Riley.

Study Purpose and Goals

The goal of the study is to assess the water quality in Rice Marsh Lake and Lake Riley based on more recent physical, chemical, and biological data. The overarching purpose of the UAA update is to identify and evaluate watershed and in-lake best management practices (BMPs) that can be implemented to improve and/or preserve water quality in both lakes.



The Rice Marsh Lake and Lake Riley watersheds are mostly developed, with predominantly residential land use. Numerous stormwater best management practices (BMPs), primarily stormwater sedimentation ponds, are located throughout the watershed. Some existing onsite BMPs were constructed as part of the RPBCWD's historic permitting program. Several large regional stormwater ponds were improved or constructed in 2006-2007 as part of the RPBCWD Lake Riley Water Quality Improvement Project.

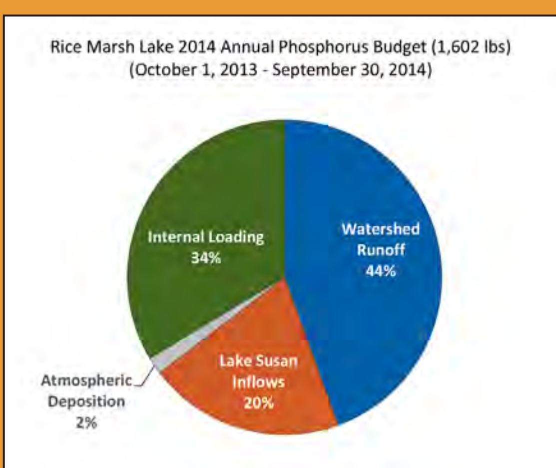
Water Quality Findings, Problems, and Causes

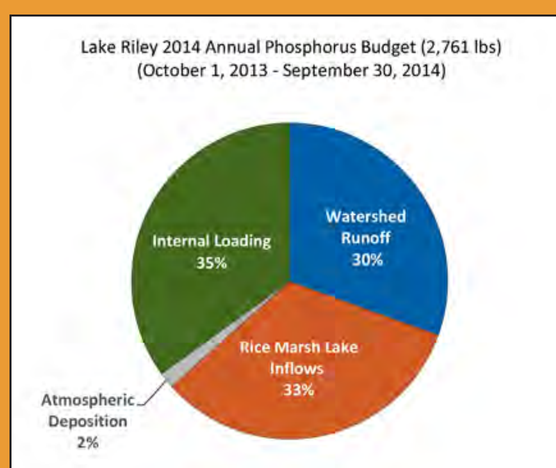
Rice Marsh Lake is a shallow lake located upstream of Lake Riley. Its water quality has improved significantly in recent decades, with 2014 conditions showing a clear water state with abundant aquatic plant growth (typical in a healthy shallow lake). However, the summer-average phosphorus concentrations are generally higher than the MPCA shallow lake criteria. Watershed and in-lake modeling confirm that the excess phosphorus to Rice Marsh Lake comes from both external (watershed runoff and inflows from Lake Susan) and internal sources (e.g., release of phosphorus from lake bottom sediments). Soluble, or dissolved, phosphorus is especially prevalent in the watershed runoff reaching the lake, as much of the particulate phosphorus appears to be settled out in the existing stormwater ponds. Study findings suggest lake management should address all of these phosphorus sources.

Lake Riley is a deep lake that serves as a regional recreational amenity, with public boat access, a public swimming beach, and fishing pier. While its water quality is better than Rice Marsh Lake's and it has maintained relatively good water quality throughout recent decades of watershed development, the lake does not consistently meet the MPCA deep lake criteria or RPBCWD lake goals. Similar to Rice Marsh Lake, lake water quality is influenced by watershed runoff and internal loading. The lake is also heavily influenced by the inflows from upstream Rice Marsh Lake. The strong thermal stratification that occurs in Lake Riley limits the amount of phosphorus transferred from the deep water to the lake's surface waters.

Topic		Rice Marsh Lake	Lake Riley
MPCA Lake Classification		shallow	deep
Surface Area		83	297
Mean Depth		5	23
Thermal Stratification Pattern		dimictic	polymictic
Recent 10-year growing season average	Total phosphorus	96 ug/L	44 ug/L
	Chlorophyll a	18 ug/L	23 ug/L
	Secchi disk (m)	1.7	1.6
Meeting RPBCWD goals		no	no
Meeting RPBCWD long-term clarity vision		no	no
Meeting MPCA water quality standards		no	no
Impact of unmitigated watershed development		water quality degradation	water quality degradation
Fisheries		susceptible to winterkill	diverse with below-average carp levels
Macrophyte community		fair plant diversity	low plant diversity
Non-native macrophytes		curlyleaf pondweed	curlyleaf pondweed and Eurasian watermilfoil
Mercury		not assessed	impaired

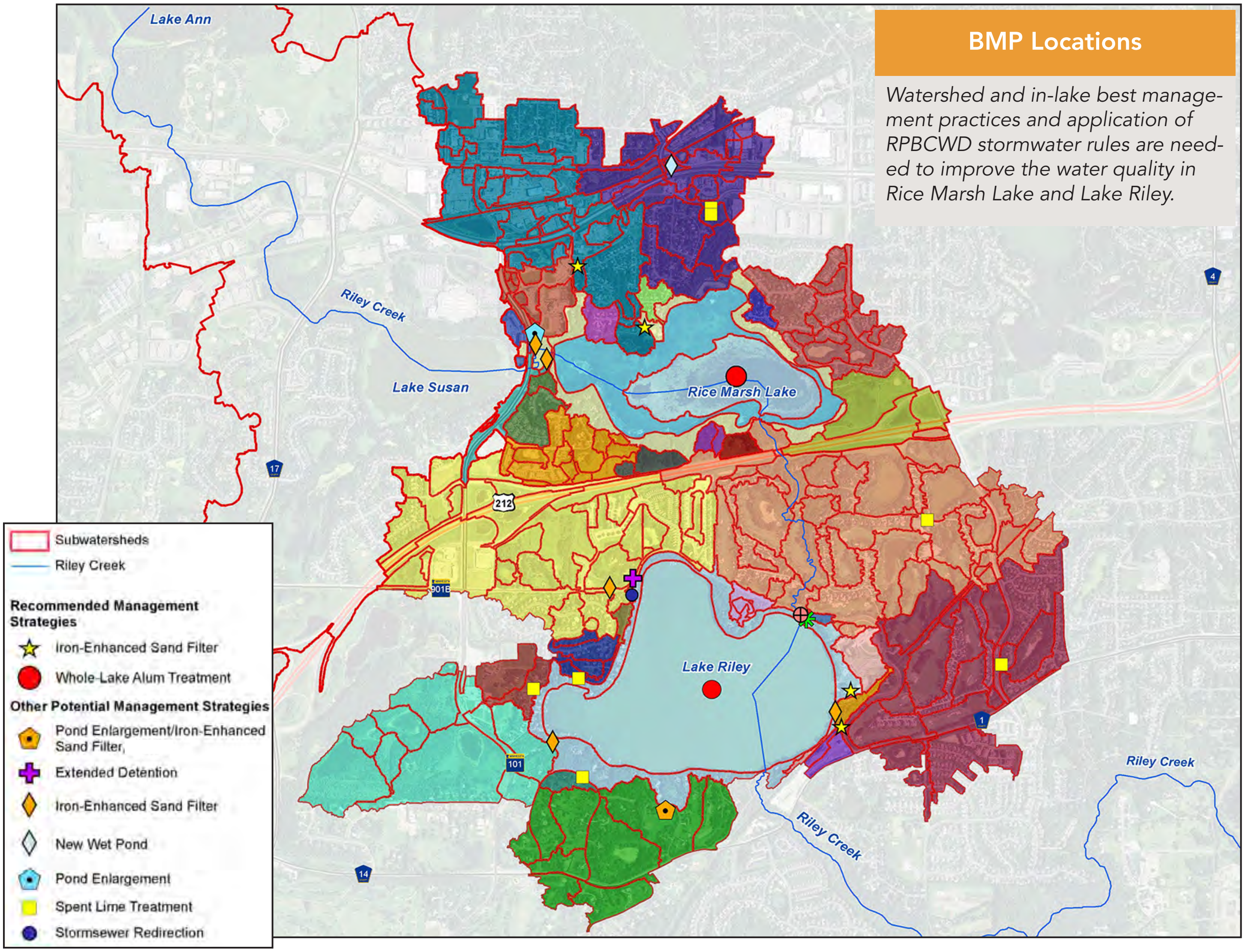
Sources of Phosphorus





The pie charts above show the sources of phosphorus to each lake. For Rice Marsh Lake nearly half of the phosphorus is coming from watershed runoff, with approximately one-third (34%) coming from internal sources (primarily sediment release). For Lake Riley, approximately one-third of the phosphorus comes from watershed sources, one-third from internal loading, and one-third from Rice Marsh Lake inflows. The distribution of sources indicates the importance of managing both internal and external phosphorus throughout the chain of lakes.

Management Strategies for Rice Marsh Lake and Lake Riley

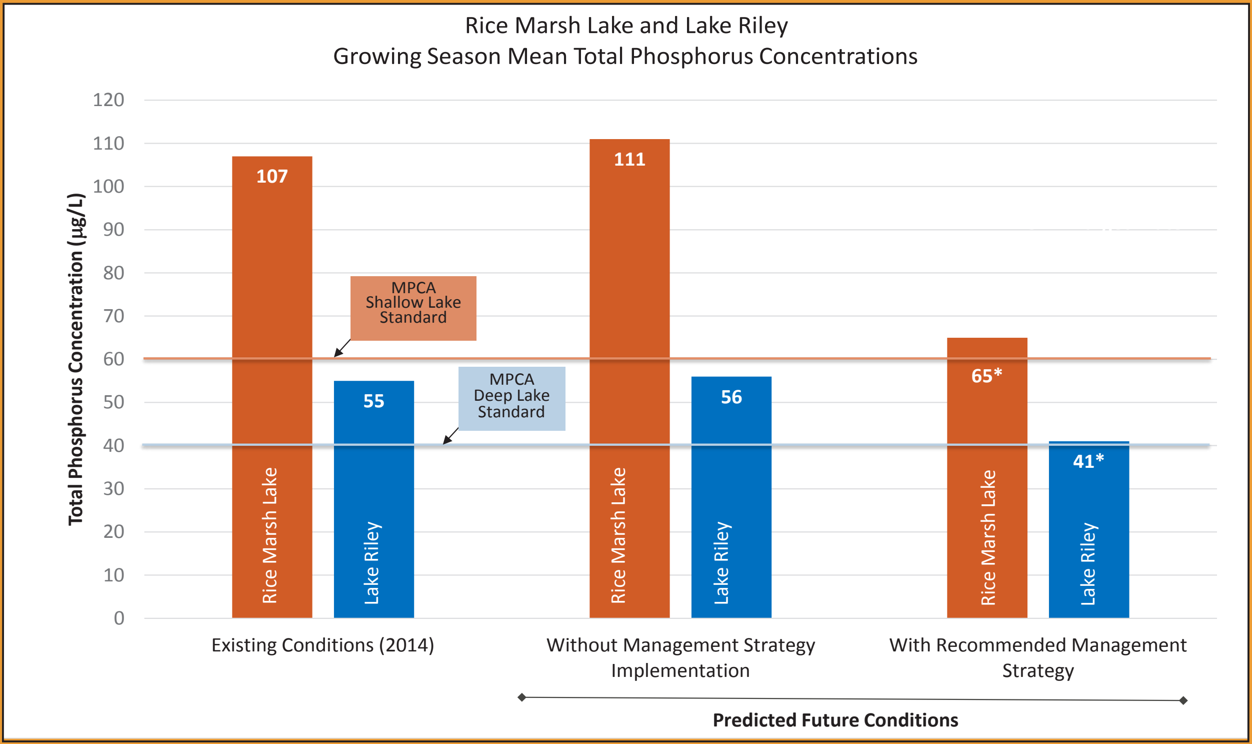


Numerous management strategies were evaluated based on phosphorus removal effectiveness, improvements to lake water quality and habitat, cost, and feasibility. The following management strategies are recommended:

- Apply RPBCWD stormwater rules as development or redevelopment occurs within the watershed, reducing the stormwater volume and pollutant loading to the lakes.
- Improve water quality of upstream Lake Susan to meet MPCA shallow-lake standards.
- Improve the water quality in Rice Marsh Lake, which is essential for achieving MPCA deep-lake standards in Lake Riley.
- Construct stormwater BMPs, such as iron-enhanced sand filtration, to remove soluble phosphorus from significant stormwater inflow locations.
- Conduct alum treatments of both Rice Marsh Lake and Lake Riley to control internal loading.
- Continue winter aeration in Rice Marsh Lake to promote a healthy bluegill population that can limit successful carp reproduction.
- Continue targeted herbicide treatments in Lake Riley to control invasive curlyleaf pondweed and Eurasian watermilfoil.

The figure on page 4 compares the improvements in water quality of Rice Marsh Lake and Lake Riley, respectively, through implementation of the evaluated management strategies.

Current and Predicted Lake Water Quality Conditions, With and Without Implementation of the Recommended Improvement Strategies



** Additional improvements in Rice Marsh Lake's water quality would directly benefit Lake Riley.*

Recommendations

The table below summarizes the major components (and opinions of cost) of the water quality improvement strategy for Rice Marsh Lake and Lake Riley.

Water-quality-management strategy component	Planning-level opinion of cost[1]	Annual phosphorus load reduction (lbs)	Annualized cost per pound of phosphorus removed[2]
Rice Marsh Lake — Recommended Management Strategies			
Iron-enhanced sand filtration in subwatersheds RM_10 and RM_12a	$682,000 ($545,000 – $955,000)	90	$312
Whole-lake alum treatment of Rice Marsh Lake[3]	$300,000 ($240,000 – $420,000)	450	$22
Lake Riley — Recommended Management Strategies			
Iron-enhanced sand filtration in subwatersheds LR_88 and LR_90	$836,000 ($668,000 – $1,170,000)	64	$538
Whole-lake alum treatment of Lake Riley[3]	$900,000 ($720,000 – $1,080,000)	811	$37
Recommended Ongoing Operations/Efforts			
Apply stormwater rules to new development and redevelopment			
Continue operating winter aeration system in Rice Marsh Lake to prevent winterkill			
Continue herbicide treatments in Lake Riley for curlyleaf pondweed and Eurasian watermilfoil			
Improve Lake Susan water quality to achieve the MPCA's shallow lake standard			

1. Implementation costs are subject to change due to site investigations, additional project definition, and increased level of design.
2. Annual costs per pound of phosphorus removal are based on a 30-year life span.
3. Alum treatment life span is typically 7–10 years. Future alum treatments may be needed; however, this would be evaluated at a future time. The planning-level opinions of cost and the annualized costs assume treatments occur every 10 years over a 30-year period.

Rice Marsh Lake and Lake Riley Use Attainability Analysis Update

January 20, 2016

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1.0 Surface Water Resource Data

The approved *Riley-Purgatory-Bluff Creek Watershed District, Water Management Plan*, (CH2M Hill, February 2011) (Plan), articulates the Riley-Purgatory-Bluff Creek Watershed District's (RPBCWD) vision of achieving sustainable uses appropriate for each water body in the District. Achieving this vision will result in:

- Waters dominated by diverse native fish and plant populations
- Lakes with water clarity of 2 meters or more
- Delisting of half of all impaired (303d) lakes or stream reaches
- An engaged and educated public and scientific community participating in adaptive management activities
- Regulatory recommendations necessary for municipal, county, and state authorities to sustain the achieved conditions

Rice Marsh Lake and Lake Riley are identified in the Plan as important resources for the RPBCWD with lake-specific water quality goals. Lake Riley has a public boat access and swimming beach and is one of the primary recreational resources in the RPBCWD. Rice Marsh Lake primarily provides aesthetic viewing and serves as valuable wildlife habitat, including fish spawning.

The RPBCWD undertook this update to past lake studies as part of the RPBCWD's continued efforts to achieve the District's vision for these valuable recreational resources. The previous RPBCWD studies include the 1999 Lake Susan and Rice Marsh Use Attainability Analysis and the 2002 Lake Riley Use Attainability Analysis. A use attainability analysis (UAA) is a scientific assessment that uses an outcome-based evaluation and planning process to obtain or maintain water quality conditions and achieve beneficial uses in a waterbody, such as swimming, fishing, or wildlife habitat. This study includes a water quality analysis and prescription of protective measures for Rice Marsh Lake, Lake Riley, and their respective watersheds based on historical water quality data, the results of intensive lake water quality monitoring, and computer simulations of land-use impacts on water quality. In addition, best management practices (BMPs) are evaluated to compare their relative effect on total phosphorus concentrations and water clarity (i.e., Secchi disc transparencies).

1.1 Study Purpose

The goals of this study are to assess the water quality in both Rice Marsh Lake and Lake Riley based on more recent physical, chemical, and biological data; improve the understanding of current water quality concerns in the lakes; and identify BMPs to improve and protect the water quality in both lakes. The overarching purpose of this UAA update is to identify and evaluate watershed and in-lake BMPs that can be implemented through an adaptive management approach to improve and/or protect the water quality in both lakes and achieve the District's long-term vision.

1.2 Past Studies

The following is a list of the past studies and reports related to Rice Marsh Lake, Lake Riley, and their watersheds:

- *Diagnostic-Feasibility Study of Seven Metropolitan Area Lakes; Part Two: Lake Riley* (Metropolitan Council of the Twin Cities Area, 1983)
- *Lake Susan and Rice Marsh Lake Use Attainability Analysis* (Barr, December 1999)
- *Lake Riley Use Attainability Analysis* (Barr, April 2002)
- *Engineer's Report Lake Riley Water Quality Improvement Project (Lake Riley and Rice Marsh Lake)* (Barr, May 2004)
- *Lake Riley Outlet Improvements and Riley Creek Lower Valley Stabilization Feasibility Study (Draft)* (Barr, Marsh 2007)
- *In situ Measurement of Sediment Oxygen Demand Lake Lucy, Lake Susan, Lake Riley, Lake Ann* (HydrO$_2$, Inc. for CH2M Hill, November 2009)
- *Stormwater Pond Protocols and Prioritization Report: 2011* (CH2M Hill, January 2012)
- *Fish Barrier and Invasive Species Control Project – University of Minnesota* (U of MN, 2007 – 2012)
- Aquatic Plant Community of Lakes Ann, Lucy, Susan, Riley, and Staring: 2011 Summary of Results (Knopik and Newman, U of MN, January 2012)
- Lake and Pond Monitoring Results for Eden Prairie, Minnesota, 2012 (Blue Water Science, 2012)
- Aquatic Invasive Species Suitability Assessment for Lake Riley, Eden Prairie, Minnesota (Blue Water Science, 2013)
- Aquatic Plan Point Intercept Survey for Lake Riley, Eden Prairie, Minnesota (Blue Water Science, 2014a
- Feasibility of an Alum Application to Lake Riley, Eden Prairie, Minnesota (Blue Water Science, 2014b)
- Historical Water Quality and Ecological Change in Rice Marsh Lake (Ramstack Hobbs, 2014)
- Aquatic Plant Community of Lakes Ann, Lotus, Lucy, Mitchell, Susan, Riley and Staring within the Riley Purgatory Bluff Creek Watershed: Final Report 2009-2014 (Jaka, J.D. et al, 2014)
- Aquatic Plant Point Intercept Survey for Rice Marsh Lake, Carver County, Minnesota, 2014 (Blue Water Science, 2015)
- Curlyleaf Pondweed in Riley Lake, Spring Delineation Survey (2015a, Freshwater Scientific Services, LLC)
- Eurasian Watermilfoil in Lake Riley, Spring Delineation Survey (2015b, Freshwater Scientific Services, LLC)
- Technical Memo: DRAFT Riley Lake Alum Dosing (Wenck Associates, 2015)

1.3 Watershed Characteristics

Rice Marsh Lake and Lake Riley are part of the Riley Creek chain of lakes. Riley Creek, which originates at Lake Ann in Chanhassen, flows through Lake Susan, Rice Marsh Lake, and Lake Riley and ultimately discharges to the Minnesota River (see Figure 1).

The overall watershed to Rice Marsh Lake is approximately 3,442 acres and includes the areas that drain through Lake Lucy, Lake Ann, and Lake Susan. The direct watershed to Rice Marsh Lake is approximately 966 acres, including the surface area of the lake, and comprises portions of Chanhassen and Eden Prairie.

The overall watershed to Lake Riley is approximately 5,218 acres, including the areas that drain through lakes Lucy, Ann, and Susan and Rice Marsh Lake. The direct watershed to Lake Riley is 1,776 acres, including the surface area of the lake, and comprises portions of Chanhassen and Eden Prairie. Figure 2 and Figure 3 show the major watersheds, subwatersheds, and flow direction for the Rice Marsh Lake and Lake Riley watersheds, respectively.

1.3.1 Drainage Patterns

The stormwater conveyance systems in the Rice Marsh Lake and Lake Riley watersheds are comprised of storm sewer networks, constructed stormwater detention ponds, and natural wetlands within the watersheds tributary to the lakes.

There are 15 major drainage areas within the Rice Marsh Lake watershed that ultimately contribute surface runoff to the lake, along with the direct drainage area (see Figure 2). Each major drainage area is named after the terminating watershed in each conveyance network.

There are also 15 major drainage areas within the Lake Riley watershed that ultimately contribute surface runoff to the lake, along with the direct drainage area (see Figure 3). Each major drainage area is named after the terminating watershed in each conveyance network.

The subwatershed delineations and conveyance networks are based on the subwatershed divides updated topographic data (MDNR, 2011), storm sewer data, and other information from the cities of Chanhassen and Eden Prairie, as well as development plans submitted as part of the RPBCWD permit review process for projects implemented after the original UAA was completed through 2006.

Most of the constructed stormwater ponds within the Rice Marsh Lake and Lake Riley watersheds are wet detention ponds. These ponds are designed to provide water quality treatment of stormwater runoff, by allowing particles to settle out in the permanent pool of water and by having the capacity to temporarily store excess runoff volumes and release it at lower rates than incoming flows. Wet detention ponds are used to interrupt the transport phase of sediment and pollutants associated with it, such as trace metals, hydrocarbons, nutrients, and pesticides. Wet detention often results in good pollutant removal from small storm events, while runoff from larger storms will experience pollutant removal with lower efficiency levels.

Additionally, there are a few wetlands and ponds within the Rice Marsh Lake and Lake Riley watersheds in which the normal water levels are located below the outlet structure or overflow elevations when comparing storm sewer data and other information from the cities of Chanhassen and Eden Prairie to the most recent topographic information. During dry climatic conditions, these areas might not discharge and could occasionally act as land-locked areas. These areas are listed in Table 1 and Table 2.

Table 1 Rice Marsh Lake Potentially Landlocked Subwatersheds

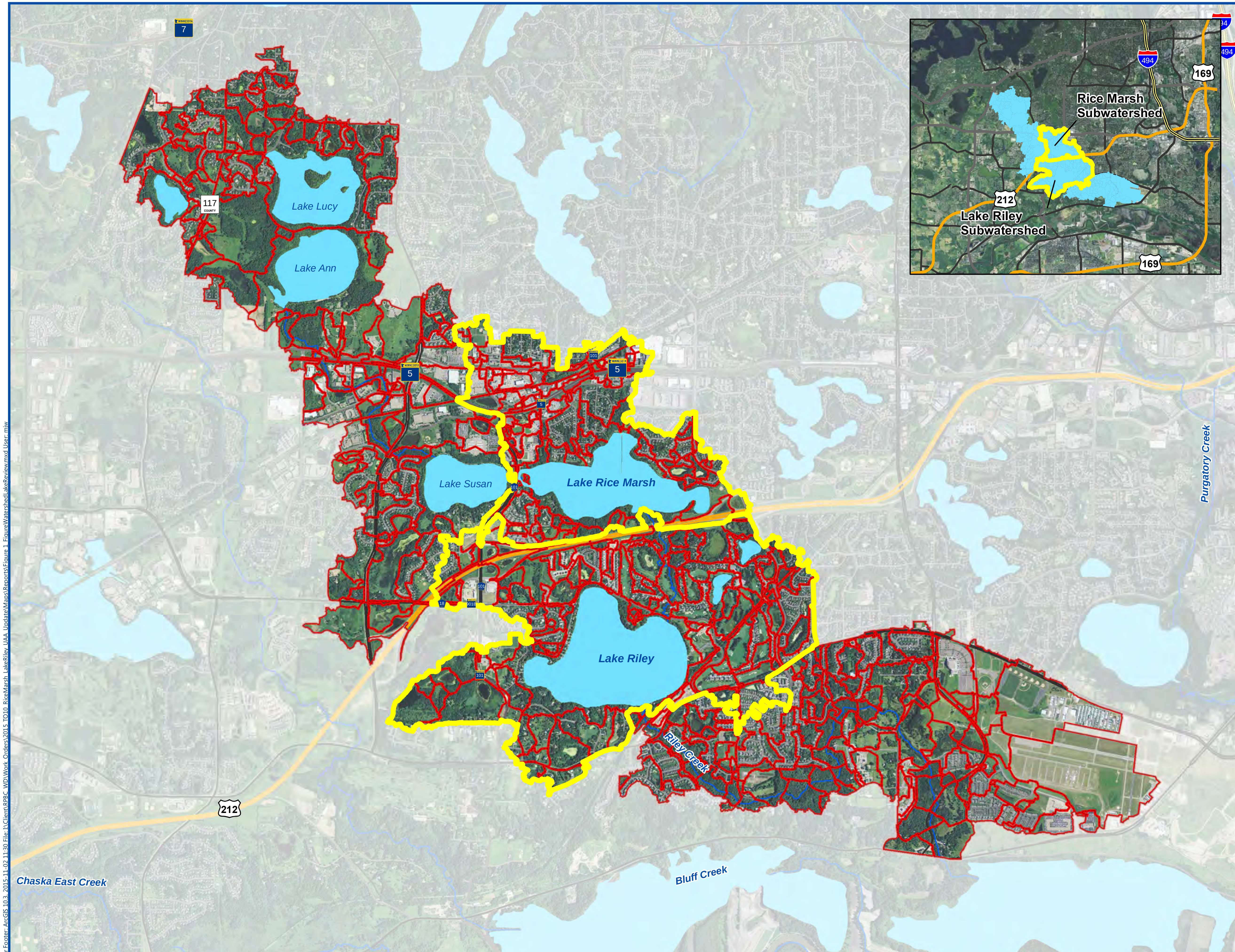
RM_39a	RM_44	RM_45

Table 2 Lake Riley Potentially Landlocked Subwatersheds

LR_7	LR_9a	LR_24	LR_22b	LR_53	LR_54	LR_54a	LR_74
LR_82	LR_82a	LR_84	LR_85	LR_94	LR_108	LR_113	LR_Cr7e

There are also two lift stations located in the Eden Prairie portion of the Lake Riley watershed that limit the discharge from subwatersheds LR_55 and LR_76, including all watershed areas upstream of these two subwatersheds.

There are no public ditch systems within the Rice Marsh Lake and Lake Riley watersheds.



Rice Marsh Lake and Lake Riley Watershed Divides

Lakes

Subwatershed Boundary

Public Water Inventory Watercourses

DRAFT

0 1,500 3,000

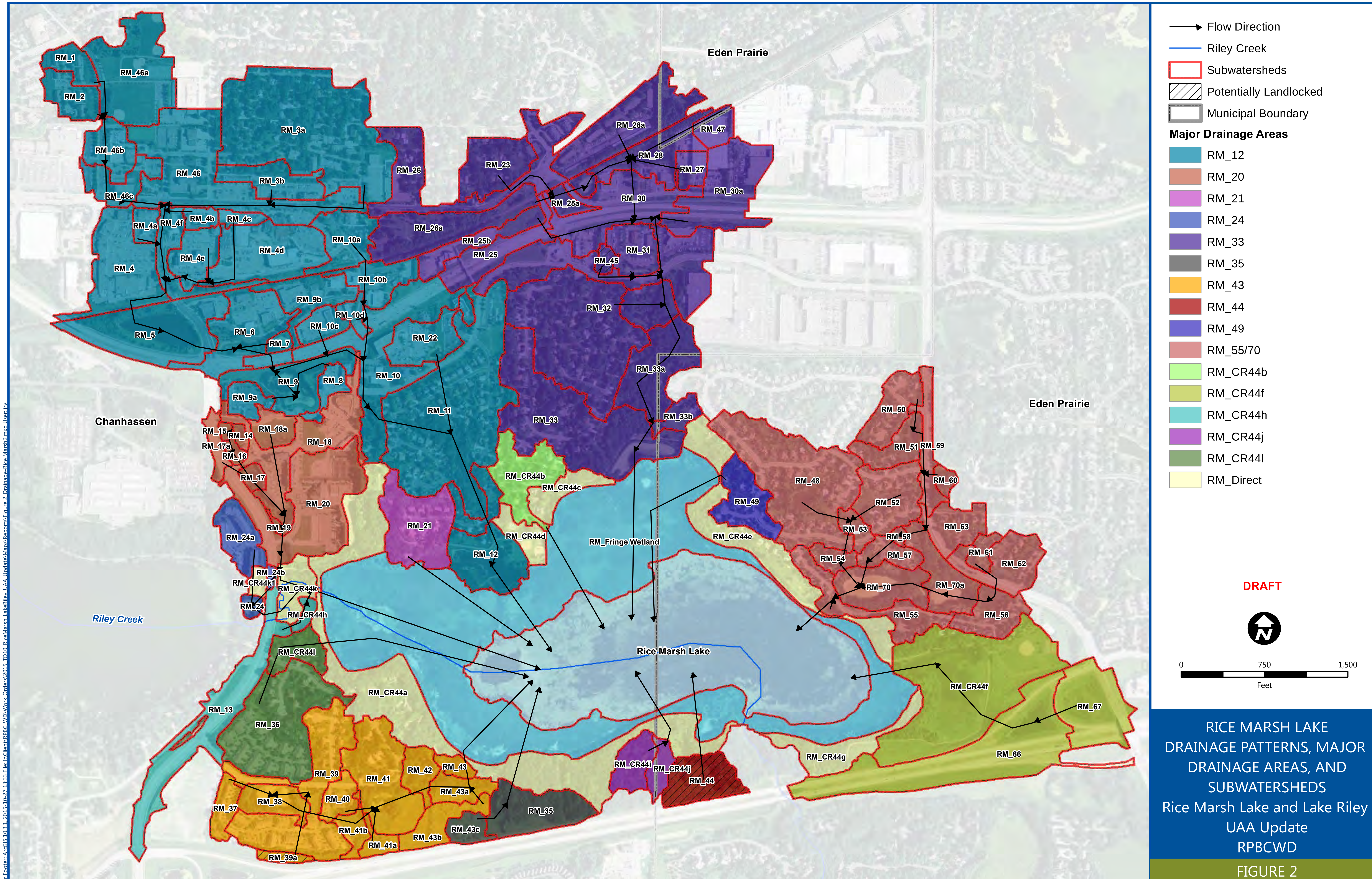
Feet

LOCATION OF RICE MARSH LAKE AND LAKE RILEY WATERSHEDS WITHIN THE RILEY CREEK WATERSHED

Rice Marsh Lake and Lake Riley UAA Update

RPBCWD

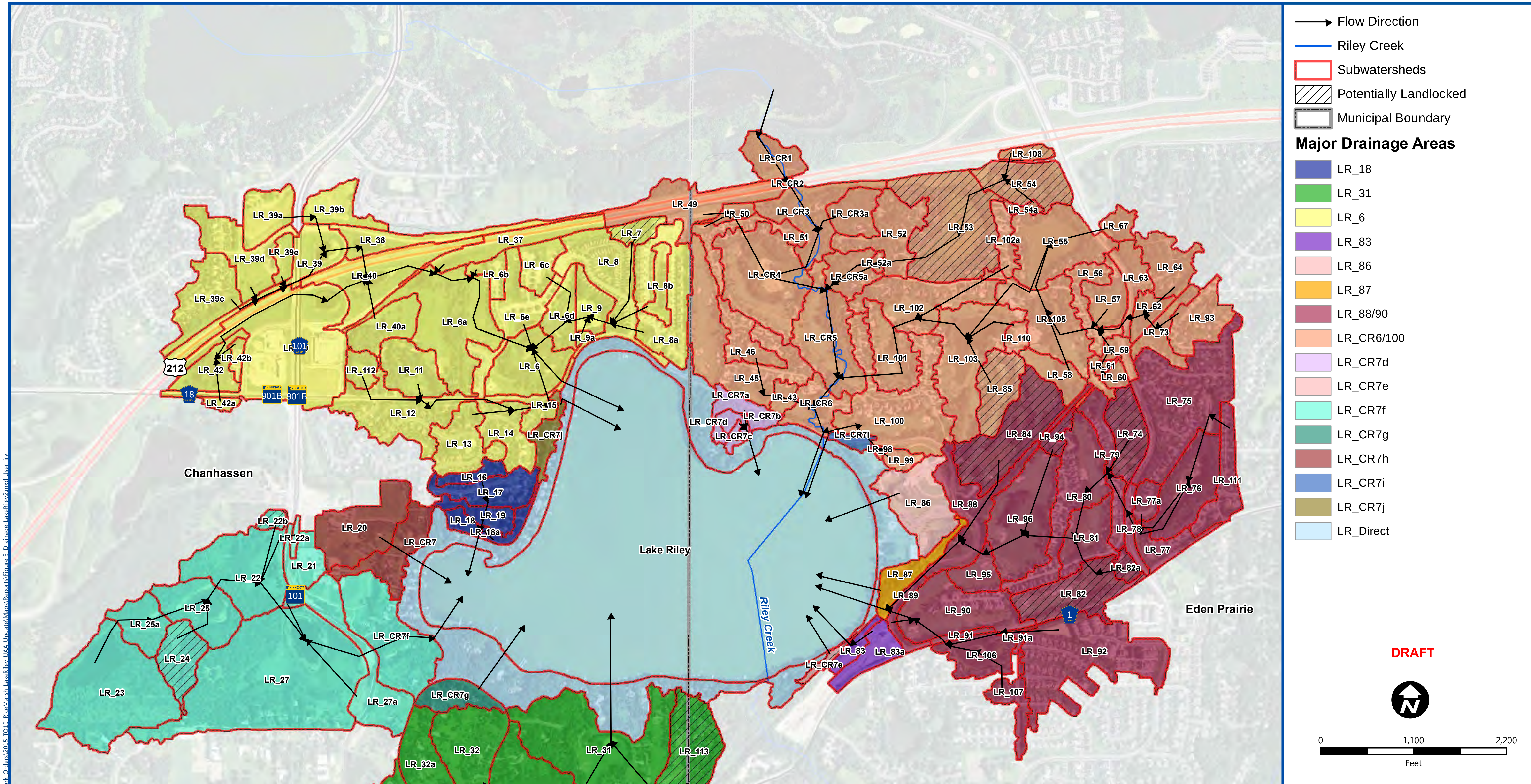
FIGURE 1



RICE MARSH LAKE DRAINAGE PATTERNS, MAJOR DRAINAGE AREAS, AND SUBWATERSHEDS
Rice Marsh Lake and Lake Riley UAA Update
RPBCWD

FIGURE 2

Barr Footer: ArcGIS 10.3.1, 2015-10-27 13:33 File: I:\Client\RPBC_WD\Work_Orders\2015_TO10_RiceMarsh_LakeRiley_UAA_Update\Maps\Reports\Figure 2 Drainage Rice Marsh2.mxd User: rrv



LAKE RILEY
DRAINAGE PATTERNS, MAJOR DRAINAGE AREAS, AND SUBWATERSHEDS
Rice Marsh Lake and Lake Riley UAA Update
RPBCWD

FIGURE 3

1.3.2 Land Use

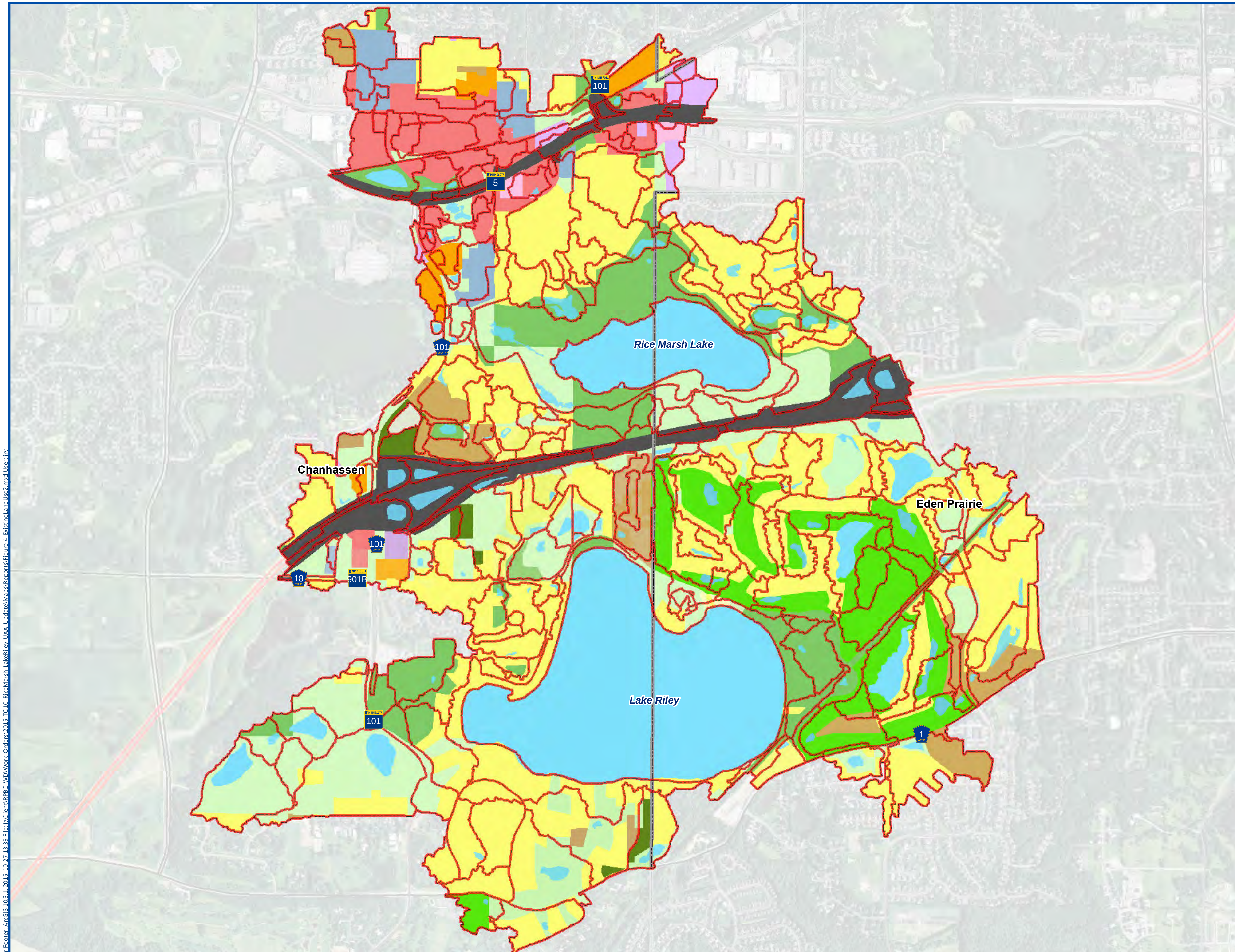
Land use within a lake's watershed can impact the hydrology and water quality of a lake. In addition to the amount of runoff generated, impacts result from the export of sediment and nutrients, primarily phosphorus, to a lake from its watershed. Varying land uses contribute different quantities of phosphorus to downstream waterbodies, due primarily to differences in the amount of impervious surfaces associated with the different land-use types.

Existing (2010) and future (2030) land-use patterns used to estimate the amount of impervious surface and expected change in imperviousness for each watershed were based on information from the Metropolitan Council and modified using recent aerial imagery and development as-builts. The assumptions about the land-use classifications and the amount of total impervious surface and directly connected impervious surface (i.e., impervious surfaces that contribute runoff directly to a stormwater conveyance system) associated with each type are summarized in Appendix A.

Much of the Rice Marsh Lake watershed is developed with only a few areas expected to have changes in land use in the future, mostly in the western portion of the watershed. The existing land use within the Rice Marsh Lake watershed is primarily low- and medium-density residential, commercial, and open-space/park areas with some undeveloped, institutional, and high-density residential areas. The small agricultural and undeveloped areas in the western watershed are expected to be developed mixed-use areas in the future. The large park and undeveloped areas around Rice Marsh Lake are not expected to change significantly under future conditions.

The existing land-use conditions in the Lake Riley watershed are primarily low and medium residential, park, golf course, and undeveloped land uses. There are smaller areas of commercial, agricultural, and high density residential land use. Under future conditions, the large undeveloped area in the western watershed, along with the small agricultural areas, are expected to be developed into low-density residential housing. The small mixed-use area near the Highway 212/101 interchange is also expected to be fully developed under future conditions

Figure 4 shows the existing-conditions land uses in the Rice Marsh Lake and Lake Riley watersheds. Figure 5 shows the future-conditions land uses in the Rice Marsh Lake and Lake Riley watersheds, as well as the areas where there are expected changes in land use between existing and future conditions.



Subwatersheds
Municipal Boundary

Existing Land Use*

Farmstead
Major Highway
Industrial and Utility
Institutional
Office
Retail and Other Commercial
Seasonal/Vacation
Multifamily
Single Family Attached
Single Family Detached
Open Water
Agricultural
Park, Recreational, or Preserve
Undeveloped
Golf Course

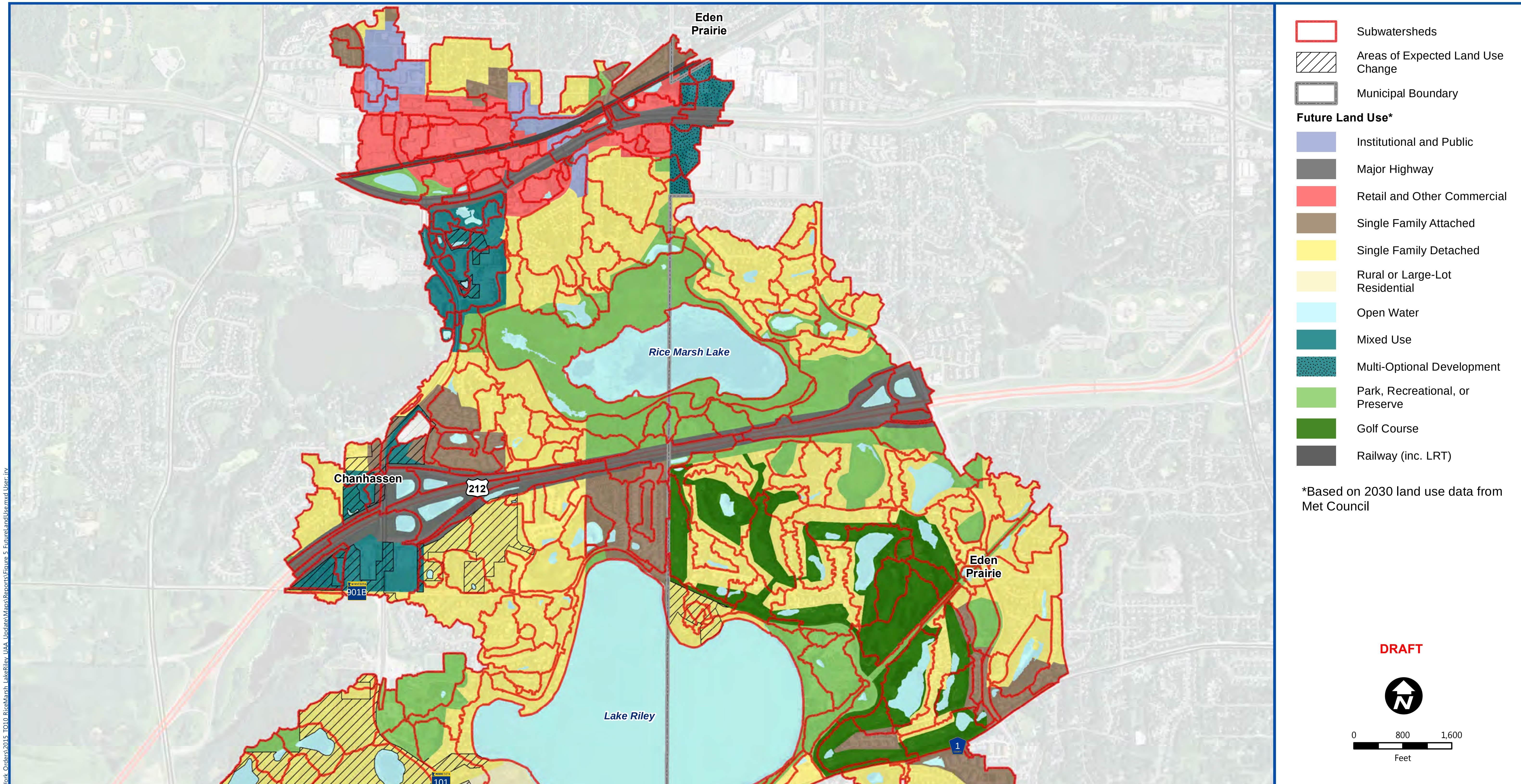
*Based on 2010 land use data from Met Council with updates to reflect 2014 conditions.

DRAFT

0 800 1,600
Feet

EXISTING LAND USE (2010)
Rice Marsh Lake and Lake Riley
UAA Update
RPBCWD

FIGURE 4



FUTURE LAND USE (2030)
Rice Marsh Lake and Lake Riley
UAA Update
RPBCWD

FIGURE 5

1.3.3 Soils

The infiltration capacity of soils affects the amount of direct runoff resulting from rainfall. Soils with a higher infiltration rate have a lower runoff potential. Conversely, soils with low infiltration rates produce high runoff volumes and high peak runoff rates. According to the Natural Resource Conservation Service's (NRCS) Soil Survey Geographic (SSURGO) Database map for Carver and Hennepin counties, the underlying soils in the Rice Marsh Lake watershed are predominantly classified as hydrologic soil group (HSG) B or C/D with moderate to low infiltration rates. Soils in the area around the lake and the wetland areas are typically B/D and C/D soils with low infiltration capacities. According to the same database, the Lake Riley watershed soils are also predominantly B or C/D soils, with some areas of A soils with high infiltration rates in the northwest watersheds and C soils with low infiltration rates in the eastern watersheds. There are a mix of A, B, and B/D soils around the lake, and the wetland areas are generally B/D or C/D soils.

1.4 Lake Characteristics

1.4.1 Physical Characteristics

Table 3 provides a summary of the physical characteristics for Rice Marsh Lake and Lake Riley.

