Lake Lucy and Lake Ann
Use Attainability Analysis Update

Prepared for: Riley-Purgatory-Bluff Creek Watershed District

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Executive Summary

Prepared for the Riley-Purgatory-Bluff Creek Watershed District
September 2013

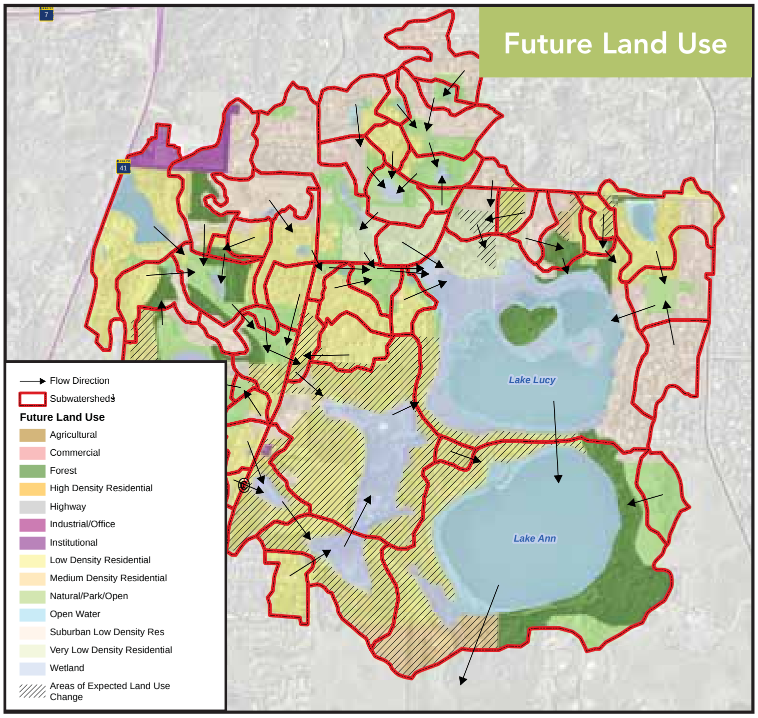
Introduction

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.

Earlier this year, the Riley-Purgatory-Bluff Creek Watershed District (RPBCWD) began updating the original 1999 Lake Lucy and Lake Ann UAA in an effort to address current water quality issues. The UAA includes a water quality analysis and prescription of protective measures for Lake Lucy, Lake Ann, 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.

Study Purpose and Goals

The goal of the study summarized in this report is to assess the water quality in Lake Lucy and Lake Ann 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 current Lake Lucy watershed consists predominantly of low-density residential land use and contains an extensive network of natural wetlands and constructed stormwater ponds. The existing Lake Ann watershed is primarily undeveloped forest or natural area. Roughly 230 acres of the currently natural area in the Lake Lucy and Ann watersheds will likely be developed into residential land use in the future, which has the potential to degrade the water quality in both lakes.

Water Quality Findings, Problems, and Causes

Water quality in Lake Lucy and Lake Ann has been fairly stable—neither degrading nor improving—in recent years.