Table 3 Rice Marsh Lake and Lake Riley Physical Characteristics

Lake Characteristic	Rice Marsh Lake	Lake Riley
Lake MDNR ID	10000100	10000200
MPCA Lake Classification	Shallow	Deep
Water Level Control Elevation (feet MSL)	875.0[1]	864.5
Surface Area (acres)	83	297
Mean Depth (feet)	5	23
Maximum Depth (feet)	11	49
Littoral Area (acres)	81	113
Volume (below the control elevation) (acre-feet)	375	6,230
Thermal Stratification Pattern	Dimictic	Polymictic
Estimated Residence Time (years) – 2014 Climatic Conditions	0.13	1.32
Estimated Residence Time (years) – 2010 Climatic Conditions	0.22	2.16
Watershed Area Tributary to Upstream Lake	2,476	3,442
Total Watershed Area	3,442	5,218
Subwatershed Area (acres)	966[2,3]	1,776[2,4]
Trophic Status Based on 2014 Growing Season Average Water Quality Data	Hypereutrophic	Eutrophic

1 – The water level control elevation from Rice Marsh Lake based on channel elevation determined from MDNR LiDAR data (2011) and Barr survey data (Data)
2 – Watershed area includes surface area of lake.
3 – Does not include Lake Lucy, Lake Ann or Lake Susan Lake watersheds
4 – Does not include Rice Marsh Lake watershed

1.4.1.1 Rice Marsh Lake

Rice Marsh Lake has an open-water surface area of approximately 83 acres (the open water area is variable, depending on the seasonally varying coverage of the lake's aquatic vegetation fringe). The lake is shallow, with a maximum depth of approximately 11 feet and mean depth of approximately 5 feet. The lake area, depth, and volume depend on the water level of the lake, which has been observed to vary between a high measurement of 877.25 feet mean sea level (MSL) (2012) to a low measurement of 872.0 feet MSL (1976). Since 1970, water levels have typically been between 874 and 877 feet MSL. Riley

Creek flows through Rice Marsh Lake, with the natural channel outlet located on the south side of the lake. Water levels in Rice Marsh Lake are controlled mainly by weather conditions (snowmelt, rainfall, and evaporation) and by the elevation of the streambed of Riley Creek, which is approximately 875 feet MSL. The water levels are also impacted by several beaver dams across Riley Creek between the Rice Marsh Lake outlet and Highway 212.

Given the shallow nature of Rice Marsh Lake, especially in comparison with its large surface area, the lake would be expected to be prone to frequent wind-driven mixing. While daily monitoring of the lake would be necessary to precisely characterize its mixing characteristics, review of temperature and dissolved oxygen profile data along the depth of the lake suggests that Rice Marsh Lake is polymictic, thermally stratifying and destratifying numerous times throughout the summer.

The lake's volume, outflow volume, and hydrologic residence time vary with climatic conditions (See Table 4).

Table 4 Rice Marsh Lake Estimated Volume, Outflow Volume and Hydrologic Residence Time during the Four Modeled Years (Existing Watershed Land Use)

Climatic Conditions during Modeled Years (Water Year, Inches of Precipitation)	Estimated Lake Volume in m^3 (Volume in acre-ft)	Estimated Lake Outflow in m^3 (Volume in acre-feet)	Estimated Hydrologic Residence Time (Years)
Model Calibration Year (2014, 35.21 inches)	544,169 (441)	3,963,325 (3,213)	0.14
Model Validation Year (2013, 27.38 inches)	538,205 (436)	2,992,823 (2,426)	0.18
Model Validation Year (2012, 25.58 inches)	531,889 (431)	3,196,451 (2,591)	0.17
Model Validation Year (2010, 30.89 inches)	536,324 (435)	2,295,973 (1,861)	0.23

1.4.1.2 Lake Riley

Of the lakes within the RPBCWD, Lake Riley has the largest surface area and volume. Lake Riley has a surface area of 297 acres, a maximum depth of approximately 49 feet, and a mean depth of approximately 23 feet. Riley Creek flows through Lake Riley, entering on the northeast side of the lake and exiting at the lake outlet on the southeast side.

The estimated littoral area of Lake Riley is 113 acres according to the Minnesota Department of Natural Resources (MDNR), or about 38 percent of the lake. Lake Riley is classified as a deep lake by the Minnesota Pollution Control Agency (MPCA). Review of temperature profile data along the depth of the lake shows that Lake Riley thermally stratifies during the summer, indicating that it is a dimictic system.

The normal water level of Lake Riley is controlled at elevation 864.5 MSL by a 20-foot long weir structure, which is located in the creek channel approximately 170 feet downstream of the lake. Discharge from Lake Riley is controlled by a 60-inch equivalent reinforced concrete arch pipe (RCPA), located underneath Lakeland Terrace (approximately 700 feet downstream of Lake Riley).

The lake's volume, outflow volume, and hydrologic residence time vary with climatic conditions (see Table 5).

Table 5 Lake Riley Estimated Volume, Outflow Volume, and Hydrologic Residence Time during Varying Climatic Conditions (Existing Watershed Landuse)

Climatic Conditions during Modeled Years (Water Year, Inches of Precipitation)	Estimated Lake Volume in m^3 (Volume in acre-ft)	Estimated Lake Outflow in m^3 (Volume in acre-feet)	Estimated Hydrologic Residence Time (Years)
Model Calibration Year **(2014, 35.21 inches)**	7,779,361 **(6,307)**	5,706,850 **(4,627)**	**1.4**
Model Validation Year **(2013, 27.38 inches)**	7,666,097 **(6,215)**	3,845,524 **(3,118)**	**2.0**
Model Validation Year **(2012, 25.58 inches)**	7,671,267 **(6,219)**	4,084,449 **(3,311)**	**1.9**
Model Validation Year **(2010, 30.89 inches)**	7,764,806 **(6,295)**	3,358,889 **(2,723)**	**2.3**

1.4.2 Ecosystems Data

The term "ecosystem" describes a community of living things and its interaction with the environment in which those living things live with each other. The ecosystem includes all the organisms associated with the lake's food chain including: macrophytes (aquatic plants), phytoplankton (algae), zooplankton (which prey upon algae), and the fisheries (which include the smaller planktivores (small fish that feed on zooplankton) and predator fish (larger fish that feed on the planktivores)). Decomposers, a less visible component of the food chain, include bacteria living at the lake bottom, which break down dead and decaying organisms into nutrients and other essential elements. All life in the lake's food chain is interdependent. If any one group becomes unbalanced, all life in the food chain is adversely impacted. An aquatic ecosystem is managed to maintain balance between the phytoplankton, zooplankton, small fish (bluegill sunfish and crappies), and large fish (bass and northern pike).

1.4.2.1 Phytoplankton

Phytoplankton, also called algae, are small aquatic plants naturally present in lakes that derive energy from sunlight (through photosynthesis) and from dissolved nutrients found in lake water. The phytoplankton (algae) species in Rice Marsh Lake and Lake Riley form the base of the lake's food web and directly impact fish production in the lakes. An inadequate phytoplankton population reduces the lake's zooplankton population and adversely impacts the lake's fishery. Excess phytoplankton, however, reduce water clarity, and reduced water clarity can interfere with the recreational usage of a lake. Phytoplankton growth is typically stimulated by excess phosphorus loads.

RPBCWD has collected phytoplankton data in Rice Marsh Lake for numerous years including: 1975, 1981, 1984, 1988, 1990, 1994, 1997, 2004, and 2012. Additionally, phycocyanin (cyanobacteria (blue-green algae) pigment) readings have been collected from 2010 through 2012 in Rice Marsh Lake.

Based on the most recent Rice Marsh Lake phytoplankton sampling year (2012), chlorophyta (green algae) and cyanobacteria (blue-green) were the dominant types of phytoplankton observed in the lake during much of the growing season, with cyanobacteria increasing in concentration later in the season. The 2010-2012 phycocyanin data collected in Rice Marsh Lake indicates that cyanobacteria were present through the water profile of the lake during these years. The estimated number of cyanobacteria cells per milliliter (based on the phycocyanin measurements) at the surface of Rice Marsh Lake typically fall within the World Health Organization's relatively low risk of adverse health effects (WHO, 2003).

RPBCWD has collected phytoplankton data in Lake Riley for several years including: 1975, 1978, 1981, 1988, 1990, 1994, 1997, 1998, 2001, and 2010. Additionally, phycocyanin (cyanobacteria (blue-green algae) pigment) readings have been collected in 2001, 2008, 2009, and 2010 in Lake Riley.

Based on review of the 2010 phytoplankton data, Lake Riley was dominated by cyanobacteria throughout the growing season, with much smaller concentrations of diatoms, chlorophyte, and dinoflagellates observed. More recent phytoplankton and phycocyanin data collected in Lake Riley indicates that cyanobacteria were present in all layers of the lake but were most prevalent in epilimnetic layers of the lake (4 to 6 meters in depth) in 2009 and 2010. At the surface of Lake Riley, the estimated number of cyanobacteria cells per milliliter (based on the phycocyanin measurements) typically fall within the World Health Organization's relatively low risk of adverse health effects (WHO, 2003)

While green algae are edible to zooplankton and serve as a valuable food source, cyanobacteria are considered a nuisance type of algae because they:

- Are generally inedible to fish, waterfowl, and most zooplankters
- Float at the lake surface in expansive algal blooms
- May be toxic to animals when occurring in large blooms
- Can disrupt lake recreation because they are most likely to be present during the summer months

1.4.2.2 Zooplankton

Zooplankton are microscopic animals that feed on particulate matter, including algae and are, in turn, eaten by fish. As a result, zooplankton populations are considered vital to the fishery. Protection or enhancement of the lake's zooplankton community through judicious management practices affords protection to the lake's fishery.

The rotifers and copepods graze primarily on extremely small particles of plant matter and do not significantly affect the lake's water quality. However, the cladocera graze primarily on algae and can improve water quality if present in abundance.

In the most recent zooplankton data for Rice Marsh Lake that spans the entire growing season (2012), the rotifera were the most abundant zooplankton throughout the spring and summer, with the exception of July when cladocera were more numerous. The copepod were most numerous in the spring and declined gradually through the summer. Ostracoda were never found in high numbers.

In the most recent zooplankton data for Lake Riley that spans the entire growing season (2013), the cladocera numbers were low in spring and the copepods comprised the most significant numbers of zooplankton in the spring and peaked in early July. Cladocera numbers increased in the summer months, peaking in late September. In late July and August, zooplankton numbers declined overall in Lake Riley, remaining low until fall—likely after the fall turnover. This decline may be linked to grazing by fish or dominance of the phytoplankton by cyanobacteria, which are generally inedible to zooplankton.

1.4.2.3 Macrophytes

Aquatic plants (macrophytes) are a natural part of most lake communities and provide many benefits to fish, wildlife, and people. Typical functions of a lake's macrophyte community include the following:

- Provide habitat for fish, insects, and small invertebrates
- Provide food for waterfowl, fish, and wildlife
- Produce oxygen
- Provide spawning areas for fish in early spring/provide cover for early life stages of fish
- Help stabilize marshy borders and protect shorelines from wave erosion
- Provide nesting sites for waterfowl and marsh birds

The RPBCWD has historically collected macrophyte data on Rice Marsh Lake and Lake Riley, typically conducting these surveys in June and August of the respective survey years. These surveys are qualitative surveys of the location and relative densities (low, medium, high) of the various species of macrophytes within the lake.

Two point-intercept surveys were conducted for Rice Marsh Lake in June and August of 2014. The objectives of the June survey were to evaluate the presence and densities of curlyleaf pondweed and native species. The objectives of the August survey were to characterize the native plant communities and determine the presence of Eurasian watermilfoil. Results of the surveys indicate fair plant diversity in the macrophyte community (Blue Water Science, 2015). The most common macrophyte on both survey dates was coontail (Ceratophyllum demersum, a native species), occurring at 52 percent and 78 percent of the sampled sites in June and August, respectively. Eurasian watermilfoil (Myriophyllum spicatum, an exotic species) was not found in Rice Marsh Lake. Curlyleaf pondweed (Potamogeton crispus) was observed at five of the 145 sites in June, out to approximately 9 feet of water depth. Curlyleaf covered approximately 3 acres in early summer, with mostly light growth.

The University of Minnesota has conducted point intercept surveys on Lake Riley from 2011 through 2014. Results of the surveys indicate low plant diversity in Lake Riley (University of Minnesota, 2015). Coontail is the most dominant native species, both in frequency of occurrence and native plant biomass. Eurasian watermilfoil and curlyleaf pondweed, also frequently occurring and dominant in biomass, have been problematic in Lake Riley. Eurasian watermilfoil is present at nuisance levels, with the high occurrence and density in late summer further inhibiting establishment of rooted native plants (University of Minnesota, 2015).

To combat curlyleaf pondweed, lake-wide early season endothal treatments were conducted in Lake Riley in spring 2013 and 2014. These treatments have significantly reduced curlyleaf pondweed densities and coverage and have increased native plant frequency. However, the increase in native species has been slight due to poor water clarity. Chara, Canada waterweed, bushy pondweed, narrow leaf pondweed, and sago pondweed were all observed at their highest frequency in 2014 (University of Minnesota, 2015).

1.4.2.4 Fishery

During 1992, the MDNR classified Minnesota lakes relative to fisheries. This ecological classification is a function of lake area, percentage of the lake surface area that is littoral, maximum depth, degree of shoreline development, Secchi disc transparency, and total alkalinity. According to its ecological classification, Rice Marsh Lake is a Class 42 lake (Schupp, 1992). Class 42 lakes, being relatively shallow and eutrophic, can be expected to experience frequent winter kills. The MDNR considers lakes of this class to be “marginal” fish lakes and has historically suggested that these lakes may be better suited for wildlife than for support of a thriving game fish population. The ecological classification of Lake Riley is a Class 24 lake, which signifies a good permanent fish lake (Schupp, 1992).

The native fish communities in Rice Marsh Lake and Lake Riley are dominated by blue gill, black crappie, largemouth bass, northern pike, and black and yellow bullhead. The lakes also had large common carp populations that have been diminished through recent implementation of a carp management program.

The RPBCWD funded the University of Minnesota to conduct multi-year research on the movement of common carp through the Riley Creek chain of lakes and document the key factors that influence carp recruitment. Key outcomes of the study were the removal of carp with winter seining and the installation of an aeration system in Rice Marsh Lake. RPBCWD continues operating the aeration system to prevent winter kill in Rice Marsh Lake as part of the carp management program.

The most recent MDNR fishery survey of Lake Riley was completed in 2011. The survey indicated that the predator community within the lake is typical of other Minnesota lakes. The abundance of northern pike was above average for lakes similar to Lake Riley, while the largemouth bass abundance was average. Walleye, which are stocked, were also found in average abundance. Five panfish species were found at varying abundance, including bluegill (above-average abundance), black crappie (below-average abundance), and yellow perch (average abundance). Rough fish were present, including common carp, black bullhead, and yellow bullhead.

MDNR fishery survey information is not available for Rice Marsh Lake. However, anecdotal information indicates that the fishery in Rice Marsh Lake has been less stable than the fishery in Lake Riley due to low oxygen levels during winter months and periodic winter kills.

2.0 Water Quality Assessment

2.1 Typical Urban Lake Water Quality Problems – Background Information

Eutrophication, or lake degradation, is the accumulation of sediments and nutrients in lakes. Typically, the nutrient of concern in fresh-water lake systems is phosphorus, as it often acts as the limiting nutrient that controls algal growth. As a lake naturally becomes more fertile, algae and weed growth increases. The increasing biological production and sediment inflow from the lake's watershed eventually fills the lake's basin. Over a period of many years, the lake successively becomes a pond, a marsh, and, ultimately, a terrestrial site. This process of eutrophication is natural and results from the normal environmental forces that influence a lake. Cultural eutrophication, however, is an acceleration of the natural process caused by human activities. Nutrient and sediment inputs (i.e., loadings) from wastewater treatment plants, septic tanks, and stormwater runoff can far exceed the natural inputs to the lake. The accelerated rate of water quality degradation caused by these pollutants results in unpleasant consequences. These include profuse and unsightly growths of algae (algal blooms) and/or the proliferation of rooted aquatic plants (macrophytes).

2.1.1 Trophic State

Not all lakes are at the same stage of eutrophication; therefore, criteria have been established to evaluate the nutrient status, or trophic status, of lakes. Trophic status categories include oligotrophic (i.e., excellent water quality), mesotrophic (i.e., good water quality), eutrophic (i.e., poor water quality), and hypereutrophic (i.e., very poor water quality). Water quality characteristics of lakes in the various trophic status categories are listed below:

1. **Oligotrophic**: clear, low productivity lakes, with total phosphorus concentrations less than or equal to 10 µg/L, chlorophyll *a* concentrations of less than or equal to 2 µg/L, and Secchi disc transparencies greater than or equal to 4.6 meters (15 feet)
2. **Mesotrophic**: intermediate productivity lakes, with total phosphorus concentrations between 10 and 25 µg/L, chlorophyll *a* concentrations between 2 and 8 µg/L, and Secchi disc transparencies between 2 and 4.6 meters (6 to 15 feet)
3. **Eutrophic**: high productivity lakes relative to a neutral level, with 25 to 57 µg/L total phosphorus, chlorophyll *a* concentrations between 8 and 26 µg/L, and Secchi disc measurements between 0.85 and 2 meters (2.7 to 6 feet)
4. **Hypereutrophic**: extreme productivity lakes which are highly eutrophic and unstable (i.e., their water quality can fluctuate on daily and seasonal basis, experience periodic anoxia and fish kills, possibly produce toxic substances, etc.) with total phosphorus concentrations greater than 57 µg/L, chlorophyll *a* concentrations of greater than 26 µg/L, and Secchi disc transparencies less than 0.85 meters (2.7 feet)

2.1.2 Typical Nutrient Sources

Phosphorus enters a lake from a variety of external sources, such as watershed runoff, direct atmospheric deposition, and discharges from upstream water bodies. More recently, data collected by RPBCWD identified that some of the constructed stormwater ponds and natural wetlands can also experience internal loading from the accumulated sediments and organic materials and can act as sources of phosphorus to the downstream lakes, rather than phosphorus sinks. Because external phosphorus sources can be significant, the phosphorus concentrations in a lake can be reduced by decreasing the external load of phosphorus to the lake.

All lakes, however, also accumulate phosphorus (and other nutrients) in the sediments from the settling of particles and dead organisms and organic matter. In some lakes, this reservoir of phosphorus can be reintroduced in the lake water and become available again for plant uptake. This resuspension or dissolution of nutrients from the sediments to the lake water is known as "internal loading." As long as the lake's sediment surface remains sufficiently oxidized (i.e., dissolved oxygen remains present in the water above the sediment), the phosphorus will remain bound to ferric iron in sediment particles. When dissolved oxygen levels become extremely low at the water-sediment interface (as a result of microbial activity using the oxygen), the chemical reduction of ferric iron to its ferrous form causes the release of dissolved phosphorus, which is readily available for algal growth, into the water column. Low-oxygen conditions at the sediments, with resulting phosphorus release, are to be expected in eutrophic lakes where relatively large quantities of organic material (decaying algae and macrophytes) are deposited on the lake bottom.

In addition to the dissolved oxygen levels along the sediment interface, the pH of the water column can also play a vital role in affecting the phosphorus release rated under oxic conditions. Photosynthesis by macrophytes and algae during the day tend to raise the pH in the water column, which can enhance the phosphorus release rate from the oxic sediment. Enhancement of the phosphorus release at elevated pH (pH great than 7.5) is thought to occur through replacement of the phosphate ion (PO_4^{-3}) with the excess hydroxyl ion (OH^-) on the oxidized iron compound (James et. al., 2001). How this internal phosphorus load from the sediments impacts the observed water quality in the lake is highly dependent on the thermal stratification and mixing dynamics within the lake (see Section 2.1.3 summarizing lake dynamics).

Another potential source of internal phosphorus loading is the die-off and subsequent decay of curlyleaf pondweed, an exotic (i.e., non-native) lake weed prevalent in many Minnesota lakes. Curlyleaf pondweed grows over the winter and tenaciously during early spring, crowding out native species. It releases a small reproductive pod (turion) that resembles a small pinecone during late June. After curlyleaf pondweed dies out, often in late-June and early-July, it may sink to the lake bottom and decay, releasing phosphorus and causing oxygen depletion and exacerbating internal sediment release of phosphorus. This potential increase in phosphorus concentration during early July can result in algal blooms during the peak of the recreational season.

Another common source of internal loading in some lakes is related to the activities of benthivorous (bottom feeding) fish. Benthivorous fish, such as carp and bullhead, can have a direct influence on the phosphorus concentration in a lake (LaMarra, 1975), as these fish typically feed on decaying plant and animal matter and other organic particulates found at the sediment surface and convert these nutrients into a soluble form that is then available for algal uptake. They also cause resuspension of sediments that reduce water clarity as well as high phosphorus concentrations (Cooke et al., 1993). Additionally, benthivorous fish can destroy the aquatic rooted vegetation, which can have a significant impact on the overall lake water quality (Sorensen, University of Minnesota, phone conversation, 6/19/2013).

2.1.3 Lake Dynamics

Thermal stratification, or the changes in the temperature profile with depth within a lake system, profoundly influences a lake's chemistry and biology. When the ice melts and air temperature warms in spring, lakes generally progress from being completely mixed to stratified with an upper layer or warm well-mixed water (epilimnion), cold temperatures in a bottom layer (hypolimnion), and a layer of varying depth that will have a sharp temperature gradient (thermocline). Because of the density differences between the lighter warm water and the heavier cold water, stratification in a lake can become very resistant to mixing. When this occurs, generally in mid-summer, oxygen from the air cannot reach the bottom lake water and, if the lake sediments have sufficient organic matter, biological activity can deplete the remaining oxygen in the hypolimnion. The epilimnion can remain well oxygenated, while the water above the sediments in the hypolimnion becomes completely devoid of dissolved oxygen (anoxic).

Thermal stratification can significantly influence the amount of internal phosphorus loading from the sediments that can occur in the lake, and in some lakes, can significantly influence the water quality in the epilimnion (surface layer). Complete loss of oxygen changes the chemical conditions in the water and sediment, allowing phosphorus that had remained bound to the sediments to reenter the water column. As the summer progresses, phosphorus concentrations in the hypolimnion can continue to rise until oxygen is again introduced (recycled). Dissolved oxygen concentrations in the hypolimnion will increase if the lake sufficiently mixes to disrupt the thermal stratification. Phosphorus in the hypolimnion is generally not available for plant uptake because there is not sufficient light penetration to the hypolimnion to allow for growth of algae. The phosphorus, therefore, remains trapped and unavailable to the plants until the lake is completely mixed.

In shallow lakes, this mixing (bringing phosphorus from the hypolimnion to the surface) can occur throughout the summer, with sufficient wind energy (referred to as polymictic lake, or "many mixings"). In deeper lakes, however, only extremely high wind energy is sufficient to destratify a lake during the summer, and complete mixing only occurs in the spring and fall (referred to as dimictic lake, or "two mixings"). Cooling air temperature in the fall reduces the epilimnion water temperature, and consequently increases the density of water in the epilimnion. As the epilimnion water density approaches the density of the hypolimnion water, very little energy is needed to cause complete mixing of the lake. When this fall mixing occurs, phosphorus that has built up in the hypolimnion is mixed with the epilimnion water and becomes available for plant and algal growth. Often, similar thermal stratification pattern can occur during the winter under the ice as well.

2.2 Water Quality Potential in Rice Marsh Lake and Lake Riley

There are several tools that can be used to evaluate the expected water quality in a lake. This study utilizes two different tools to estimate the expected water quality in Rice Marsh Lake and Lake Riley, including the relationship develop by Vighi and Chiaudani (1985) and the Minnesota Lake Eutrophication Analysis Program (MINLEAP) as developed by Heiskary and Wilson (1990) and programmed as part of the Wisconsin Department of Natural Resources Wisconsin Lake Modeling Suite (WiLMS, 2005). In addition, the RPBCWD conducted a paleolimnological study of Rice Marsh Lake in 2014.

2.2.1 Vighi and Chiaudani

Vighi and Chiaudani (1985) developed a method to determine the phosphorus concentration in lakes that are not affected by anthropogenic (human) inputs. Using their method and information about the lake's mean depth and alkalinity or conductivity, the phosphorus concentration in a lake resulting from natural, background phosphorus loadings can be predicted. Alkalinity is considered more useful for this analysis because it is less influenced by the modifying effect of anthropogenic inputs. There are both alkalinity and specific conductivity data available for Rice Marsh Lake and Rice Marsh Lake; therefore, both methods were used to estimate the background phosphorus concentrations for each of the lakes.

For Rice Marsh Lake, the Vighi and Chiaudani relationship using conductivity predicted phosphorus concentration from natural, background loadings to be 29 µg/L (ranging from 13 µg/L to 48 µg/L). The expected total phosphorus concentration in Rice Marsh Lake based on the average alkalinity since 2010 was 33 µg/L. Both methods indicated that historically, Rice Marsh Lake was a eutrophic lake.

For Lake Riley, the Vighi and Chiaudani relationship using conductivity predicted phosphorus concentration from natural, background loadings to be 17 µg/L (ranging from 10 µg/L to 26 µg/L). The expected total phosphorus concentration in Lake Riley based on the average alkalinity since 2009 was 19 µg/L. Both methods indicated that historically, Lake Riley was a mesotrophic lake.

2.2.2 Minnesota Lake Eutrophication Analysis Program (MINLEAP)

MINLEAP is intended to be used as a screening tool for estimating lake conditions and identifying "problem" lakes. MINLEAP is particularly useful for identifying lakes requiring "protection" versus those requiring "restoration" (Heiskary and Wilson, 1990). In addition, MINLEAP modeling has been conducted in the past to identify Minnesota lakes that may be in better or worse condition than they "should be" based upon their location, watershed area, and lake basin morphometry (Heiskary and Wilson, 1990). Using the long-term summer average total phosphorus, chlorophyll *a*, and Secchi depth, MINLEAP estimated the expected concentration or depth of each of the above parameters as well as the standard error associated with the average values.

In Rice Marsh Lake, the predicted total phosphorus concentration was estimated to be 60 µg/L (with a range of 41 µg/L to 79 µg/L). The chlorophyll *a* concentration was estimated to be 26 µg/L (with a range of 11 µg/L to 41 µg/L). The estimated Secchi depth for Rice Marsh Lake was 1.1 meters (with a range of 0.7 meters to 1.5 meters). These estimates place Rice Marsh Lake in the eutrophic classification. The observed growing season average total phosphorus concentrations in Rice Marsh Lake over the past 10 years are frequently greater than the upper-range value of a minimally impacted lake with similar characteristics to Rice Marsh Lake, confirming that the lake is impacted by anthropogenic inputs. The observed chlorophyll *a* concentrations fall within the expected range of a minimally impacted lake, while the Secchi disc transparency value are actually frequently greater than the expected upper-range value.

In Lake Riley, the predicted total phosphorus concentration was estimated to be 25 µg/L (with a range of 15 µg/L to 35 µg/L). The estimated chlorophyll *a* concentration was estimated to be 7 µg/L (with a range of 2 µg/L to 12 µg/L). The estimated Secchi depth for Lake Riley was 2.4 meters (with a range of 1.3 meters to 3.5 meters). These estimates place Lake Riley in the eutrophic classification. The observed growing season average total phosphorus and chlorophyll *a* concentrations in Lake Riley over the past 10 years are frequently greater than upper-range values of a minimally impacted lake with similar characteristics to Lake Riley, confirming that the lake is impacted by anthropogenic inputs. The actual Secchi disc transparency measurements do fall within the range of a minimally impacted lake with similar characteristics to Lake Riley.

2.2.3 Paleolimnological Total Phosphorus Reconstruction in Rice Marsh Lake

In 2014, RPBCWD contracted with St. Croix Watershed Research Station to use paleolimnological techniques to reconstruct the trophic and sedimentation history of Rice Marsh Lake (Ramstack Hobbs, J.M. and M.B. Edlund. 2014). A sediment core was collected from the lake, and lead-210 activity was analyzed to develop a dating model and determine the sediment accumulation rate over the past 150 to 200 years. Figure 6 illustrates how the diatom-inferred total phosphorus concentration in the lake has change over time. It appears that the pre-settlement total phosphorus concentration in Rice Marsh Lake was between 40-50 µg/L. The analysis concludes that Rice March Lake was a nutrient-enriched lake during the late 1800s through the mid-1900s; however, the lake became increasingly eutrophic at the time that the wastewater treatment plant began operation. The change in the diatom community at the core top and decline in cyanobacteria production, combined with a decrease in the sedimentation rate, suggests that recent management efforts on Rice Marsh Lake and Lake Susan are having positive effects.

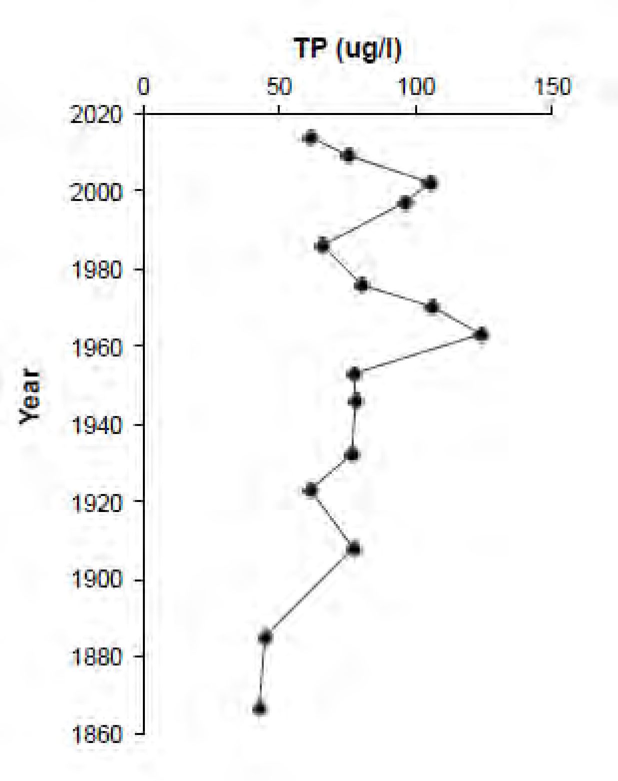


Figure 6 **Diatom-inferred Total Phosphorus Concentration in Rice Marsh Lake (Ramstack Hobbs, J.M. and M.B. Edlund. 2014)**

2.3 Water Quality Standards

The MPCA lake eutrophication criteria establish water quality standards for lakes based on total phosphorus, chlorophyll *a*, and Secchi disc transparency (Minnesota Rules, 7050). The standards are based on the geographic location of the water body within the state (and the associated ecoregion) and the depth of the water body, distinguishing shallow and deep lakes. The standards are based on the growing-season average of the surface data available for any given lake. The growing season is defined as June through September. Surface data is considered to be any water quality data collected in the depth range of 0 to 2 meters from the water surface of the lake. These criteria are used to determine if a lake is impaired by excess nutrients and are the criteria used to list lakes on the MPCA 303(d) list of impaired waters.

Rice Marsh Lake and Lake Riley are located within the North Central Hardwood Forest ecoregion of the state. Rice Marsh Lake is considered a shallow lake by the MPCA, while Lake Riley is a deep lake.

As part of the Plan (CH2M Hill, 2011), the RPBCWD adopted national and state goals for the water resources within the watershed, including the MPCA lake water quality standards. Additionally, as part of the RPBCWD's vision, an additional long-term goal is to have all lakes achieve water clarity of 2 meters or more. Table 6 summarizes the MPCA and RPBCWD water quality goals and standards as would be applied to Rice Marsh Lake and Lake Riley.

Table 6 **Water Quality Goals and Standards for Rice Marsh Lake and Lake Riley**

Agency	Parameter	Rice Marsh Lake	Lake Riley
MPCA	Ecoregion	North Central Hardwood Forest	North Central Hardwood Forest
	Depth Classification	Shallow	Deep
	Total Phosphorus	TP ≤ 60 µg/L	TP ≤ 40 µg/L
	Chlorophyll a	Chl-a ≤ 20 µg/L	Chl-a ≤ 14 µg/L
	Secchi Disc Transparency	SD ≥ 1.0 m	SD ≥ 1.4 m
RPBCWD	Total Phosphorus		TP ≤ 40 µg/L
	Chlorophyll a		Chl-a ≤ 14 µg/L
	Secchi Disc Transparency		SD ≥ 1.4 m
	Goal for all Lakes	SD ≥ 2.0 m	SD ≥ 2.0 m

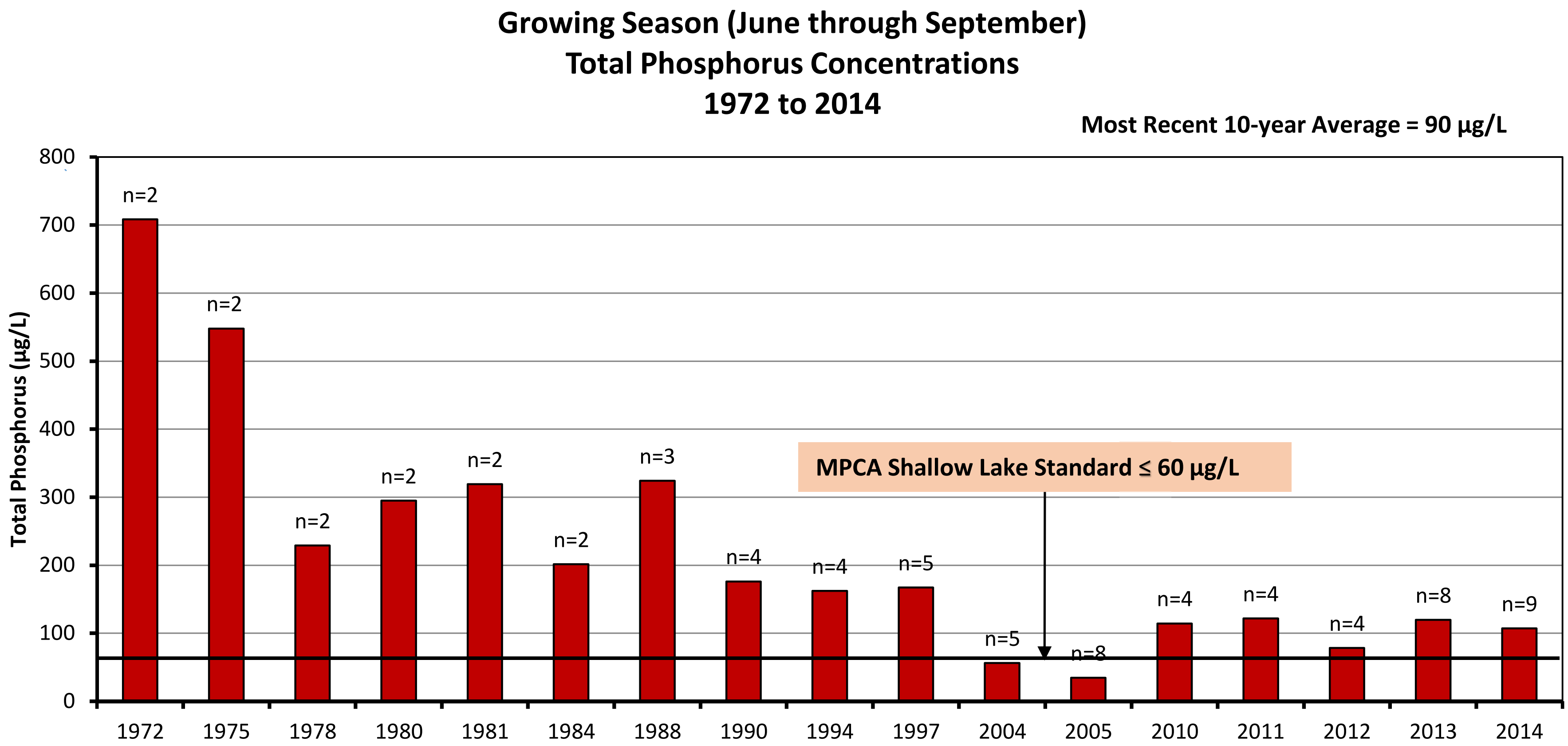
2.4 Water Quality Monitoring Program

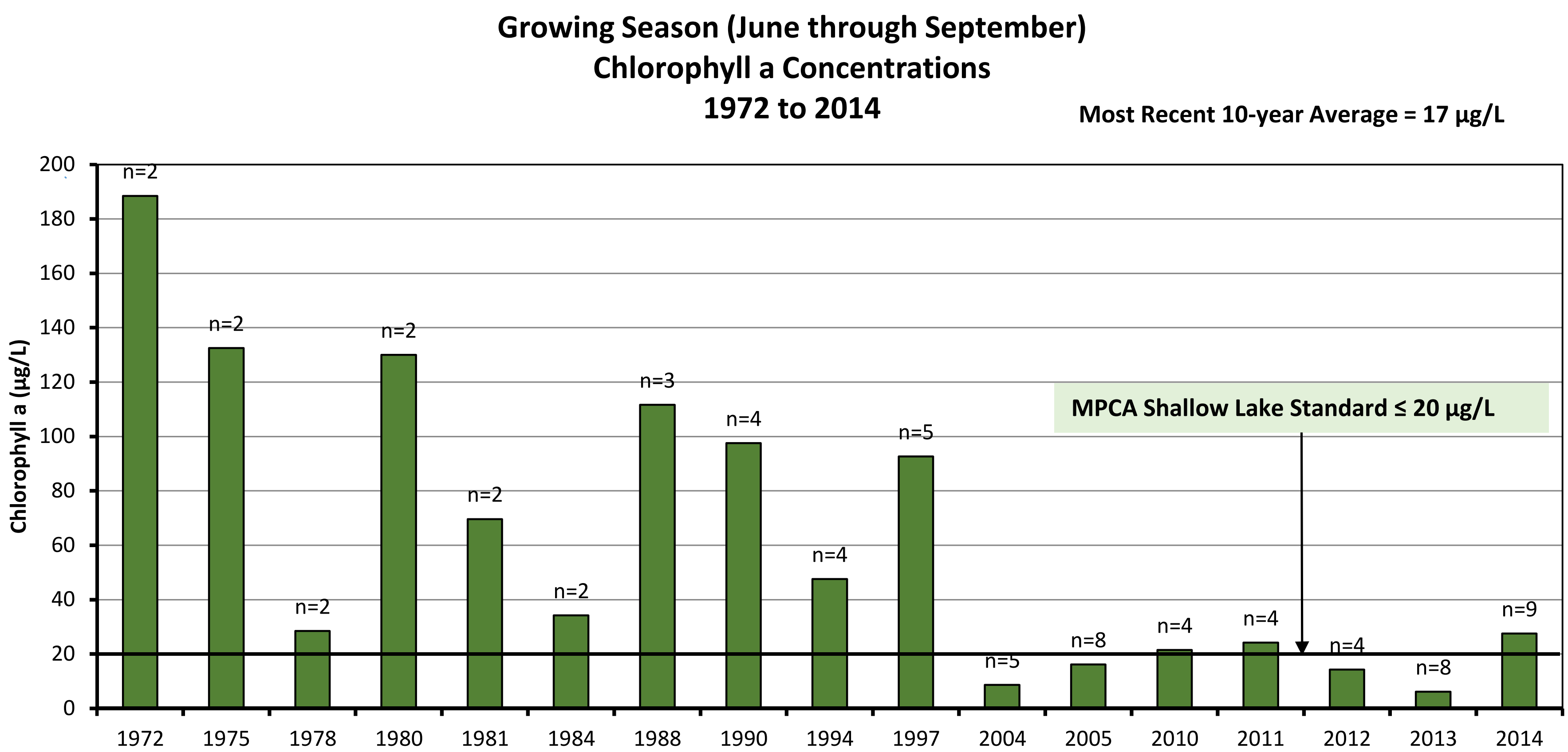
The water quality in Rice Marsh Lake has historically been monitored by the RPBCWD, the Metropolitan Council as part of the Citizen-Assisted Monitoring Program (CAMP), the MDNR Citizen Lake Monitoring Program (CLMP), and more recently by the University of Minnesota. For the three typical water quality parameters, there is historical total phosphorus and chlorophyll *a* water quality data available for 1972, 1975, 1978, 1980, 1981, 1984, 1988, 1990, 1994, 1997, 2004, 2005, and 2010-2014.

The water quality in Lake Riley has historically been monitored by the RPBCWD, the Metropolitan Council as part of the Citizen-Assisted Monitoring Program (CAMP), the MDNR Citizen Lake Monitoring Program (CLMP), and more recently by the University of Minnesota. For the three typical water quality parameters, there is historical total phosphorus and Secchi disc transparency water quality data available for 1971, 1972, 1975, 1978, 1979, 1980-1982, 1984-1988, 1990, 1991, 1993, 1994, 1997, 1998, 2000, 2002-2012, and 2014. For chlorophyll a, there is data from 1971, 1972, 1975, 1978, 1980-1982, 1984-1988, 1990, 1991, 1993, 1994, 1998, and 2002-2014.

2.5 Historic Water Quality Summary

Historical water quality data, in terms of growing-season average total phosphorus concentrations, chlorophyll *a* concentrations, and Secchi disc transparency for Rice Marsh Lake and Lake Riley are presented in Figure 7 and Figure 8. Also shown in these figures are the number of samples used to determine the growing-season average, the MPCA water quality standards for each parameter, the RPBCWD goals for each lake, and the average of the past 11 years of water quality monitoring data (2004-2014).





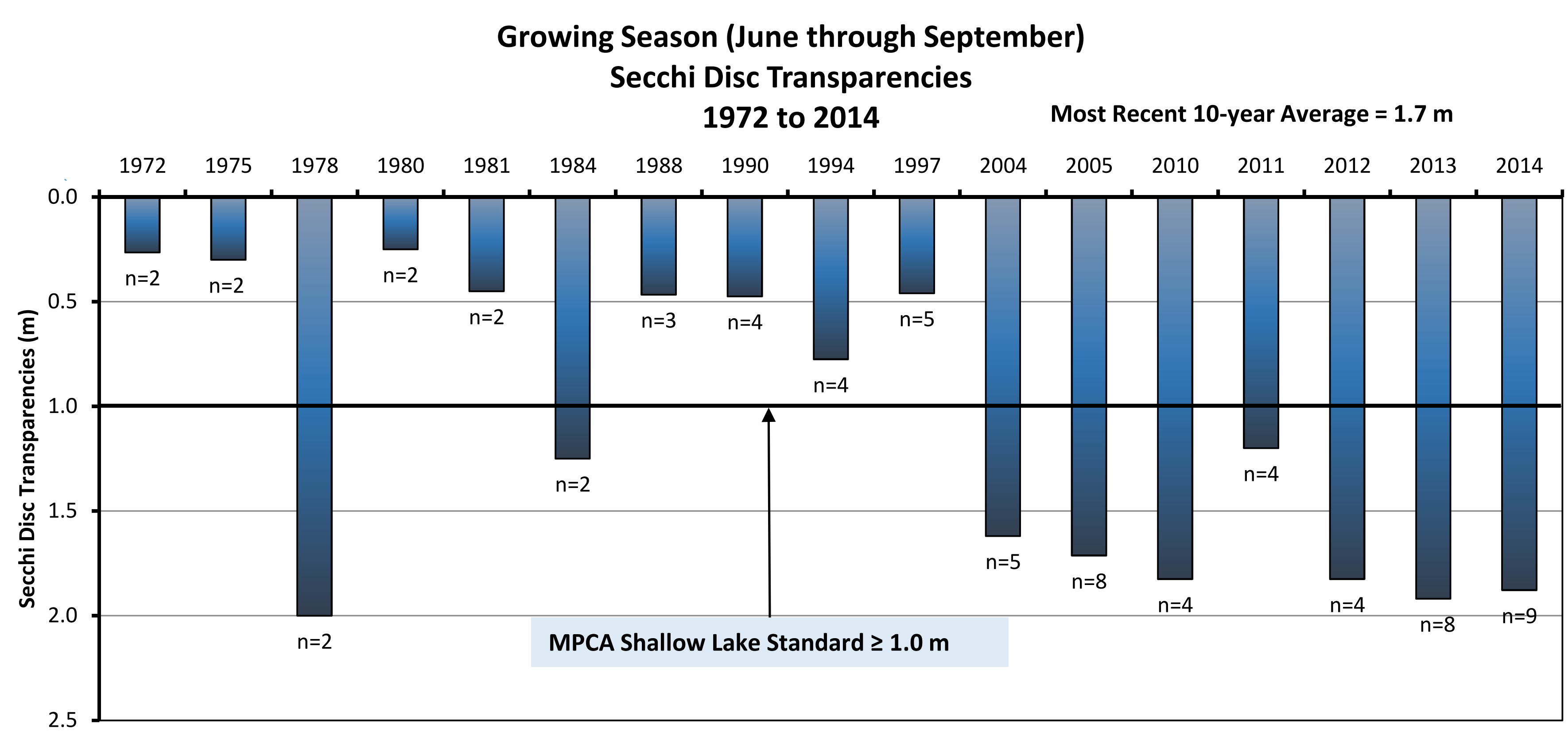
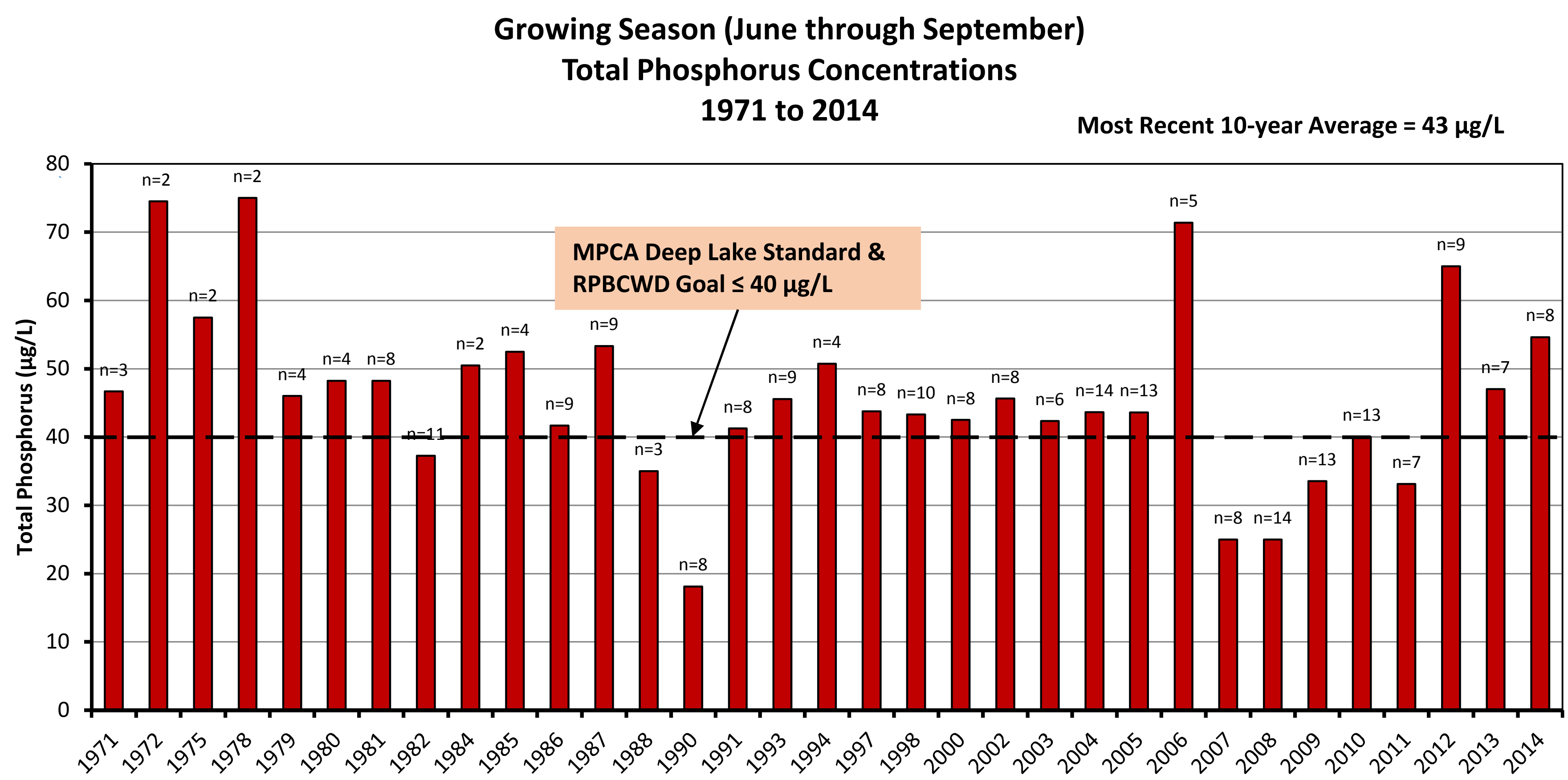
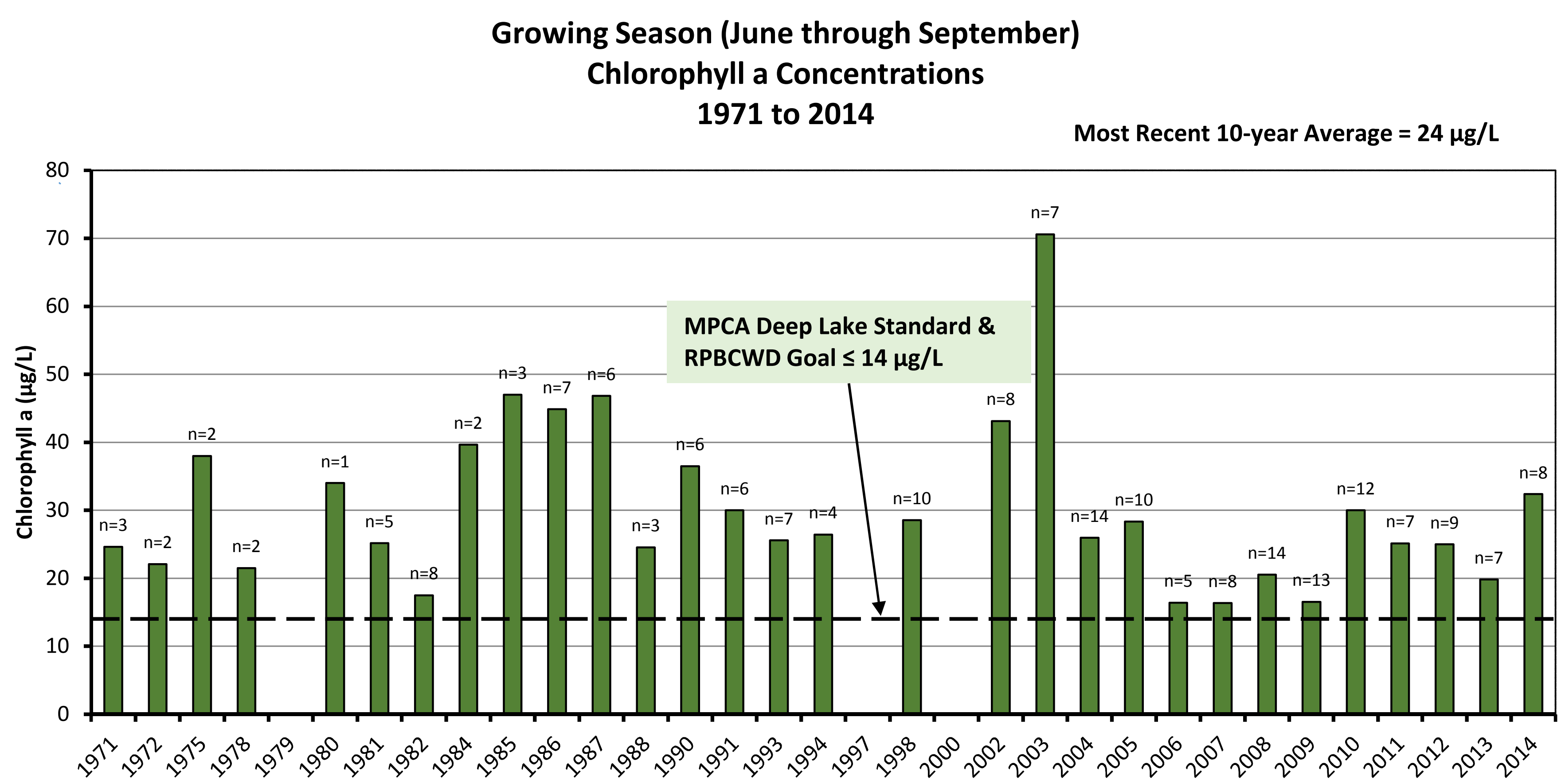


Figure 7
Rice Marsh Lake
Historic Growing Season Water Quality
Total Phosphorus, Chlorophyll-a, and Secchi Disc Transparency





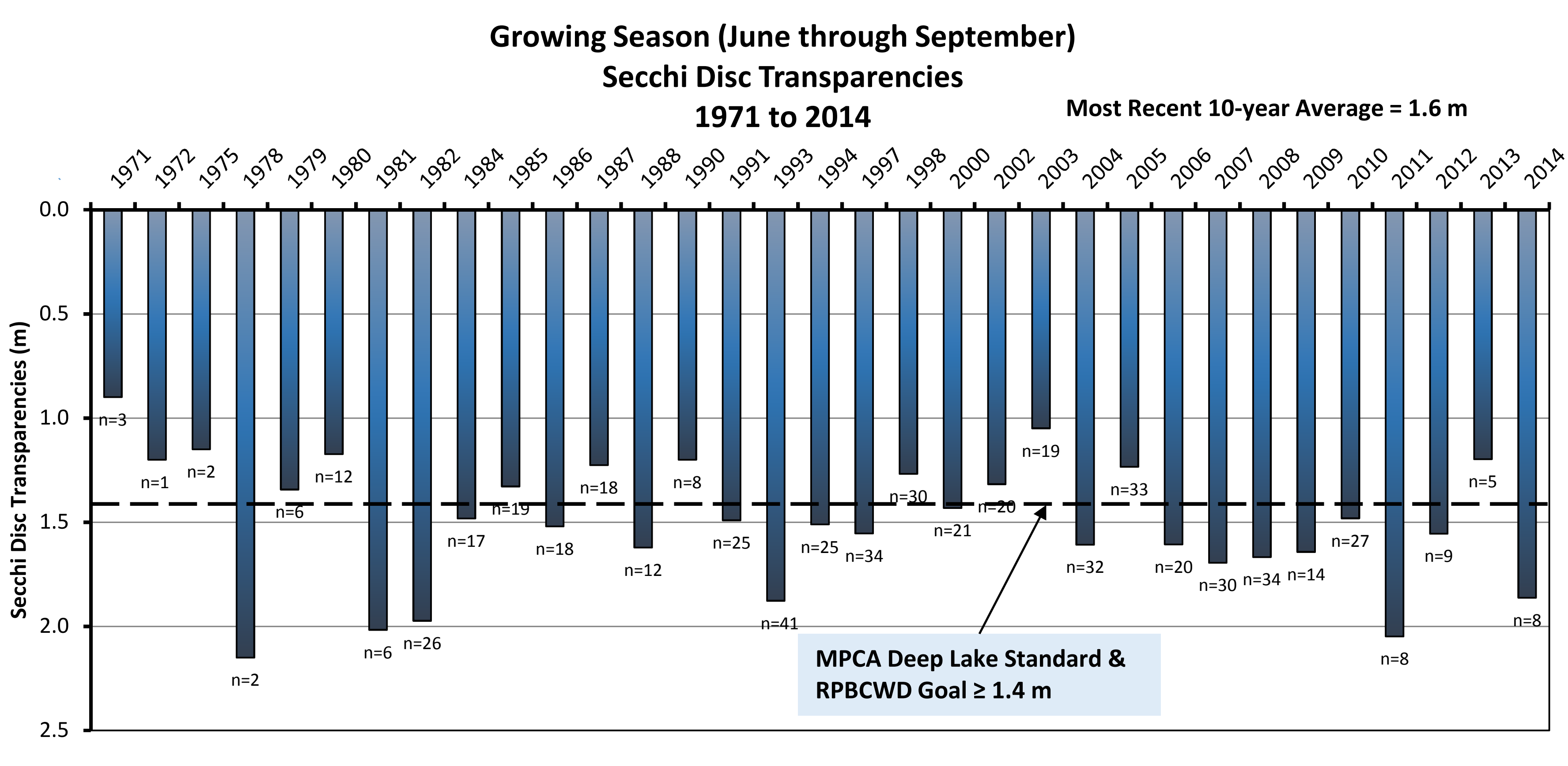


Figure 8
Lake Riley
Historic Growing Season Water Quality
Total Phosphorus, Chlorophyll-a, and Secchi Disc Transparency

2.5.1 Water Quality Relationships

The compiled data for the water quality variables from Rice Marsh Lake and Lake Riley were analyzed to develop relationships between the water quality parameters: total phosphorus, chlorophyll *a*, and Secchi depth. Relationships were evaluated based on individual sampling dates and based on the growing season averages. In addition to developing the water quality relationships based on the observed data, the regression equations developed by the MPCA based on a statewide lake data base (MPCA, 2005) were also plotted against these data for both lakes.

The relationships between the various water quality parameters for the actual Rice Marsh Lake data did indicate some correlation between the water quality parameters. The MPCA regression equations resulted in similar fit for the chlorophyll *a* and Secchi disc transparency data but did not correlate well with the total phosphorus data points. For this reason, the observed data regression equations were selected to estimate the resulting chlorophyll *a* and Secchi disc transparency for Rice Marsh Lake

The relationships between the various water quality parameters for the actual Lake Riley data did not indicate a significant correlation. Because the MPCA statewide standards provided a similar fit to the observed data, the statewide regression equations were selected to estimate the resulting chlorophyll *a* and Secchi disc transparency for Lake Riley.

Figure 9 and Figure 10 show the individual water quality data points for Rice Marsh Lake and Lake Riley respectively, along with plots of the MPCA statewide regression equations.

The statewide regression equations developed by the MPCA are summarized below:

- Log10 Chla = 1.31 Log10 TP – 0.95
- Log10 Secchi = -0.59 Log10 Chla + 0.89
- Log10 Secchi = -0.81 Log10 TP + 1.51

The Rice Marsh Lake regression equations are given below.

- Log10 Chla = 1.029 Log10 TP – 0.757
- Log10 Secchi = -0.534 Log10 Chla + 0.745
- Log10 Secchi = -0.691 Log10 TP + 1.444

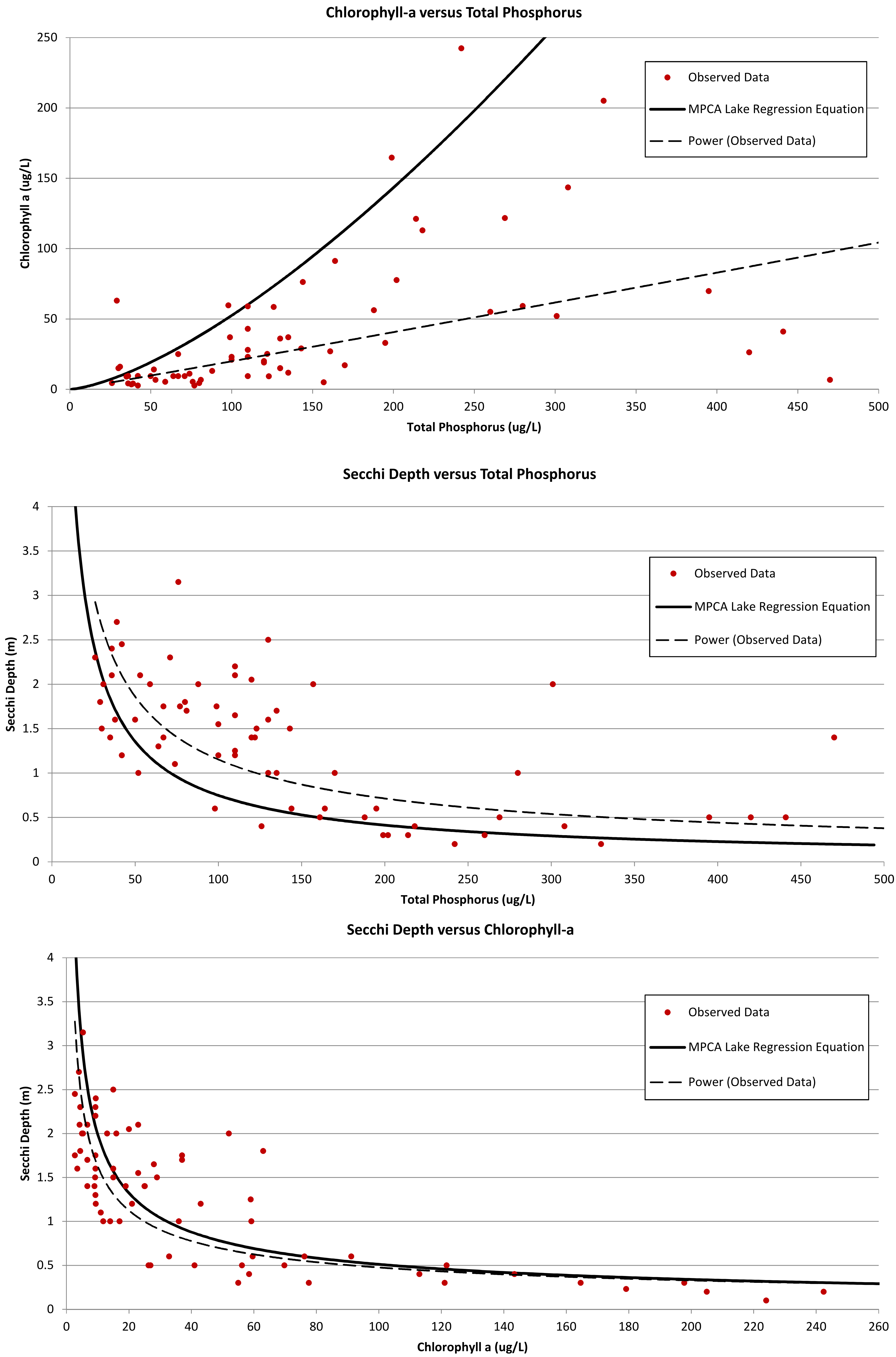
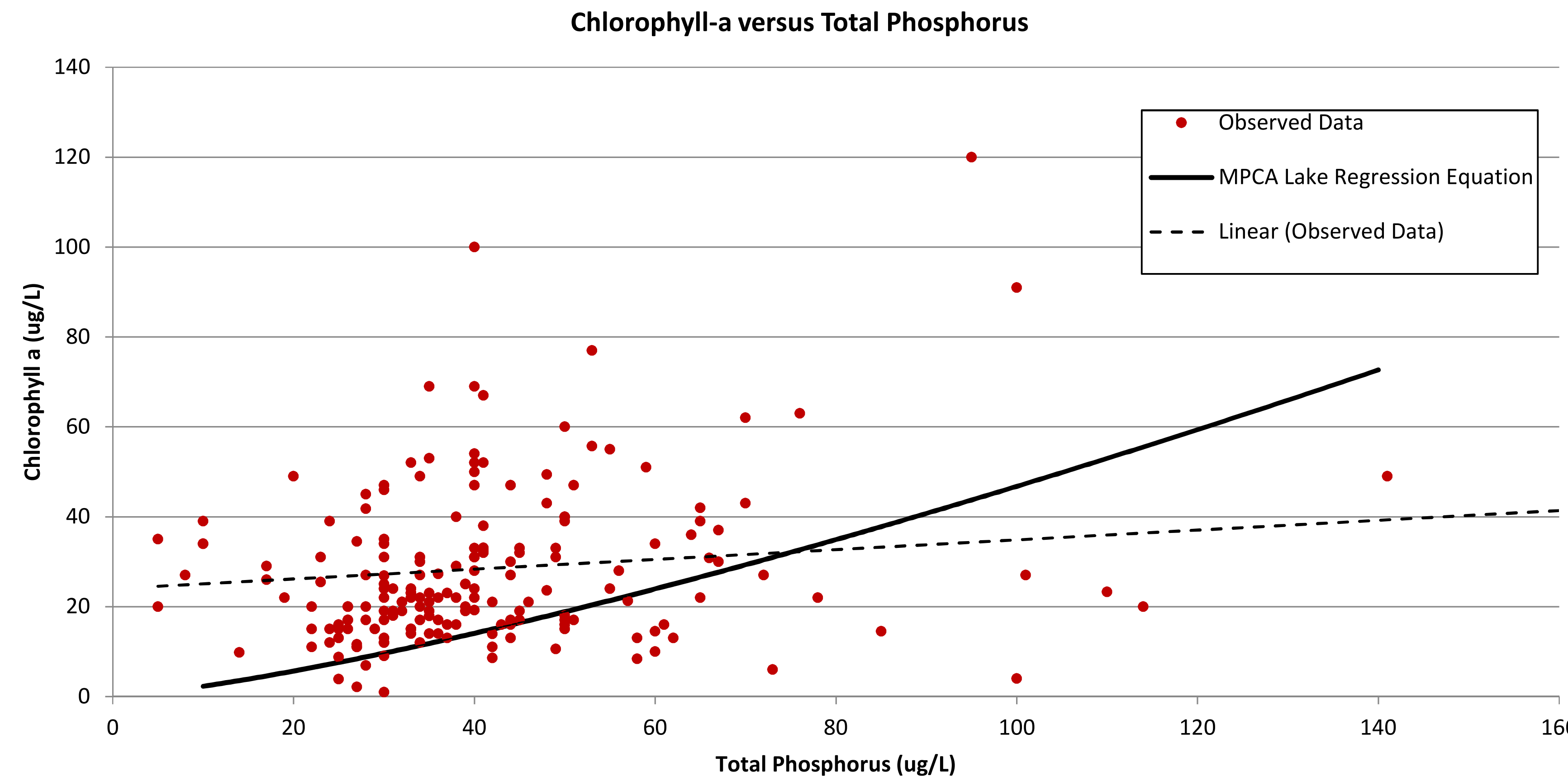
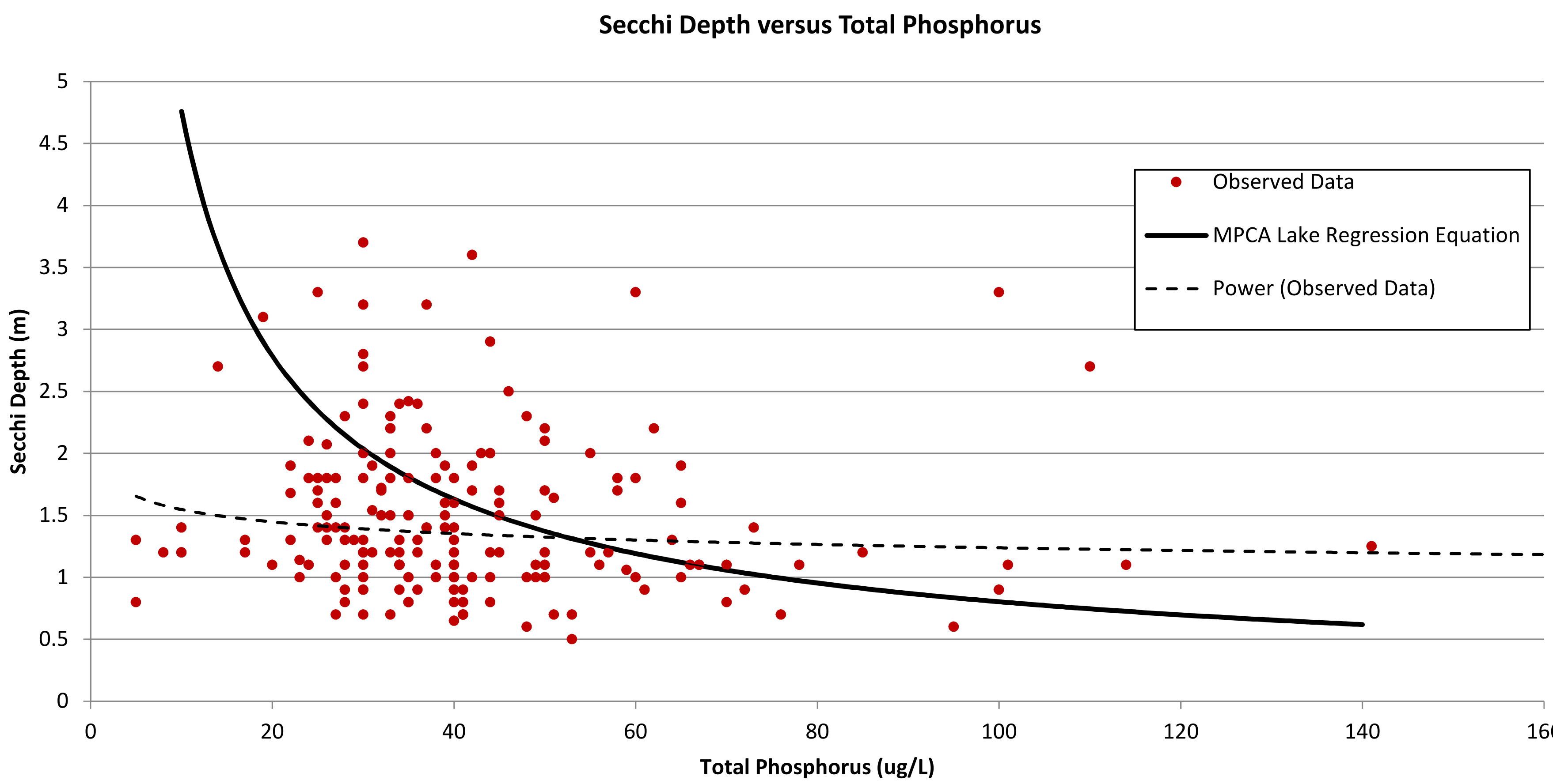


Figure 9
Rice Marsh Lake Individual Samples
Water Quality Parameter
Regression Relationships





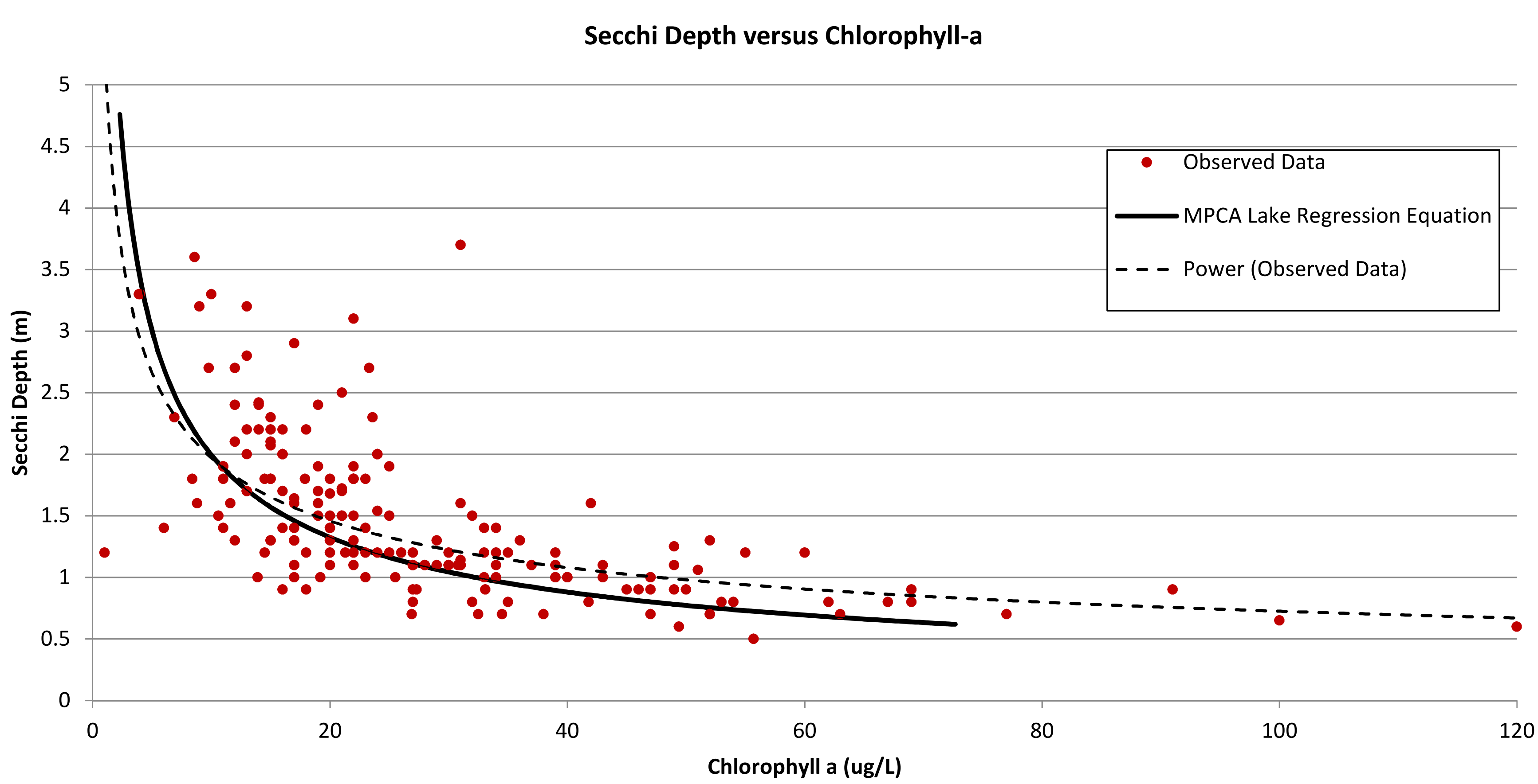


Figure 10
Lake Riley Individual Samples
Water Quality Parameter
Regression Relationships

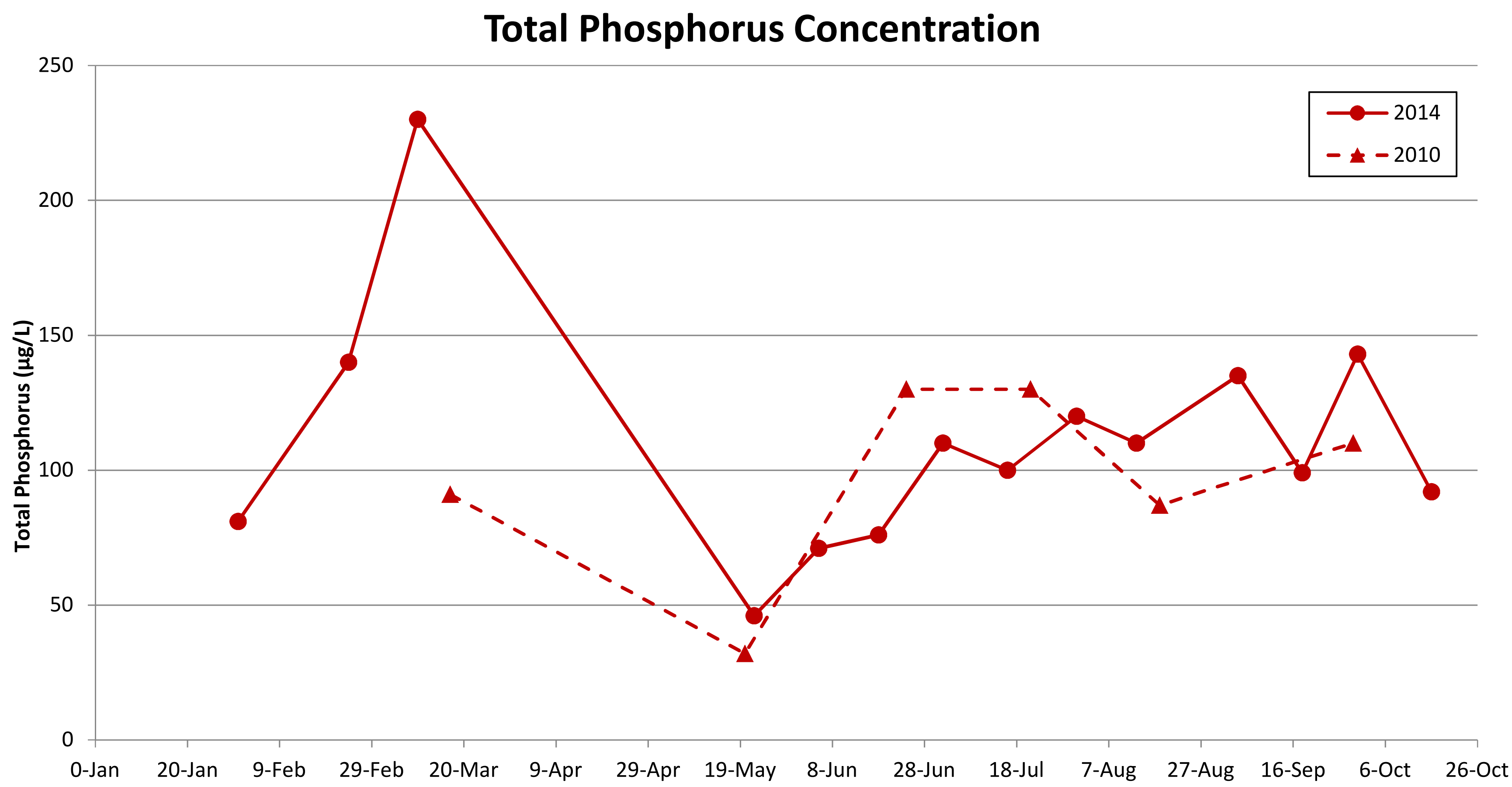
2.6 Water Quality Modeling Analysis

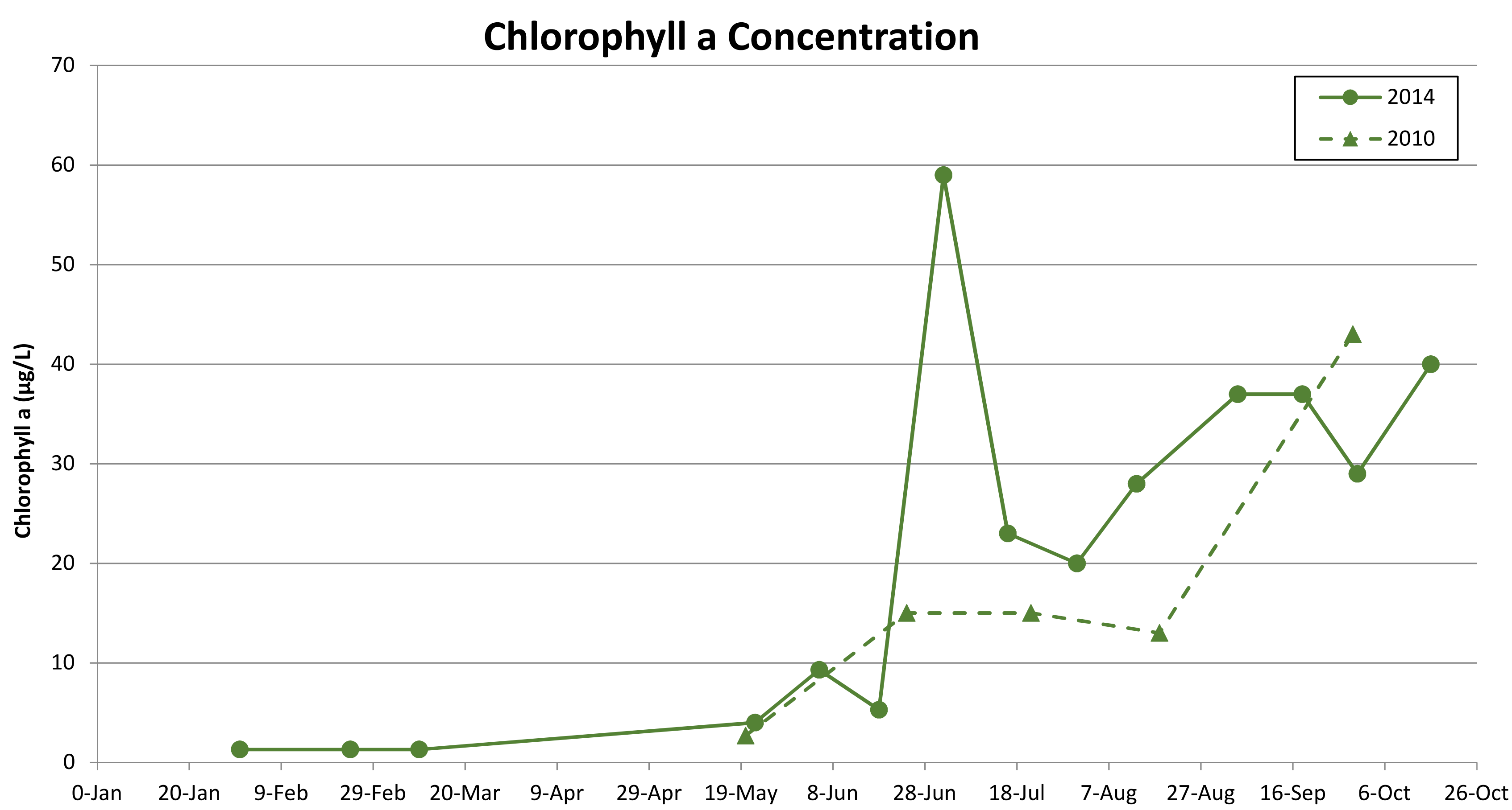
The Rice Marsh Lake and Lake Riley water quality evaluations were conducted for water years (October 1 to October 1) 2010 and 2014. These years were selected because they are the two most recent years that have water quality sample profiles for both lakes. In addition, these years reflect different climatic conditions influencing water quality in these lakes.

2.6.1 Seasonal Patterns in the 2010 and 2014 Water Quality Conditions

The following section includes discussion of the seasonal patterns observed in the water quality during 2010 and 2014 in both Rice Marsh Lake and Lake Riley. The focus of the discussion will primarily be on total phosphorus, chlorophyll *a*, and Secchi disc transparency.

Figure 11and Figure 12 show the total phosphorus, chlorophyll *a*, and Secchi disc transparency for 2010 and 2014 in Rice Marsh Lake and Lake Riley, respectively.





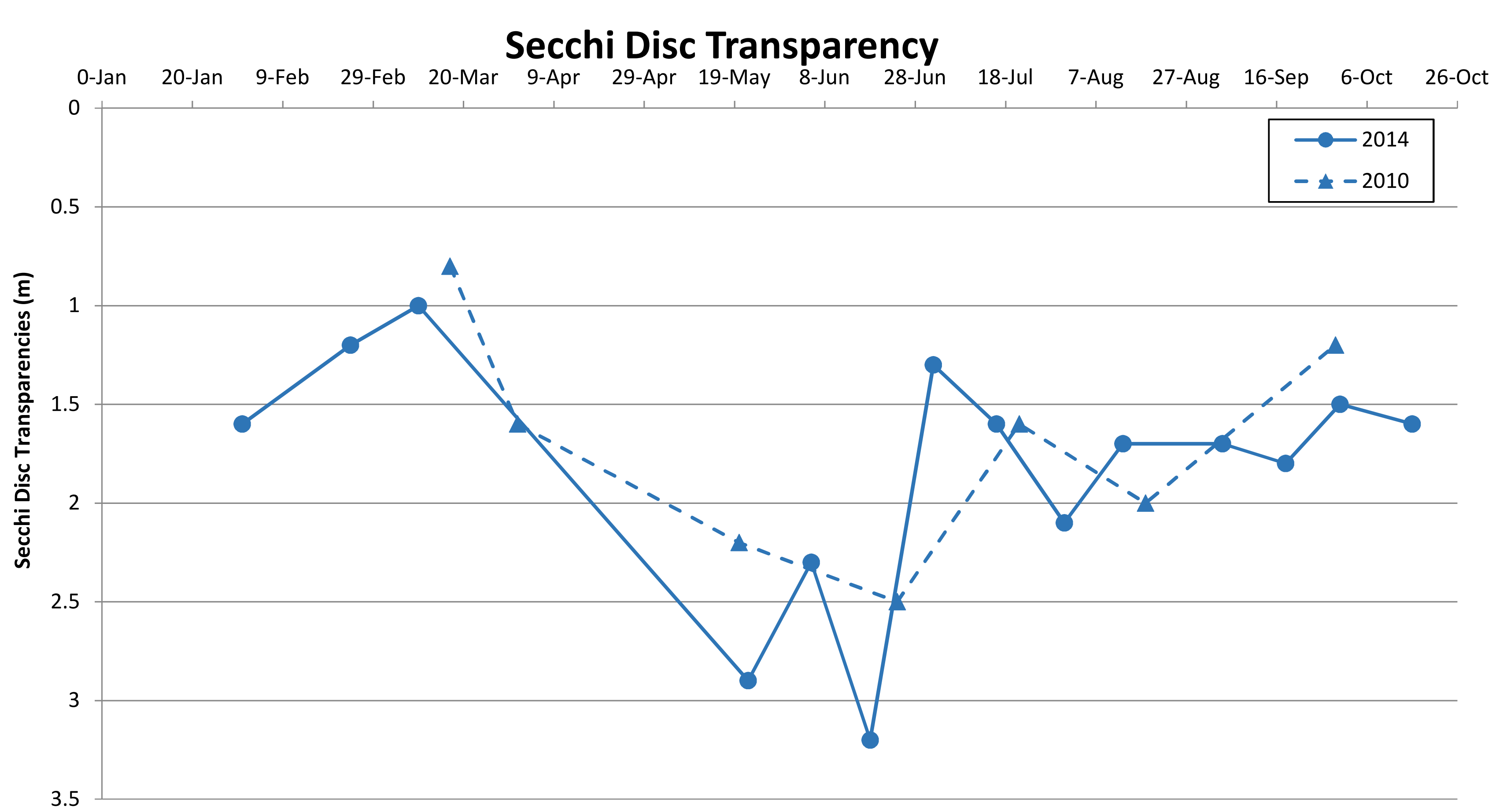


Figure 11
Rice Marsh Lake 2010 and 2014
Seasonal Water Quality

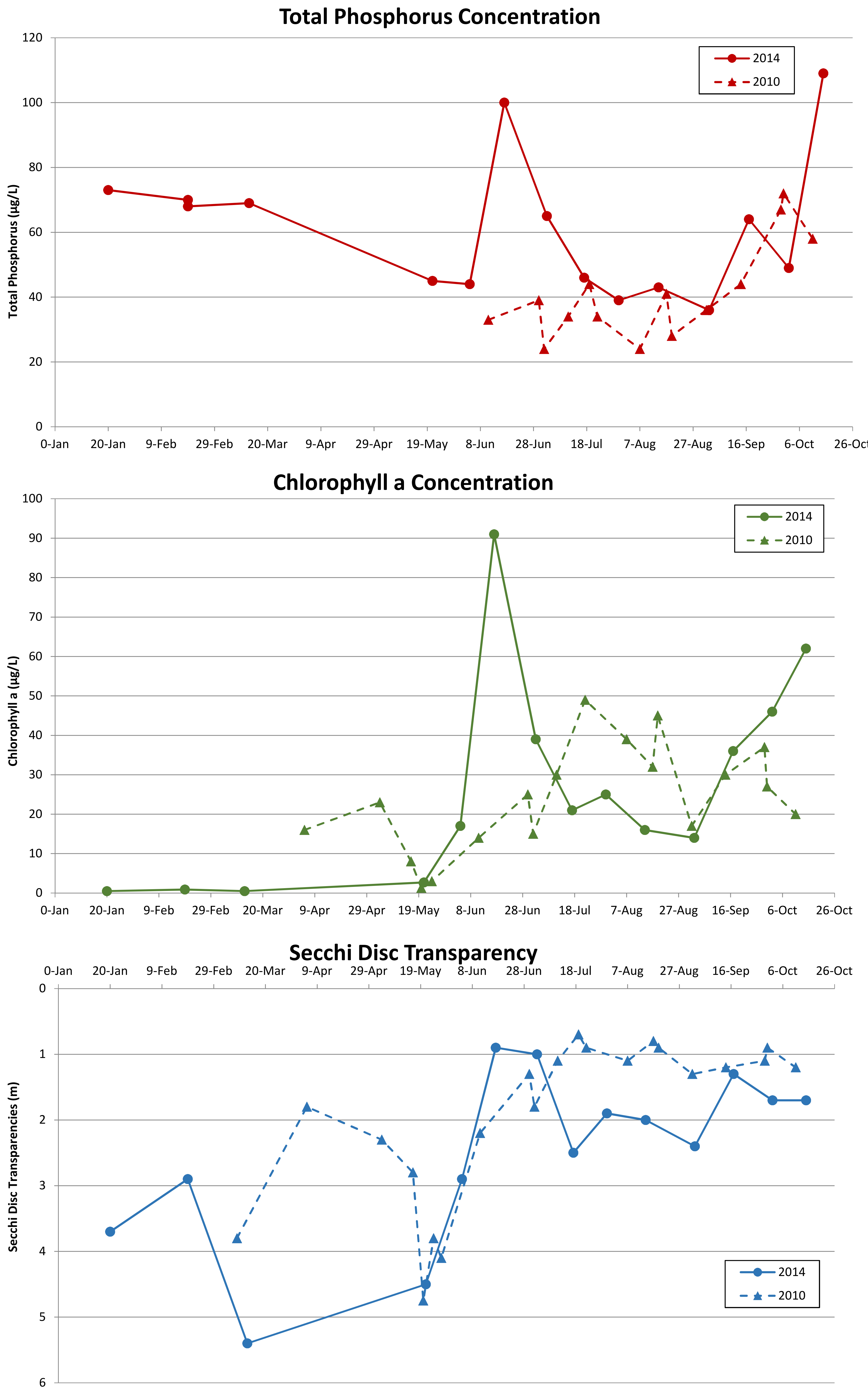


Figure 12
Lake Riley 2010 and 2014 Seasonal Water Quality

2.6.1.1 Total Phosphorus

In Rice Marsh Lake, the total phosphorus concentrations at the beginning of the growing season in 2010 and 2014 were 32 µg/L and 46 µg/L, respectively. These early season concentrations are typically the lowest concentration during the growing season. In both 2010 and 2014, the total phosphorus concentrations steadily increased over the first couple months of the growing season and then leveled in August and generally stayed above 100 µg/L until the fall turnover. In 2010, the peak phosphorus concentration observed in Rice Marsh Lake was 130 µg/L. In 2014, the peak growing season phosphorus concentration observed in Rice Marsh Lake was 143 µg/L. As a polymictic lake, it is likely that Rice Marsh experiences intermittent internal loading as it goes through cycles of mixing due to rain or wind events. It is interesting to note that there is a large increase in phosphorus concentration during the 2014 winter period, when the lake is more stable due to ice cover. This large increase is likely due to internal loading during this ice-on period. Large precipitation events early in both the 2010 and 2014 growing seasons contributed to the more rapid rise in phosphorus concentrations during this period. In general, the phosphorus concentrations in Rice Marsh Lake place the lake in the eutrophic category early in the season and the hypereutrophic category later in the summer. The growing-season average total phosphorus concentration in Rice Marsh Lake in 2010 was 115 µg/L, while in 2014 the growing-season average was 107 µg/L.

In Lake Riley, the first total phosphorus sample of the 2010 growing season was collected in early June with a concentration of 33 µg/L. There was some volatility in the phosphorus concentrations early in the 2010 growing season, possibly due to rainfall events. The 2010 phosphorus concentrations started to increase rapidly in mid-August until reaching a peak at the end of September (72 µg/L). This rapid increase is likely due to internal loading since there were not any large precipitation events or other phosphorus inputs during this time. The 2010 growing-season average total phosphorus concentration in Lake Riley was 40 µg/L. In 2014, the phosphorus concentrations at the beginning of the growing season was 44 µg/L. The 2014 total phosphorus concentrations rapidly increased following the large rain events in early and mid-June, reaching a peak of 100 µg/L. The total phosphorus concentrations dropped rapidly after this peak, reaching a low of 36 µg/L in early September before again rising, likely due to internal loading, in late summer and reaching their highest point of 109 µg/L in mid-October, likely due to an influx of phosphorus-rich hypolimnion water during the fall turnover. The growing season average in 2014 was 55 µg/L.

2.6.1.2 Chlorophyll *a*

In Rice Marsh Lake, the chlorophyll *a* concentrations at the beginning of the growing season (late May) in 2010 and 2014 were 2.7 µg/L and 4.0 µg/L, respectively. These early-season concentrations are typically the lowest concentration during the growing season, and then rise gradually throughout the growing season. The exception of this trend was the large spike in chlorophyll *a* concentration in June 2014 following the large rain events that occurred earlier in the month. In 2010, the peak chlorophyll *a* concentration was 43 µg/L in late September, with a summer average of 22 µg/L. In 2014, the peak chlorophyll *a* concentration was 59 µg/L in mid-June, with a summer average of 28 µg/L.

In Lake Riley, the chlorophyll *a* concentrations at the beginning of the growing season (late May) in 2010 and 2014 were 1.3 µg/L and 2.7 µg/L, respectively. In 2010, there were several peaks in the chlorophyll *a* concentrations in Lake Riley, the first peak at the end of July (49 µg/L), a second peak in mid-August (45 µg/L), and a final peak in late September (39 µg/L). The 2010 growing-season average chlorophyll *a* concentration in Lake Riley was 30 µg/L. In 2014, the first chlorophyll *a* concentrations followed a pattern similar to the total phosphorus concentrations, peaking in late June at 91 µg/L and dropping to 14 µg/L in early September before again rising to 62 µg/L in late October. The growing season average in 2014 was 32 µg/L.

2.6.1.3 Secchi Disc Transparencies

In Rice Marsh Lake, the Secchi disc transparencies began the 2010 growing season at around 2.2 meters in late May and dropped to an annual low of 2.5 meters in late June. The Secchi disc transparency generally decreased over the rest of the growing season, with a transparency of 1.2 meters measured in late September. The 2010 growing-season average transparency was 1.5 meters. The 2014 water clarity followed a similar pattern, starting the growing season at around 2.9 meters in late May, increasing to 3.2 meters of transparency in late June, and then generally declining over the rest of the growing season to a value of 1.5 meters in late September. The transparency also declined very rapidly following the June rainfall events, reaching a low of 1.3 meters in early July. The 2014 growing-season average transparency was 1.9 meters.

In Lake Riley, the 2010 early growing-season Secchi disc transparencies were round 4 meters. The transparency depths declined rapidly after this early-season low, leveling off at around 1.0 meter in mid-July and remaining near this depth for the rest of the growing season. The 2010 growing season average transparency was 1.5 meters. In 2014, the transparency followed a similar pattern to 2010, starting at 4.5 meters at the beginning of the growing season, then declining rapidly in transparency reaching a depth of 0.9 meters in mid-June. The transparency rebounded slightly in mid-July, reaching back down to 2.5 meters before again decreasing, reaching a depth of 1.2 meters in mid-September. The 2014 growing-season average Secchi disc transparency was 1.9 meters.

2.6.2 P8 Watershed Modeling

The computer model P8 (Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds, IEP, Inc., 1990) was used to estimate both the stormwater runoff and phosphorus loads introduced from the Rice Marsh Lake and Lake Riley watersheds to the lakes. P8 is a diagnostic tool used for evaluating and designing watershed improvements and BMPs.