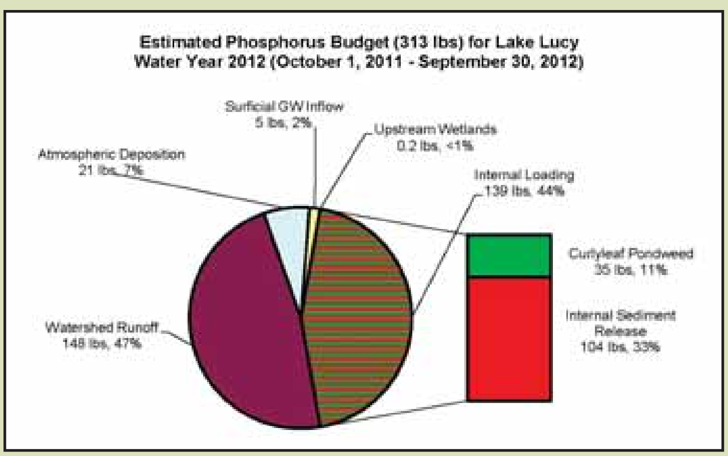
Lake Lucy is meeting the MPCA shallow lake water quality standards; however, excess phosphorus results in algal blooms and reduced water clarity that does not meet the RPBCWD's goals. The annual phosphorus loading to Lake Lucy, based on the 2012 water year, indicates nearly half of the phosphorus load to the lake is from watershed runoff. Since the watershed to Lake Lucy has many ponds and wetlands that settle out particulates, much of the phosphorus that reaches Lake Lucy is in the soluble, or non-settleable, form that is readily available for algal uptake. The other primary contributions of phosphorus are internal sources, including release from the bottom sediments and from the dieback of Curlyleaf pondweed.

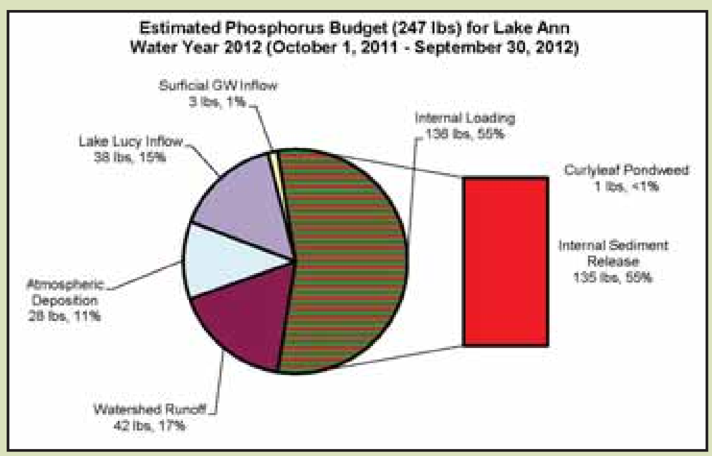
While Lake Ann is currently meeting both the RPBCWD and MPCA water quality goals, the release of phosphorus from the lake sediments appears to lead to periodic blue-green algal blooms suspended below the water surface. During the 2012 water year, more than half of the phosphorus load to Lake Ann came from internal sources, primarily the release from the bottom sediments. Approximately 30 percent of the phosphorus load was from the Lake Ann watershed and discharge from Lake Lucy.

Topic		Lake Lucy	Lake Ann
Recent 10-year growing season average	Total phosphorus	55	27
	Chlorophyll a	25.7	7.9
	Secchi disk (m)	1.1	2.6
Water quality trend		stable	stable
Meeting RPBCWD goals		no	yes
Meeting RPBCWD long-term clarity vision		no	yes
Meeting MPCA water quality standards		yes	yes
Impact of unmitigated watershed development		water quality degradation	water quality degradation
Fisheries		diverse with very low carp levels	diverse with very low carp levels
Macrophyte community		15 plant species	25 plant species
Non-native macrophytes		Curlyleaf pondweed	Curlyleaf pondweed and Eurasian watermilfoil
Cyanobacteria		blooms occur during growing season	blooms occur during growing season
Mercury		impaired	impaired

The table above summarizes the key findings from the Lake Lucy and Lake Ann water quality assessment.