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

2.6.2.1 Updates to the Original UAA P8 Models

The P8 watershed models developed for the original Rice Marsh Lake and Lake Riley UAAs were updated to reflect the current watershed conditions. Subwatershed divides and drainage patterns were reviewed, and updated where appropriate, based on 2011 MDNR LiDAR topographic data, storm sewer data, record drawings, and other information provided by the RPBCWD as well as the cities of Chanhassen and Eden Prairie. Development plans submitted as part of the RPBCWD permit review process for projects implemented after the original UAA was completed were also used as a data source. Hydrologic model parameters were developed using 2010 (existing conditions) and 2030 (future conditions) land-use data in combination with the NRCS's SSURGO soils dataset. The 2010 land-use layer was manually adjusted to match 2014 land-use conditions based on aerial imagery and development plans.

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

See Appendix A for additional information on the P8 watershed model input files.

2.6.2.2 Varying Climatic Conditions

The amount of stormwater runoff and associated pollutant loading from a watershed is dependent on hydrologic conditions such as precipitation patterns and soil saturation conditions. To evaluate the watershed loading under different hydrologic conditions, the watershed model was run for four years with different climatic scenarios. The water year precipitation (October to September) and the growing season (June to September) precipitation for all four years is summarized in Table 7.

The watershed model requires hourly precipitation and daily temperature data for each of the modeled time periods. For all four modeled years, precipitation and temperature data was obtained from the Flying Cloud Airport weather station.

Table 7 Summary of 2010, 2012, 2013 and 2014 Precipitation Conditions

Year	Water Year Precipitation (inches)	Growing Season Precipitation (inches)
2010	30.89	18.51
2012	25.58	9.74
2013	27.38	14.19
2014	35.21	20.99

2.6.3 In-Lake Water Quality Mass Balance Modeling

The following sections discuss the methodology used for the in-lake water quality mass balance modeling that first includes the development of a water balance model followed by the development of a phosphorus mass balance model.

2.6.3.1 Water Balance Modeling

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

For Rice Marsh Lake and Lake Riley, the same precipitation information that was used in the watershed modeling was used to estimate the direct precipitation volume over the surface area of the lake. The daily evaporation losses were calculated using the Lake Hefner Equation as well as air temperature, lake water temperature, relative humidity, and wind velocity. The climatic data used in these calculations came from the Flying Cloud Airport. The lake water temperature was linearly interpolated between observed measurements. It was assumed that there was zero evaporation between December 1 and April 1.

Table 8 summarizes the stage-storage-discharge relationship developed for Rice Marsh Lake based on basin bathymetry data and outlet characteristics.

Table 8 Stage-Storage-Discharge for Rice Marsh Lake

Elevation (feet)	Water Surface Area (acres)	Cumulative Storage Volume (acre-feet)	Discharge (cfs)
865	0.6	0	0.0
866	1	0	1
867	3	0	3
868	7	0	8
869	12	0	18
870	25	0	36
871	48	0	73
872	68	0	131
873	81	0	206
874	87	0	290
875	87	0	375
876	108	1	435
877	148	15	553
878	180	55	715

Table 9 summarizes the stage-storage-discharge relationship developed for Lake Riley based on basin bathymetry data and outlet characteristics.

Table 9 Stage-Storage-Discharge for Lake Riley

Elevation (feet)	Water Surface Area (acres)	Cumulative Storage Volume (acre-feet)	Discharge (cfs)
815	0	0	0
820	7	17	0
825	22	88	0
830	50	281	0
835	81	622	0
840	121	1,145	0
845	162	1,878	0
850	192	2,781	0
855	216	3,810	0
860	253	4,995	0
864.5	297	6,232	0
864.6	290	6,258	1
865	292	6,366	5
866	297	6,654	46
867	302	6,947	126

The lake level data used for the 2014 water balance calibration year and the 2010, 2012, and 2013 water balance validation years was 15-minute data collected by the RPBCWD, converted to daily average lake levels. This data was available for Lake Riley for all four years and for Rice Marsh Lake for the years 2012-2014. The 2010 Rice Marsh Lake water levels were estimated based on the observed 2010 Lake Riley water surface elevations using the correlation between the observed water surface elevations between the two lakes for 2012-2014.

2.6.3.2 Phosphorus Mass Balance Modeling

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

Key calibration parameters for the in-lake model included selection of the sedimentation rate and estimation of the net internal load that affects the phosphorus concentration in the water column during the growing season. The methods used to create and calibrate each of these models are discussed in Appendix B.

2014 and 2010 were chosen as the model calibration and validation years since they are the two most recent years that have total phosphorus sampling profiles for both lakes. For the initial calibration of the in-lake water quality models, the 2014 water quality data was used. The 2014 calibration was then validated against the 2010 water quality data.

2.7 Summary of Water Quality Modeling and Phosphorus Source Assessment

2.7.1 Summary of Existing Conditions Phosphorus Sources

The watershed and in-lake water quality models were used to estimate the external and internal loading sources to Rice Marsh Lake and Lake Riley. Table 10 and Table 11 summarize the 2014 and 2010 annual water and phosphorus budgets for Rice Marsh Lake and Lake Riley, including the relative contributions of the internal and external phosphorus loads. These phosphorus and water budgets are shown graphically in Figure 13and Figure 14 for 2014 conditions. These budgets help explain the sources of phosphorus to each of the lakes and help direct and prioritize implementation strategies. Each of the sources are discussed further in the following section(s).

The phosphorus budgets for both 2010 and 2014 climatic conditions tell a similar story for Rice Marsh Lake. The major sources of phosphorus to the lake are from watershed runoff (44 percent), internal sediment loads (35 to 34 percent), and upstream lakes (19 to 20 percent). The remainder of the phosphorus load is from direct atmospheric deposition (approximately 2 percent).

The 2010 and 2014 annual phosphorus budgets for Lake Riley indicated that the major source of phosphorus to Lake Riley is from internal sediment release (52 to35 percent). External loads from the watershed and from upstream Rice Marsh Lake make up 21 to 30 percent and 25 to 33 percent of the phosphorus load to the lake, respectively. The remaining 2 percent of the loading comes from atmospheric deposition.

Table 10 Summary of 2014 Annual Water and Phosphorus Budgets to Rice Marsh Lake and Lake Riley

Source	Rice Marsh Lake		Lake Riley	
	2014 Annual Load	% of Total Annual Load	2014 Annual Load	% of Total Annual Load
Water Load Summary				
Direct Precipitation (ac-ft)	541	15%	872	16%
Watershed Runoff (acre-ft)	1,233	33%	1,452	26%
Surficial Groundwater (acre-ft)	0	0%	0	0%
Upstream Lakes (acre-ft)	1,913	52%	3.213	58%
Total Annual Water Load (acre-ft)	3,687	100%	5,537	100%
Phosphorus Load Summary				
External Phosphorous Sources				
Atmospheric Deposition (lbs)	28	2%	44	2%
Watershed Runoff (lbs)	712	44%	843	30%
Surficial Groundwater (lbs)	0	0%	0	0%
Upstream Lakes (lbs)	323	20%	908	33%
Internal Sediment Release (lbs)[1]	539	34%	966	35%
Total Phosphorus Load (lbs)	1,602	100%	2,761	100%
Resulting Growing Season Average Water Quality				
Observed Total Phosphorus (Growing Season) (µg/L)	107		53	
Model Predicted Total Phosphorus (Growing Season) (µg/L)	110		55	

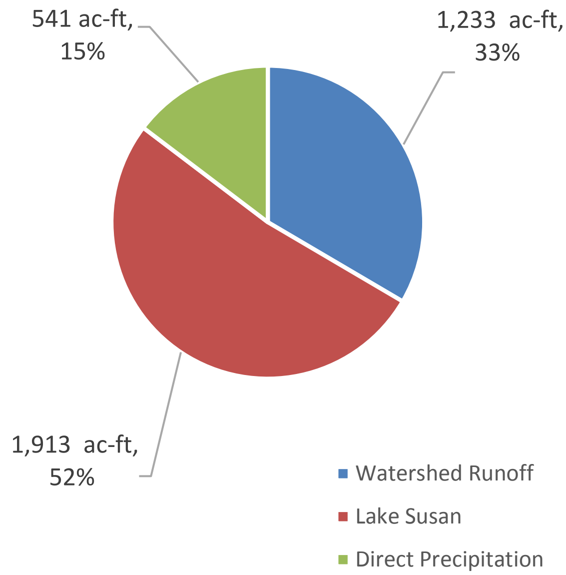
[1]Internal loading varies from year to year due to a variety of climatic and biological factors. Variation in air temperature, wind speed and direction, and precipitation influence the timing, duration and strength of lake stratification which impacts the timing and amount of phosphorus released. Biological factors affecting internal loading include benthic fish (e.g., carp) activity, curlyleaf pondweed density, and algal blooms.

Table 11 Summary of 2010 Annual Water and Phosphorus Budgets to Rice Marsh Lake and Lake Riley

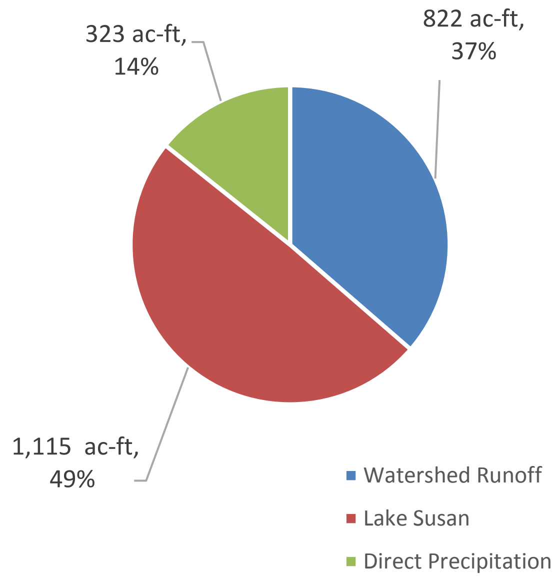
Source	Rice Marsh Lake		Lake Riley	
	2010 Annual Load	% of Total Annual Load	2010 Annual Load	% of Total Annual Load
Water Load Summary				
Direct Precipitation (ac-ft)	475	19	765	21
Watershed Runoff (acre-ft)	916	37	1,028	28
Surficial Groundwater (acre-ft)	0	0%	0	0%
Upstream Lakes (acre-ft)	1,081	44	1,861	51
Total Annual Water Load (acre-ft)	2,472	100%	3,654	100%
Phosphorus Load Summary				
External Phosphorous Sources				
Atmospheric Deposition (lbs)	28	2%	44	2%
Watershed Runoff (lbs)	506	44%	513	21%
Surficial Groundwater (lbs)	0	0%	0	0%
Upstream Lakes (lbs)	226	19%	629	25%
Internal Sediment Release (lbs)[1]	405	35%	1,283	52%
Total Phosphorus Load (lbs)	1,165	100%	2,469	100%
Resulting Growing Season Average Water Quality				
Observed Total Phosphorus (Growing Season) (µg/L)	123		52	
Model Predicted Total Phosphorus (Growing Season) (µg/L)	123		55	

[1]Internal loading varies from year to year due to a variety of climatic and biological factors. Variation in air temperature, wind speed and direction, and precipitation influence the timing, duration and strength of lake stratification which impacts the timing and amount of phosphorus released. Biological factors affecting internal loading include benthic fish (e.g., carp) activity, curlyleaf pondweed density, and algal blooms.

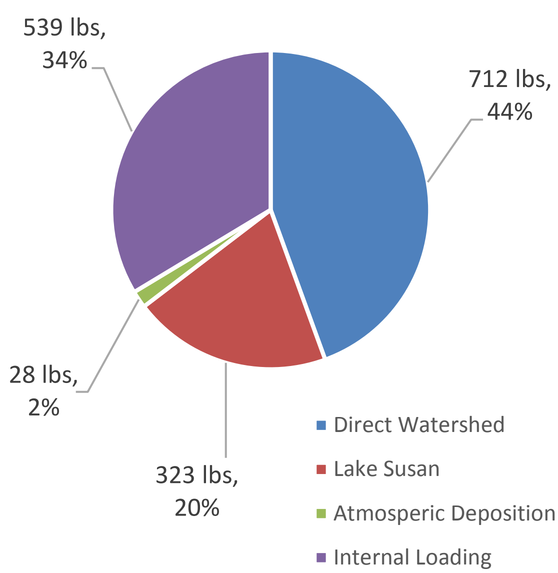
2014 Annual Water Budget
for Rice Marsh Lake
(3,687 ac-ft)
(October 1, 2013 - September 30, 2014)



2014 Growing Season Water Budget
for Rice Marsh Lake
(2,260 ac-ft)
(June 1 - September 30, 2014)



2014 Annual Phosphorus Budget
for Rice Marsh Lake
(1,602 lbs)
(October 1, 2013 - September 30, 2014)



2014 Growing Season Phosphorus Budget
for Rice Marsh Lake
(999 lbs)
(June 1 - September 30, 2014)

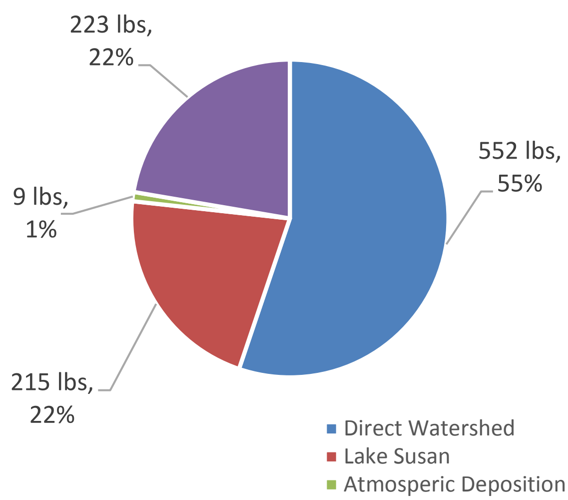
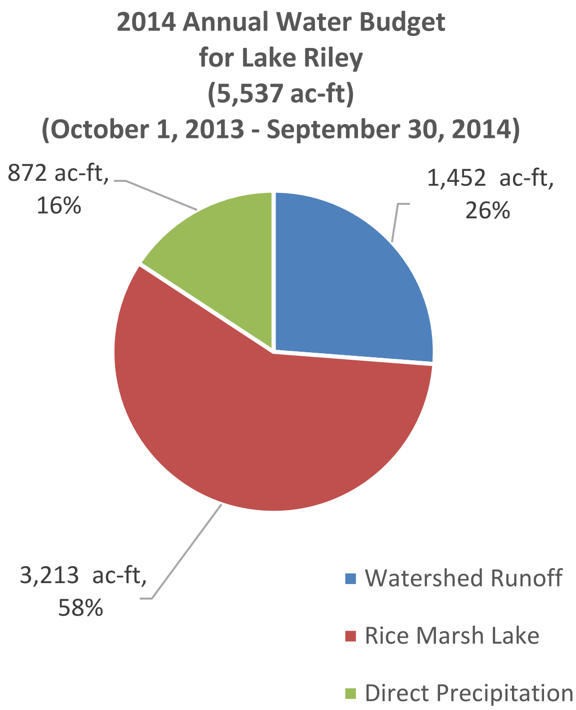
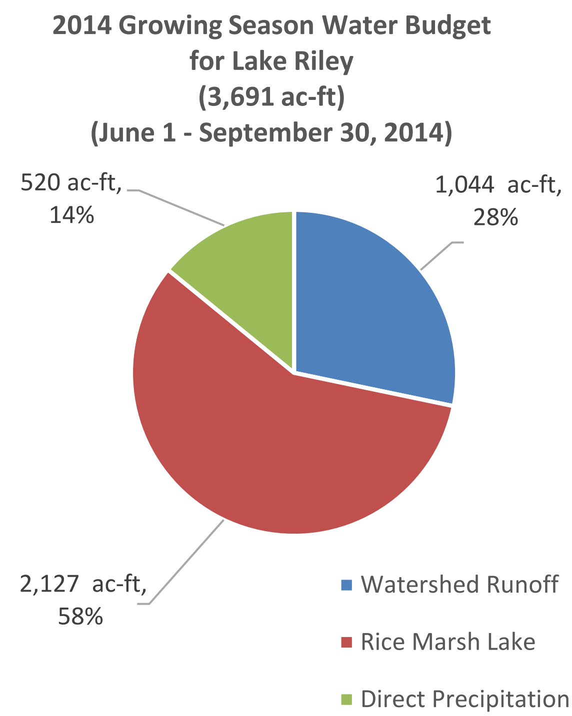
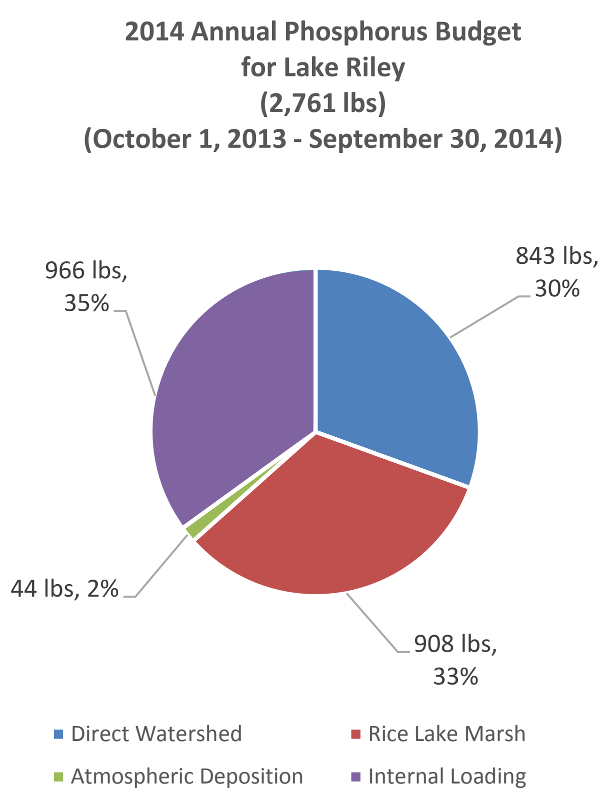


Figure 13
Rice Marsh Lake Water and Total Phosphorus Budget
2014 Existing Conditions







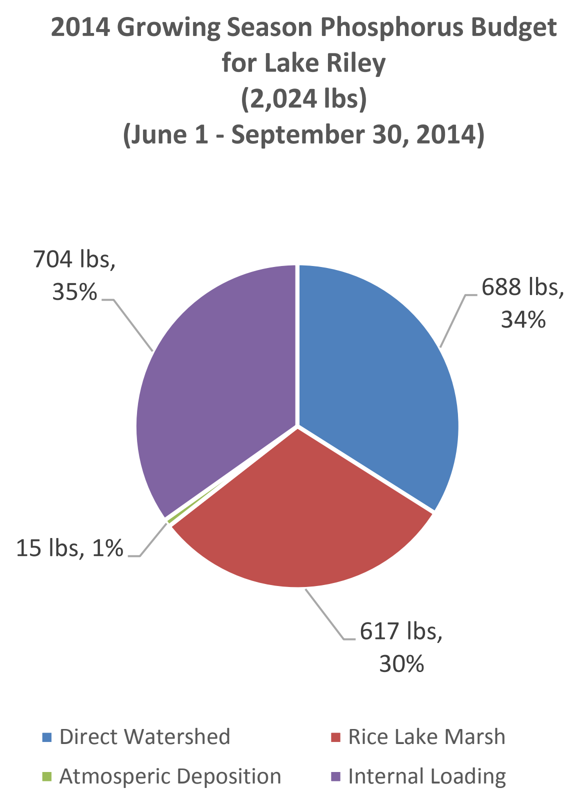


Figure 14
Lake Riley Water and Total Phosphorus Budget
2014 Existing Conditions

2.7.2 External Loads

2.7.2.1 Atmospheric Deposition

Atmospheric deposition of phosphorus onto the lake water surface was calculated by using the estimated statewide phosphorus atmospheric deposition rate of 0.17 kg/ha/year (Barr, 2004). For Rice Marsh Lake, this loading rate was applied to the combined open water and wetland fringe area of 185 acres resulting in an annual total phosphorus (TP) load of 28 pounds. For Lake Riley, this loading rate was applied to the open-water surface area of the lake resulting in an annual TP load of 44 pounds.

2.7.2.2 Watershed Loads

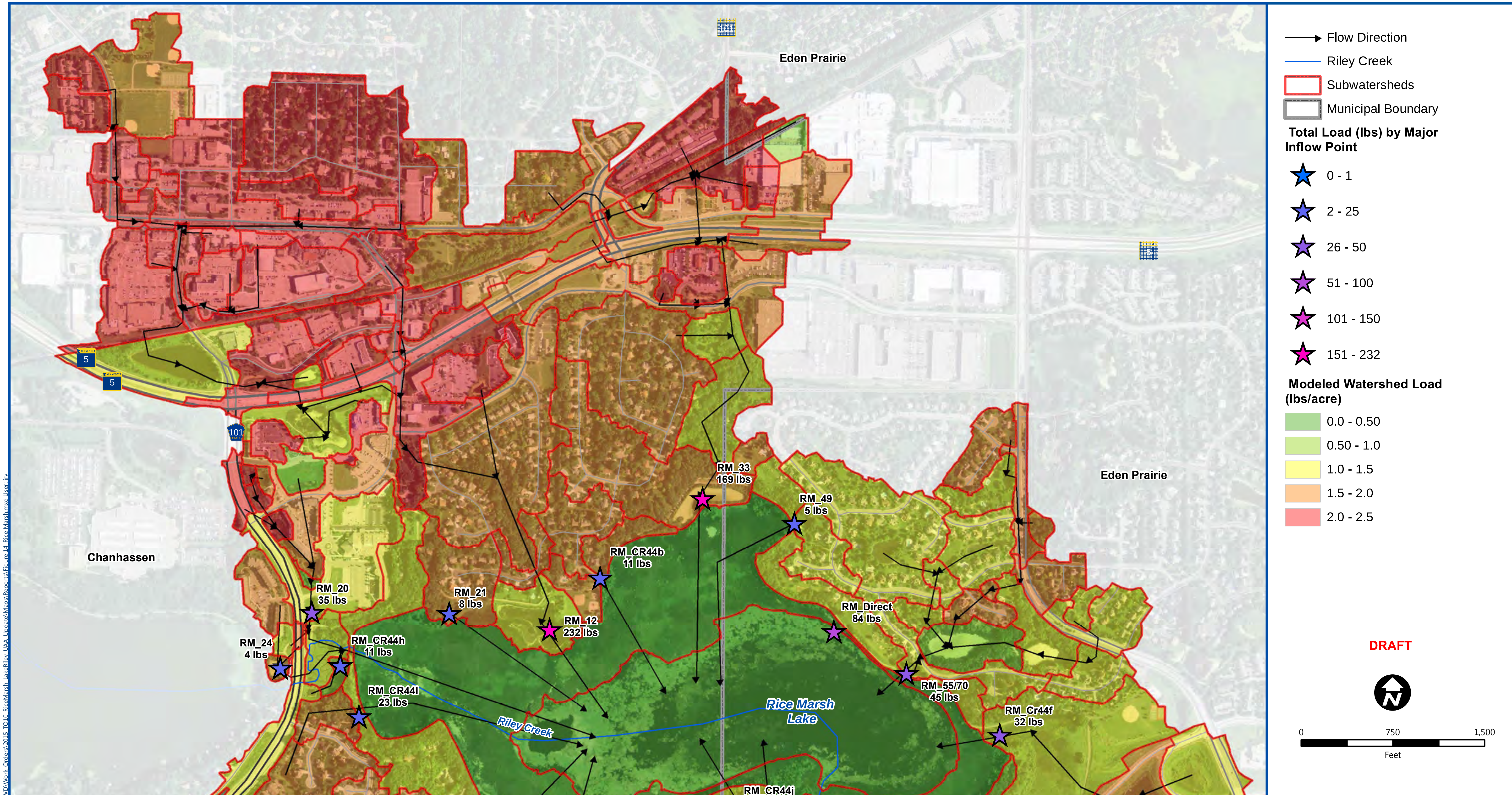
The watershed model was used to estimate the surface runoff to the lakes from the lake's subwatershed (not passing through upstream lakes) based on observed climatic data (precipitation and temperature) for Rice Marsh Lake and Lake Riley. The estimated water and phosphorus loads to each lake from the direct watershed are summarized for 2014 in Table 10 and 2010 in Table 11. Figure 15 and Figure 16 show the relative contributions of the 2014 annual watershed phosphorus load (in pounds) from each major drainage area to Rice Marsh Lake and Lake Riley.

2.7.2.3 Surficial Groundwater

Based on the 2014 water balance modeling for each lake, it appears that there was no net surficial groundwater inflows or outflows from either Rice Marsh Lake or Lake Riley. The 2010 Lake Riley water balance indicated that there may have been a small outflow (approximately 0.5 cfs) during the 2010 water year.

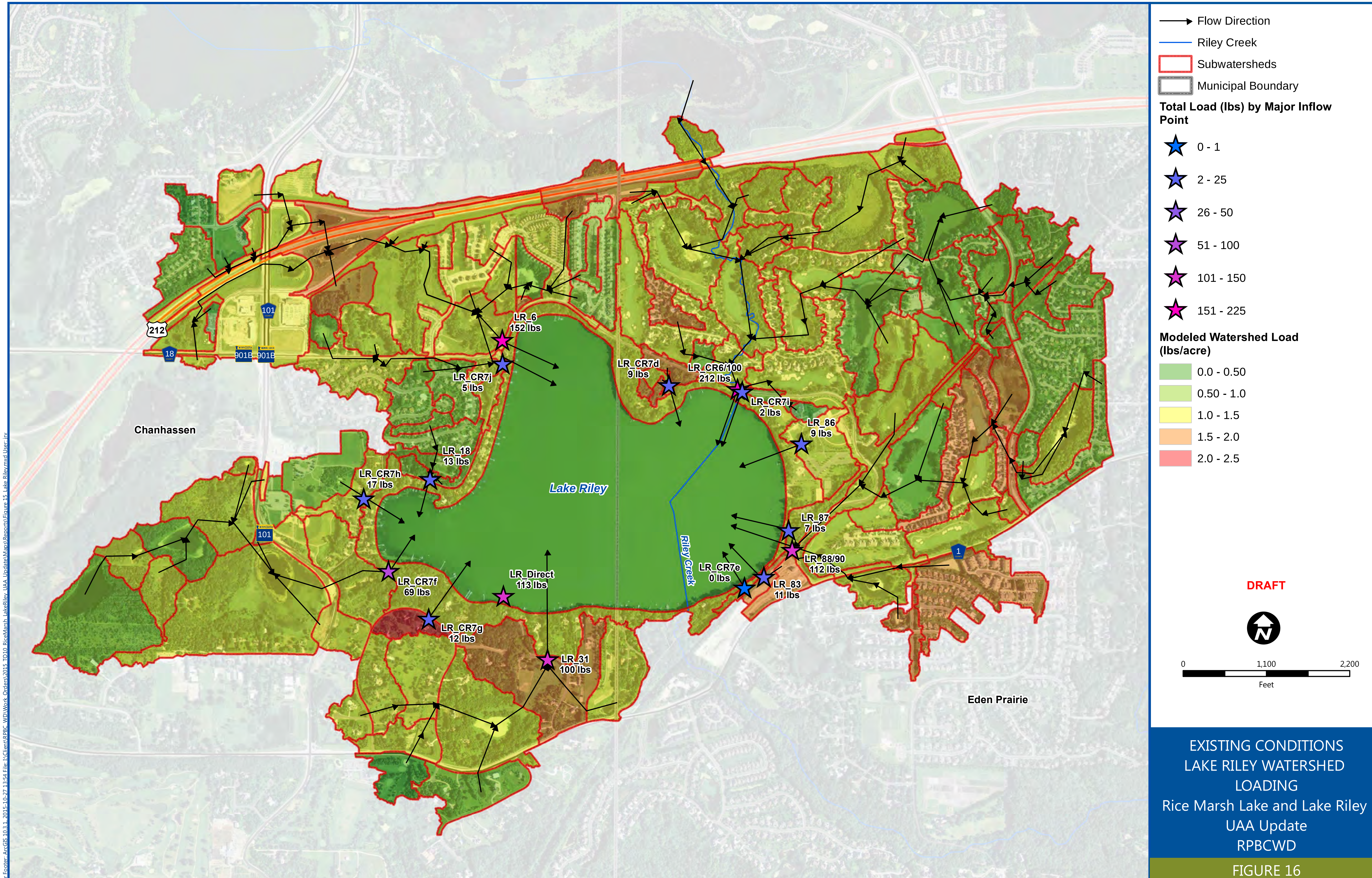
2.7.2.4 Upstream Lakes

The mass balance modeling accounts for the water and phosphorus loads from upstream waterbodies (that have not been modeled as part of the watershed model). Typically, those upstream water bodies are lakes that have actual monitoring data (lake levels and water quality) that can be used in the estimates. Lake Susan is located immediately upstream of Rice Marsh Lake. Water and phosphorus loads from Lake Susan to Rice Marsh Lake were estimated based on the observed water levels at Lake Susan and water quality data during the growing season. Rice Marsh Lake is located immediately upstream of Lake Riley. Water and phosphorus loads from Rice Marsh Lake to Lake Riley were estimated based on the Rice Marsh Lake water balance model and the modeled lake water quality data during the growing season. The estimated loads from upstream lakes are summarized in Table 10 for 2014 and in Table 11 for 2010.



EXISTING CONDITIONS
RICE MARSH LAKE
WATERSHED LOADING
Rice Marsh Lake and Lake Riley
UAA Update
RPBCWD

FIGURE 15



EXISTING CONDITIONS
LAKE RILEY WATERSHED LOADING
Rice Marsh Lake and Lake Riley UAA Update
RPBCWD
FIGURE 16

2.7.2.5 Internal Loads from Upstream Ponds and Wetlands

While the RPBCWD has collected water quality data in several ponds within the Rice Marsh Lake and Lake Riley watersheds, the internal loading within the ponds and wetlands was not evaluated for this study.

2.7.3 Internal Loads

The following sections discuss the results of the in-lake water quality modeling, summarizing the internal loading sources to Rice Marsh Lake and Lake Riley.

2.7.3.1 Curlyleaf Pondweed

Because of the relatively low occurrence in Rice Marsh Lake and successful management of curlyleaf pondweed in Lake Riley, total phosphorus loading from curlyleaf pondweed was not explicitly modeled for this study. The internal loading calibration parameter was used to simulate this release along with other sources of internal loading. Curlyleaf pondweed densities have been greatly reduced in Lake Riley over the last few years through herbicide treatments and is likely a very minor source of total phosphorus to Lake Riley. A similar condition is present in Rice Marsh Lake due to the low occurrence of curlyleaf pondweed.

2.7.3.2 Benthivorous Fish Activity

Although carp and other rough fish (e.g., bullheads) have historically been present in Rice Marsh Lake and Lake Riley, the current carp densities estimated in each lake suggest that carp activity does not have a significant impact on the observed water quality in the lakes. Carp populations have been reduced through the recent implementation of a carp management program following extensive RPBCWD-funded research by the University of Minnesota. Key components of the plan include telemetry-guided winter seining to remove excess carp and an aeration system in Rice Marsh Lake to prevent the winter kills of bluegills, which feed on carp eggs and fry. Through these measures, the carp biomass has been reduced to below the water impairment threshold of 100 kg/hectare determined by the University of Minnesota research.

As a result, this analysis assumes that the activities of carp and other benthivorous fish are not a significant source of phosphorus in the Rice Marsh Lake and Lake Riley systems and were not quantified as part of the in-lake water quality modeling in 2010 or 2014.

2.7.3.3 Sediment Release

For both Rice Marsh Lake and Lake Riley, internal loading appears to be a significant source of phosphorus to each of the lakes during the growing season.

Review of recent dissolved oxygen and total phosphorus depth profiles (available in 2010, 2012, 2013, and 2014) indicate that Rice Marsh Lake can experience intermittent internal loading from the sediments. Rice Marsh Lake does thermally stratify, though not strongly, for periods during the growing season, and the bottom sediments are often under anoxic conditions during the growing season. However, elevated phosphorus concentrations are not seen as frequently in the bottom samples, indicating that the lake mixes frequently, preventing phosphorus from building up in the bottom layers. Microcosm experiments conducted on sediment core samples in 1988 and 2004 indicate that the potential phosphorus release rate from the Rice Marsh Sediments is greater than 20 mg/m^2/d. This rate is greater than the range that has been observed in several Twin Cities metropolitan area lakes (Huser et al., 2009; Pilgrim et al., 2007) but could be explained by the domestic wastewater discharge to the lake that continued until 1971. This internal loading rate was used in the in-lake model as the internal loading calibration parameter and resulted in a very good fit with the observed total phosphorus concentrations.

Review of recent dissolved oxygen and total phosphorus depth profiles (available in 2004, 2010, and 2014) indicate that Lake Riley experiences significant internal loading from the sediments. The bottom sediments are often under anoxic conditions for much of the growing season, and elevated phosphorus levels are observed in the hypolimnion. A 2015 analysis of sediment core samples (Wenck, 2015) indicated a potential total phosphorus sediment release rate of 7.6 mg/m^2/d. While elevated, this rate falls within the range that has been observed in several Twin Cities metropolitan area lakes and was used in the in-lake model as the internal loading calibration parameter and resulted in a very good fit with the observed total phosphorus concentrations.

2.7.4 Summary of Future Conditions on Rice Marsh Lake and Lake Riley

Although much of the Rice Marsh Lake and Lake Riley watersheds is developed, there are still areas that are expected to change land use. Figure 5 shows the future land use within the Rice Marsh Lake and Lake Riley watersheds, including areas where there is an expected change in land use from existing to future conditions. These changes in land use will result in increases in the impervious coverage within these areas, increasing the expected stormwater runoff volumes and pollutant loads from the surfaces.

To understand the potential impacts of future development and redevelopment on lake water quality, the future conditions of the watershed were modeled and resulting in-lake water quality evaluated based on 2014 climatic conditions. Table 12 summarizes the growing-season average total phosphorus and chlorophyll *a* concentrations and Secchi disc transparencies in Rice Marsh Lake and Lake Riley for existing and future conditions, assuming that RPBCWD stormwater rules are applied to the areas with changes between existing and future impervious conditions.

2.7.4.1 Future Conditions without Stormwater Rules

To evaluate the impact of future changes in land use, the P8 and in-lake modeling were updated to reflect the changes in the watershed characteristics from existing (2010) land use to the expected future (2030) land use. The most significant changes in land use will occur in the western portions of the Rice Marsh Lake and Lake Riley watersheds.

Based on the modeling results, development and redevelopment in the watershed is expected to increase the phosphorus loading to Rice Marsh Lake and Lake Riley. Despite the increase in phosphorus loading, the lake dynamics are such that the lakes can assimilate to the extra load with limited impact on the predicted in-lake phosphorus concentration. However, this potential increased load will increase the effort needed to achieve state water-quality standards. Based on the 2014 climatic year, the modeled growing-season average total phosphorus concentration in Rice Marsh Lake will increase from 110 µg/L to

111 µg/L. In Lake Riley, the growing-season average total phosphorus concentration is also expected to increase slightly from 55 to 56 µg/L. Note that these scenarios assume land-use change only, and that no additional stormwater BMPs will be implemented.

2.7.4.2 Future Conditions with Stormwater Rules

The RPBCWD stormwater rules require that loading off new and disturbed impervious surfaces be reduced by 60 percent. Because of the challenge of knowing how future development will occur, a simplified modeling approach was used to simulate the protective aspect of the RPBCWD stormwater rule. This simplified approach reduced the watershed load increase caused by future development by 60 percent rather than explicitly simulating BMPs.

Model results suggest that the implementation BMPs consistent with RPBCWD's stormwater management criteria will reduce the potential increase in loading to the lakes from future watershed development. Based on the 2014 climatic year, the growing-season average total phosphorus concentration in Rice Marsh Lake will remain approximately the same as existing conditions at 110 µg/L, versus 111 µg/L without stormwater rules. In Lake Riley, the future conditions with rules results in a growing-season average total phosphorus concentration nearly the same as future conditions without BMPs even though the actual loading is reduced by 28 pounds of phosphorus over the course of the growing season.

This future-conditions scenario with the implementation of stormwater rules has been used as the baseline land-use condition for the evaluation of the various implementation strategies to protect and improve the water quality in Rice Marsh Lake and Lake Riley.

Table 12 Summary of Annual Total Phosphorus (TP) Load and Growing Season TP Concentration for Rice Marsh Lake and Lake Riley under Existing, Future, and Future with RPBCWD Stormwater Rule Conditions

	2014 Water Quality Conditions (Existing Conditions)[1]		Future Conditions[1]		Future Conditions with Stormwater Rules[1]	
Lake	Annual TP Load (lbs)	Growing Season TP (µg/L)[2]	Annual TP Load (lbs)	Growing Season TP (µg/L)	Annual TP Load (lbs)	Growing Season TP (µg/L)
Rice Marsh Lake	1,602	110 (107)	1,638	111	1,623	110
Lake Riley	2,761	55 (53)	2,851	57	2,815	56

1 – Model predictions based on 2014 climatic conditions.
2 – Measured existing conditions results shown in parentheses.

2.8 Summary of Diagnostic Findings

Table 13 provides a summary of the key water-quality findings for Rice Marsh Lake and Lake Riley. Additional discussion of the diagnostic findings in relation to the sources of phosphorus and water quality of the lakes based on the data analyses, watershed and in-lake modeling, and review of recent studies and information is included in the following sections. These conclusions influenced the implementation strategies evaluated for the management of Rice Marsh Lake and Lake Riley water quality (see Section 3.0).

Table 13 Summary of Diagnostic Findings for Rice Marsh Lake and Lake Riley

Topic	Rice Marsh Lake	Lake Riley
Water Quality Standards and Goals	- Does not meet MPCA Shallow Lake Standards - Does not meet RPBCWD goals or long term vision	- Does not meet MPCA Shallow Lake Standards - Does not meet RPBCWD goals or long term vision
Baseline Water Quality	- Water quality is not as expected for a minimally impacted lake	- Water quality is not as expected for a minimally impacted lake
Water Quality Trends	- Improving	- Stable, neither improving or degrading
Watershed Runoff	- Represents 44% of annual phosphorus load - Receives significant removal of particulate phosphorus in existing ponds and wetlands	- Represents 21-30% of annual phosphorus load - Receives significant removal of particulate phosphorus in existing ponds and wetlands
Future Conditions	- Expected minor water quality degradation with future land use changes	- Expected minor water quality degradation with future land use changes
Macrophyte Status	- Fair macrophyte community dominated by native coontail - Curlyleaf pondweed is present in low numbers - Eurasian water milfoil is not present	- Low macrophyte diversity dominated by native coontail - Eurasian watermilfoil has been problematic but was managed in 2015 with early herbicide treatment - Curlyleaf pondweed has been problematic but is currently greatly reduced through early season herbicide treatments
Fishery Status	- Carp populations currently below water quality degradation threshold	- Carp populations currently below water quality degradation threshold
Cyanobacteria (blue green algae)	- Has historically experienced cyanobacteria blooms during the summer	- Has historically experienced cyanobacteria blooms during the summer
Internal Loading from sediments	- Does not have stable stratification - Observed temperature and dissolved oxygen data indicates frequent mixing with varying anoxic conditions along bottom sediment - Internal loading from sediment estimated to be 35-39% of annual phosphorus load	- Thermally stratifies with anoxic conditions along bottom sediment - Internal loading from sediment estimated to be 34-39% of annual phosphorus load
Methylmercury in Fish Tissues	- No studies have been conducted, not currently listed as impaired - No consumption advisories	- Listed as impaired by mercury on the Minnesota statewide mercury impairment list - Fish consumption advisories from MDNR and MDH

2.8.1 Diagnostic Findings for Rice Marsh Lake

- While Rice Marsh Lake is not currently listed on the MPCA 303(d) impaired waters list for excess nutrients, a review of historic water quality for Rice Marsh Lake indicates that the lake does not currently meet either the MPCA shallow lake water quality standards or the RPBCWD's water clarity goals. Likewise, the water quality in Rice Marsh is worse than would be expected for a "minimally impacted lake" with similar characteristics in the north central hardwood forest ecoregion. However, the trend analyses performed on the water quality data for the past 10 years indicate that the water quality in Rice Marsh Lake is improving.

- Watershed runoff receives a significant amount of treatment prior to entering Rice Marsh Lake due to the number of stormwater ponds and other waterbodies within the watershed. As stormwater runoff passes through the many constructed stormwater ponds and natural wetlands in the watershed, significant removal of phosphorus associated with particulates in the runoff occurs due to particle settling. As a result, the watershed modeling suggests that the majority of phosphorus in the watershed runoff reaching the lake is in a soluble form or associated with very small particles that are difficult to settle. Therefore, watershed BMPs should target this soluble fraction of phosphorus.

- There are only a few portions of the watershed that are currently "untreated" (runoff does not pass through a wetland or pond prior to entering the lake), including the watershed directly adjacent to Rice Marsh Lake. The untreated portion of the watershed to Rice Marsh Lake contributes 14 percent of the watershed phosphorus load to the lake.

- The watershed phosphorous load to Rice Marsh Lake typically represents 44 percent of the total annual phosphorus budget to the lake, internal loading represents another 34 to 35 percent of the total annual phosphorus budget, and inflows from Lake Susan is the third major source contribute 19 to 20 percent of the total annual phosphorus load to the lake (see Table 10 and Table 11). Internal loading varies from year to year due to a variety of climatic (e.g., air temperature, wind speed and direction, and precipitation) and biological factors (e.g., carp activity, curlyleaf pondweed density, and algal blooms).

- Water quality data collected along the depth profile of Rice Marsh Lake indicates that the interface along the bottom sediments can become anoxic during the summer and elevated phosphorus levels have been observed near the lake bottom, supporting that internal loading is a source of phosphorus in Rice Marsh.

- Based on future land-use changes, increased watershed phosphorus loading to Rice Marsh Lake will likely occur if additional stormwater management is not incorporated into the watershed as the area is developed or redeveloped.

- Figure 15 shows the estimated phosphorus loading from the major drainage basins in the Rice Marsh Lake watershed. The watershed modeling suggests that 33 percent of the watershed load to Rice Marsh Lake passes through the RM_12 major drainage areas. This drainage area appears to provide the best opportunity for the implementation of additional watershed BMPs or modifications to existing BMPs.

- Based on the 2014 macrophyte data collected by Blue Water Science (Blue Water Science, 2015), Rice Marsh Lake has a fair macrophyte community dominated by native coontail. Eurasian watermilfoil was not found during the 2014 survey, and low levels of curlyleaf pondweed were seen.

- The carp population in Rice Marsh Lake has been reduced since the implementation of a carp management plan for both Rice Marsh Lake and Lake Riley. A winter aeration system provides oxygen to help prevent winter kills of bluegills, which are known to feed on carp eggs, thus keeping the carp population in check. Carp seining has also helped to reduce the carp population.

2.8.2 Diagnostic Findings for Lake Riley

- Based on review of historic water quality for Lake Riley, the lake does not currently meet MPCA deep-lake water quality standards and is listed on the MPCA 303(d) impaired waters list. Additionally, Lake Riley also does not achieve the RPBCWD water quality goals nor the RPBCWD long-term water clarity vision (2 meters). The water quality in Lake Riley is worse than other lakes in the north central hardwood forest ecoregion that are “minimally impacted” by human impacts. Additionally, the trend analyses performed on the water quality data for the past 10-years indicate that the water quality in Lake Riley is stable (neither improving nor degrading).

- Lake Riley thermally stratifies throughout the growing season. Water quality data collected along the depth profile of Lake Riley indicates that the interface along the bottom sediments can become anoxic during the summer, and elevated phosphorus levels have been observed in the hypolimnion, supporting that internal loading is a source of phosphorus in the lake.

- Based on the 2010 and 2014 water quality modeling, the watershed phosphorous load to Lake Riley typically represents 21 to 30 percent of the total annual phosphorus budget to the lake. Discharge from Rice Marsh Lake represents 25 to 33 percent of the phosphorous load. Internal loading represents 35 to 52 percent of the total annual phosphorus budget (see Table 10 and Table 11). Internal loading varies from year to year due to a variety of climatic (e.g., air temperature, wind speed and direction, and precipitation) and biological factors (e.g., carp activity, curlyleaf pondweed density, and algal blooms).

- There are only a few portions of the watershed that are currently “untreated” (runoff does not pass through a wetland or pond prior to entering the lake), including the watershed directly adjacent to Lake Riley. However, this untreated portion of the watershed is relatively developed and contributes 21 percent of the watershed phosphorus load to the lake while covering only 10 percent of the area.

- Based on future land-use changes, phosphorus loading to Lake Riley will increase if additional stormwater management is not incorporated into the watershed as the area is developed or redeveloped. This increase could further hinder the restoration measures needed to improve the overall health of the lake.

- Based on the 2011-2014 macrophyte data collected by the University of Minnesota, Lake Riley has low plant diversity and is dominated by native coontail. Non-native Eurasian water milfoil is also present in large numbers and reaches nuisance levels. Curlyleaf pondweed was previously problematic, but early-season endothal treatments in 2013 and 2014 have greatly reduced its occurrence.

- Carp densities have been a concern in Lake Riley, but carp management practices such as seining and the aeration of Rice Marsh Lake have reduced their numbers and kept them below the threshold of concern.

- Lake Riley is included on the Minnesota statewide list of mercury-impaired water bodies. Additionally, there are fish consumption advisories for Lake Riley from the MDNR and the Minnesota Department of Health (MDH).

3.0 Water Quality Goal Attainment and Implementation Strategies

3.1 Typical Stormwater Management Strategies

This section discusses improvement options and general BMPs to remove phosphorus and/or reduce sediment and litter entering a lake. Three types of BMPs were considered during the preparation of this report: structural, in-lake, and nonstructural.

1. Structural BMPs remove a fraction of the pollutants and sediment loads contained in stormwater runoff prior to discharge into receiving waters.

2. In-Lake BMPs reduce phosphorus already present in a lake, and/or prevent the release of phosphorus from anoxic lake sediments.

3. Nonstructural BMPs (source control) eliminate pollutants at the source and prevent pollutants from entering stormwater flows.

3.1.1 Structural Watershed Practices

Structural BMPs temporarily store and treat urban stormwater runoff to reduce flooding, remove pollutants, and provide other amenities (Schueler, 1987). Water quality BMPs are specifically designed for pollutant removal, and their typical effectiveness is summarized in Table 14. Structural BMPs control total suspended solids and total phosphorus loadings by slowing stormwater and allowing particles to settle or be filtered in areas before reaching receiving waters. More recently, these structural BMPs have been modified and enhanced with materials such as iron filings or spent lime to improve removal of not only the pollutants associated with particulates but to also begin addressing the soluble fraction of pollutants such as phosphorus that cannot be filtered or settled out of the runoff.

Examples of structural BMPs installed to improve water quality include:

- Wet detention ponds
- Bioretention (rainwater gardens)
- Infiltration basins or trenches
- Sand filters
- Iron-enhanced sand filters
- Vegetative buffer strips
- Oil and grit separators
- Alum or ferric chloride treatment plants
- Spent lime treatment

The general effectiveness of each of the BMPs is summarized in Table 14.

Table 14 General Phosphorus Removal Effectiveness of Stormwater BMPs (source: adapted from the Minnesota Stormwater Manual, MPCA 2005)

BMP group	BMP design variation	Average TP removal rate (%)[b]	Maximum TP removal rate (%)[c]	Average soluble P removal rate (%)[d,f,g,i]
Bioretention[f]	Underdrain	50	65	0
	Infiltration	100	100	100
Filtration	Sand filter	50	55	0
	Dry swale	0	55	0
	Wet swale	65	75	70
Infiltration[f]	Infiltration trench	100	100	100
	Infiltration basin	100	100	100
Stormwater ponds	Wet pond	50	65	0
	Multiple pond	60	75	0
Stormwater wetlands	Shallow wetland	40	55	0
	Pond/wetland	55	75	0
Iron-Enhanced Sand Filtration[i]	Basin	N/A	N/A	40-90
Spent Lime Treatment[j]	Basin	N/A	N/A	80

[a]Removal rates show in table are a composite of five sources: 1) Caraco (Center for Watershed Protection, 2001), 2) Maryland Department of the Environment (2000), 3) Winer (Center for Watershed Protection, 2000), 4) P8 modeling (William Walker)
[b] Average removal efficiency expected under MPCA Sizing Rules 1 and 3
[c] Upper limit on phosphorus removal with increased sizing and design features, based on national review
[d] Average rate of soluble phosphorus removal in the literature
[e] See section on calculating credits for each BMP in this Manual.
[f] Note that the performance numbers apply only to that portion of total flow actually being treated; it does not include any runoff that bypasses the BMP
[g]Note that soluble P can transfer from surface water to groundwater, but this column refers only to surface water
[h]Note that 100% is assumed for all infiltration, but only for that portion of the flow fully treated in the infiltration facility; by-passed runoff or runoff diverted via underdrain does not receive this level of treatment.
[i]Range based on City of Bellvue, WA, 1999; Erickson et. al., 2006; Erickson et. al., 2009
[j]Based on 2012 monitoring data from experimental spent lime treatment system installed in Ramsey-Washington Metro Watershed District

When choosing a structural BMP, the ultimate objective must be well understood. The BMP should accomplish the following (Schueler 1987). General description of several of the BMPs are provided below.

- Reproduce, as nearly as possible, the stream flow before development
- Remove at least a moderate amount of most urban pollutants
- Require reasonable maintenance
- Have a neutral impact on the natural and human environments
- Be reasonably cost effective compared with other BMPs

3.1.1.1 Wet Detention Ponds

Wet detention ponds (sometimes called "NURP" ponds after the Nationwide Urban Runoff Program) are impoundments that have a permanent pool of water and the capacity to hold runoff and release it at slower rates than incoming flows. Wet detention ponds are one of the most effective methods available for treatment of stormwater runoff. They are used to interrupt the transport phase of sediment and pollutants associated with it, such as trace metals, hydrocarbons, nutrients, and pesticides. When designed properly, wet detention ponds can also provide some removal of dissolved nutrients. In addition, detention ponds have been credited with reducing the amount of bacteria and oxygen-demanding substances as runoff flows through the pond.

During a storm, polluted runoff enters the detention basin and displaces "clean" water until the plume of polluted runoff reaches the basin's outlet structure. When the polluted runoff does reach the outlet, it has been diluted by the water previously held in the basin. This dilution further reduces the pollutant concentration of the outflow. In addition, much of the total suspended solids and total phosphorus being transported by the polluted runoff and the pollutants associated with these sediments are trapped in the detention basin. A well-designed wet detention pond could remove approximately 80 to 95 percent of total suspended solids and 40 to 60 percent of total phosphorus entering the pond (MPCA, 1989).

As storm flows subside, finer sediments suspended in the pond's pool will have a relatively longer period of time to settle out of suspension during the intervals between storm events. These finer sediments eventually trapped in the pond's permanent pool will continue to settle until the next storm flow occurs. In addition to efficient settling, this long detention time allows some removal of dissolved nutrients through biological activity (Walker, 1987). These dissolved nutrients are mainly removed by algae and aquatic plants. After the algae die, the dead algae can settle to the bottom of the pond, carrying with them the dissolved nutrients that were consumed, to become part of the bottom sediments.

The wet detention process results in good pollutant removal from small storm events. Runoff from larger storms will experience pollutant removal, but not with the same high efficiency levels as the runoff from smaller storms. Studies have shown that because of the frequency distribution of storm events, good control for more frequent small storms (wet detention's strength) is very important to long-term pollutant removal.

3.1.1.2 Infiltration

Infiltration is the movement of water into the soil surface. For a given storm event, the infiltration rate will tend to vary with time. At the beginning of the storm, the initial infiltration rate represents the maximum infiltration that can occur because the soil surface is typically dry and full of air spaces. The infiltration rate tends to gradually decrease as the storm event continues because the soil air spaces fill with water. For long-duration storms, the infiltration rate will eventually reach a constant value, or the minimum infiltration rate (the design infiltration rate). The infiltrated runoff helps recharge the groundwater and mitigate the impacts of development. Stormwater flows into an infiltration basin, pools on the ground surface, and gradually infiltrates into the soil bed. Pollutants are removed by adsorption, filtration, volatilization, ion exchange, and decomposition. Therefore, infiltration is one of a few BMPs that can reduce the amount of dissolved pollutant in stormwater. Infiltration BMP devices, such as porous pavements, infiltration trenches and basins, and rainwater gardens, can be utilized to promote a variety of water management objectives, including:

- Reduced downstream flooding
- Increased groundwater recharge
- Reduced peak stormwater discharges and volumes
- Improved stormwater quality

An infiltration basin collects and stores stormwater until it infiltrates the surrounding soil and evaporates into the atmosphere. Infiltration basins remove fine sediment, nutrients (including dissolved nutrients), trace metals, and organics through filtration by surface vegetation, and through infiltration through the subsurface soil. Deep-rooted vegetation can increase infiltration capacity by creating small conduits for water flow. Infiltration basins are designed as a grass-covered depression underlain with geotextile fabric and coarse gravel. A layer of topsoil is usually placed between the gravel layer and the grassed surface. Pretreatment is often required to remove any coarse particulates (leaves and debris), oil and grease, and soluble organics to reduce the potential of groundwater contamination and the likelihood of the soil pores being plugged. Infiltration can also be promoted in existing detention ponds by excavating excess sediments (typically the fines that have seal the bottom of the pond) and exposing a granular sub-base (assuming one was present prior to the original construction of the detention pond).

Rainwater gardens (a form of bio-retention) are shallow, landscaped depressions that channel and collect runoff. To increase infiltration, the soil bed is sometimes amended with mulch or soils with greater infiltration capacity. Vegetation in the rainwater gardens take up nutrients, and stored runoff is reduced through evapotranspiration. Bio-retention is commonly located in parking lot islands, or within small pockets in residential areas, and is primarily designed to remove sediment, nutrients, metals, and oil and grease. Secondary benefits include flow attenuation; volume reduction; and removal of floatables, fecal coliform, and Biological Oxygen Demand (BOD).

3.1.1.3 Iron-Enhanced Sand Filtration

Iron-enhanced sand filtration is a stormwater BMP that incorporates iron into a filtration media to remove soluble phosphorus. In conditions with sufficient oxygen, the iron in the filter binds with dissolved constituents in stormwater, including dissolved phosphorus. If conditions within the filter media become anoxic, the bond between the phosphorus and iron can break down and the phosphorus can be re-released into the water. Because of the need to maintain an oxygenated filter media, iron-enhanced sand filters are most suitable to conditions with minimal groundwater intrusion or tailwater effects and should include underdrains to convey filtered water and to help aerate the filter bed between storms. Studies of iron enhanced sand filters have resulted in soluble phosphorus reductions ranging from 40 to 90 percent (City of Bellevue, Washington, 1999; Erickson et al. 2006; Erickson et al. 2009). A relatively short contact time (20 to 30 minutes) is required for the surface sorption to bind phosphorus to the iron oxide on the iron filings. Therefore, the filter must be drawn down within 48 hours of a rainfall event. This means that the BMP footprint is proportional to the volume of water to be treated. The estimated lifespan of the iron material is approximately 35 years, although this has not been confirmed in the field (Erickson et al. 2012). Simple, periodic maintenance activities are required, including inspection of inlet and outlet structures, cleanout of the underdrain system, and occasional addition of filtration media to maintain the design depth (i.e., contact time) of the material. Figure 17 includes photographs of iron-enhanced sand filtration systems.

Construction of Beam Avenue iron-enhanced sand filtration system.

Iron-enhanced sand filtration system near Beam Avenue following a rainfall event.

Figure 17 Photographs of iron-enhanced sand filtration system

The use of iron-enhanced filtration in stormwater management is recognized by the MPCA and included as a BMP in the *Minnesota Stormwater Manual* (MPCA 2014). Monitoring data reported in this manual has shown promising results for the removal of both total and dissolved phosphorus. Total phosphorus removal through the system is approximately 71 percent (MPCA 2014).

3.1.1.4 Vegetated Buffer Strips

Vegetative buffer strips are low, sloping areas designed to accommodate stormwater runoff traveling by overland sheet flow. Vegetated buffer strips perform several pollutant attenuation functions, mitigating the impact of development. Urban watershed development often involves disturbing natural vegetated buffers for the construction of homes, parking lots, and lawns. When natural vegetation is removed, pollutants are given a direct path to the lake; sediments cannot settle out, and nutrients and other pollutants cannot be removed. Additional problems resulting from removal of natural vegetation include streambank erosion and loss of valuable wildlife habitat (Rhode Island Department of Environmental Management, 1990).

The effectiveness of buffer strips is dependent on the width of the buffer, the slope of the site, and the type of vegetation present. Buffer strips should be 20 feet wide at a minimum; however, 50 to 75 feet is recommended. Many attractive native plant species can be planted in buffer strips to create aesthetically pleasing landscapes, as well as havens for wildlife and birds. When properly designed, buffer strips can remove 30 to 50 percent of total suspended solids from lawn runoff. In addition, well-designed buffer strips will discourage waterfowl from nesting and feeding on shoreland lawns. Such waterfowl can be a significant source of phosphorus to ponds, by grazing turfed areas adjacent to the water and defecating in or near the water's edge where wash-off into the pond is probable.

3.1.1.5 Spent Lime Treatment

Spent lime consists of calcium and carbonate and is a byproduct of the drinking-water treatment process. Since this material is fresh (e.g., recently precipitated), it has properties that allow it to bind with phosphorus. When water with dissolved phosphorus contacts the lime material, calcium from the lime binds with phosphorus and forms calcium phosphate, which is a solid material and does not dissolve in the stormwater, thus remaining within the treatment system. Figure 18 includes photographs of spent-lime treatment systems that have been constructed.

Spent-lime treatment system upstream of Wakefield Pond during construction before spent lime has been added.

Completed spent-lime treatment system upstream of Wakefield Pond.

Figure 18 Photographs of spent-lime treatment system

Although the use of spent lime in stormwater management is still an emerging technology, over two years of monitoring a test spent-lime treatment system in Maplewood (2012 and 2013) have shown promising results for the removal of both total and dissolved phosphorus. Total phosphorus removal through the system is approximately 65 percent. However, for most monitored events, the dissolved phosphorus levels at the discharge were at laboratory detection limits, suggesting that dissolved phosphorus removal may be higher than the reported removal. Additionally, removal of total suspended solids and heavy metals has been observed.

Spent-lime treatment is a cost-effective BMP, using a waste byproduct of the drinking-water treatment system typically disposed of via agricultural land application. Because only a short contact time (5 to 10 minutes) is required for the chemical reaction to bind phosphorus to the calcium in the lime, a fairly small

BMP footprint can be used to treat a significant volume of water. Additionally, the spent-lime material has a significant phosphorus-binding capacity and an estimated lifespan of 100-plus years (unconfirmed in the field). Routine maintenance is required, including inspection of inlet and outlet structures, annual mixing of the lime material to maintain its porosity and hydraulic conductivity, and occasional addition of spent-lime material to maintain the design depth (contact time) of the material.

3.1.1.6 Oil and Grit Separators

Oil-grit separators (e.g., StormCeptors) are concrete chambers designed to remove oil, sediments, and floatable debris from runoff, and are typically used in areas with heavy traffic or high potential for petroleum spills such as parking lots, gas stations, roads, and holding areas. A three-chamber design is common; the first chamber traps sediment, the second chamber separates oil, and a third chamber holds the overflow pipe. The three-chambered unit is enclosed in reinforced concrete. Oil-grit separators remove coarse particulates well, but soluble pollutants tend to pass through. To operate properly, the devices must be cleaned out regularly (at least twice a year). Oil-grit separators can be especially beneficial when used as pre-treatment for an infiltration basin or pond. They can also be incorporated into existing stormwater systems or included in underground vault detention systems when no available land exists for a surface detention basin. Only moderate removals of total suspended solids can be expected; however, oil and floatable debris are effectively removed from properly designed oil- grit separators.

3.1.1.7 Alum Treatment Plants

In addition to the commonly installed structural BMPs discussed above, alum treatment plants are becoming an option for efficiently removing phosphorus from tributaries, rather than directly treating the lake with alum to remove phosphorus. Alum (aluminum sulfate) is commonly used as a flocculent in water treatment plants and as an in-lake treatment for phosphorus removal. To treat inflows in streams or storm sewers, part of the flow is diverted (e.g., 5 cfs) from the main flow and treated with alum. After the alum is injected in the diverted flow, it passes to a detention pond to allow the flocculent to settle out before the water enters the lake. Alum treatment has been shown to remove up to 90 percent of the soluble and particulate phosphorus from the inflows.

3.1.2 In-Lake Management Activities

In-lake management activities are intended to target the “internal” sources of phosphorus in the lake, which can include the prevention of the release of phosphorus from the lake sediments. In-lake management practices intended to reduce phosphorus include:

- Removal of benthivorous (bottom-feeding) fish, including carp
- Application of alum (aluminum sulfate) to reduce sediment phosphorus release
- Application of herbicides to control non-native macrophyte species such as curlyleaf pondweed
- Mechanical harvesting of lake macrophytes
- Hypolimnetic withdrawal
- Hypolimnetic aeration
- Iron salt applications

Several in-lake BMPs are discussed below.

3.1.2.1 Removal of Benthivorous (Bottom-Feeding) Fish

Benthivorous fish, such as carp and bullhead, can have a direct influence on the phosphorus concentration in a lake (LaMarra, 1975). These fish typically feed on decaying plant and animal matter and other organic particulates found at the sediment surface. The fish digest the organic matter, and excrete soluble nutrients, thereby transforming sediment phosphorus into soluble phosphorus available for uptake by algae at the lake surface. Depending on the number of benthivorous fish present, this process can occur at rates similar to watershed phosphorus loads.

Benthivorous fish can also cause resuspension of sediments in shallow ponds and lakes, causing reduced water clarity and poor aquatic plant growth, as well as high phosphorus concentrations (Cooke et al., 1993). In some cases, the water quality impairment caused by benthivorous fish can negate the positive effects of BMPs and lake restoration. Depending on the numbers of fish present, the removal of benthivorous fish may cause an immediate improvement in lake water quality. The predicted water quality improvement following removal of the bottom-feeding fish is difficult to estimate, and require permitting and guidance from the MDNR. In addition, using fish barriers to prevent benthivorous fish from spawning may adversely affect the spawning of game fish, such as northern pike.

3.1.2.2 Application of Alum (Aluminum Sulfate)

Internal loading due to release from the sediment can be a significant source of phosphorus loading to a lake. Sediment release of phosphorus to the lake occurs during the summer months, when the water overlying the sediments is depleted of oxygen. This internal load of phosphorus is transported to the entire lake during late summer or early fall, when the surface waters cool sufficiently for wind-mixing to mix the entire lake (often referred to as "fall turnover"). Phosphorus released from the sediments is typically in a dissolved form, which can be quickly utilized by algae, leading to intense algae blooms. Areal application of alum has proven to be a highly effective and long-lasting control of phosphorus release from the sediments, especially where an adequate dose has been delivered to the sediments and where watershed sediment and phosphorus loads have been minimized (Moore and Thorton, 1988). Alum will remove phosphorus from the water column as it settles and then forms a layer on the lake bottom that covers the sediments and prevents phosphorus from entering the lake as internal load. An application of alum to the lake sediments can decrease the internal phosphorus load by 80 percent (*Effectiveness and Longevity of Phosphorus Inactivation with Alum*, Welch and Cook, 1999) and will likely be effective for approximately seven to 10 years, depending on the control of watershed nutrient loads.

3.1.2.3 Application of Herbicides

Curlyleaf pondweed can be controlled by herbicide treatments applied from a barge or boat or by mechanical harvesting, or by a combination of these methods. Herbicide treatments are more effective at eradicating the plant, but MDNR regulations limit the extent of the lake that can be treated in a given year. Aquatic herbicides are among the most closely scrutinized compounds, and must be registered for use by both the U.S. Environmental Protection Agency and the State of Minnesota. Registration of an aquatic herbicide requires extensive testing. Consequently, all of the aquatic herbicides currently registered for use are characterized by excellent toxicology packages, are only bio-active for short periods of time, have relatively short-lived residuals, and are not bioconcentrated (*The Lake Association Leader's Aquatic Vegetation Management Guidance Manual*, Pullmann, 1992). Examples of two aquatic herbicides appropriate for use in controlling the curlyleaf pondweed growth in lakes are Reward (active ingredient = Diquat) and Aquathol-K (active ingredient = Endothall).

The use of low-level Sonar application has recently been found to selectively control exotic weed species such as Eurasian watermilfoil and curlyleaf pondweed (*Whole-Lake Applications of Sonar for Selective Control of Eurasian Watermilfoil*, Getsinger *et al*, 2001). Due to past history of Sonar applications and the limited research on the new low-level applications, the use of Sonar is not feasible at this time.

Both chemical and mechanical harvesting of macrophytes has been occurring in Lake Riley for several decades. Until 2009, the MDNR permit for macrophyte management in Lake Riley allowed for treatment of approximately 62 acres annually (up to 28 percent of the littoral area), which is greater than what the MDNR typically permits for herbicide treatment of macrophytes. Unless otherwise approved, the MDNR will currently only permit 15 percent of the littoral zone of a given lake be treated with herbicides.

3.1.2.4 Application of Copper Sulfate

Copper sulfate applications can be a highly effective algaecide in some cases, but these efforts are always temporary (days) and can have high annual costs. In addition, care must be taken to limit the impacts on non-target organisms, such as invertebrates, and possible sediment contamination with copper. The primary effects on algae include inhibition of photosynthesis and cell division as a result of the additional cupric ion, the form of copper toxic to algae, present in the water column (Cooke *et al*, 1993). Blue-green algae are particularly sensitive to copper sulfate treatments. As a result, after a copper sulfate treatment is made, the blue-green algae concentration is knocked back. However, after a few days, the green algae (fast growers) take control, and within a few weeks the chlorophyll *a* concentration can be back to pretreatment levels (Ed Swain, MPCA). As the algae die and settle out of the water column, they take with them the nutrients they used for growth. Therefore, copper sulfate application may temporarily reduce the total phosphorus concentration in a water body by removing the phosphorus that is associated with algal biomass. Once the algae have settled out of the water column and start to decompose, soluble phosphorus is released back into the water column that can be used for future algal growth. As a result, copper sulfate treatments are typically not considered a long-term solution to nutrient loading problems.

3.1.2.5 Mechanical Harvesting

Harvesting of lake macrophytes is typically used to remove plants that are interfering with uses such as boating, fishing, swimming, or aesthetic viewing. Mechanical control involves macrophyte removal via harvesting, hand pulling, hand digging, rotovation/cultivation, or diver-operated suction dredging. Small-scale harvesting may involve the use of the hand or hand-operated equipment such as rakes, cutting blades, or motorized trimmers. Individual residents frequently clear swimming areas via small-scale harvesting or hand pulling or hand digging.

Large-scale mechanical control often uses floating, motorized harvesting machines that cut the plants and remove them from the water onto land, where they can be disposed. Mechanical harvesters consist of a barge, a reciprocating mower in front of the barge that can cut up to a depth of roughly 8 feet, and an inclined porous conveyer system to collect the cuttings and bring them to the surface. Typically, a lake association or homeowner will contract a large-scale harvesting operation at an estimated cost of $500-plu per acre (McComas, 2007).

Removal of aquatic vegetation through mechanical harvesting has been shown to not be an effective nutrient control method (Cooke et al, 1993). However, none of this research was focused on the internal phosphorus load reduction due to mechanical harvesting of curlyleaf pondweed. Blue Water Science's 2000 *Orchard Lake Management Plan* suggests that there are up to 5.5 pounds of phosphorus per acre of curlyleaf pondweed. Additional research mentions that harvesting can reduce the extent of nuisance curlyleaf pondweed growth if harvesting occurs for several years and can reduce stem densities by up to 80 percent (McComas and Stuckert, 2000). Therefore, harvesting of curlyleaf pondweed may significantly reduce the phosphorus in the water column of a lake assuming enough biomass can be removed from the lake. This assumes that enough time and equipment is available to harvest the curlyleaf pondweed prior to die-back in early July.

While more acceptable to the MDNR than chemical methods, chemical harvesting still requires an MDNR permit, provides only temporary benefits, and must be repeated annually. The MDNR regulations state that the maximum area that can be harvested is 50 percent of the littoral zone.

3.1.2.6 Hypolimnetic Withdrawal

Hypolimnetic withdrawal involves discharging the nutrient-rich waters from hypolimnion instead of surface waters. This typically results in a reduced hypolimnetic detention time, decreased chance for anaerobic conditions to develop, and reduced phosphorus availability for epilimnetic entrainment. The withdrawal is accomplished by extending a pipe from the lake's outlet along the lake bottom to the deepest part of the lake. This pipe can act as either a siphon, or water can be pumped at a predetermined rate. By discharging nutrient-rich water from the hypolimnion the internal phosphorus load available when stratification breakdowns can be reduced.

3.1.2.7 Hypolimnetic Aeration

Hypolimnetic aeration involves the oxygenation in the hypolimnion of a thermally stratified lake to raise the dissolved oxygen content within this layer of the lake without disrupting the stratification or temperature. By aerating the hypolimnion, the anoxic conditions that often develop along the sediment-water interface during the summer months in many thermally stratified lakes can be minimized, reducing the internal phosphorus loading from the lake sediments into the water column. Hypolimnetic aeration can be achieved through a variety of designs and setups, which can include mechanical agitation, injection of pure oxygen, and injection of air.

3.1.2.8 Iron Salt Applications

The application of iron salts (such as ferric chloride or ferric sulfate) can be used to reduce TP concentrations within a lake. In aerobic conditions, the iron salts can be used to precipitate and/or inactivate the TP associated with lake sediments. Application of iron salts alone has not been shown to be effective in the long term. However, when used in combination with hypolimnetic aeration, the results of the treatment have been more effective.

3.1.3 Non-Structural Practices

Nonstructural practices are generally thought of as "good housekeeping" activities, intended to reduce pollutants at the source. Examples of non-structural BMPs include:

- Public education
- City ordinances
- Street sweeping
- Deterrence of waterfowl

3.1.3.1 Public Education

Public education regarding proper lawn care practices, such as fertilizer use and disposal of lawn debris, can result in reduced organic matter and phosphorus loadings to the lake. A public information and education program may be implemented to teach residents within the Lake Riley watersheds how to protect and improve the quality of the lake. The program could include distribution of fliers to all residents in the watershed as well as placement of advertisements and articles in the city's newsletters and the local newspapers. Information could also be distributed through organizations such as lake associations, local schools, Girl Scouts and Boy Scouts, and other local service clubs.

Initiation of a stenciling program to educate the public about stormwater could help reduce loadings to the storm sewer system. Volunteers could place stenciled messages (i.e., "Dump No Waste, Drains to Lake Riley") on all storm-sewer catch basins within the Lake Riley watershed.

3.1.3.2 City Ordinances

Fortunately, Minnesota already has a statewide phosphorus fertilizer ban in place that restricts the residential use of phosphorus fertilizer.

3.1.3.3 Street Sweeping

Most often, street sweeping is performed only in the spring, after the snow has melted, and in the fall, after the leaves have fallen, to reduce this potential source of phosphorus from entering the storm sewer. For most urban areas, street sweeping has relatively low effectiveness from late spring (after the streets are cleaned of accumulated loads) until early fall (prior to the onset of leaf fall) (Bannerman, 1983). The use of vacuum sweepers is preferred over the use of mechanical brush sweepers. The vacuum sweepers are more efficient at removing small phosphorus-bearing particles from impervious surfaces within the watershed. Fall street sweeping is particularly important in the watersheds directly tributary to the lakes, where treatment of stormwater is not available.

3.1.3.4 Deterrence of Waterfowl

The role of waterfowl in the transport of phosphorus to lakes is often not considered. However, when the waterfowl population of a lake is large relative to the lake size, a substantial portion of the total phosphorus load to the lake may be caused by waterfowl. Waterfowl tend to feed primarily on plant material in or near a lake; the digestive processes alters the form of phosphorus in the food from particulate to dissolved. Waterfowl feces deposited in or near a lake may result in an elevated load of dissolved phosphorus to the lake. One recent study estimated that one Canada goose might produce 82 grams of feces per day (dry weight) while a mallard may produce 27 grams of feces per day (dry weight) (Scherer et al., 2002). Waterfowl prefer to feed and rest on areas of short grass adjacent to a lake or pond. Therefore, shoreline lawns that extend to the water's edge will attract waterfowl. The practice of feeding bread and scraps to waterfowl at the lakeshore not only adds nutrients to the lake, but attracts more waterfowl to the lake and encourages migratory waterfowl to remain at the lake longer in the fall.

Two practices often recommended to deter waterfowl are construction of vegetated buffer strips, and prohibiting the feeding of waterfowl on public shoreline property. As stated above, vegetated strips along a shoreline will discourage geese and ducks from feeding and nesting on lawns adjacent to the lake, and may decrease the waterfowl population.

3.2 Recent Water Quality Studies and Projects Implemented

The following is a summary of the various water quality management studies and implementation activities that have been completed for Rice Marsh Lake and Lake Riley.

3.2.1 1999 UAA Implementation Strategy

A summary of the implementation strategy from the original UAA developed for Lake Susan and Rice Marsh Lake (Barr Engineering Co., 1999) is presented below:

- Fully implement the water management plans of the City of Chanhassen, the City of Eden Prairie, and the RPBCWD, including eight ponds in the Lake Susan watershed and five ponds in the Rice Marsh watershed that would be improved or added in developing areas.
- Upgrade one existing pond in the Lake Susan watershed and five existing ponds in the Rice Marsh Lake watershed that do not meet NURP criteria.
- Add eight new ponds to the Lake Susan watershed and four new ponds to the Rice Marsh watershed to reduce loading from already developed areas.
- Conduct in-lake alum treatments for both Lake Susan and Rice Marsh Lake.

3.2.2 2002 UAA Implementation Strategy

A summary of the implementation strategy from the original UAA developed for Lake Riley (Barr Engineering Co., 2002) is presented below:

- Conduct in-lake alum/lime slurry treatment for Rice Marsh Lake.
- Conduct in-lake alum treatment for Lake Riley.
- In cooperation with the Minnesota Department of Transportation (MnDOT), construct four to five new ponds along the proposed Highway 212 project route that meet MPCA and NURP criteria to treat highway runoff waters.

3.2.3 2004 Engineer's Report: Lake Riley Water Quality Improvement Project

A summary of the implementation strategy from the Lake Riley Water Quality Improvement Project (Barr Engineering Co., 2004) is presented below:

- Construct and/or upgrade stormwater treatment ponds in the Rice Marsh Lake watershed.
- Conduct in-lake alum/lime slurry treatment for Rice Marsh Lake.
- In cooperation with the MnDNR, construct two fish barriers between Rice Marsh Lake and Lake Susan to isolate carp in Rice Marsh Lake where they will be subject to winter kill. If the winter kill strategy is not effective, consider use of chemical treatment (e.g., rotenone) to remove rough fish at some later date.
- Conduct in-lake alum/lime slurry treatment for Lake Riley.
- In cooperation with MnDOT, construct four to five new ponds along the proposed Highway 212 project route that meet MPCA and NURP criteria to treat highway runoff waters.

3.2.4 2005-2007 Lake Riley/Rice Marsh Lake Water Quality Improvement Project

A summary of the designs implemented to improve water quality in Rice Marsh Lake and Lake Riley (Barr Engineering Co., 2005).

- Improve three existing stormwater ponds in the Rice Marsh watershed in the urbanized areas north of Highway 5 by adding forebays and deepening and enlarging the main ponds to improve settling and particulate removal.
- Add two new, large ponds on the north side of Rice Marsh Lake to further treat the two main watershed inflows from the north side of the lake.

3.2.5 Carp Management

In 2007, RPBCWD funded the University of Minnesota to conduct extensive research on the movement of common carp through the Riley Creek chain of lakes and identify the key factors that influence carp recruitment. The study found that maintaining a healthy bluegill sunfish population can prevent carp reproductive success, as the bluegill feed on carp eggs and larvae (Bajer, 2014). While bluegill populations tend to be healthy in Lake Riley, shallow conditions in Rice Marsh Lake lead to increased risk for winter kill. For this reason, the study recommended that aeration continue in Rice Marsh Lake to prevent winter kill.

Several additional outcomes of the University of Minnesota study were used to develop a sustainable carp management program for the Riley Creek chain of lakes, including:

- Determination that carp biomass levels should be maintained below 100 kg/hectare to prevent significant damage to lake water quality (Bajer, 2014)
- Development of a rapid assessment protocol to determine carp biomass using an electrofishing boat
- Demonstration that telemetry-guided winter seining can be effective in efficiently removing excess carp from lakes

Through carp seining events in recent years, the carp biomass in Lake Riley and Rice Marsh Lake has been reduced below the threshold identified by the University of Minnesota researchers.

3.2.6 Paleolimnological Analysis in Rice Marsh Lake

In 2014, RPBCWD contracted with the St. Croix Watershed Research Station to use paleolimnological techniques to reconstruct the trophic and sedimentation history of Rice Marsh Lake (Ramstack Hobbs, J.M. and M.B. Edlund. 2014). A sediment core was collected from the lake, and lead-210 activity was analyzed to develop a dating model and determine the sediment accumulation rate over the past 150 to 200 years. The key findings of the study are summarized below:

1. The sedimentation rate in Rice Marsh Lake increased in the mid-1940s and remained elevated into the early 2000s. The most recent sample suggests that the sedimentation rate in the lake may be returning to the pre-settlement rate.

2. A change in the diatom community assemblage appears to begin around the 1960s, coinciding with the beginning of operation of the wastewater treatment plant. The shift in the diatom community suggests a change from a mesotrophic assemblage to a eutrophic assemblage. The more recent diatom sample also suggest the community is returning to the pre-settlement condition.

3. The analysis concludes that Rice March Lake was a nutrient-enriched lake during the late 1800s through the mid-1900s, becoming increasingly eutrophic at the time the wastewater treatment plant began operation. The change in the diatom community at the top of the core and decline in cyanobacteria production, combined with a decrease in the sedimentation rate, suggests that recent management efforts on Rice Marsh Lake and Lake Susan are having positive effects.

3.3 Implementation Strategies

The following implementation plan outlines strategies to improve the existing water quality in Rice Marsh Lake and Lake Riley towards meeting MPCA and RPBCWD water quality standards and goals using an adaptive management approach. These strategies will also help to prevent water quality degradation due to future development.

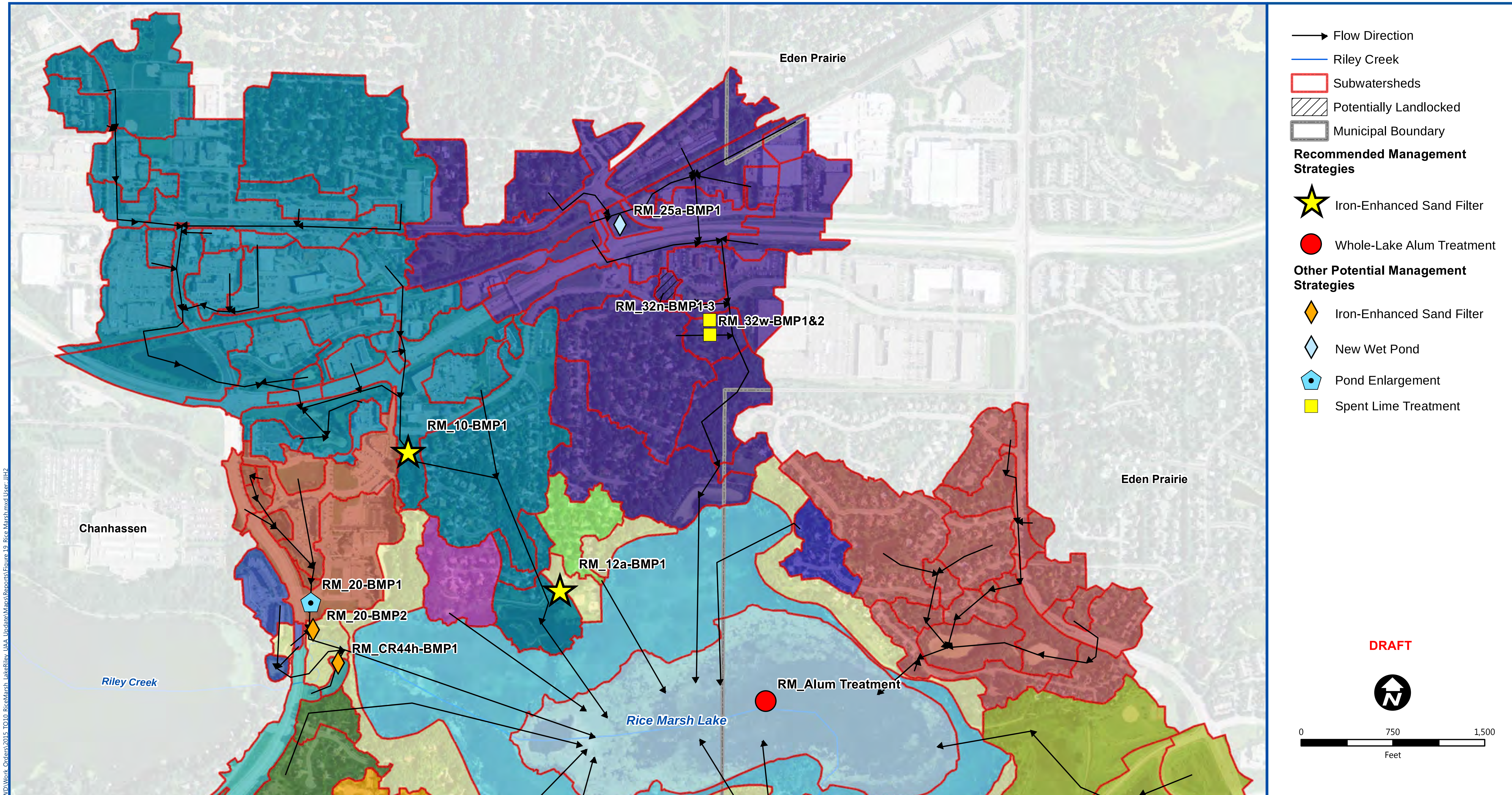
The intent of the presented implementation strategies is to provide a selection of potential water-quality improvement projects that the RPBCWD (in partnership with the cities of Chanhassen and Eden Prairie and/or other local, regional, or state agencies) can implement if funding or opportunities arise.

Because much of the runoff from the Rice Marsh Lake and Lake Riley watersheds already passes through several ponds and wetlands prior to discharging to the lake, this evaluation focused on more regional stormwater BMPs, targeting soluble phosphorus from the watershed areas that contribute the greatest fraction of phosphorus loads to the lakes. In addition to identifying potential projects in the watershed, in-lake management practices were assessed to help address the internal phosphorus loads to the lakes. BMPs were also identified that could treat few remaining point sources that currently have no treatment prior to discharging to the lake. A key component in improving the water quality in both lakes is reducing the load coming from the upstream lakes as well.

Planning-level opinions of probable cost are presented for various management strategies based on conceptual designs of the BMPs. However, there is cost uncertainty and risk associated with this concept level of design, so cost range of +40 percent to -20 percent from the point opinion of probable cost was used. The costs generally include permitting (5 percent), legal (5 percent), planning, engineering and design (30 percent), and contingencies (30 percent). The costs do not include any wetland mitigation costs. The range of probable costs provided reflects the level of uncertainty, unknowns, and risk due to the concept nature of the individual BMP designs. Utilizing industry resources for cost estimating (*AACE International Recommended Practice No. 18R-97* and *ASTM E 2516-06 Standard Classification for Cost Estimate Classification System*) provide guidance on cost uncertainty. Additional details about the estimated costs can be found in Appendix C.

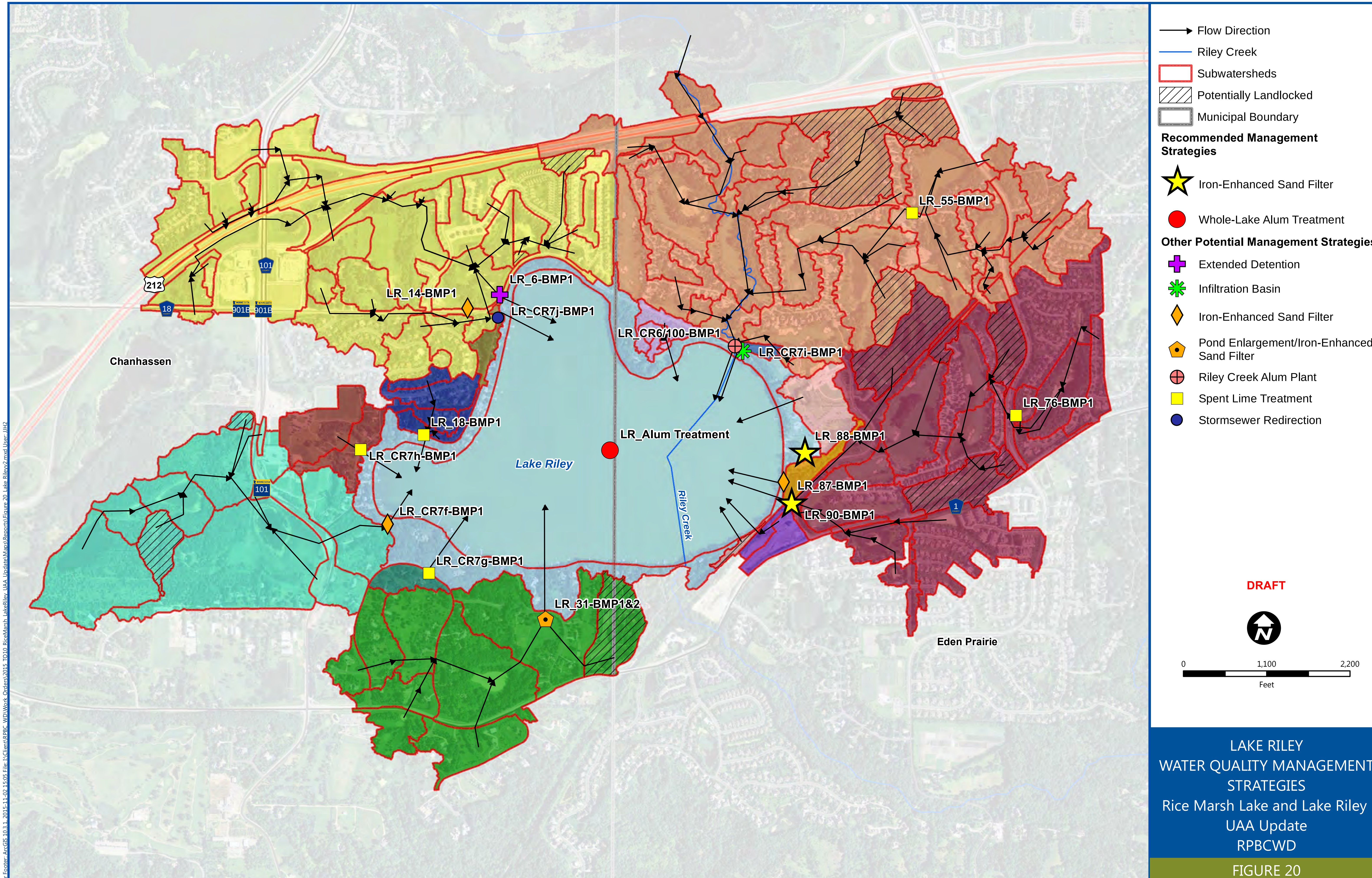
The BMP cost-per-pound phosphorus removed (BMP effectiveness) was estimated on an annual basis to provide a comparison of the BMPs and their overall cost effectiveness. The annualized costs are based on the point opinion of probable cost combined with the annual estimated operation and maintenance costs over the lifespan of the various BMPs. Reserved for:

Table 15 summarizes the estimated capital costs, maintenance costs, lifespan, and BMP effectiveness as well as the simulated in-lake water quality of Rice Marsh Lake under various management strategies. Table 16 presents similar information for Lake Riley. Figure 19 and Figure 20 shows the locations of the various BMPs evaluated as part of this study within the Rice Marsh Lake and Lake Riley subwatersheds, respectively. Figure 21 and Figure 22 show the impact of the various strategies on Rice Marsh Lake and Lake Riley water quality in comparison to the current MPCA standards.



RICE MARSH LAKE
WATER QUALITY MANAGEMENT STRATEGIES
Rice Marsh Lake and Lake Riley UAA Update
RPBCWD

FIGURE 19



LAKE RILEY
WATER QUALITY MANAGEMENT STRATEGIES
Rice Marsh Lake and Lake Riley
UAA Update
RPBCWD

FIGURE 20

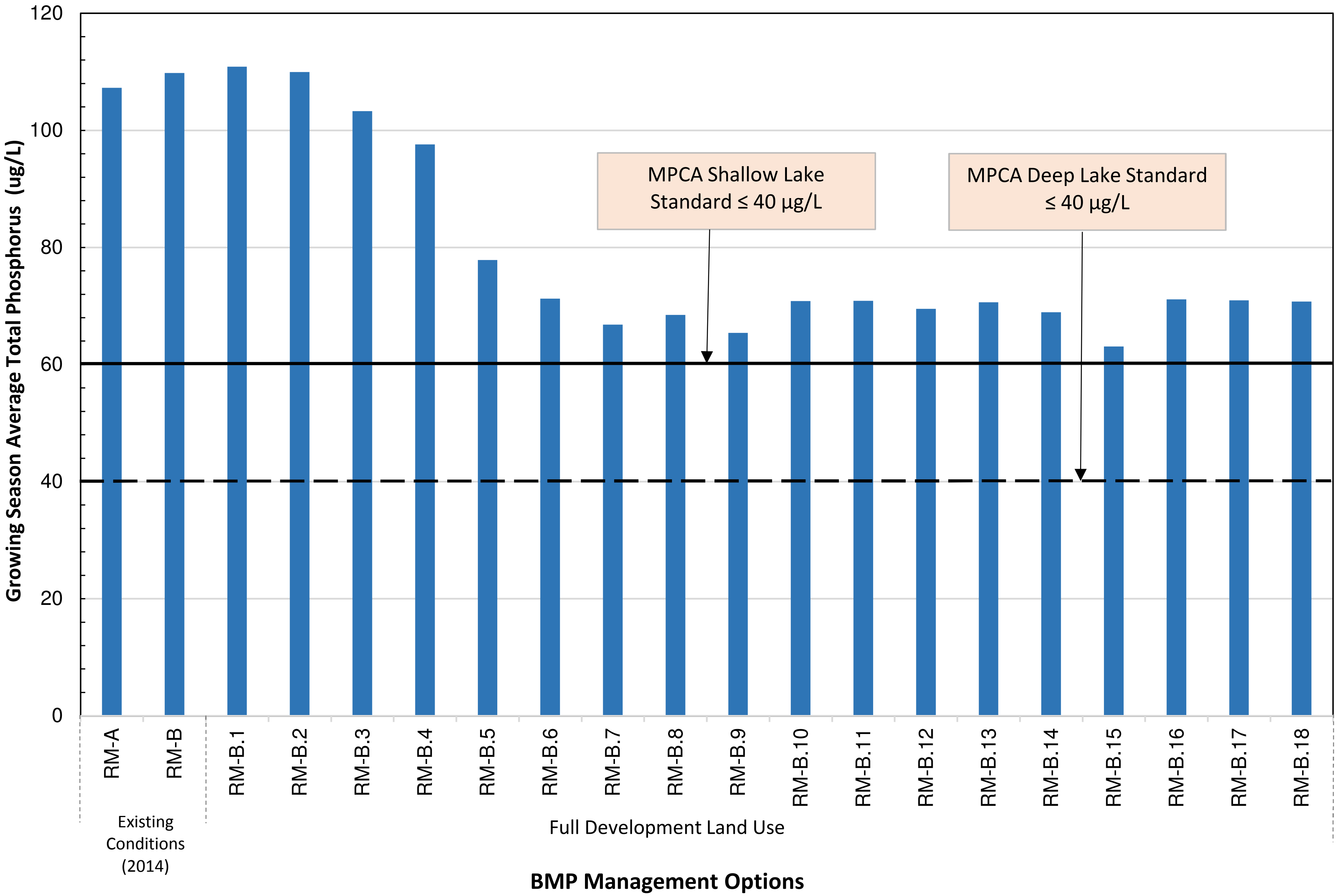


Figure 21. Rice Marsh Lake Total Phosphorus Concentration for BMP Management Option

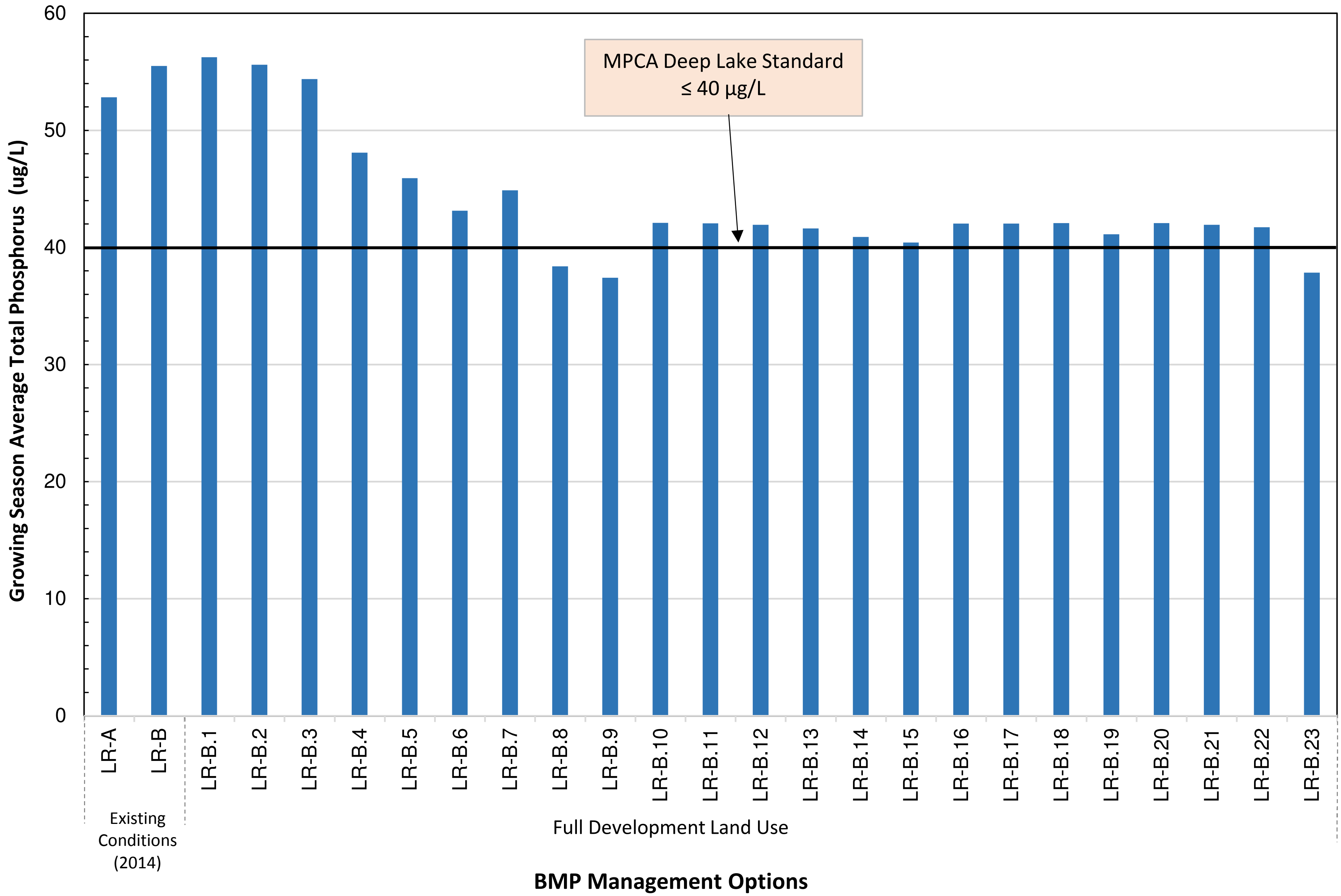


Figure 22. **Lake Riley Total Phosphorus Concentration for BMP Management Option**

Table 15. Summary of BMP Combinations, Resulting Rice Marsh Lake Summer Average Water Quality, and Cost Estimates

Best Management Practices (BMPs)	Existing Conditions Observed	Existing Conditions Modeled	Full Development Land Use No BMPs RM-B.1	BMP Combinations RM-B.2	RM-B.3	RM-B.4	RM-B.5	RM-B.6	RM-B.7	RM-B.8	RM-B.9	RM-B.10	RM-B.11	RM-B.12	RM-B.13	RM-B.14	RM-B.15	RM-B.16	RM-B.17	RM-B.18	Modeled Load Reduction to Rice Marsh Lake from BMP	Planning Level Opinion of Cost[3]	Estimated Annual O&M	BMP 30-Year Cost Effectiveness ($/lbs TP Removed)
Future Land Use			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	NA			
Source Reduction Efforts - Stormwater Rules Only: Assume 60% Reduction in Total Phosphorus Loading from New Impervious Surfaces				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	15			
Manage Lake Susan to Meet MPCA Shallow Lake Water Quality Standard					X			X	X	X	X	X	X	X	X	X	X	X	X	X	82	See Lake Susan UAA Update		
Manage Lake Susan to Meet MPCA Deep Lake Water Quality Standard						X															158	See Lake Susan UAA Update		
In-Lake Alum Treatments in Rice Marsh Lake[4]							X	X	X	X	X	X	X	X	X	X	X	X	X	X	450	$300,000	$0	$22
Build new iron-enhanced sand filter basin at RM_10									X		X						X				69	$386,300	$3,090	$239
Build new iron-enhanced sand filter basin at RM_12a										X	X						X				46	$295,600	$2,365	$265
Build new iron-enhanced sand filter basin at RM_CR44h												X									6	$200,100	$1,601	$1,351
Build new iron-enhanced sand filter basins at RM_20													X								6	$134,300	$1,074	$888
Build underground spent lime treatment chamber at RM_32n														X		X	X				29	$1,809,400	$14,475	$2,552
Build underground spent lime treatment chamber at RM_32w															X	X	X				9	$1,243,700	$9,950	$5,411
Wet pond expansion in RM_20																		X			1	$118,500	$948	$3,355
Expand wet pond in RM_25																			X		5	$359,900	$2,879	$3,227
Expand RM_20 pond and add iron-enhanced sand filtration																				X	7	$252,800	$2,022	$1,395

BMP Alterentiave Probable Cost

	Existing Conditions Observed	Existing Conditions Modeled	RM-B.1	RM-B.2	RM-B.3	RM-B.4	RM-B.5	RM-B.6	RM-B.7	RM-B.8	RM-B.9	RM-B.10	RM-B.11	RM-B.12	RM-B.13	RM-B.14	RM-B.15	RM-B.16	RM-B.17	RM-B.18
Planning Level Opinion of Cost[3] ($1,000's)	$0	$0	$0	$0	$0	$0	$300	$300	$686	$596	$982	$500	$434	$2,109	$1,544	$3,353	$4,035	$419	$660	$553
Planning Level Range of Opinion of Cost[3] ($1,000's)	$0	$0	$0	$0	$0	$0	$240 - $420	$240 - $420	$549 - $961	$476 - $834	$786 - $1375	$400 - $700	$347 - $608	$1688 - $2953	$1235 - $2161	$2682 - $4694	$3228 - $5649	$335 - $586	$528 - $924	$442 - $774
Annual Maintenance Costs ($1,000's)	$0	$0	$0	$0	$0	$0	$0	$0	$3	$2	$5	$2	$1	$14	$10	$24	$30	$1	$3	$2

Predicted Water Quality

	Existing Conditions Observed	Existing Conditions Modeled	RM-B.1	RM-B.2	RM-B.3	RM-B.4	RM-B.5	RM-B.6	RM-B.7	RM-B.8	RM-B.9	RM-B.10	RM-B.11	RM-B.12	RM-B.13	RM-B.14	RM-B.15	RM-B.16	RM-B.17	RM-B.18
Summer Average Total Phosphorus Concentration (µg/L)	107	110	111	110	103	98	78	71	67	68	65	71	71	70	71	69	63	71	71	71
Summer Average Chlorophyll a Concentration[1] (µg/L)	28	22	22	22	21	19	15	14	13	13	13	14	14	14	14	14	12	14	14	14
Summer Average Secchi Deph Transpanencies[1,5] (meters)	1.9	1.1	1.1	1.1	1.1	1.2	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.6	1.5	1.5	1.5
Annual Total Phosphorus Load to Lake Riley (lbs)		1,603	1,638	1,623	1,541	1,466	1,188	1,106	1,037	1,060	1,016	1,100	1,100	1,077	1,097	1,068	977	1,105	1,102	1,099
Estimated Annual Total Phoshorus Reduction to Lake Riley[2] (lbs)				15	97	172	450	531	601	578	622	537	538	561	541	570	660	533	536	539

Notes:
1. Modeled and Future Landuse chlorophyll a concentrations and Secchi Depth Transparencies estimated from regression equations derived from lake water quality data
2. Based on comparison with Future Conditions with Stormwater Rules Condition
3. Planning level opinions of probable cost point estimates with range of costs provided to reflect the level of uncertainty, unknowns and risk due to concept design
4. The life span of an alum treatment is typically 7-10 years, the 30 year life span assumes treatments every 10 years. The subsequent 2 treatments will be at half the dose (and cost) of the initial treatment.
5. 2014 water clarity in Rice Marsh Lake was exceptionally high relative to the total phosphorus concentrations

Table 16. Summary of BMP Combinations, Resulting Lake Riley Summer Average Water Quality, and Cost Estimates

Best Management Practices (BMPs)	Existing Conditions Observed	Existing Conditions Modeled	Full Development Land Use: No BMPs LR-B.1	BMP Combinations LR-B.2	LR-B.3	LR-B.4	LR-B.5	LR-B.6	LR-B.7	LR-B.8	LR-B.9	LR-B.10	LR-B.11	LR-B.12	LR-B.13	LR-B.14	LR-B.15	LR-B.16	LR-B.17	LR-B.18	LR-B.19	LR-B.20	LR-B.21	LR-B.22	LR-B.23	Modeled Load Reduction to Lake Riley from BMP	Planning Level Opinion of Cost[3]	Estimated Annual O&M	BMP 30-Year Cost Effectiveness ($/lbs TP Removed)
Future Land Use			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	NA			
Source Reduction Efforts - Stormwater Rules Only: Assume 60% Reduction in Total Phosphorus Loading from New Impervious Surfaces				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	36			
Manage Lake Susan to Meet MPCA Shallow Lake Water Quality Standard					X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	90	See Lake Susan UAA Update		
Manage Rice Marsh Lake to Meet MPCA Shallow Lake Water Quality Standard						X				X	X															343	See Rice Marsh UAA Update		
In-Lake Alum Treatment in Lake Riley[4]							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	811	$900,000	$0	$37
In-Lake Alum Treatments in Rice Marsh Lake[4]								X				X	X	X	X	X	X	X	X	X	X	X	X	X	X	186	$300,000	$0	$215
Build new iron-enhanced sand filter basin at LR_87													X													3	$68,700	$550	$1,051
Build new iron-enhanced sand filter basin at LR_14														X										X		10	$419,500	$3,356	$1,742
Build new iron-enhanced sand filter basin at LR_CR7f															X		X									27	$133,500	$1,068	$203
Build new iron-enhanced sand filter basins at LR_88 and LR_90											X					X	X									64	$835,500	$6,684	$538
Build underground spent lime treatment chamber at LR_CR7g																		X								4	$394,400	$3,155	$3,686
Build underground spent lime treatment chamber at LR_CR7h																			X							4	$326,700	$2,614	$3,289
Build new infiltration basin at LR_CR7i																				X						1	$75,700	$606	$4,121
Expand existing pond at location LR_31 and add new iron enhanced sand filter																					X					55	$1,283,300	$10,266	$969
Re-route watershed LR_CR7j's storm sewer outlet from Lake Riley to pond LR_15																						X		X		2	$58,200	$466	$1,481
Modify outlet from wetland LR_6 to provide enhanced detention																							X	X		8	$40,700	$326	$203
Alum Treatment Facility to Treat Riley Creek Inflow with Alum																									X	354	$1,683,000	$40,000	$272

BMP Alterentiave Probable Cost

	Existing Conditions Observed	Existing Conditions Modeled	LR-B.1	LR-B.2	LR-B.3	LR-B.4	LR-B.5	LR-B.6	LR-B.7	LR-B.8	LR-B.9	LR-B.10	LR-B.11	LR-B.12	LR-B.13	LR-B.14	LR-B.15	LR-B.16	LR-B.17	LR-B.18	LR-B.19	LR-B.20	LR-B.21	LR-B.22	LR-B.23
Planning Level Opinion of Cost[3] ($1,000's)	$0	$0	$0	$0	$0	$0	$900	$1,200	$900	$900	$1,736	$1,200	$1,269	$1,620	$1,334	$2,036	$2,169	$1,594	$1,527	$1,276	$2,483	$1,258	$1,241	$1,718	$2,883
Planning Level Range of Opinion of Cost[3] ($1,000's)	$0	$0	$0	$0	$0	$0	$720 - $1260	$960 - $1680	$720 - $1260	$720 - $1260	$1388 - $2430	$960 - $1680	$1015 - $1776	$1296 - $2267	$1067 - $1867	$1628 - $2850	$1735 - $3037	$1276 - $2232	$1221 - $2137	$1021 - $1786	$1987 - $3477	$1007 - $1761	$993 - $1737	$1375 - $2406	$2306 - $4036
Annual Maintenance Costs ($1,000's)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$7	$0	$0.5	$3	$1	$7	$8	$3	$3	$0.6	$10	$0.5	$0.3	$4	$40

Predicted Water Quality

	Existing Conditions Observed	Existing Conditions Modeled	LR-B.1	LR-B.2	LR-B.3	LR-B.4	LR-B.5	LR-B.6	LR-B.7	LR-B.8	LR-B.9	LR-B.10	LR-B.11	LR-B.12	LR-B.13	LR-B.14	LR-B.15	LR-B.16	LR-B.17	LR-B.18	LR-B.19	LR-B.20	LR-B.21	LR-B.22	LR-B.23
Summer Average Total Phosphorus Concentration (μg/L)	53	55	56	56	54	48	46	43	45	38	37	42	42	42	42	41	40	42	42	42	41	42	42	42	38
Summer Average Chlorophyll a Concentration[1] (μg/L)	32	22	22	22	21	18	17	16	16	13	13	15	15	15	15	14	14	15	15	15	15	15	15	15	13
Summer Average Secchi Deph Transpanencies[1,5] (meters)	1.9	1.3	1.3	1.3	1.3	1.4	1.5	1.5	1.5	1.7	1.7	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.7
Annual Total Phosphorus Load to Lake Riley (lbs)		2,761	2,851	2,815	2,725	2,381	2,040	1,854	1,989	1,607	1,580	1,804	1,801	1,794	1,777	1,740	1,712	1,799	1,800	1,803	1,749	1,802	1,795	1,784	1,558
Estimated Annual Total Phoshorus Reduction to Lake Riley[2] (lbs)				36	126	470	811	997	862	1,244	1,271	1,047	1,050	1,057	1,074	1,111	1,139	1,052	1,051	1,048	1,102	1,049	1,056	1,067	1,293

Notes:
1. Modeled and Future Landuse chlorophyll a concentrations and Secchi Depth Transparencies estimated from MPCA egression equations
2. Based on comparison with Future Conditions with Stormwater Rules Condition
3. Planning level opinions of probable cost point estimates with range of costs provided to reflect the level of uncertainty, unknowns and risk due to concept design
4. The life span of an alum treatemnt is typically 7-10 years, the 30 year life span assumes treatments every 10 years. The subsequent 2 treatments will be at half the dose (and cost) of the initial treatment.
5. 2014 water clarity in Lake Riley was exceptionally high relative to the total phosphorus concentrations

3.3.1 Rice Marsh Lake Water Quality Improvement Strategies

The following sections describe the various BMP strategies considered as part of this study. Individual cost estimates and BMP effectiveness information is summarized in Table 15.

3.3.1.1 No Action in Response to Watershed Development

Water quality modeling simulations show that the phosphorus load to Rice Marsh Lake will increase as development proceeds within the watershed. As a result, the phosphorus concentration in the lake will increase as well. Most of the stormwater runoff entering Rice Marsh Lake is first detained in wetlands, stormwater runoff detention ponds, or Lake Susan. Therefore, water quality model simulations indicate that much of the particulate phosphorus is removed from stormwater runoff upstream of Rice Marsh Lake. The phosphorus that is discharged to the lake is mainly associated with small particles (with slow settling rates), or is dissolved (i.e., not associated with particles).

The watershed and in-lake water quality modeling demonstrates that the expected land-use changes from existing (2010) to future (2030) conditions will increase phosphorus loading to Rice Marsh Lake by 35 pounds annually, assuming that no new stormwater BMPs are implemented in the watershed. This increase in phosphorus loading could increase the simulated, summer-average phosphorus concentration from 110 μg/L to 111 μg/L.

3.3.1.2 Application of Stormwater Management Rules

Application of the RPBCWD stormwater management rule and MPCA National Pollutant Discharge Elimination System (NPDES) requirements will help reduce the expected impact of future land-use changes in the watershed on the water quality in Rice Marsh Lake. This increase in loading will exacerbate the water quality challenges and would likely offset some of the improvement gained recently. The future-conditions scenario with the implementation of RPBCWD stormwater rules was used as part of the baseline condition for evaluation of the various implementation strategies to protect and improve water quality in Rice Marsh Lake. The cost of conforming to the stormwater rules will typically be the responsibility of the developers, with the exception of programmatic costs to implement the regulatory program. Because the RPBCWD stormwater management rules require a 60-percent reduction in the phosphorus loading from new and disturbed impervious surfaces, the increase in phosphorus loading would be partially mitigated by application of the rules. Model simulation indicates the 35-pound annual increase without requiring conformance to the stormwater rules would be reduced to 20 pounds of phosphorus annually. This represents a 43-percent reduction in the anticipated load to Rice Marsh Lake and would offset the increase in the modeled growing season phosphorus concentration (110 μg/L).

3.3.1.3 Lake Susan Water Quality at the MPCA's Shallow Lake Standard (SLS)

A baseline assumption is that Lake Susan's average growing-season total phosphorus concentration will be below 60 µg/L at some point in the future and that development in the Rice Marsh Lake subwatershed would be regulated for conformance with the RPBCWD stormwater management rules. This scenario was evaluated to quantify the impact of Lake Susan's water quality on Rice Marsh Lake. Costs associated with achieving the shallow-lakes water quality standard in Lake Susan were presented in the *2013 Lake Susan UAA Update* (Wenck 2013). Managing Lake Susan to achieve the MPCA's shallow Lake standard would reduce the annual phosphorus loading to Rice Marsh Lake to 1,541 pounds, a 6-percent reduction from future watershed development without BMPs. Simply improving Lake Susan water quality and the application of stormwater management rules will reduce the summer average concentration from 111 µg/L to 103 µg/L, a 7-percent reduction in in-lake phosphorus concentration.

3.3.1.4 Lake Susan Water Quality at the MPCA's Deep Lake Standard (DLS)

The scenario is similar to the one previously described, except that instead of managing Lake Susan to achieve the MPCA's shallow lake standard, it was assumed that the average growing-season total phosphorus concentration will be below 40 µg/L at some point in the future—the MPCA's deep lake standard. This scenario was evaluated to further quantify the impact of Lake Susan's water quality on Rice Marsh Lake. Managing Lake Susan to achieve the MPCA's shallow lake standard would reduce the annual phosphorus loading to Rice Marsh Lake to 1,466 pounds, a nearly 11-percent reduction from future watershed development without BMPs. Simply improving Lake Susan water quality and the application of stormwater management rules will reduce the summer average concentration from 111 µg/L to 98 µg/L, a 12-percent reduction in in-lake phosphorus concentration. Costs associated with achieve the deep-lakes water quality standard in Lake Susan were not assessed for this study.

3.3.1.5 Whole-Lake Alum Treatment of the Lake Bottom Sediments

Water quality monitoring data and the in-lake water quality modeling results indicate that internal phosphorus loading from the lake-bottom sediments is a significant phosphorus source to Rice Marsh Lake and contributes to the lake-water quality degradation during the growing season. The water quality modeling suggests that approximately 34 percent of the total phosphorus load to Rice Marsh Lake is from the bottom sediments. To address this internal load, the application of an aluminum sulfate (alum) to the lake sediments is proposed. Alum is commonly used in lakes to bind with phosphorus in lake sediments and prevent it release into the water column.

Lake water quality modeling suggests that an alum treatment of Rice Marsh Lake, which was assumed to decrease the internal phosphorus load from the sediment by 80 percent based on literature, combined with requiring stormwater controls as development occurs, would reduce the growing-season average phosphorus in the Rice Marsh Lake by nearly 30 percent. Modeling suggests that an alum treatment would remove 450 pounds of phosphorus per year from the Rice Marsh Lake system, reducing the growing season average in-lake phosphorus concentration from 111 µg/L to 78 µg/L, based on 2014 climatic conditions. This is a significant reduction in phosphorus concentration but will not meet the MPCA water quality standards for Rice Marsh Lake.

The estimated capital cost of three in-lake alum applications in Rice Marsh Lake over a 30-year period is $300,000 ($240,000 to $420,000). The cost of an alum treatment in Rice Marsh Lake was estimated to be approximately one-third of the Lake Riley cost based on the ratio of surface areas between the two lakes. The initial treatment was estimated to be $150,000, and each subsequent treatment, assuming half of the initial dose, would be roughly $75,000. This results in a total cost of $300,000 for three individual application of a 30-year period. The longevity of an alum treatment is difficult to estimate, as it depends on many factors, including the degree to which watershed sediment and phosphorus loads are controlled, flow regimes (especially in shallow lakes), the activity of benthivorous fish, and the accuracy with which the alum treatment was dosed. Appropriately dosed alum treatments typically have longevity of 7 to 10 years (Welch and Cook, 1999).

Because alum treatments have longevity of approximately 10 years, to convert to a 30-year lifespan to compare all management strategies, it was assumed that the alum treatment would need to be repeated once every 10 years. Whether or not an alum treatment will be necessary at that interval will need to be evaluated at a future time. Assuming multiple applications over a 30-year lifespan, cost-benefit of an alum treatment is $22 per pound of phosphorus per year. The collection and analysis of the sediment cores needed to appropriately estimate the alum dosing rate represents the first step in refining the associated application cost.

3.3.1.6 Rice Marsh Alum Treatment with Lake Susan Water Quality at the MPCA's Shallow Lake Standard (SLS)

Model simulations indicate that combining the alum treatment discussed above with the assumption that Lake Susan will be managed to achieve the MPCA's shallow-lake water quality standard and that the watershed development will be regulated to reduce loading from future development would reduce the annual phosphorus loading to Rice Marsh Lake to 1,106 pounds, a 32-percent reduction from future watershed development without BMPs. This would reduce the summer average concentration from 111 μg/L to 71 μg/L, a 36-percent reduction in in-lake phosphorus concentration.

3.3.1.7 Sand Filter in Subwatershed RM_10

Construction of an iron-enhanced sand filter is proposed in subwatershed RM_10, located just southeast of the intersection of Highways 5 and 101. The existing basin at this location will be converted into the 0.27-acre iron-enhanced sand filter and up to 6 cfs of the discharge from subwatershed RM_10 and its tributary watersheds will be routed through it.

Simulation of total phosphorus concentrations and loading following the possible implementation of this BMP also assume that future land use with stormwater rules will be implemented, Lake Susan water quality will meet the MPCA shallow lake standard, and in-lake alum treatments in Rice Marsh Lake will be conducted. Under future conditions with stormwater rules, P8 and in-lake modeling of this BMP results in a load reduction to Rice Marsh Lake of 69 pounds, resulting in a combined loading reduction to Rice Marsh Lake of 1,037 pounds. This reduction in phosphorus loading could reduce the growing-season average in-lake phosphorus concentration in Rice Marsh Lake from 111 µg/L to 67 µg/L based on 2014 climatic conditions.

3.3.1.8 Sand Filter in Subwatershed RM_12a

Construction of an iron-enhanced sand filter is proposed in subwatershed RM_12a, located on the north side of Rice Marsh Lake just south of Dakota Lane near the baseball field in Rice Marsh Lake Park. The new basin would be a 0.13-acre iron-enhanced sand filter, and the discharge that currently goes to the existing RM_12 pond would be diverted through it before being routed back to RM_12.

Under future conditions with stormwater rules, Lake Susan water quality meeting the MPCA shallow lake standard and an in-lake alum treatment in Rice Marsh Lake P8 and in-lake modeling of this BMP result in an annual load reduction to Rice Marsh Lake of 578 pounds, 46 pounds of which are the direct result of sand filter RM_12a. This reduction in phosphorus loading could reduce the growing season average in-lake phosphorus concentration in Rice Marsh Lake from 111 µg/L to 68 µg/L (39-percent reduction) based on 2014 climatic conditions.

3.3.1.9 Sand Filters in Subwatersheds RM-10 and RM_12a Combined

Construction of these two iron-enhanced sand filters would be the same as described previously. Because these BMPs are in series, the phosphorus reduction would not be the sum of the individual BMPs discussed above. The construction of these two BMPs in a series will result in an estimated annual phosphorus load to Rice Marsh Lake of 1,016 pounds; assuming that future conditions with storm water rules are implemented, Lake Susan is at the shallow lake standard; and the Rice Marsh Lake alum treatment has been applied. This represents a 622-pound reduction (38 percent), 90 pounds of which are the result of the two BMPs. This reduction in phosphorus loading could reduce the growing-season average in-lake phosphorus concentration in Rice Marsh Lake from 111 µg/L to 65 µg/L based on 2014 climatic conditions.

3.3.1.10 Sand Filter in Subwatershed RM_CR44h

Construction of an iron-enhanced sand filter is proposed in subwatershed RM_CR44h, located just east of Highway 101 along Riley Creek and within Rice Marsh Lake Park. The existing basin was constructed during the Highway 101 reconstruction to act as a temporary stormwater basin and was left in place after the permanent basin was built. The revised basin would be a 0.12-acre iron-enhanced sand filter treating discharge from existing pond RM_13 that currently discharges directly to Riley Creek.

Under future conditions with stormwater rules, Lake Susan water quality meeting the MPCA shallow lake standard and an in-lake alum treatment in Rice Marsh Lake P8 and in-lake modeling of this BMP result in an annual load reduction to Rice Marsh Lake of 537 pounds, only 6 pounds of which are the direct result of sand filter RM_CR44h. The resulting annual phosphorus load to Rice Marsh Lake would be about 1,100 pounds and reduce the growing season average in-lake phosphorus concentration in Rice Marsh Lake from 111 µg/L to 71 µg/L (36-percent reduction) based on 2014 climatic conditions.

3.3.1.11 Sand Filter in Subwatershed RM_20

Construction of an iron-enhanced sand filter is proposed in subwatershed RM_20, located southeast of the intersection of Main Street and Highway 101 and within Rice Marsh Lake Park. The new basin would be a 700-square-foot iron-enhanced sand filter treating the discharge from existing pond RM_20 that currently discharges directly to Riley Creek.

Under future conditions with stormwater rules, P8 and in-lake modeling of this BMP results in an annual load reduction to Rice Marsh Lake of about 6 pounds. Alone, this modest reduction in phosphorus loading would not have a significant impact on the growing season average in-lake phosphorus concentration in Rice Marsh Lake. When combined with stormwater management requirement, Lake Susan water quality meeting the MPCA shallow lake standard and an in-lake alum treatment in Rice Marsh Lake the summer concentration is estimated at 71 µg/L based on 2014 climatic conditions, the same as without the addition of this iron enhanced sand filter.

3.3.1.12 Spent Lime Treatment in Subwatershed RM_32n

Construction of a spent-lime treatment chamber is proposed in subwatershed RM_32, located in the northeast corner of Rice Marsh Lake watershed just south of Lake Drive East. The new underground chamber consists of 600 linear feet of 10-foot by 12-foot reinforced box culvert with 1.2 feet of spent lime laid in the bottom. Watershed runoff from watershed RM_32n and upstream tributary areas would be diverted through this chamber before returning to the existing storm sewer pipe and continuing downstream to pond RM_33. The proposed site for this BMP is near a drinking water well in a city park, which may significantly impact the constructability of this BMP.

P8 and in-lake modeling of this BMP results in an estimated annual load reduction to Rice Marsh Lake of 29 pounds. Combining this BMP with a baseline condition of future land use with stormwater rules implemented, Lake Susan water quality meeting the MPCA shallow lake standard and an in-lake alum treatments in Rice Marsh Lake, the annual phosphorus load to Rice Marsh Lake would be reduced to 1,077 pounds, a 561-pound reduction in the annual load. This reduction in phosphorus loading could reduce the growing-season average in-lake phosphorus concentration in Rice Marsh Lake from 111 µg/L to 70 µg/L based on 2014 climatic conditions.

3.3.1.13 Spent Lime Treatment in Subwatershed RM_32w

Construction of a spent-lime treatment chamber is proposed in subwatershed RM_32, located in the northeast corner of Rice Marsh Lake watershed just south of Lake Drive East, very close to the proposed spent-lime chamber used to treat RM_32n. Similar to the proposed system RM_32n, this underground chamber consists of 400 linear feet of 10-foot by 12-foot reinforced box culvert with 1.2 feet of spent lime and would have similar constructability concerns that would need further evaluation prior to design. Watershed runoff from watershed RM_32w would be diverted through this chamber before returning to the existing storm sewer pipe and continuing on to pond RM_33.

Under future conditions with stormwater rules, Lake Susan at the shallow lake standard and an in-lake alum treatment in Rice Marsh Lake, P8 and in-lake modeling indicates a combined annual load reduction to Rice Marsh Lake of 541 pounds, 9 pounds from BMP RM_32w. This additional 9-pound reduction in phosphorus loading does not have a significant impact on the growing-season average in-lake phosphorus concentration in Rice Marsh Lake as it remains at 71 µg/L based on 2014 climatic conditions.

3.3.1.14 Spent Lime Treatment in Subwatershed RM_32n and RM_32w Combined

Construction of these two spent-lime systems together would be the same as described in the preceding sections. Under future conditions with stormwater rules, P8 and in-lake modeling of these combined BMPs results in an annual load reduction to Rice Marsh Lake of 39 pounds. Combining this with the load reduction from stormwater regulation, Lake Susan at the shallow lakes standard and an in-lake alum treatment in Rice Marsh Lake would reduce the annual phosphorus load to Rice Marsh Lake to 1,068 pounds. This reduction in phosphorus loading could reduce the growing-season average in-lake phosphorus concentration in Rice Marsh Lake from 111 µg/L to 69 µg/L based on 2014 climatic conditions.

3.3.1.15 Combine Sand Filters in Subwatersheds RM-10 and RM_12a with Spent Lime Treatment in Subwatersheds RM_32n and RM_32w

Construction of the iron-enhanced sand filters in subwatershed RM_10 and RM_12a (as described above) with the spent lime systems RM_32n and RM_32w would result a combined load reduction of 129 pounds. Combining this reduction with the load reduction caused by stormwater regulation, Lake Susan at the shallow Lake standard and a Rice Marsh Lake alum treatment would lower the annual phosphorus load to the lake to 977 pounds. Under future conditions with stormwater rules, P8 and in-lake modeling suggest that these BMPs would reduce the growing-season average in-lake phosphorus concentration in Rice Marsh Lake from 111 µg/L to 63 µg/L based on 2014 climatic conditions, very near the MPCA's shallow lakes standard.

3.3.1.16 Wet Pond Expansion in Subwatershed RM_20

Expansion of an existing wet pond is proposed in subwatershed RM_20, located on the west side of Rice Marsh Lake at the intersection of Highway 101 and Main Street. The new basin would result in an increase of approximately 0.03 acre-feet of storage in the existing wet pond and would treat runoff from watersheds RM_20 and its tributary areas prior to discharging into Riley Creek upstream of Rice Marsh Lake.

Under future conditions with stormwater rules, P8 and in-lake modeling of this BMP results in an annual load reduction to Rice Marsh Lake of 1 pound, which alone would have no impact on the growing-season average in-lake phosphorus concentration in Rice Marsh Lake. The other BMPs combined with the expansion of the wet pond, stormwater regulation, Lake Susan improvement, and Rice Marsh alum treatment are the primary reason this BMP combination results in a growing-season average total phosphorus concentration of 71 µg/L based on 2014 climatic conditions.

3.3.1.17 New Wet Pond in Subwatershed RM_25a

Construction of a new wet pond is proposed in subwatershed RM_25a, located in the northeast corner of Rice Marsh between Highways 101 and 5 and West 78th Street. The new basin will be a 0.39-acre wet pond treating runoff from watersheds RM_26, RM_23, and RM_25a prior to discharging into the existing RM_26 wet pond.

Under future conditions with stormwater rules, P8 and in-lake modeling of this BMP results in an annual load reduction to Rice Marsh Lake of only 5 pounds. This reduction in phosphorus loading alone does not have an impact on the growing-season average in-lake phosphorus concentration in Rice Marsh Lake beyond what is realized from the combined alum treatment in Rice Marsh Lake, stormwater regulation, and assumption that Lake Susan management achieves the shallow lake standard as the concentration remains at 71 µg/L based on 2014 climatic conditions.

3.3.1.18 Expansion RM_20 Pond and Add Iron Enhanced Sand Filter

P8 and in-lake modeling indicates that expanding the existing pond and adding an iron enhanced sand filter as described above would result in an annual load reduction to Rice Marsh Lake of only 7 pounds. This reduction in phosphorus loading alone does not have an impact on the growing-season average in-lake phosphorus concentration in Rice Marsh Lake beyond what is realized from the combined alum treatment in Rice Marsh Lake, stormwater regulation, and assumption that Lake Susan management achieves the shallow lake standard. However, the combined annual phosphorus load would be reduced to 1,099 pounds, a 539-pound reduction when compared to future land-use conditions with no BMPs. The in-lake phosphorus concentration remains at 71 µg/L based on 2014 climatic conditions.

3.3.2 Lake Riley Water Quality Improvement Strategies

The following sections describe the various BMP strategies considered for Lake Riley as part of this study. Individual cost estimates and BMP effectiveness information is summarized in Table 16.

3.3.2.1 No Action in Response to Watershed Development

Water quality modeling simulations show that the phosphorus load to Lake Riley will increase as development proceeds within the watershed. As a result, the phosphorus concentration in the lake will increase as well. Most of the storm water runoff entering Lake Riley is first detained in wetlands, storm water runoff detention ponds, or Rice Marsh Lake. Therefore, water quality model simulations indicate that much of the particulate phosphorus is removed from storm water runoff upstream of Lake Riley. The phosphorus that is discharged to the lake is mainly associated with small particles (with slow settling rates), or is dissolved (i.e., not associated with particles).

The watershed and in-lake water quality modeling demonstrates that the expected land use changes from existing (2010) to future (2030) conditions will increase phosphorus loading to Lake Riley by 90 pounds annually, assuming no new stormwater BMPs are implemented in the watershed, leading to an annual load to the lake of 2,851 pounds based on 2014 climatic conditions. This increase in phosphorus loading could increase the simulated, summer average phosphorus concentration from 55 µg/L to 56 µg/L. This

1 μg/L provides a good indication of the phosphorus assimilation capacity of Lake Riley and suggests that significant load reductions are needed to achieve the MPCA's deep-lake water quality standard of 40 μg/L.

3.3.2.2 Application of Stormwater Management Rules

Application of the RPBCWD stormwater management rule and MPCA's NPDES requirements will help reduce the expected impact of future land-use changes in the watershed on the water quality in Lake Riley. The future-conditions scenario with the implementation of stormwater regulation was used as part of the baseline condition for the evaluation of the various implementation strategies to protect and improve the water quality in Lake Riley. The cost of conforming to the stormwater rules will typically be the responsibility of the developers, with the exception of programmatic costs to implement the regulatory program. Because the RPBCWD stormwater management rules require a 60-percent reduction in the phosphorus loading from new and disturbed impervious surfaces, the increase in phosphorus loading would be partially mitigated by application of the rules. Model simulation indicates that the 90-pound annual load increase without requiring conformance to the stormwater rules would be reduced to 54 pounds of phosphorus annually. This represents a 40-percent reduction in the future load to Lake Riley and would only partially offset the increase in the modeled growing season phosphorus concentration.

3.3.2.3 Lake Susan Water Quality at the MPCA's Shallow Lake Standard (SLS)

A baseline assumption is that Lake Susan's average growing-season total phosphorus concentration will be at or below 60 μg/L at some point in the future and development in the Lake Riley and Rice Marsh Lake subwatershed will be regulated for conformance with the RPBCWD stormwater management rules. This scenario was evaluated to quantify the impact of Lake Susan's water quality on Rice Marsh Lake. Costs associated with achieving the shallow-lakes water quality standard in Lake Susan were presented in the *2013 Lake Susan UAA Update* (Wenck 2013). Managing Lake Susan to achieve the MPCA's shallow lake standard would reduce the annual phosphorus loading to Lake Riley to 2,725 pounds, a 4-percent reduction from future watershed development without BMPs. Simply improving Lake Susan water quality and the application of stormwater management rules will reduce the summer average concentration from 56 μg/L to 54 μg/L, a 3-percent reduction in in-lake phosphorus concentration.

3.3.2.4 Rice Marsh Lake Water Quality at the MPCA's Shallow Lake Standard (SLS)

The scenario is similar to the one previously described, except that this simulation assumes that Rice Marsh Lake is also managed to achieve the MPCA's shallow lake standard (60 μg/L) at some point in the future. This scenario was evaluated to further quantify the impact of Lake Susan's water quality on Rice Marsh Lake. Managing Rice Marsh Lake to achieve the MPCA's shallow lake standard would reduce the annual phosphorus loading to Lake Riley to 2,381 pounds, a more than 16-percent reduction from future watershed development without BMPs. Simply improving Rice Marsh Lake water quality and the application of stormwater management rules will reduce the summer average concentration from 56 μg/L to 48 μg/L, a 14-percent reduction in in-lake phosphorus concentration. Costs associated with achieving the shallow-lakes water quality standard in Rice Marsh Lake were discussed previously. To avoid duplication of cost, the Rice Marsh Lake improvement costs are typically excluded from the Lake Riley improvement strategies with the exception of Rice Marsh Lake alum treatment.

3.3.2.5 Lake Riley Whole-Lake Alum Treatment of the Lake Bottom Sediments

Water quality monitoring data and in-lake water quality modeling indicate that internal phosphorus loading from the lake-bottom sediments also contributes about 35 percent of the total phosphorus load to Lake Riley. An aluminum sulfate (alum) treatment to the Lake Riley sediment is proposed to address this internal load in the lake.

An alum treatment of Lake Riley, which, based on literature, was assumed to decrease the internal phosphorus load from the sediment by 80 percent, would reduce the growing-season average phosphorus in the Lake Riley by 28 percent. An alum treatment combined with stormwater would remove roughly 811 pounds of phosphorus per year from the Lake Riley system, reducing the growing season average in-lake phosphorus concentration in Lake Riley from 56 µg/L to 46 µg/L based on 2014 climatic conditions. Because Rice Marsh Lake is located upstream of Lake Riley, an alum treatment in Lake Riley would have no impact on the Rice Marsh Lake water quality.

The estimated capital cost of three in-lake alum applications in Lake Riley over a 30-year timeframe is $900,000 ($720,000 to $1,080,000), based on the cost estimate prepared by Wenck Associates, Inc. (Wenck, 2015). The cost of the first application was estimated at $450,000 with two additional half-dose treatments at roughly years 10 and 20, each estimated at $225,000. Because alum treatments have longevity of approximately 10 years, to convert to a 30-year lifespan to compare all management strategies, it was assumed that the alum treatment would need to be repeated once every 10 years. However, whether or not an alum treatment will be necessary at that interval will need to be evaluated at a future time. Assuming multiple applications over a 30-year lifespan, the cost-benefit of an alum treatment is $37 per pound of phosphorus per year in Lake Riley.

3.3.2.6 Lake Riley and Rice Marsh Lake Whole-Lake Alum Treatment of the Lake Bottom Sediments

Conducting an alum treatment in both Rice Marsh Lake and Lake Riley would further reduce the annual load to Lake Riley by an additional 186 pounds through the improved water quality leaving Rice Marsh Lake. An alum treatment in Rice Marsh Lake would result in an in-lake growing-season average phosphorus concentration in Rice Marsh Lake of 78 µg/L as previously discussed in this report. These alum treatments combined with stormwater would remove nearly 1,000 pounds of phosphorus per year from the Lake Riley system, reducing the growing-season average in-lake phosphorus concentration in Lake Riley from 56 µg/L to 43 µg/L based on 2014 climatic conditions. This further supports the need to improve the water quality discharged from Rice Marsh Lake to Riley Creek.

3.3.2.7 Lake Riley Alum Treatment Combined with Lake Susan Achieving Shallow Lake Standards

As previously discussed, improvement to the upstream resources will provide benefit to Lake Riley. Assuming that Lake Susan achieves a summer average concentration of 60 µg/L or better and applying alum to the Lake Riley sediment would result in an annual phosphorus load to Lake Riley of 1,989 pounds. This loading would lead to a growing-season average phosphorus concentration in the lake of 45 µg/L, a

20-percent reduction. Costs associated with achieving the shallow-lakes water quality standard in Lake Susan were presented in the *2013 Lake Susan UAA Update* (Wenck 2013). The RPBCWD is currently in the construction phase of one of the BMPs recommended in that study and the evaluation phase for a second BMP in the Lake Susan watershed.

3.3.2.8 Lake Riley Alum Treatment Combined with Lake Susan and Rice Marsh Lake Achieving Shallow Lake Standards

Combining an alum treatment in Lake Riley with the assumption that Lake Susan and Rice Marsh Lake achieve a summer average concentration of 60 µg/L or better would result in an annual phosphorus load to Lake Riley of 1,607 pounds, a 44-percent reduction. This loading would lead to a growing-season average phosphorus concentration in the lake of 38 µg/L, achieving the MPCA's water quality standard. Costs associated with achieving the shallow-lakes water quality standard in Lake Susan were presented in the *2013 Lake Susan UAA Update* (Wenck 2013), while those costs for Rice Marsh Lake are presented earlier in this report. The model simulation highlights the importance of the District's One Water's approach and the need to improve upstream resources in order to achieve downstream water quality goals.

3.3.2.9 Combine Lake Riley Alum Treatment, Rice Marsh Lake and Lake Susan at SLS and Sand Filters at LR_88 and LR_90

The combination of two iron-enhanced sand filters is proposed on the east side of Lake Riley in subwatersheds LR_87 and LR_CR7 and was evaluated assuming that both Lake Susan and Rice Marsh Lake are meeting the shallow-lake standard of 60 µg/L along with an alum treatment in Lake Riley and stormwater regulation for new development. LR_90 is located north of the intersection of Riley Lake Road and old Riley Lake Road. This new basin would be a 0.21-acre iron-enhanced sand filter treating outflows from existing pond LR_90 before discharging into Lake Riley. LR_88 would be a 0.23-acre iron-enhanced sand filter located within Riley Lake Park west of the sand volleyball courts. This new basin would treat the outflows from existing pond LR_88 before discharging into Lake Riley.

P8 and in-lake modeling of these BMPs results in an annual load reduction to Lake Riley of 1,271 pounds, 64 pounds of which are from the two iron enhance sand filters. The annual phosphorus load to Lake Riley with these BMPs in place was estimated at 1,580 pounds. The reduction in phosphorus loading from anticipated future conditions could reduce the growing season average in-lake phosphorus concentration in Lake Riley from 56 µg/L to 37 µg/L based on 2014 climatic conditions. This BMP combination achieves the state's deep-lake water quality criteria and provides for a margin of safety of 3 µg/L when compared to the standard. This BMP combination highlights the need for managing the upstream resources to achieve that state's water quality standards, stormwater regulation, watershed BMPs, and in-lake BMPs.

3.3.2.10 Lake Riley and Rice Marsh Alum Treatments Combined with Lake Susan Achieving Shallow Lake Standards

Improvement to the upstream resources will provide benefit to Lake Riley. This BMP combination assumes that Lake Susan achieves a summer average concentration of 60 µg/L or lower, implementation of stormwater regulations for development, and alum application to both Rice Marsh Lake and Lake Riley. Combining these BMPs would result in an annual phosphorus load to Lake Riley of 1,804 pounds. This loading would lead to a growing-season average phosphorus concentration in the lake of 42 µg/L, a 25-percent reduction. This BMP combination does not achieve the water quality standard for Lake Riley. This is likely due to the fact that Riley Creek would still convey a significant amount of phosphorus to the lake as the result of Rice Marsh Lake growing-season lake phosphorus concentration only being reduced to 71 µg/L. Achieving the shallow-lake standard in Rice Marsh Lake would further decrease the phosphorus discharge from the lake and likely reduce the loading to Lake Riley sufficiently to achieve the state's deep-lake water quality goal.

The BMP options discussed below incorporate this BMP combination into the watershed and in-lake modeling.

3.3.2.11 Sand Filter in Subwatershed LR_87

Construction of an iron-enhanced sand filter is proposed in subwatershed LR_87, located on the east side of Lake Riley near the public boat ramp. The new basin would be a 0.03-acre iron-enhanced sand filter and treat runoff from watershed LR_87 before discharging into Lake Riley.

Under future conditions with stormwater rules, P8 and in-lake modeling of this BMP results in an annual load reduction to Lake Riley of 3 pounds. This reduction, when combined with the baseline of protective stormwater regulation and in-lake alum treatments in Rice Marsh Lake and Lake Riley, result in an annual load to the lake of 1,801 pounds. This phosphorus loading remains too large to achieve the water quality goals for Lake Riley and would yield a growing-season average in-lake phosphorus concentration of 42 µg/L based on 2014 climatic conditions. This is essentially the same lake concentration without the addition of the proposed sand filter in subwatershed LR-87.

3.3.2.12 Sand Filter in Subwatershed LR_14

Construction of an iron-enhanced sand filter is proposed in subwatershed LR_14, located on the northwest of the intersection of Lyman Boulevard and Reflections Road in Riley Ridge Park. The new basin would be a 0.11-acre iron-enhanced sand filter treating flows up to 2.5 cubic feet per second from pond LR_13 that currently discharge to pond LR_15. The treated water would then flow to wetland LR_6 before discharging to Lake Riley.

P8 and in-lake modeling of this BMP results in an annual load reduction to Lake Riley of 10 pounds. Combining this reduction the expected reductions from future land use with stormwater rules implemented, Lake Susan water quality meeting the MPCA shallow lake standard and in-lake alum treatments in both Rice Marsh Lake and Lake Riley would reduce the annual phosphorus load to the lake by 1,057 pounds. This reduction in phosphorus loading would lead to a growing season average in-lake phosphorus concentration in Lake Riley of 42 µg/L based on 2014 climatic conditions.

3.3.2.13 Sand Filter in Subwatershed LR_Cr7f

Construction of an iron-enhanced sand filter is proposed in subwatershed LR_Cr7f, located on the west side of Lake Riley. The new basin would be a 0.08-acre iron-enhanced sand filter designed to treat runoff from watershed LR_Cr7f and tributary areas before discharging into Lake Riley. This proposed location has the largest undeveloped upstream area and is expected to have the greatest change in upstream impervious area of any of the lake inflow points. Modeling suggests 8 percent of the watershed load enters Lake Riley from this inflow location and that the loading is expected to increase even with RPBCWD's protective stormwater regulation.

P8 and in-lake modeling of this BMP results in an annual load reduction to Lake Riley of 27 pounds. As previously discussed, modeling indicates that it takes roughly 125 pounds of phosphorus reduction to have a 1 µg/L improvement in the lake's phosphorus concentration. Therefore, this BMP alone would not have a significant impact on the growing-season average in-lake phosphorus concentration in Lake Riley but represents nearly 1-percent reduction in the watershed load to the lake. However, combining this BMP with alum treatments in Lake Riley and Rice Marsh Lake, Lake Susan achieving the shallow lake standard and protective stormwater regulation results in an annual load reduction to Lake Riley of 1,074 pounds. This reduction would produce an in-lake phosphorus concentration of 42 µg/L based on 2014 climatic conditions.

3.3.2.14 Combine Sand Filters in Subwatersheds LR_88 and LR_90

Construction of these two iron-enhanced sand filter is proposed on the east side of Lake Riley in subwatersheds LR_87 and LR_CR7. These filters would target soluble phosphorus in the runoff entering the in the southeast corner of the lake. Modeling indicates that 13 percent of the watershed phosphorus load enters the lake at this location. LR_90 would be located north of the intersection of Riley Lake Road and old Riley Lake Road. This new basin would be a 0.21-acre iron-enhanced sand filter treating the outflows from existing pond LR_90 before discharging into Lake Riley. LR_88 would located within Riley Lake Park west of the sand volleyball courts. This new basin would be a 0.23-acre iron-enhanced sand filter and treat the outflows from existing pond LR_88 before discharging into Lake Riley.

P8 and in-lake modeling of these BMPs combined with alum treatments in Lake Riley and Rice Marsh Lake, Lake Susan achieving a summer concentration of 60 µg/L, and protective stormwater regulation results in an annual load reduction to Lake Riley of 1,111 pounds, 64 pounds of which is from the two iron-enhanced sand filters. The annual phosphorus load to Lake Riley with these BMPs in place was estimated at 1,740 pounds. The reduction in phosphorus loading from anticipated future conditions could reduce the growing-season average in-lake phosphorus concentration in Lake Riley from 56 µg/L to 41 µg/L based on 2014 climatic conditions, nearly achieving the RPBCWD's and state's water quality goals for the lake without extensive management in the Rice Marsh Lake watershed. Following the District's adaptive management approach, additional structural BMPs could be added in the Rice Marsh Lake subwatershed in the future to further reduce the flow entering the Lake Riley from Riley Creek if additional phosphorus load reduction is needed.

3.3.2.15 Combine Sand Filters in Subwatersheds LR_88, LR_90 and LR_Cr7f

Construction of these three iron-enhanced sand filters would be the same as described in the preceding sections. P8 and in-lake modeling of these three BMPs results in an estimated annual load reduction to Lake Riley of 91 pounds. When combined with the anticipated load reduction from protective stormwater regulation, improving Lake Susan water quality and in-lake alum treatments in Rice Marsh Lake and Lake Riley the annual phosphorus load to the lake would be reduced by about 40 percent to an annual load of 1,712 pounds. This phosphorus loading would achieve a growing-season average in-lake phosphorus concentration of 40 µg/L based on 2014 climatic conditions, thus meeting the MPCA's and RPBCWD's phosphorus goals for Lake Riley.

3.3.2.16 Spent Lime Treatment in Subwatershed LR_CR7g

Construction of an underground spent-lime system was analyzed in subwatershed LR_Cr7g, located on the southwest side of Lake Riley. The underground chamber consists of 100 linear feet of 10-foot by 12-foot reinforced box culvert with 1.2 feet of spent lime. This chamber would be located beneath Foxford Road to treat runoff from the street prior to discharging in to Lake Riley. Spent lime was selected for this location because of its relatively small footprint and limited space at this site. Modeling indicates that runoff from this area currently does not receive treatment prior to discharging to the lake and contributes 12 pounds of phosphorus annually to Lake riley

Because of the limited space, the BMP analyzed would only remove 4 pounds of phosphorus from the runoff. Like other BMPs, this reduction is insufficient to have a measurable impact on the water quality in Lake Riley based on modeled improvement from the baseline condition. This BMP also has a high-cost effectiveness, which is typical when retrofitting BMPs in tight, developed locations that could prevent implementation (see Table 16).

3.3.2.17 Spent Lime Treatment in Subwatershed LR_CR7h

Construction of an underground spent-lime system was analyzed in subwatershed LR_Cr7h, located on the west side of Lake Riley near Bandimere Park. This would be near the area the City of Chanhassen recently reconstructed a parking area using pervious pavement. This treatment system would consist of 100 linear feet of 1-foot by 12-foot reinforced box culvert with 1.2 feet of spent lime to filter runoff. This chamber would be located beneath Kiowa Trail and treat outflow from the upstream pond and runoff from the street prior to discharging in to Lake Riley.

Similar to the previous system discuss in subwatershed LR-CR7g, modeling indicates this BMP results in an annual load reduction to Lake Riley of 4 pounds. This reduction in phosphorus loading does not have a significant impact on the growing season average in-lake phosphorus concentration in Lake Riley as it remains at the modeled concentration of the baseline condition of stormwater rule requirement for development, alum treatments in Rice Marsh Lake and Lake Riley and Lake Susan meeting the shallow lakes standards, 42 µg/L based on 2014 climatic conditions.

3.3.2.18 Subwatershed LR_CR7i Infiltration Basin

This basin is located on Lake Riley Road just east of Riley Creek crossing on the north side of Lake Riley. The outflow from LR_CR7i currently discharges directly into Lake Riley with no treatment. The proposed infiltration basin would route the street runoff to a new infiltration basin on the south side of Lake Riley Road. Modeling of this BMP results in an annual load reduction to Lake Riley of 1 pound. This reduction in phosphorus loading does not have an impact on the growing-season average in-lake phosphorus concentration in Lake Riley.

3.3.2.19 Subwatershed LR_31Wet Pond Expansion and New Iron Enhanced Sand Filter

Model simulation analyzed the expansion of an existing wet pond in subwatershed LR_31, located on the south side of Lake Riley on the south side of Meadowlark Lane, to treat the upstream watershed that appears to contribute almost 12 percent of the watershed loading to Lake Riley. The expanded pond would be a 1.13-acre wet pond treating runoff from watersheds RM_31 and upstream tributary areas prior to discharging into the proposed new iron enhanced sand filter adjacent to the pond. This new sand filter would be a 0.71-acre iron enhanced sand filter that will treat the runoff prior to discharging to Lake Riley. While this BMP is technically feasible, potential wetland impacts and existing wetland regulation may limit the ability to implement it.

P8 and in-lake modeling indicates that the combination of this BMP with alum treatments in Lake Riley and Rice Marsh Lake, stormwater regulation, and improvements to Lake Susan water quality would result in a total load reduction of 1,102 pounds annually, 55 pounds of which are removed with the proposed BMPs in subwatershed LR-31. This reduction in phosphorus loading could reduce the growing season average in-lake phosphorus concentration in Lake Riley from 56 µg/L to 41 µg/L based on 2014 climatic conditions.

3.3.2.20 Redirection of Storm Sewer Outflow from Subwatershed LR_CR7j

This storm sewer is located on Lake Riley Boulevard at its intersection with Lyman Boulevard. The outflow from LR_CR7j currently discharges directly into Lake Riley with no treatment, contributing about 5 pounds of phosphorus to the lake. The proposed redirection would route the street runoff to the existing pond LR_15 on the west side of Lake Riley Boulevard. From there, it will flow through the wetland complex LR_6 prior to discharging into Lake Riley.

P8 and in-lake modeling of this BMP results in an estimated annual load reduction to Rice Marsh Lake of 2 pounds. Combining this BMP with a baseline condition of future land use with stormwater rules implemented, Lake Susan water quality meeting the MPCA shallow-lake standard, and alum treatments in Rice Marsh Lake and Lake Riley, the annual phosphorus load to Lake Riley would be reduced to 1,802 pounds, a 1,049-pound reduction in the annual load. This reduction in phosphorus loading could reduce the growing season average in-lake phosphorus concentration in Rice Marsh Lake from 56 µg/L to 42 µg/L based on 2014 climatic conditions.

3.3.2.21 Outlet Alteration from Subwatershed LR_6 to Provide Extended Detention

This wetland outlet is located on Lyman Boulevard on the northwest side of Lake Riley. The proposed outlet alteration would raise the outlet weir 1 foot and add a small orifice at the current normal water level to allow drawdown within 24 hours of the rainfall event. Raising the outlet weir will slow the outflow and provide a longer time for particulates to settle out. Outflows going under Lyman Boulevard would continue to discharge into Lake Riley.

Modeling of this BMP results in an annual load reduction to Lake Riley of 8 pounds but would require a relatively small capital investment to modify the outlet. While modeling indicates this reduction alone does not appear to have a measurable impact on the in-lake phosphorus concentration, it does provide a cost-effective means of reducing the phosphorus load to Lake Riley, as presented in Table 16. Combining this BMP with the baseline modeling of protective stormwater requirements, upstream resource improvements, and whole-lake alum treatment in Lake Riley and Rice Marsh Lake would produce a growing-season average in-lake phosphorus concentration in Lake Riley of 42 µg/L based on 2014 climatic conditions.

3.3.2.22 Combination of BMPs LR_14, LR_CR7j and LR_6

The watershed loading conveyed to Lake Riley from the pipe leaving subwatershed LR_6 in the northwest corner of Lake Riley contributes about 152 pounds of phosphorus annually to the lake. In addition, a comparison of watershed modeling and pond monitoring data of the wetland in LR-6 suggest this wetland could potentially be experiencing internal release of phosphorus from the sediment. Because of the relatively large portion of the watershed loading is conveyed through this area, a BMP combination of several improvements was analyzed to assess potential load reductions.

P8 and in-lake modeling results show an annual load reduction to Lake Riley of 20 pounds from this BMP combination. Combining these BMPs with stormwater regulation, upstream lake improvement, and alum treatments in Rice Marsh Lake and Lake Riley would future reduce the annual loading to 1,784, representing a 37-percent reduction. This reduction in phosphorus loading reduces the growing season average in-lake phosphorus concentration in Lake Riley from 56 µg/L to 42 µg/L based on 2014 climatic conditions.

3.3.2.23 Riley Creek Alum Treatment Facility

Phosphorus loading from Riley Creek contributes roughly 25 percent of the watershed load or nearly 8 percent of the overall load to Lake Riley. Therefore, treating the creek flows has the potential to lower the summer average phosphorus concentration observed in Lake Riley. One method to remove phosphorus from the creek flows would be to improve the water quality in Rice Marsh Lake as described in previous BMP alternatives. Another option would be to construct an in-line alum treatment facility located along Lake Riley Road just east of the Riley Creek crossing. Flows up to 5 cfs would pass through the treatment plant where alum would be added to precipitate soluble phosphorus and other particulates. The treated flows would enter a sedimentation basin to allow the floc to settle prior to discharging into Lake Riley. Flows larger than 5 cfs would bypass the plant and flow directly into the lake.

Under future conditions with stormwater rules, P8 and in-lake modeling of this BMP results in an annual load reduction to Lake Riley of 245 pounds, assuming an alum treatment in Rice Marsh Lake, stormwater management rules, and Lake Susan meeting shallow lake standards. Without these upstream improvements, the overall phosphorus removal from an alum treatment facility would be greater. This reduction in phosphorus loading could reduce the growing-season average in-lake phosphorus concentration in Lake Riley by about 4 µg/L. If additional BMPs, such as an alum treatment in Lake Riley, are implemented in concert with the alum treatment facility, the state's deep-lake standard can be achieved in Lake Riley. Modeling predicts a reduction in the growing season average phosphorus concentration from 56 µg/L to 38 µg/L.

4.0 Rice Marsh Lake and Lake Riley Management Recommendations

Through the review of past studies, water quality data, and the watershed and in-lake modeling performed for this study, several BMPs have been identified that will improve water quality in Rice Marsh Lake and Lake Riley. Structural, in-lake, and nonstructural types of BMPs were assessed during this UAA update, and all play a role in the improvement and protection of these lakes. A summary of the water quality management recommendations for these lakes is provided below.

- **Structural BMPs**
    - Implement BMPs at targeted locations within the Rice Marsh Lake watershed to reduce the phosphorus and sediment loading from the watershed to the lake. These BMPs would include the iron-enhanced sand filtration system in subwatersheds RM_10 and RM_12a.
    - Implement BMPs at targeted locations within the Lake Riley watershed to reduce the phosphorus and sediment loading from the watershed to the lake. These BMPs would include the iron-enhanced sand filtration system in subwatersheds LR_88 and LR_90.
    - Continue to work with the cities of Chanhassen and Eden Prairie to identify potential redevelopment and road reconstruction projects that might provide the opportunity to retrofit additional BMPs into the watershed. Additionally, retrofits of iron-enhanced sand filtration benches to existing ponds (such as RM_6) should be pursued as opportunities arise.
- **In-Lake BMPs**
    - Conduct Rice Marsh Lake alum treatment of the internal sediment loading.
    - Conduct Lake Riley alum treatment of the internal sediment loading.
    - Continue Lake Riley herbicide treatments to control curlyleaf pondweed.
    - Continue carp management by operating the aeration system in Rice Marsh Lake and monitoring carp population.
- **Nonstructural Measures and Programs**
    - Implement RPBCWD stormwater management rules to help minimize phosphorus load increase and degradation of water quality in Rice Marsh Lake and Lake Riley as future development occurs within the watersheds.
    - Evaluate opportunities to work with landowners in the direct untreated watersheds riparian to Rice Marsh Lake and Lake Riley. These efforts should focus on implementing stormwater BMPs on private parcels and educating about shoreline/vegetation management (if applicable). The RPBCWD could target the promotion of the cost-share program to residents in the watersheds direct to Rice Marsh Lake and Lake Riley. Additionally, this could also include preservation of the currently undeveloped shorelines surrounding most of Rice Marsh Lake and portions of Lake Riley.

- Continue routine monitoring of the lakes. This would include the collection of water quality data, lake level data, and biological data (such as macrophytes, zooplankton, and phytoplankton).
  - Based on the recommendations from the University of Minnesota aquatic plant study, conduct macrophyte surveys one to two times per year in both Rice Marsh Lake and Lake Riley, in early June to capture the curlyleaf pondweed and again in late summer.
  - In Rice Marsh Lake and Riley, continue to monitor cyanobacteria levels within the lake.
  - Conduct water quality monitoring in select ponds and wetlands throughout the watershed to determine if they are potential sources of phosphorus to the lakes and to help refine future watershed models.
  - Collect total phosphorus sample profiles in Lake Riley at 1-meter increments to help better define the build-up of total phosphorus in the hypolimnion from sediment release and the percentage of this internal load that reaches the epilimnion.

- **Upstream Lake Improvements**
  - Improve the water quality in Lake Susan to achieve the MPCA's shallow-lake standard by continually implementing the improvements recommended in the 2013 Lake Susan UAA Update.

Implementation of the recommended BMPs through an adaptive management approach would significantly reduce the phosphorus loads to the lakes and allow time to evaluate the effectiveness of the measures implemented to ensure cost-effective use of District resources while striving to improve the overall water quality. Table 17 provides a summary of the modeled phosphorus load reduction, water quality improvements, planning-level BMP costs, and BMP effectiveness.

Table 17 Summary of Recommended Structural and In-Lake Strategies for Rice Marsh Lake and Lake Riley

Lake	Water Quality Management Strategy	Planning-level Opinion of Cost[1]	Annual Phosphorus Reduction to Lake	BMP Effectiveness ($/lb TP removed)
Rice Marsh Lake	Whole-Lake Alum Treatment of Rice Marsh Lake[3]	$300,000 ($240,000 - $420,000)	450	$22
	Iron-Enhanced Sand Filtration in subwatersheds RM_10 and RM_12a	$682,000 ($545,000 - $955,000)	90	$312
Lake Riley	Whole-Lake Alum Treatment of Lake Riley[3]	$900,000 ($720,000 - $1,080,000)	811	$37
	Iron-Enhanced Sand Filtration in subwatersheds LR_88 and LR_90	$836,000 ($668,000 - $1,170,000)	64	$538

1. Implementation costs are subject to change due to site investigations, additional project definition, and increased level of design.
2. Annual costs per pound of phosphorus removal are based on a 30-year life span.
3. Alum treatment life span is typically 7-10 years. Future alum treatments may be needed; however, this would be evaluated at a future time. The planning-level opinions of cost and the annualized costs assume treatments occur every 10 years over a 30-year period.

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Appendices

Appendix A

P8 Model Parameter Selection

Appendix A: P8 Model Parameter Selection

P8 Model Parameter Selection

There was no recent Rice Marsh Lake or Lake Riley watershed monitoring data gathered to use in calibrating the P8 models. During the development of the original Lake Susan and Rice Marsh Lake UAA P8 watershed models (which were used as the basis for the UAA update), there was no monitoring of stormwater inflows for Rice Marsh Lake; this limited the amount of P8 calibration that could be performed. However, the P8 models used in the original Lake Riley UAA were calibrated to monitoring data collected from the Lake Riley watershed during the 1998 water year. The original Lake Riley P8 model parameters were used as a starting point for the updated Rice Marsh and Lake Riley P8 models. Model parameters used in the P8 models for the 2013 Lake Lucy and Lake Ann UAA Update were also referenced.

The parameters selected for the Lake Lucy and Lake Ann P8 model are discussed in the following paragraphs. P8 parameters not discussed in the following paragraphs were left at the default setting. P8 version 3.4 was used for the UAA update P8 modeling.

- **Time Steps Per Hour (Integer) = 20.** Modified from original UAA P8 model to eliminate continuity errors greater than 2%.

- **Minimum Inter-Event Time (Hours) = 10.** Preserved from the original UAA P8 model. Similar to the original model calibration year of 1998, during 2014 frequent storms were noted during the summer. Use of this parameter resulted in a good fit between the observed and modeled lake volumes and was preserved from the original model. It should be noted that the average minimum inter-event time in the Minneapolis area is 6 hours.

- **Snowmelt Melt Coef (Inches/Day-Deg-F) = 0.06**. Preserved from the original UAA P8 model. This selection was based on the snowmelt rate that provided the best match between observed and predicted snowmelt in the original UAA.

- **Snowmelt Scale Factor for Max Abstraction = 1**. This factor controls the quantity of snowmelt runoff (i.e., controls losses due to infiltration). Selection was based upon the factor that resulted in the closest fit between modeled and observed runoff volumes, based on the original Lake Riley P8 model calibration. Preserved from the original UAA P8 model.

- **Growing Season Antecedent Moisture Conditions AMC-II = 0 and AMC-III = 0**. Selection of this factor was based upon the observation that the model accurately predicted runoff water volumes from monitored watersheds when the Antecedent Moisture Condition III was selected (i.e., curve numbers selected by the model are based upon antecedent moisture conditions). Modeled water volumes were less than observed volumes when Antecedent Moisture Condition I or II was selected. The selected parameters tell the model to only use Antecedent Moisture Condition III. Preserved from the original UAA P8 model.

- **Particle Scale Factor for TP = 1.** The particle scale factor determines the total phosphorus load generated by the particles predicted by the model in watershed runoff. Modified from the original UAA P8 model (1.42) in order to reduce the loading to the lakes and produce a better fit to observed lake data.

- **Particle File = NURP50.PAR.** The NURP 50 particle file was found to most accurately predict phosphorus loading to Round Lake. Preserved from the original UAA P8 model.

- **Precipitation File Selection = MSP_FC4915_Corr.pcp.** For the 2008-2014 climatic conditions, a continuous hourly precipitation file was developed based on data from the Flying Cloud Airport weather station. For any gaps in the local precipitation record, the hourly data from the Minneapolis-St. Paul International Airport NWS stations (MSP) was used and adjusted based on comparison of the daily precipitation amounts at MSP to the daily data collected at the Chanhassen NWS station.

- **Air Temperature File Selection MSP_FC4915.tmp.** For the 2008-2014 climatic conditions, a continuous daily average temperature file was developed based on data from the Flying Cloud Airport weather station.

- **Device Infiltration Rate. =** The P8 model developed for the original UAA assumed that for ponds partially located on marsh soils, 0.015 (dead storage pool) and 0.02 (flood storage pool) for ponds located on loam soils, and 0.05 for ponds located on sandy loam soils. The infiltration parameter selection was based upon pond level data (i.e., from a pond located on sandy loam soils) and from adjustments to match observed and modeled flows from other watershed ponds. As part of the UAA update, infiltration was removed from all ponds and wetlands unless there was data that would suggest that the water levels in the ponds and wetlands would fall below the outlet control elevation or if the device were designed specifically for infiltration. To determine if infiltration should be incorporated into each water body, the normal water level (as either listed in the City of Chanhassen 2006 Surface Water Management Plan, the City of Chanhassen GIS file, or the development plans submitted to RPBCWD for permit review) was compared with the water surface elevation as estimated from the MDNR LiDAR data (2011). If the outlet control elevation was above the estimated water surface elevation from the LiDAR data by approximately 1 foot or more, infiltration was incorporated into the water body to allow the water levels to drawdown below the outlet. However, if the outlet control elevation was at or below the estimated water surface elevation from the LiDAR data, no infiltration was included for the water body. The infiltration rates used for the UAA update were assumed to be similar to the rates used in the P8 modeling for the original UAA.

- **Particle Removal Scale Factor. = 0.3** for ponds less than 2 feet deep and 1 for all ponds 3 feet deep or greater. The particle removal factor for watershed devices determines particle removal by devices. The factor was selected to match observed phosphorus loads and modeled loads. Insufficient information was available to say with certainty the particle removal scale factor for ponds 2 to 3 feet deep. A factor of 0.6 was used for all ponds of this depth. Preserved from the original UAA P8 model.

- **Watershed Pervious Curve Number. =** Area weighted SCS Curve number was used as outlined in the following procedure. The U.S. Department of Agriculture-National Resources Conservation Service's (USDA-NRCS) Soil Survey Geographic (SSURGO) database was consulted to determine the soil types within each subwatershed and a pervious curve number was selected for each subwatershed based upon soil types, land use, and hydrologic conditions (e.g., if watershed soils are type C and pervious areas are comprised of grassed areas with >75% cover, then a Curve Number of 74 would be selected). The pervious curve number was then area weighted based on the various land use and soil types within each subwatersheds.

- **Swept/Not Swept. =** An "Unswept" assumption was made for the entire impervious watershed area. A Sweeping Frequency of 0 was selected. Selected parameters were placed in the "Swept" column since a sweeping frequency of 0 was selected. Preserved from the original UAA P8 model.

- **Impervious Fraction. =** In P8 version 3.4, the both the directly and indirectly-connected impervious surfaces were input separately. Table A.1 summarizes the impervious coverage assumptions by 2010 land use category. Table A.2 summarizes the impervious coverage assumptions by 2030 land use category.

Table A.1 Impervious Assumption by 2010 Land Use Category

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

Table A.2 Impervious Assumption by 2030 Land Use Category

2030 Land Use Categories	Total Percent Impervious	Percent Directly Connected Impervious
Commercial	86	85
Golf course	6	5
Vehicular Right-of-way	50	50
Railway	65	65
Office/Industrial	73	72
Mixed Use	73	72
Public/Semi-Public	49	40
Residential Large Lot	35	20
Residential Low Density	35	20
Residential Medium Density	50	30
Residential High Density	59	37
Park/Open Space	6	5
Open Water	100	100

- **Impervious Depression Storage = 0.0065.** Preserved from the original UAA P8 model.
- **Impervious Runoff Coefficient = 1.** Preserved from the original UAA P8 model.
- **Passes thru Storm File = 10.** The number of passes through the storm file was determined after the model had been set up and a preliminary run completed. The selection of the number of passes through the storm file was based upon the number required to achieve model stability. Multiple passes through the storm file were required because the model assumes that dead storage waters contain no phosphorus. Consequently, the first pass through the storm file results in lower phosphorus loading than occurs with subsequent passes. Stability occurs when subsequent passes do not result in a change in phosphorus concentration in the pond waters. Preserved from the original UAA P8 model.
- In cases where insufficient data was available to calculate a pond device inputs, the pond removal efficiencies were calculated using the ratio of the contributing watershed impervious area to the pond surface area and an assumed pond depth following the method described in the *Phosphorus Removal by Urban Runoff Detention Basins* document (Walker, 1987). The curves calculated from this document relating pond surface area, impervious watershed area and pond depth are shown in Figure A.1 below.

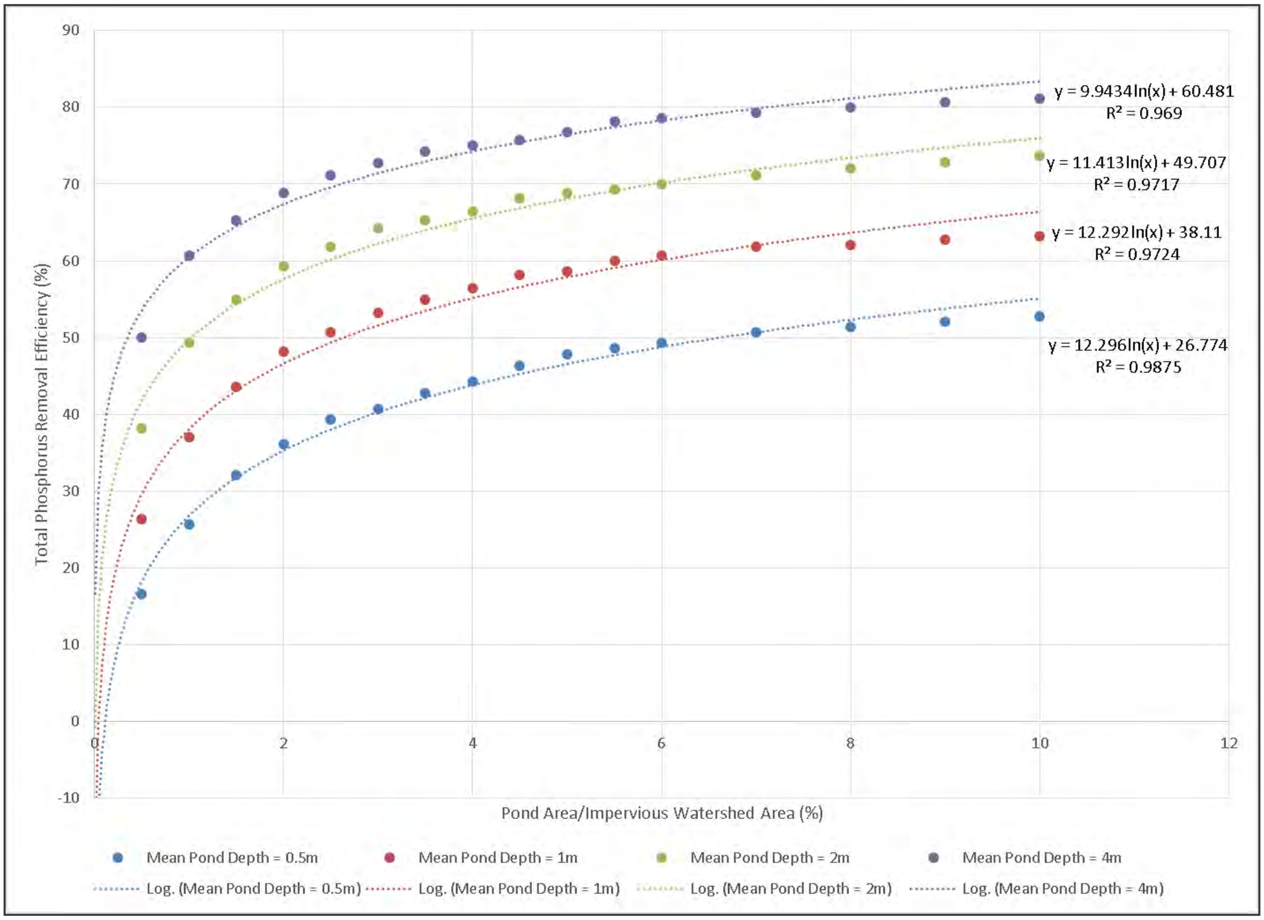


Figure A.1 Curves relating detention pond surface area, watershed impervious area, pond depth, and total phosphorus removal efficiency

Appendix B

In-Lake Model Parameter Selection and Calibration

Appendix B: In-Lake Model Parameter Selection and Calibration

B.1 Lake Modeling Methods

In-lake modeling of Rice Marsh Lake and Lake Riley was accomplished through the creation of a daily time-step mass balance model that tracked the flow of water and phosphorus through the lakes over a range of climatic conditions. The model was constructed to simulate the entire water year as well as the growing season.

B.1.1 Lake Model Water Balance

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

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

Where:

V = Lake volume (acre-ft)
i = Daily time step
I_W = Inflow from modeled lake's direct watershed (acre-ft/day)
I_{LC} = Total daily inflow from upstream lake (acre-ft/day)
P = Daily precipitation depth (ft/day)
E = Daily evaporation depth (ft/day)
A_S = Lake surface area (acres)
O = Outflow (acre-ft/day)
G = Groundwater flow (acre-ft/day)

Key input parameters into the lake models include lake depth recorded every 15 minutes while the level sensor is in place during ice free period, lake volume estimated using a relationship between lake elevation and lake cumulative volume (Figure B.1), daily inflow rate from the direct watershed calculated using the P8 watershed model, daily inflow rate from upstream lakes (Lake Susan for Rice Marsh and Rice Marsh Lake for Lake Riley) and outflow rates estimated using lake water elevation data with the creation of outflow rating curves (Figure B.3), daily precipitation data recorded at the Flying Cloud airport weather station over the lakes surface area (Figure B.2), and evaporation calculated using the Lake Hefner equation (Marciano and Harbeck, 1954) described below:

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

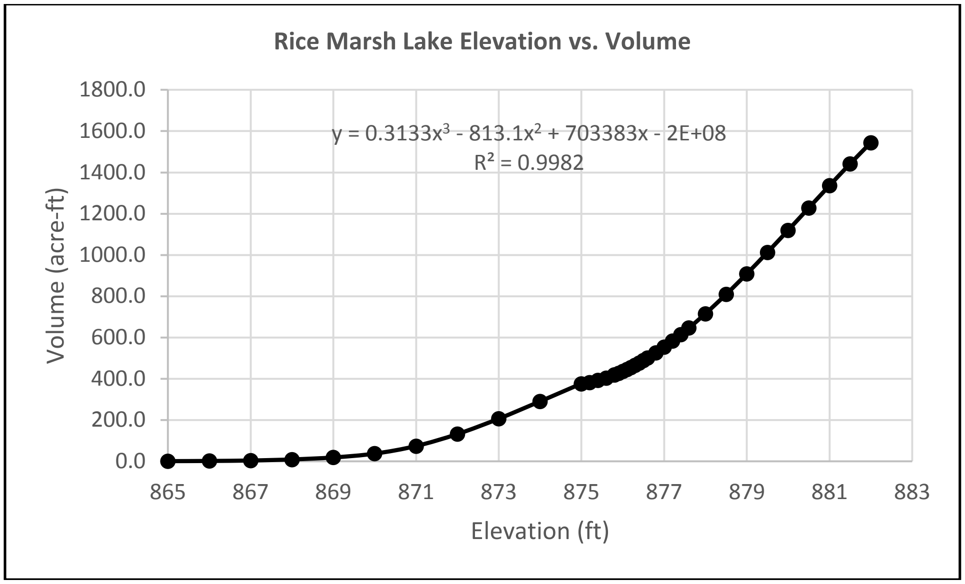
$$e_0 = 6.11 * 10^{\frac{7.5*T_W}{237.7+T_W}}$$

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

Where:

E = evaporation (inches)
U = wind speed (mph)
e_o = vapor pressure of the saturates area at the temperature of the water surface
e_a = vapor pressure of the air
T_W = surface water temperature in (^oC)
T_A = air temperature in (^oC)

If used, groundwater flows are simulated as a constant input value over the course of the water year.



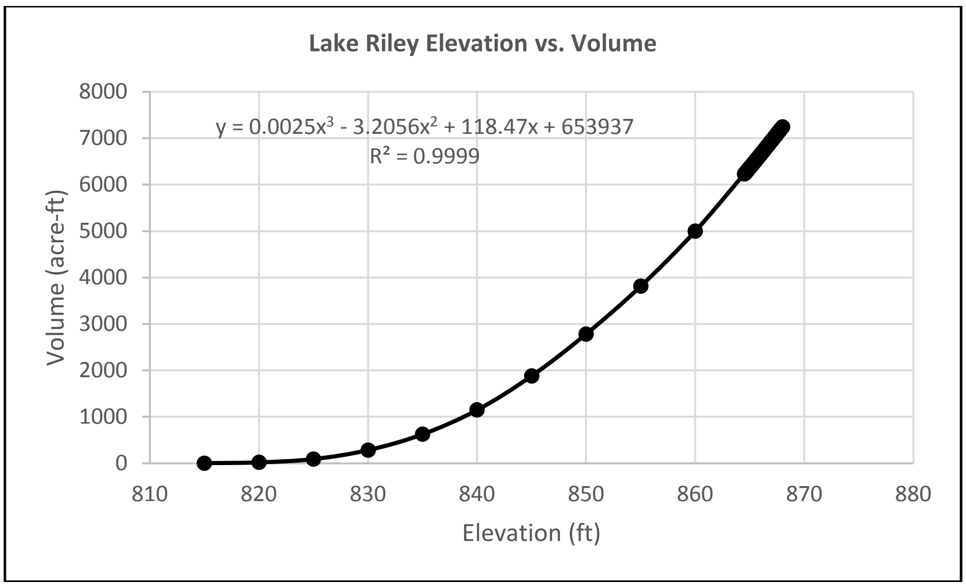
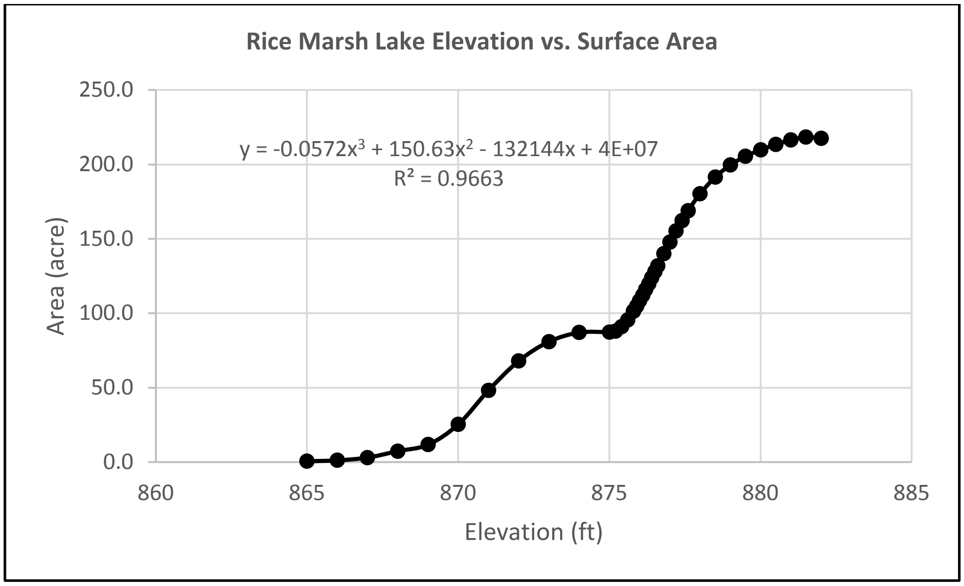


Figure B.1 Relationship between lake volume and elevation



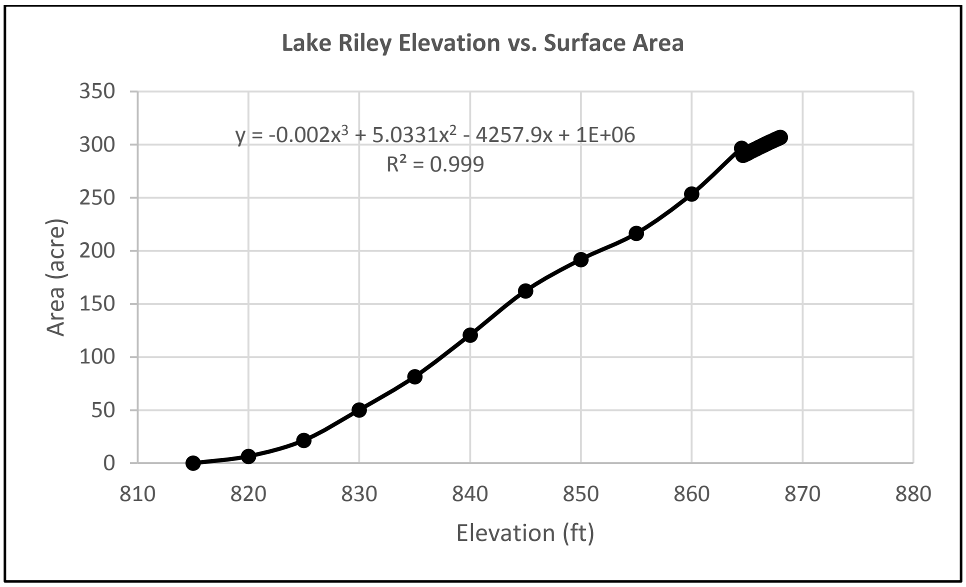
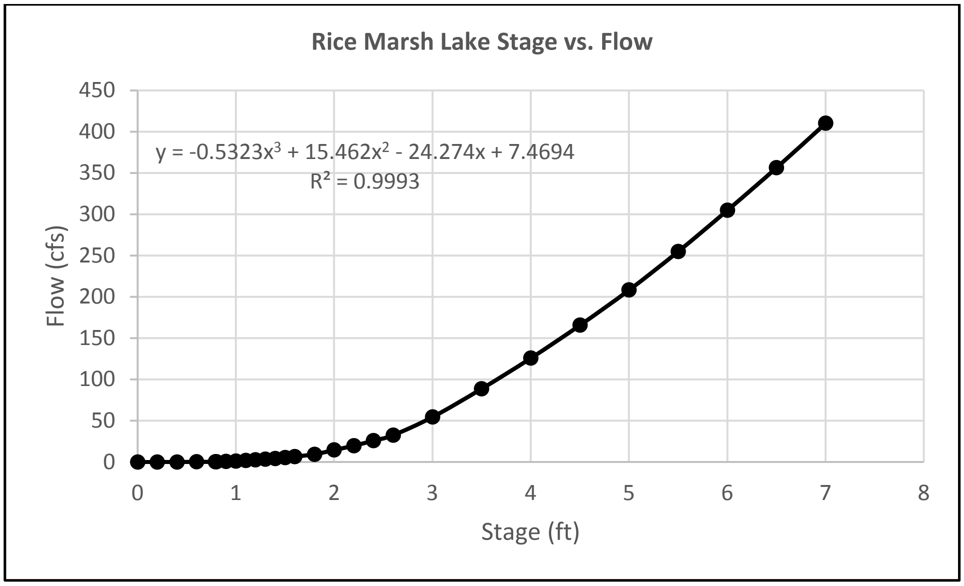


Figure B.2 **Relationship between elevation and lake surface area**



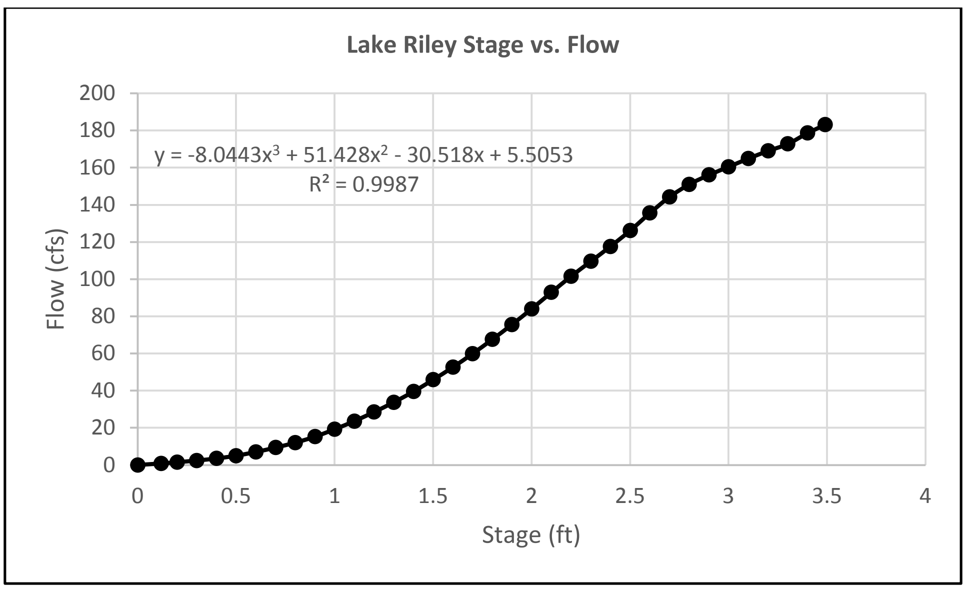


Figure B.3 Relationship between stage and outflow

B.1.2 Lake Model Phosphorus Balance

The lake phosphorus budget for Rice Marsh Lake and Lake Riley is based on the Vollenweider (1969) mass balance equation:

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

Where:

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

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

The loading from Lake Susan to Rice Marsh Lake was calculated using inflow rates estimated from the Lake Susan water surface elevation and rating curve combined with the surface phosphorus concentration recorded in Lake Susan. The outflow values from the Rice Marsh model were used as the loading from Rice Marsh Lake to Lake Riley. The phosphorus load from the lakes direct watersheds was calculated using the P8 modeling results. Atmospheric deposition of phosphorus onto the lakes water surfaces was calculated by using the estimated statewide phosphorus atmospheric deposition rate of 0.17 kg/ha/year (Barr, 2004) combined with the lakes water surface areas based on the current water elevation. Groundwater loads were either a source or a sink for phosphorus depending on if water was flowing into or out of the lake respectively. If the net daily groundwater flow was into the lake, the load of phosphorus was calculated using the groundwater flow rate and an estimate for groundwater phosphorus concentration of 0.035 mg/l. If the net flow was out of the lake then the loss of phosphorus was estimated using the flow rate and the average lake phosphorus concentration. The loss of phosphorus through outflow from the lakes was calculated using the measured surface concentrations of total phosphorus and the outflow rate calculated in the water balance.

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

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

B.1.3.1 Rice Marsh Lake Model Calibration

The Rice Marsh Lake model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity. The final calibrated phosphorus settling velocity was set at 5 m/y or 0.0137 m/day. The final internal loading rate 22 $mg/m^2/day$ was based on microcosm experiments performed on sediment core samples in 1988 and 2004. The model was calibrated using the volumetric average phosphorus concentrations in 2014 and validated using 2012 and 2013 data. Figure B.4 shows the results of the Nash Sudcliff statistical comparison between the 2014 modeled and measured volumetric averaged total phosphorus concentrations. Figure B.5 shows the comparison between the modeled, monitored surface and monitored volumetric averaged total phosphorus concentrations over the course of the 2014 water year.

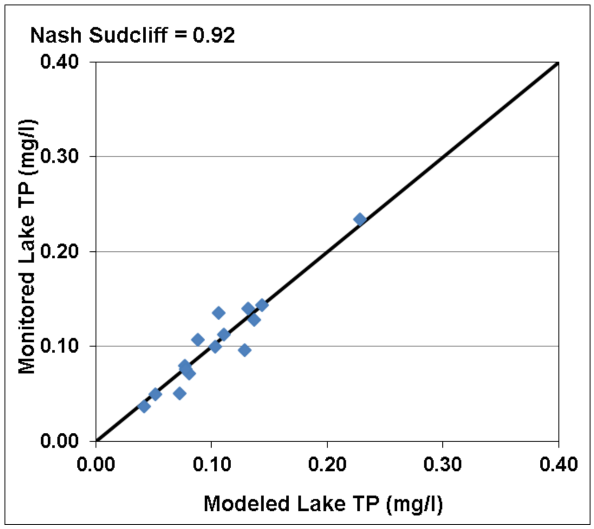


Figure B.4 Comparison between 2014 modeled and monitored volumetric average total phosphorus concentrations

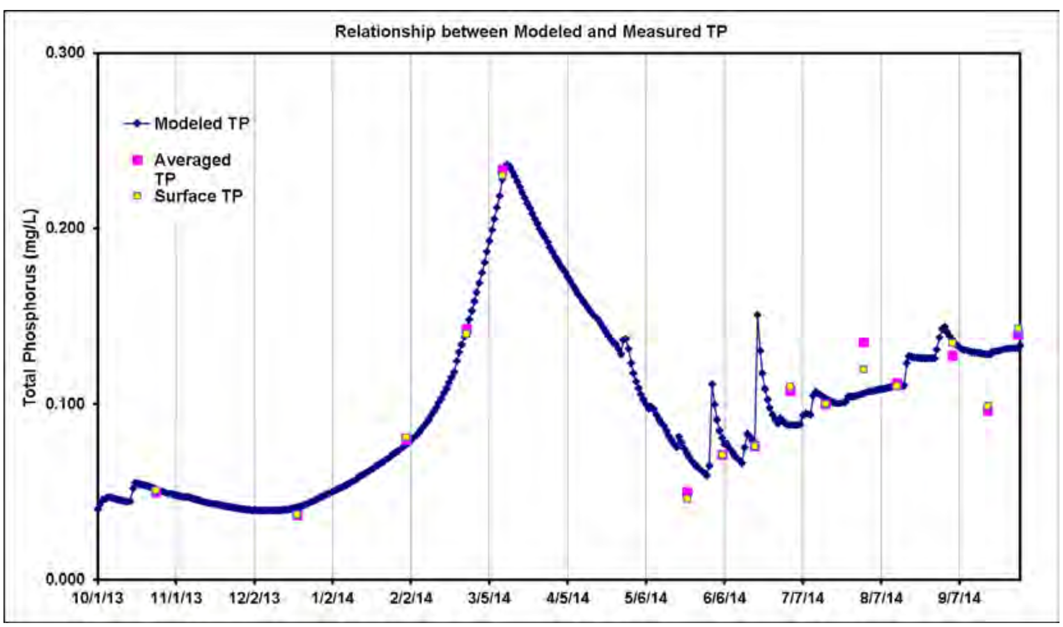


Figure B.5 Time series comparison between modeled and measured volumetric total phosphorus concentrations

Rice Marsh Lake was evaluated on a whole lake basis due to its polymictic nature. There is usually very little difference between the top and bottom total phosphorus sample concentration.

B.1.3.2 Lake Riley Model Calibration

The Lake Riley model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity. The final calibrated phosphorus settling velocity was set at 35 m/y or 0.0959 m/day during the ice off period and 15 m/y or 0.0411 m/day during the ice on period. The final internal loading rate 7.6 mg/m^2/day was based on microcosm experiments performed on sediment core samples in 2014. The model was calibrated using the volumetric average phosphorus concentrations in the epilimnion layer in 2014 and validated using 2010 data.

Surface water phosphorus concentration are required to determine if a lake is meeting or exceeding the phosphorus standard. Therefore, the volumetric average lake model was further divided into two completely mixed models representing the lake Epilimnion and Hypolimnion. The main change between the two approaches was the internal loading and groundwater sources were only applied to the hypolimnion and all other phosphorus sources (atmospheric, direct watershed, and Rice Marsh Lake inflow) were applied to the epilimnion. Mixing between the hypolimnion and the epilimnion were determined based on the change in temperature profile depths. The point of the maximum temperature gradient was used as the dividing depth between the two layers. Temperature profiles taken periodically (usually every two weeks) during open water periods were used to calculate the thermocline depth. As this depth moved up or down in the lake water was mixed between the two layers appropriately. Calibration was conducted for this model to ensure that the model was correctly predicting the epilimnetic total phosphorus concentrations. The parameters were then applied to the whole lake volumetric model to check that they produced a reasonable result in this analysis as well. Figure B.6 shows the results of the Nash Sudcliff statistical comparison between the 2014 modeled and measured volumetric averaged epilimnetic total phosphorus concentrations. Figure B.7 shows the comparison between the modeled, monitored surface and monitored epilimnetic volumetric averaged total phosphorus concentrations over the course of the 2014 water year.

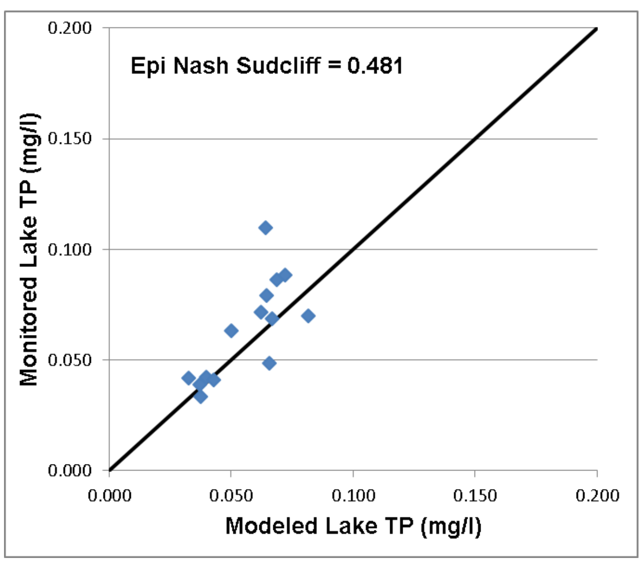


Figure B.6 Comparison between modeled volumetric average TP concentration and measured concentrations

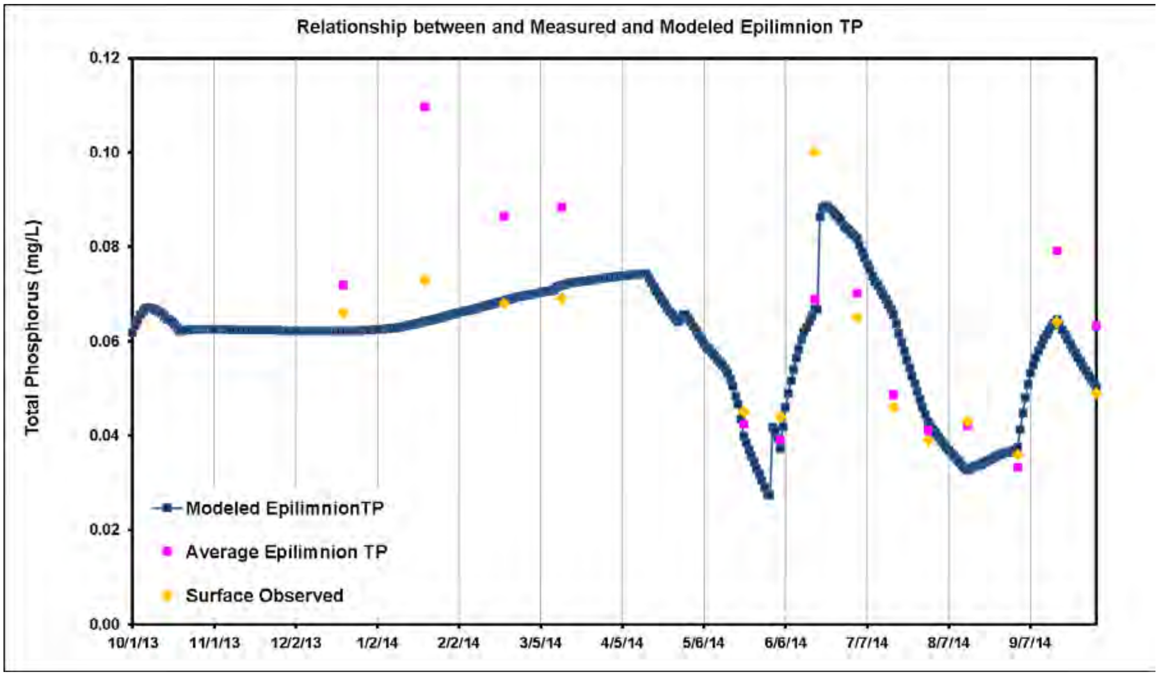


Figure B.7 **Comparison between modeled and measured surface water TP concentrations**

Appendix C

Planning Level Opinion of Costs

Rice Marsh and Riley Lakes Water Quality Improvements

Location: LR 14 - BMP1 (Spent Lime)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 20,840.00	$ 20,800.00
Erosion Control BMPs	L.S.	1	$ 5,380.00	$ 5,400.00
Clear and Grub	AC.	0.17	$ 15,000.00	$ 2,600.00
Remove Concrete Curb and Gutter	L.F.	40	$ 5.50	$ 200.00
Saw Cut Bituminous Pavement	L.F.	72	$ 11.50	$ 800.00
Remove Bituminous Pavement	S.Y.	80	$ 6.00	$ 500.00
Utility Conflicts	L.S.	1	$ 1,000.00	$ 1,000.00
Spent Lime Pit	L.S.	1	$ 185,276.00	$ 185,300.00
Diversion Structure	EACH	1	$ 3,800.00	$ 3,800.00
Storm Sewer Piping	L.S.	1	$ 3,300.00	$ 3,300.00
Outlet Control Structure	EACH	1	$ 3,800.00	$ 3,800.00
Replace Concrete Curb and Gutter	L.F.	40	$ 14.00	$ 600.00
Replace Bituminous Pavement and Base	S.Y.	80	$ 65.00	$ 5,200.00
Top Soil	C.Y.	89	$ 24.00	$ 2,100.00
Seeding	AC.	0.17	$ 4,500.00	$ 800.00
Traffic Control	L.S.	1	$ 2,000.00	$ 2,000.00
Restoration	L.S.	1	$ 1,500.00	$ 1,500.00
Subtotal				$ 239,700.00
Permitting (5%)				$ 12,000.00
Legal Agreements (10%)				$ 24,000.00
Planning, Engineering, Design and Construction Management (30%)				$ 71,900.00
Contingencies (30%)				$ 71,900.00
Total				**$ 419,500.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: LR 31 - BMP1 (Enlarge Pond)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 20,960.00	$ 21,000.00
Erosion Control BMPs	L.S.	1	$ 9,970.00	$ 10,000.00
Clear and Grub	L.S.	1	$ 1,000.00	$ 1,000.00
Control of Water	L.S.	1	$ 3,000.00	$ 3,000.00
Excavation and Disposal of Materials	C.Y.	8250	$ 21.00	$ 173,300.00
Pond Inlet Control Structure	EACH	1	$ 4,500.00	$ 4,500.00
Riprap	Ton	102	$ 94.00	$ 9,600.00
Outlet Control Structure	EACH	1	$ 7,845.00	$ 7,800.00
Grading	S.Y.	800	$ 2.00	$ 1,600.00
Top Soil	C.Y.	89	$ 24.00	$ 2,100.00
Seeding	AC.	0.16	$ 4,500.00	$ 700.00
Traffic Control	L.S.	1	$ 4,000.00	$ 4,000.00
Restoration	L.S.	1	$ 2,000.00	$ 2,000.00
Subtotal				$ 240,600.00
Permitting (5%)				$ 12,000.00
Legal Agreements (10%)				$ 24,100.00
Planning, Engineering, Design and Construction Management (30%)				$ 72,200.00
Contingencies (30%)				$ 72,200.00
Total				**$ 421,100.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: LR 31 - BMP2 (Iron Enhanced Sand Treatment System)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 44,120.00	$ 44,100.00
Erosion Control BMPs	L.S.	1	$ 7,352.00	$ 7,400.00
Clear and Grub	L.S.	1	$ 3,000.00	$ 3,000.00
Control of Water	L.S.	1	$ 3,500.00	$ 3,500.00
Excavation and Disposal of Materials	C.Y.	4199	$ 21.00	$ 88,200.00
Impervious Geotextile Liner	S.Y.	3149	$ 12.00	$ 37,800.00
Underdrain System (Pipe and Fittings)	L.S.	1	$ 13,440.00	$ 13,400.00
Drainage Rock	Ton	78	$ 40.00	$ 3,100.00
Clean Washed Sand	Ton	2284	$ 30.00	$ 68,500.00
Iron Aggregate	Ton	114.2	$ 1,700.00	$ 194,100.00
Storm Sewer Piping	L.S.	1	$ 3,780.00	$ 3,800.00
Flow Diversion Structure	EACH	1	$ 7,616.00	$ 7,600.00
Outlet Control Structure	EACH	1	$ 11,639.00	$ 11,600.00
Top Soil	C.Y.	79	$ 24.00	$ 1,900.00
Seeding	AC.	0.15	$ 4,500.00	$ 700.00
Traffic Control	L.S.	1	$ 2,500.00	$ 2,500.00
Restoration	L.S.	1	$ 1,500.00	$ 1,500.00
Subtotal				$ 492,700.00
Permitting (5%)				$ 24,600.00
Legal Agreements (10%)				$ 49,300.00
Planning, Engineering, Design and Construction Management (30%)				$ 147,800.00
Contingencies (30%)				$ 147,800.00
Total				**$ 862,200.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: LR 55 - BMP1 (Spent Lime Chamber)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 53,890.00	$ 53,900.00
Erosion Control BMPs	L.S.	1	$ 3,898.00	$ 3,900.00
Remove Concrete Curb and Gutter	L.F.	290	$ 5.50	$ 1,600.00
Saw Cut Bituminous Pavement	L.F.	68	$ 11.50	$ 800.00
Remove Bituminous Pavement	S.Y.	773	$ 6.00	$ 4,600.00
Utility Conflicts	L.S.	1	$ 4,000.00	$ 4,000.00
10' X 12' RC Box Culvert (Includes Excavation, Spent Lime & Drain Tile)	LN FT	300	$ 1,500.00	$ 450,000.00
Diversion Structure	EACH	2	$ 3,800.00	$ 7,600.00
Storm Sewer Piping	L.S.	1	$ 5,160.00	$ 5,200.00
Outlet Control Structure	EACH	1	$ 4,800.00	$ 4,800.00
Replace Concrete Curb and Gutter	L.F.	290	$ 14.00	$ 4,100.00
Replace Bituminous Pavement and Base	S.Y.	773	$ 65.00	$ 50,200.00
Traffic Control	L.S.	1	$ 4,500.00	$ 4,500.00
Restoration	L.S.	1	$ 1,500.00	$ 1,500.00
Subtotal				$ 596,700.00
Permitting (5%)				$ 29,800.00
Legal Agreements (10%)				$ 59,700.00
Planning, Engineering, Design and Construction Management (30%)				$ 179,000.00
Contingencies (30%)				$ 179,000.00
Total				**$ 1,044,200.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: LR 6 - BMP1 (Extended Detention)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 1,670.00	$ 1,700.00
Erosion Control BMPs	L.S.	1	$ 4,756.00	$ 4,800.00
Reconstruct/Modify Existing Outlet Control Structure	EACH	1	$ 15,000.00	$ 15,000.00
Top Soil	C.Y.	20	$ 24.00	$ 500.00
Seeding	AC.	0.05	$ 4,500.00	$ 200.00
Traffic Control	L.S.	1	$ 500.00	$ 500.00
Restoration	L.S.	1	$ 500.00	$ 500.00
Subtotal				$ 23,200.00
Permitting (5%)				$ 1,200.00
Legal Agreements (10%)				$ 2,300.00
Planning, Engineering, Design and Construction Management (30%)				$ 7,000.00
Contingencies (30%)				$ 7,000.00
Total				**$ 40,700.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: LR 76 - BMP1 (Spent Lime Chamber)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 29,910.00	$ 29,900.00
Erosion Control BMPs	L.S.	1	$ 3,700.00	$ 3,700.00
Remove Concrete Curb and Gutter	S.Y.	220	$ 5.50	$ 1,200.00
Saw Cut Bituminous Pavement	L.F.	88	$ 11.50	$ 1,000.00
Remove Bituminous Pavement	S.Y.	490	$ 6.00	$ 2,900.00
Utility Conflicts	L.S.	1	$ 5,000.00	$ 5,000.00
10' X 12' RC Box Culvert (Includes Excavation, Spent Lime & Drain Tile)	LN FT	150	$ 1,500.00	$ 225,000.00
Diversion Structure	EACH	1	$ 4,100.00	$ 4,100.00
Storm Sewer Piping	L.S.	1	$ 10,750.00	$ 10,800.00
Outlet Control Structure	EACH	1	$ 7,081.00	$ 7,100.00
Replace Concrete Curb and Gutter	L.F.	220	$ 14.00	$ 3,100.00
Replace Bituminous Pavement and Base	S.Y.	490	$ 65.00	$ 31,900.00
Traffic Control	L.S.	1	$ 3,500.00	$ 3,500.00
Restoration	L.S.	1	$ 3,500.00	$ 3,500.00
Subtotal				$ 332,700.00
Permitting (5%)				$ 16,600.00
Legal Agreements (10%)				$ 33,300.00
Planning, Engineering, Design and Construction Management (30%)				$ 99,800.00
Contingencies (30%)				$ 99,800.00
Total				**$ 582,200.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: LR 87 - BMP1 (Iron Enhanced Sand Filter)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 3,250.00	$ 3,300.00
Erosion Control BMPs	L.S.	1	$ 3,402.00	$ 3,400.00
Clear and Grub	AC.	0.06	$ 15,000.00	$ 900.00
Control of Water	L.S.	1	$ 500.00	$ 500.00
Excavation and Disposal of Materials	C.Y.	220	$ 21.00	$ 4,600.00
Impervious Geotextile Liner	S.Y.	147	$ 12.00	$ 1,800.00
Underdrain System (Pipe and Fittings)	L.S.	1	$ 1,680.00	$ 1,700.00
Drainage Rock	Ton	10	$ 40.00	$ 400.00
Clean Washed Sand	Ton	106	$ 30.00	$ 3,200.00
Iron Aggregate	Ton	5.3	$ 1,700.00	$ 9,000.00
Storm Sewer Piping	L.S.	1	$ 1,320.00	$ 1,300.00
Flow Diversion Structure	EACH	1	$ 3,500.00	$ 3,500.00
Outlet Control Structure	EACH	1	$ 3,500.00	$ 3,500.00
Top Soil	C.Y.	34	$ 24.00	$ 800.00
Seeding	AC.	0.06	$ 4,500.00	$ 300.00
Traffic Control	L.S.	1	$ 500.00	$ 500.00
Restoration	L.S.	1	$ 500.00	$ 500.00
Subtotal				$ 39,200.00
Permitting (5%)				$ 2,000.00
Legal Agreements (10%)				$ 3,900.00
Planning, Engineering, Design and Construction Management (30%)				$ 11,800.00
Contingencies (30%)				$ 11,800.00
Total				**$ 68,700.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: LR 88/90 - BMP1 (Iron Enhanced Sand Filter)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 17,270.00	$ 17,300.00
Erosion Control BMPs	L.S.	1	$ 6,368.00	$ 6,400.00
Clear and Grub	AC.	0.22	$ 15,000.00	$ 3,300.00
Control of Water	L.S.	1	$ 1,000.00	$ 1,000.00
Excavation and Disposal of Materials	C.Y.	1633	$ 21.00	$ 34,300.00
Impervious Geotextile Liner	S.Y.	1089	$ 12.00	$ 13,100.00
Underdrain System (Pipe and Fittings)	L.S.	1	$ 6,480.00	$ 6,500.00
Drainage Rock	Ton	38	$ 40.00	$ 1,500.00
Clean Washed Sand	Ton	762	$ 30.00	$ 22,900.00
Iron Aggregate	Ton	38.1	$ 1,700.00	$ 64,800.00
Storm Sewer Piping	L.S.	1	$ 2,150.00	$ 2,200.00
Flow Diversion Structure	EACH	2	$ 3,500.00	$ 7,000.00
Outlet Control Structure	EACH	1	$ 7,115.00	$ 7,100.00
Top Soil	C.Y.	120	$ 24.00	$ 2,900.00
Seeding	AC.	0.36	$ 4,500.00	$ 1,600.00
Traffic Control	L.S.	1	$ 2,500.00	$ 2,500.00
Restoration	L.S.	1	$ 2,000.00	$ 2,000.00
Subtotal				$ 196,400.00
Permitting (5%)				$ 9,800.00
Legal Agreements (10%)				$ 19,600.00
Planning, Engineering, Design and Construction Management (30%)				$ 58,900.00
Contingencies (30%)				$ 58,900.00
Total				**$ 343,600.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: LR 88 - BMP1 (Iron Enhanced Sand Filter)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 22,260.00	$ 22,300.00
Erosion Control BMPs	L.S.	1	$ 15,529.00	$ 15,500.00
Clear and Grub	L.S.	1	$ 2,000.00	$ 2,000.00
Control of Water	L.S.	1	$ 1,000.00	$ 1,000.00
Excavation and Disposal of Materials	C.Y.	1688	$ 21.00	$ 35,400.00
Impervious Geotextile Liner	S.Y.	1125	$ 12.00	$ 13,500.00
Underdrain System (Pipe and Fittings)	L.S.	1	$ 5,700.00	$ 5,700.00
Drainage Rock	Ton	33	$ 40.00	$ 1,300.00
Clean Washed Sand	Ton	777	$ 30.00	$ 23,300.00
Iron Aggregate	Ton	39	$ 1,700.00	$ 66,300.00
Direction Drill Storm Sewer Piping (12")	L.F.	546	$ 70.00	$ 38,200.00
Storm Sewer Piping	L.S.	1	$ 8,318.00	$ 8,300.00
48" Dia. Manhole	EACH	2	$ 2,600.00	$ 5,200.00
Flow Diversion Structure	EACH	1	$ 5,956.00	$ 6,000.00
Outlet Control Structure	EACH	1	$ 3,800.00	$ 3,800.00
Top Soil	C.Y.	249	$ 24.00	$ 6,000.00
Seeding	AC.	0.46	$ 4,500.00	$ 2,100.00
Traffic Control	L.S.	1	$ 1,500.00	$ 1,500.00
Restoration	L.S.	1	$ 3,000.00	$ 3,000.00
Subtotal				$ 260,400.00
Permitting (5%)				$ 13,000.00
Legal Agreements (10%)				$ 26,000.00
Planning, Engineering, Design and Construction Management (30%)				$ 78,100.00
Contingencies (30%)				$ 78,100.00
Total				**$ 455,600.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: LR 90 - BMP1 (Iron Enhanced Sand Filter)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 18,970.00	$ 19,000.00
Erosion Control BMPs	L.S.	1	$ 8,368.00	$ 8,400.00
Clear and Grub	AC.	0.22	$ 15,000.00	$ 3,300.00
Control of Water	L.S.	1	$ 1,000.00	$ 1,000.00
Excavation and Disposal of Materials	C.Y.	1633	$ 21.00	$ 34,300.00
Impervious Geotextile Liner	S.Y.	1089	$ 12.00	$ 13,100.00
Underdrain System (Pipe and Fittings)	L.S.	1	$ 6,480.00	$ 6,500.00
Drainage Rock	Ton	38	$ 40.00	$ 1,500.00
Clean Washed Sand	Ton	762	$ 30.00	$ 22,900.00
Iron Aggregate	Ton	38.1	$ 1,700.00	$ 64,800.00
Direction Drill Storm Sewer Piping (12")	L.F.	255	$ 70.00	$ 17,900.00
Storm Sewer Piping	L.S.	1	$ 2,150.00	$ 2,200.00
48" Dia. Manhole	EACH	1	$ 2,600.00	$ 2,600.00
Flow Diversion Structure	EACH	1	$ 3,500.00	$ 3,500.00
Outlet Control Structure	EACH	1	$ 7,115.00	$ 7,100.00
Top Soil	C.Y.	120	$ 24.00	$ 2,900.00
Seeding	AC.	0.36	$ 4,500.00	$ 1,600.00
Traffic Control	L.S.	1	$ 2,500.00	$ 2,500.00
Restoration	L.S.	1	$ 2,000.00	$ 2,000.00
Subtotal				$ 217,100.00
Permitting (5%)				$ 10,900.00
Legal Agreements (10%)				$ 21,700.00
Planning, Engineering, Design and Construction Management (30%)				$ 65,100.00
Contingencies (30%)				$ 65,100.00
Total				**$ 379,900.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location:LR CR7f - BMP1 (Iron Enhanced Sand Filter)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 6,530.00	$ 6,500.00
Erosion Control BMPs	L.S.	1	$ 4,505.00	$ 4,500.00
Clear and Grub	AC.	0.14	$ 15,000.00	$ 2,100.00
Excavation and Disposal of Materials	C.Y.	456	$ 21.00	$ 9,600.00
Impervious Geotextile Liner	S.Y.	391	$ 12.00	$ 4,700.00
Underdrain System (Pipe and Fittings)	L.S.	1	$ 2,640.00	$ 2,600.00
Drainage Rock	Ton	15	$ 40.00	$ 600.00
Clean Washed Sand	Ton	284	$ 30.00	$ 8,500.00
Iron Aggregate	Ton	14.2	$ 1,700.00	$ 24,100.00
Storm Sewer Piping	L.S.	1	$ 1,650.00	$ 1,700.00
Flow Diversion Structure	EACH	1	$ 3,500.00	$ 3,500.00
Outlet Control Structure	EACH	1	$ 3,500.00	$ 3,500.00
Top Soil	C.Y.	73	$ 24.00	$ 1,800.00
Seeding	AC.	0.14	$ 4,500.00	$ 600.00
Traffic Control	L.S.	1	$ 1,500.00	$ 1,500.00
Restoration	L.S.	1	$ 500.00	$ 500.00
Subtotal				$ 76,300.00
Permitting (5%)				$ 3,800.00
Legal Agreements (10%)				$ 7,600.00
Planning, Engineering, Design and Construction Management (30%)				$ 22,900.00
Contingencies (30%)				$ 22,900.00
Total				**$ 133,500.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: LR CR7g- BMP1 (Spent Lime Chamber)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 20,260.00	$ 20,300.00
Erosion Control BMPs	L.S.	1	$ 2,520.00	$ 2,500.00
Remove Concrete Curb and Gutter	S.Y.	160	$ 5.50	$ 900.00
Saw Cut Bituminous Pavement	L.F.	52	$ 11.50	$ 600.00
Remove Bituminous Pavement	S.Y.	462	$ 6.00	$ 2,800.00
Utility Conflicts	L.S.	1	$ 3,000.00	$ 3,000.00
10' X 12' RC Box Culvert (Includes Excavation, Spent Lime & Drain Tile)	LN FT	100	$ 1,500.00	$ 150,000.00
Diversion Structure	EACH	1	$ 3,800.00	$ 3,800.00
Storm Sewer Piping	L.S.	1	$ 1,980.00	$ 2,000.00
Outlet Control Structure	EACH	1	$ 3,800.00	$ 3,800.00
Replace Concrete Curb and Gutter	L.F.	160	$ 14.00	$ 2,200.00
Replace Bituminous Pavement and Base	S.Y.	462	$ 65.00	$ 30,000.00
Traffic Control	L.S.	1	$ 2,500.00	$ 2,500.00
Restoration	L.S.	1	$ 1,000.00	$ 1,000.00
Subtotal				$ 225,400.00
Permitting (5%)				$ 11,300.00
Legal Agreements (10%)				$ 22,500.00
Planning, Engineering, Design and Construction Management (30%)				$ 67,600.00
Contingencies (30%)				$ 67,600.00
Total				**$ 394,400.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: LR CR7h- BMP1 (Spent Lime Chamber)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 16,570.00	$ 16,600.00
Erosion Control BMPs	L.S.	1	$ 4,396.00	$ 4,400.00
Clear and Grub	L.S.	1	$ 1,000.00	$ 1,000.00
10' X 12' RC Box Culvert (Includes Excavation, Spent Lime & Drain Tile)	LN FT	100	$ 1,500.00	$ 150,000.00
Diversion Structure	EACH	1	$ 3,800.00	$ 3,800.00
Storm Sewer Piping	L.S.	1	$ 3,960.00	$ 4,000.00
Outlet Control Structure	EACH	1	$ 3,800.00	$ 3,800.00
Top Soil	C.Y.	48	$ 24.00	$ 1,200.00
Seeding	AC.	0.09	$ 4,500.00	$ 400.00
Traffic Control	L.S.	1	$ 500.00	$ 500.00
Restoration	L.S.	1	$ 1,000.00	$ 1,000.00
Subtotal				$ 186,700.00
Permitting (5%)				$ 9,300.00
Legal Agreements (10%)				$ 18,700.00
Planning, Engineering, Design and Construction Management (30%)				$ 56,000.00
Contingencies (30%)				$ 56,000.00
Total				**$ 326,700.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: LR CR7j - BMP1 (Storm Sewer Reroute)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 2,600.00	$ 2,600.00
Erosion Control BMPs	L.S.	1	$ 3,818.00	$ 3,800.00
Clear and Grub	AC.	0.05	$ 15,000.00	$ 800.00
Remove Concrete Curb and Gutter	S.Y.	40	$ 5.50	$ 200.00
Saw Cut Bituminous Pavement	L.F.	48	$ 11.50	$ 600.00
Remove Bituminous Pavement	S.Y.	54	$ 6.00	$ 300.00
Utility Conflicts	L.S.	1	$ 700.00	$ 700.00
18" RCP Cl II	LN FT	80	$ 43.00	$ 3,400.00
18" RCP Flared End Section w/Trash Rack	EACH	1	$ 1,380.00	$ 1,400.00
Riprap	TON	29	$ 94.00	$ 2,700.00
Standard Catch Basin	EACH	2	$ 3,200.00	$ 6,400.00
Replace Concrete Curb and Gutter	L.F.	40	$ 14.00	$ 600.00
Replace Bituminous Pavement and Base	S.Y.	54	$ 65.00	$ 3,500.00
Top Soil	C.Y.	26	$ 24.00	$ 600.00
Seeding	AC.	0.05	$ 1,500.00	$ 100.00
Traffic Control	L.S.	1	$ 4,500.00	$ 4,500.00
Restoration	L.S.	1	$ 1,000.00	$ 1,000.00
Subtotal				$ 33,200.00
Permitting (5%)				$ 1,700.00
Legal Agreements (10%)				$ 3,300.00
Planning, Engineering, Design and Construction Management (30%)				$ 10,000.00
Contingencies (30%)				$ 10,000.00
Total				**$ 58,200.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: LR CR7i - BMP1 (Infiltration Basin)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 3,490.00	$ 3,500.00
Erosion Control BMPs	L.S.	1	$ 4,822.00	$ 4,800.00
Clear and Grub	AC.	0.1	$ 15,000.00	$ 1,500.00
Excavation and Disposal of Materials	C.Y.	400	$ 21.00	$ 8,400.00
Geotextile Filter Material	S.Y.	267	$ 8.00	$ 2,100.00
Distribution System (Pipe and Fittings)	L.S.	1	$ 1,680.00	$ 1,700.00
Drainage Rock	Ton	6	$ 40.00	$ 200.00
Clean Washed Sand	Ton	387	$ 30.00	$ 11,600.00
Storm Sewer Piping	L.S.	1	$ 1,320.00	$ 1,300.00
Diversion Structure	EACH	1	$ 3,800.00	$ 3,800.00
Top Soil	C.Y.	56	$ 24.00	$ 1,300.00
Seeding	AC.	0.1	$ 4,500.00	$ 500.00
Traffic Control	L.S.	1	$ 1,500.00	$ 1,500.00
Restoration	L.S.	1	$ 1,000.00	$ 1,000.00
Subtotal				$ 43,200.00
Permitting (5%)				$ 2,200.00
Legal Agreements (10%)				$ 4,300.00
Planning, Engineering, Design and Construction Management (30%)				$ 13,000.00
Contingencies (30%)				$ 13,000.00
Total				**$ 75,700.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: RM 10 - BMP1 (Spent Lime Retrofit)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 20,920.00	$ 20,900.00
Erosion Control BMPs	L.S.	1	$ 6,780.00	$ 6,800.00
Clear and Grub	L.S.	0.41	$ 15,000.00	$ 6,200.00
Control of Water	L.S.	1	$ 1,500.00	$ 1,500.00
Modifided Spent Lime Chamber (Includes Excavation, Spent Lime & Drain Tile)	LN FT	220	$ 750.00	$ 165,000.00
Diversion Structure	EACH	2	$ 4,400.00	$ 8,800.00
Storm Sewer Piping	L.S.	1	$ 3,225.00	$ 3,200.00
Outlet Control Structure	EACH	1	$ 6,750.00	$ 6,800.00
Grading	S.Y.	1760	$ 2.00	$ 3,500.00
Top Soil	C.Y.	140	$ 24.00	$ 3,400.00
Seeding	AC.	0.34	$ 4,500.00	$ 1,500.00
Trees	EACH	15	$ 350.00	$ 5,300.00
Traffic Control	L.S.	1	$ 2,000.00	$ 2,000.00
Restoration	L.S.	1	$ 2,000.00	$ 2,000.00
Subtotal				$ 236,900.00
Permitting (5%)				$ 11,800.00
Legal Agreements (10%)				$ 23,700.00
Planning, Engineering, Design and Construction Management (30%)				$ 71,100.00
Contingencies (30%)				$ 71,100.00
Total				**$ 414,600.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: RM 10 - BMP2 (Iron Enhanced Sand Filter)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 19,450.00	$ 19,500.00
Erosion Control BMPs	L.S.	1	$ 6,780.00	$ 6,800.00
Clear and Grub	AC.	0.41	$ 15,000.00	$ 6,200.00
Control of Water	L.S.	1	$ 1,500.00	$ 1,500.00
Excavation and Disposal of Materials	C.Y.	1630	$ 21.00	$ 34,200.00
Impervious Geotextile Liner	S.Y.	1222	$ 12.00	$ 14,700.00
Underdrain System (Pipe and Fittings)	L.S.	1	$ 10,320.00	$ 10,300.00
Drainage Rock	Ton	60	$ 40.00	$ 2,400.00
Clean Washed Sand	Ton	886	$ 30.00	$ 26,600.00
Iron Aggregate	Ton	44.3	$ 1,700.00	$ 75,300.00
Storm Sewer Piping	L.S.	1	$ 5,550.00	$ 5,600.00
Flow Diversion Structure	EACH	1	$ 3,800.00	$ 3,800.00
Outlet Control Structure	EACH	1	$ 7,633.00	$ 7,600.00
Top Soil	C.Y.	86	$ 24.00	$ 2,100.00
Seeding	AC.	0.16	$ 4,500.00	$ 700.00
Traffic Control	L.S.	1	$ 1,500.00	$ 1,500.00
Restoration	L.S.	1	$ 2,000.00	$ 2,000.00
Subtotal				$ 220,800.00
Permitting (5%)				$ 11,000.00
Legal Agreements (10%)				$ 22,100.00
Planning, Engineering, Design and Construction Management (30%)				$ 66,200.00
Contingencies (30%)				$ 66,200.00
Total				**$ 386,300.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: RM 12a - BMP1 & 2 (Spent Lime Chambers)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 58,150.00	$ 58,200.00
Erosion Control BMPs	L.S.	1	$ 7,710.00	$ 7,700.00
Clear and Grub	L.S.	1	$ 1,000.00	$ 1,000.00
Remove and Replace Bituminous Trail	S.Y.	200	$ 40.00	$ 8,000.00
Control of Water	L.S.	1	$ 1,500.00	$ 1,500.00
10' X 12' RC Box Culvert (Includes Excavation, Spent Lime & Drain Tile)	LN FT	360	$ 1,500.00	$ 540,000.00
Diversion Structure	EACH	1	$ 7,450.00	$ 7,500.00
Storm Sewer Piping	L.S.	1	$ 3,456.00	$ 3,500.00
Outlet Control Structure	EACH	1	$ 6,124.00	$ 6,100.00
Grading	S.Y.	1400	$ 2.00	$ 2,800.00
Top Soil	C.Y.	155	$ 24.00	$ 3,700.00
Seeding	AC.	0.29	$ 4,500.00	$ 1,300.00
Trees	EACH	6	$ 350.00	$ 2,100.00
Traffic Control	L.S.	1	$ 2,000.00	$ 2,000.00
Restoration	L.S.	1	$ 2,000.00	$ 2,000.00
Subtotal				$ 647,400.00
Permitting (5%)				$ 32,400.00
Legal Agreements (10%)				$ 64,700.00
Planning, Engineering, Design and Construction Management (30%)				$ 194,200.00
Contingencies (30%)				$ 194,200.00
Total				**$ 1,132,900.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: RM 12a - BMP3 (Iron Enhanced Sand Filter)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 14,590.00	$ 14,600.00
Erosion Control BMPs	L.S.	1	$ 8,368.00	$ 8,400.00
Clear and Grub	L.S.	1	$ 500.00	$ 500.00
Control of Water	L.S.	1	$ 1,000.00	$ 1,000.00
Remove existing Bituminous Trail	S.Y.	444	$ 5.00	$ 2,200.00
Excavation and Disposal of Materials	C.Y.	917	$ 21.00	$ 19,300.00
Impervious Geotextile Liner	S.Y.	614	$ 12.00	$ 7,400.00
Underdrain System (Pipe and Fittings)	L.S.	1	$ 4,800.00	$ 4,800.00
Drainage Rock	Ton	28	$ 40.00	$ 1,100.00
Clean Washed Sand	Ton	444	$ 30.00	$ 13,300.00
Iron Aggregate	Ton	22.2	$ 1,700.00	$ 37,700.00
Storm Sewer Piping	L.S.	1	$ 13,330.00	$ 13,300.00
48" Dia. Manhole	EACH	1	$ 2,600.00	$ 2,600.00
Flow Diversion Structure	EACH	1	$ 8,685.00	$ 8,700.00
Outlet Control Structure	EACH	1	$ 5,581.00	$ 5,600.00
Replace Bituminous trail	S.Y.	444	$ 45.00	$ 20,000.00
Top Soil	C.Y.	160	$ 24.00	$ 3,800.00
Seeding	AC.	0.46	$ 4,500.00	$ 2,100.00
Traffic Control	L.S.	1	$ 500.00	$ 500.00
Restoration	L.S.	1	$ 2,000.00	$ 2,000.00
Subtotal				$ 168,900.00
Permitting (5%)				$ 8,400.00
Legal Agreements (10%)				$ 16,900.00
Planning, Engineering, Design and Construction Management (30%)				$ 50,700.00
Contingencies (30%)				$ 50,700.00
Total				**$ 295,600.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: RM 20 - BMP1 (Pond Expansion)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 6,050.00	$ 6,100.00
Erosion Control BMPs	L.S.	1	$ 5,214.00	$ 5,200.00
Clear and Grub	AC.	0.08	$ 15,000.00	$ 1,200.00
Control of Water	L.S.	1	$ 2,500.00	$ 2,500.00
Excavation and Disposal of Materials	C.Y.	1330	$ 21.00	$ 27,900.00
Outlet Control Structure	EACH	1	$ 13,520.00	$ 13,500.00
Grading	S.Y.	667	$ 2.00	$ 1,300.00
Top Soil	C.Y.	74	$ 24.00	$ 1,800.00
Seeding	AC.	0.13	$ 4,500.00	$ 600.00
Trees	EACH	10	$ 350.00	$ 3,500.00
Shrubs	EACH	30	$ 40.00	$ 1,200.00
Traffic Control	L.S.	1	$ 2,000.00	$ 2,000.00
Restoration	L.S.	1	$ 5,000.00	$ 5,000.00
Subtotal				$ 71,800.00
Permitting (5%)				$ 3,600.00
Legal Agreements (10%)				$ 7,200.00
Planning, Engineering, Design and Construction Management (30%)				$ 21,500.00
Contingencies (20%)				$ 14,400.00
Total				**$ 118,500.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: RM 20 - BMP2 (Iron Enhanced Sand Treatment System)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 7,040.00	$ 7,000.00
Erosion Control BMPs	L.S.	1	$ 4,000.00	$ 4,000.00
Clear and Grub	AC.	0.09	$ 15,000.00	$ 1,400.00
Protection of Bituminous Trail	L.S.	1	$ 1,500.00	$ 1,500.00
Control of Water	L.S.	1	$ 2,000.00	$ 2,000.00
Excavation and Disposal of Materials	C.Y.	400	$ 21.00	$ 8,400.00
Impervious Geotextile Liner	S.Y.	267	$ 12.00	$ 3,200.00
Underdrain System (Pipe and Fittings)	L.S.	1	$ 5,040.00	$ 5,000.00
Drainage Rock	Ton	28	$ 40.00	$ 1,100.00
Clean Washed Sand	Ton	193	$ 30.00	$ 5,800.00
Iron Aggregate	Ton	12.9	$ 1,700.00	$ 21,900.00
Storm Sewer Piping	L.S.	1	$ 2,296.00	$ 2,300.00
Flow Diversion Structure	EACH	1	$ 6,680.00	$ 6,700.00
Outlet Control Structure	EACH	1	$ 3,450.00	$ 3,500.00
Top Soil	C.Y.	50	$ 24.00	$ 1,200.00
Seeding	AC.	0.09	$ 4,500.00	$ 400.00
Traffic Control	L.S.	1	$ 1,000.00	$ 1,000.00
Restoration	L.S.	1	$ 5,000.00	$ 5,000.00
Subtotal				$ 81,400.00
Permitting (5%)				$ 4,100.00
Legal Agreements (10%)				$ 8,100.00
Planning, Engineering, Design and Construction Management (30%)				$ 24,400.00
Contingencies (20%)				$ 16,300.00
Total				**$ 134,300.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: RM_25a-BMP1 (Large Pond)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 17,860.00	$ 17,900.00
Erosion Control BMPs	L.S.	1	$ 9,100.00	$ 9,100.00
Clear and Grub	AC.	0.76	$ 15,000.00	$ 11,400.00
Control of Water	L.S.	1	$ 4,000.00	$ 4,000.00
Excavation and Disposal of Materials	C.Y.	5009	$ 21.00	$ 105,200.00
42" RCP Flared End Section	EACH	1	$ 5,138.00	$ 5,100.00
24" RCP Flared End Section	EACH	1	$ 2,235.00	$ 2,200.00
12" RCP Flared End Section	Ton	1	$ 1,060.00	$ 1,100.00
Riprap	Ton	111	$ 94.00	$ 10,400.00
Outlet Control Structure	EACH	1	$ 12,485.00	$ 12,500.00
Grading	S.Y.	1711	$ 2.00	$ 3,400.00
Top Soil	C.Y.	188	$ 24.00	$ 4,500.00
Seeding	AC.	0.36	$ 4,500.00	$ 1,600.00
Trees	EACH	15	$ 350.00	$ 5,300.00
Shrubs	EACH	60	$ 40.00	$ 2,400.00
Traffic Control	L.S.	1	$ 4,500.00	$ 4,500.00
Restoration	L.S.	1	$ 5,000.00	$ 5,000.00
Subtotal				$ 205,600.00
Permitting (5%)				$ 10,300.00
Legal Agreements (10%)				$ 20,600.00
Planning, Engineering, Design and Construction Management (30%)				$ 61,700.00
Contingencies (30%)				$ 61,700.00
Total				**$ 359,900.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: RM 31 - BMP1 (Pond Clean Out)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 3,740.00	$ 3,700.00
Erosion Control BMPs	L.S.	1	$ 3,557.00	$ 3,600.00
Clear and Grub	L.S.	1	$ 1,000.00	$ 1,000.00
Control of Water	L.S.	1	$ 2,000.00	$ 2,000.00
Excavation and Disposal of Materials	C.Y.	1200	$ 21.00	$ 25,200.00
Outlet Control Structure	EACH	1	$ 6,124.00	$ 6,100.00
Grading	S.Y.	367	$ 2.00	$ 700.00
Top Soil	C.Y.	40	$ 24.00	$ 1,000.00
Seeding	AC.	0.08	$ 4,500.00	$ 400.00
Traffic Control	L.S.	1	$ 500.00	$ 500.00
Restoration	L.S.	1	$ 500.00	$ 500.00
Subtotal				$ 44,700.00
Permitting (5%)				$ 2,200.00
Legal Agreements (10%)				$ 4,500.00
Planning, Engineering, Design and Construction Management (30%)				$ 13,400.00
Contingencies (30%)				$ 13,400.00
Total				**$ 78,200.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: RM 32N - BMP1, 2, 3 (Spent Lime Chambers)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 98,900.00	$ 98,900.00
Erosion Control BMPs	L.S.	1	$ 8,711.00	$ 8,700.00
Clear and Grub	L.S.	1	$ 1,500.00	$ 1,500.00
Control of Water	L.S.	1	$ 1,500.00	$ 1,500.00
10' X 12' RC Box Culvert (Includes Excavation, Spent Lime & Drain Tile)	LN FT	600	$ 1,500.00	$ 900,000.00
Diversion Structure	EACH	1	$ 7,450.00	$ 7,500.00
Storm Sewer Piping	L.S.	1	$ 20,250.00	$ 20,300.00
Outlet Control Structure	EACH	1	$ 6,124.00	$ 6,100.00
60" Manhole	EACH	1	$ 4,630.00	$ 4,600.00
Remove and Replace Basketball Court	L.S.	1	$ 30,000.00	$ 30,000.00
Grading	S.Y.	2356	$ 2.00	$ 4,700.00
Top Soil	C.Y.	250	$ 24.00	$ 6,000.00
Seeding	AC.	0.5	$ 4,500.00	$ 2,300.00
Traffic Control	L.S.	1	$ 1,500.00	$ 1,500.00
Restoration	L.S.	1	$ 3,000.00	$ 3,000.00
Subtotal				$ 1,096,600.00
Permitting (5%)				$ 54,800.00
Legal Agreements (10%)				$ 109,700.00
Planning, Engineering, Design and Construction Management (30%)				$ 329,000.00
Contingencies (20%)				$ 219,300.00
Total				**$ 1,809,400.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: RM 32W - BMP1 & 2 (Spent Lime Chambers)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 63,860.00	$ 63,900.00
Erosion Control BMPs	L.S.	1	$ 8,164.00	$ 8,200.00
Clear and Grub	AC.	0.34	$ 15,000.00	$ 5,100.00
Control of Water	L.S.	1	$ 1,000.00	$ 1,000.00
10' X 12' RC Box Culvert (Includes Excavation, Spent Lime & Drain Tile)	LN FT	400	$ 1,500.00	$ 600,000.00
Diversion Structure	EACH	1	$ 7,450.00	$ 7,500.00
Storm Sewer Piping	L.S.	1	$ 5,160.00	$ 5,200.00
Outlet Control Structure	EACH	1	$ 6,124.00	$ 6,100.00
Grading	S.Y.	1667	$ 2.00	$ 3,300.00
Top Soil	C.Y.	183	$ 24.00	$ 4,400.00
Seeding	AC.	0.34	$ 4,500.00	$ 1,500.00
Traffic Control	L.S.	1	$ 1,500.00	$ 1,500.00
Restoration	L.S.	1	$ 3,000.00	$ 3,000.00
Subtotal				$ 710,700.00
Permitting (5%)				$ 35,500.00
Legal Agreements (10%)				$ 71,100.00
Planning, Engineering, Design and Construction Management (30%)				$ 213,200.00
Contingencies (30%)				$ 213,200.00
Total				**$ 1,243,700.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: RM 6 - BMP1 (Iron Enhanced Sand Filter Bench)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 7,070.00	$ 7,100.00
Erosion Control BMPs	L.S.	1	$ 4,120.00	$ 4,100.00
Clear and Grub	L.S.	1	$ 1,000.00	$ 1,000.00
Excavation and Disposal of Materials	C.Y.	664	$ 21.00	$ 13,900.00
Impervious Geotextile Liner	S.Y.	400	$ 12.00	$ 4,800.00
Underdrain System (Pipe and Fittings)	L.S.	1	$ 3,360.00	$ 3,400.00
Drainage Rock	Ton	20	$ 40.00	$ 800.00
Clean Washed Sand	Ton	290	$ 30.00	$ 8,700.00
Iron Aggregate	Ton	14.5	$ 1,700.00	$ 24,700.00
Storm Sewer Piping	L.S.	1	$ 5,940.00	$ 5,900.00
Outlet Control Structure	EACH	1	$ 3,500.00	$ 3,500.00
Top Soil	C.Y.	61	$ 24.00	$ 1,500.00
Seeding	AC.	0.11	$ 4,500.00	$ 500.00
Traffic Control	L.S.	1	$ 1,500.00	$ 1,500.00
Restoration	L.S.	1	$ 500.00	$ 500.00
Subtotal				$ 81,900.00
Permitting (5%)				$ 4,100.00
Legal Agreements (10%)				$ 8,200.00
Planning, Engineering, Design and Construction Management (30%)				$ 24,600.00
Contingencies (30%)				$ 24,600.00
Total				**$ 143,400.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: RM 6 - BMP2 (Iron Enhanced Sand Filter Bench)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 7,420.00	$ 7,400.00
Erosion Control BMPs	L.S.	1	$ 4,220.00	$ 4,200.00
Clear and Grub	AC.	0.12	$ 15,000.00	$ 1,800.00
Excavation and Disposal of Materials	C.Y.	831	$ 21.00	$ 17,500.00
Impervious Geotextile Liner	S.Y.	444	$ 12.00	$ 5,300.00
Underdrain System (Pipe and Fittings)	L.S.	1	$ 2,880.00	$ 2,900.00
Drainage Rock	Ton	17	$ 40.00	$ 700.00
Clean Washed Sand	Ton	322	$ 30.00	$ 9,700.00
Iron Aggregate	Ton	16.1	$ 1,700.00	$ 27,400.00
Storm Sewer Piping	L.S.	1	$ 1,320.00	$ 1,300.00
Outlet Control Structure	EACH	1	$ 3,500.00	$ 3,500.00
Top Soil	C.Y.	67	$ 24.00	$ 1,600.00
Seeding	AC.	0.12	$ 4,500.00	$ 500.00
Traffic Control	L.S.	1	$ 1,500.00	$ 1,500.00
Restoration	L.S.	1	$ 500.00	$ 500.00
Subtotal				$ 85,800.00
Permitting (5%)				$ 4,300.00
Legal Agreements (10%)				$ 8,600.00
Planning, Engineering, Design and Construction Management (30%)				$ 25,700.00
Contingencies (30%)				$ 25,700.00
Total				**$ 150,100.00**

Rice Marsh and Riley Lakes Water Quality Improvements

Location: RM CR44h - BMP1 (Raise Existing Berm to Increase Detention and Iron Enhanced Sand Treatment System)

Item	Unit	Estimated Quantity	Unit Price	Extension
Mobilization (10%)	L.S.	1	$ 9,880.00	$ 9,900.00
Erosion Control BMPs	L.S.	1	$ 5,700.00	$ 5,700.00
Clear and Grub	AC.	0.23	$ 15,000.00	$ 3,500.00
Protection of Bituminous Trail	L.S.	1	$ 2,500.00	$ 2,500.00
Control of Water	L.S.	1	$ 3,000.00	$ 3,000.00
Site Access	L.S.	1	$ 3,000.00	$ 3,000.00
Raise Existing Berm (Common Borrow)	C.Y.	75	$ 25.00	$ 1,900.00
Excavation and Disposal of Materials	C.Y.	648	$ 21.00	$ 13,600.00
Impervious Geotextile Liner	S.Y.	556	$ 12.00	$ 6,700.00
Underdrain System (Pipe and Fittings)	L.S.	1	$ 5,280.00	$ 5,300.00
Drainage Rock	Ton	31	$ 40.00	$ 1,200.00
Clean Washed Sand	Ton	403	$ 30.00	$ 12,100.00
Iron Aggregate	Ton	12.9	$ 1,700.00	$ 21,900.00
Storm Sewer Piping	L.S.	1	$ 1,260.00	$ 1,300.00
Flow Diversion Structure	EACH	1	$ 6,680.00	$ 6,700.00
Outlet Control Structure	EACH	1	$ 3,450.00	$ 3,500.00
Top Soil	C.Y.	126	$ 24.00	$ 3,000.00
Seeding	AC.	0.36	$ 4,500.00	$ 1,600.00
Traffic Control	L.S.	1	$ 2,000.00	$ 2,000.00
Restoration	L.S.	1	$ 6,000.00	$ 6,000.00
Subtotal				$ 114,400.00
Permitting (5%)				$ 5,700.00
Legal Agreements (10%)				$ 11,400.00
Planning, Engineering, Design and Construction Management (30%)				$ 34,300.00
Contingencies (30%)				$ 34,300.00
Total				**$ 200,100.00**

Preliminary Cost Estimate -- Construct a Alum Treatment Plant at Near Riley Creek inlet to Lake Riley (5 cfs)

Item	Unit	Estimated Quantity	Unit Price	Extention
Mobilization (10%)	L.S.	1	$90,000	$90,000
Building, Injection System, Alum Storage, Controls	L.S.	1	$250,000	$250,000
Monitoring System	L.S.	1	$20,000	$20,000
Piping, Diversions, Weirs and Stop Logs	L.S.	1	$350,000	$350,000
Pond Excavation	C.Y.	7,000	$30	$210,000
Pond Restoration (assumes 5' Avg Depth)	Ac.	1.0	$10,000	$10,276
Bench Testing and Dosing	L.S.	1	$60,000	$60,000
Subtotal				$990,276
Permitting (5%)				$ 49,500
Legal Agreements (5%)				$ 49,500
Planning, Engineering, Design and Construction Management (30%)				$ 297,100
Contingencies (30%)				$ 297,100
Total				$1,683,476