Sources of Phosphorus



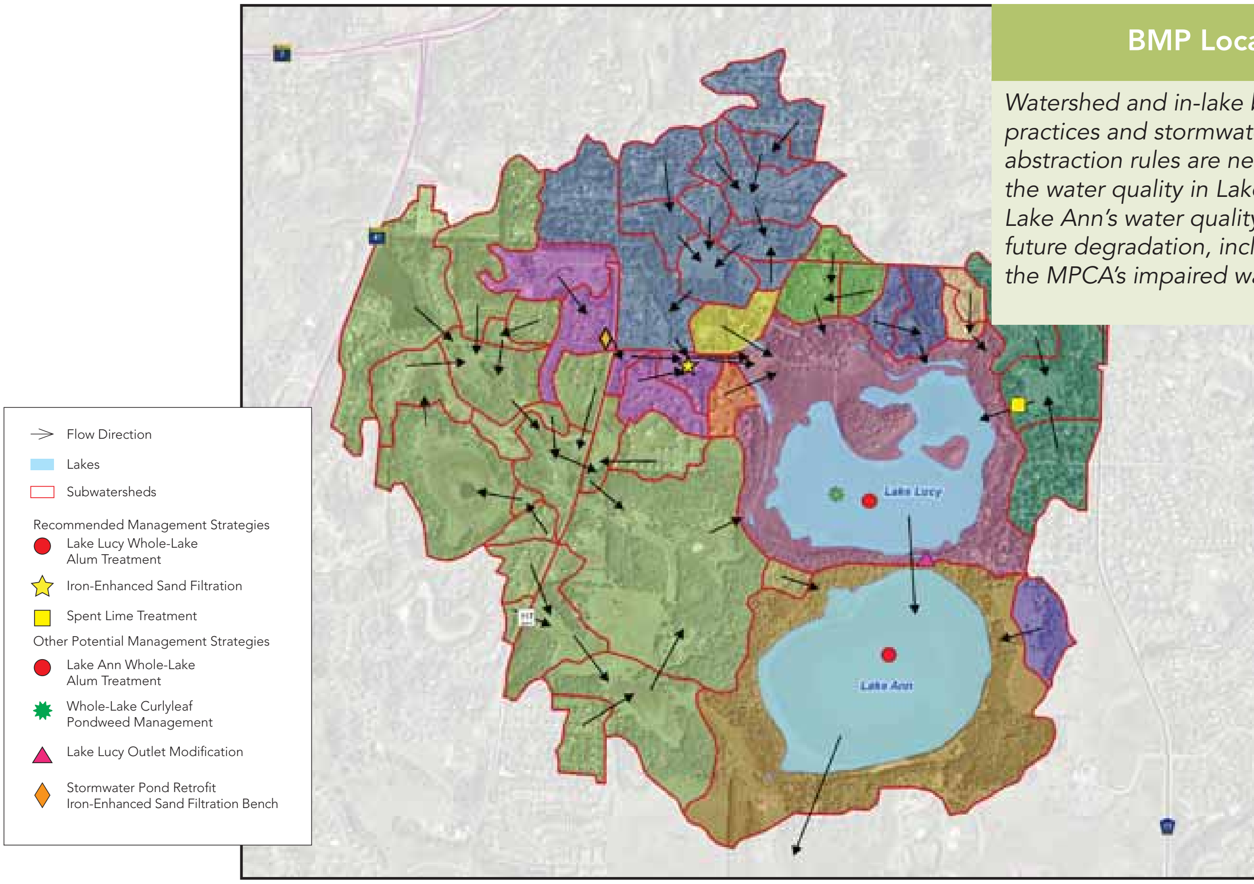


The pie charts above show the sources of phosphorus to each lake. For Lake Lucy, nearly half of the phosphorus is coming from the watershed, with an additional 44% from internal sources (primarily from sediment release). Lake Ann also gets more than half of its phosphorus load from internal sediment release, with nearly equal amounts coming from watershed runoff and discharge from Lake Lucy. Groundwater and atmospheric deposition also contribute phosphorus to each lake.

Management Strategies for Lake Lucy and Lake Ann

BMP Locations

Watershed and in-lake best management practices and stormwater volume abstraction rules are needed to improve the water quality in Lake Lucy, protect Lake Ann's water quality, and prevent future degradation, including listing on the MPCA's impaired waters list.



Several management strategies have been identified to reduce phosphorus contributions now and into the future. Input on BMPs was gathered from RPBCWD and City of Chanhassen staff as part of the evaluation process.

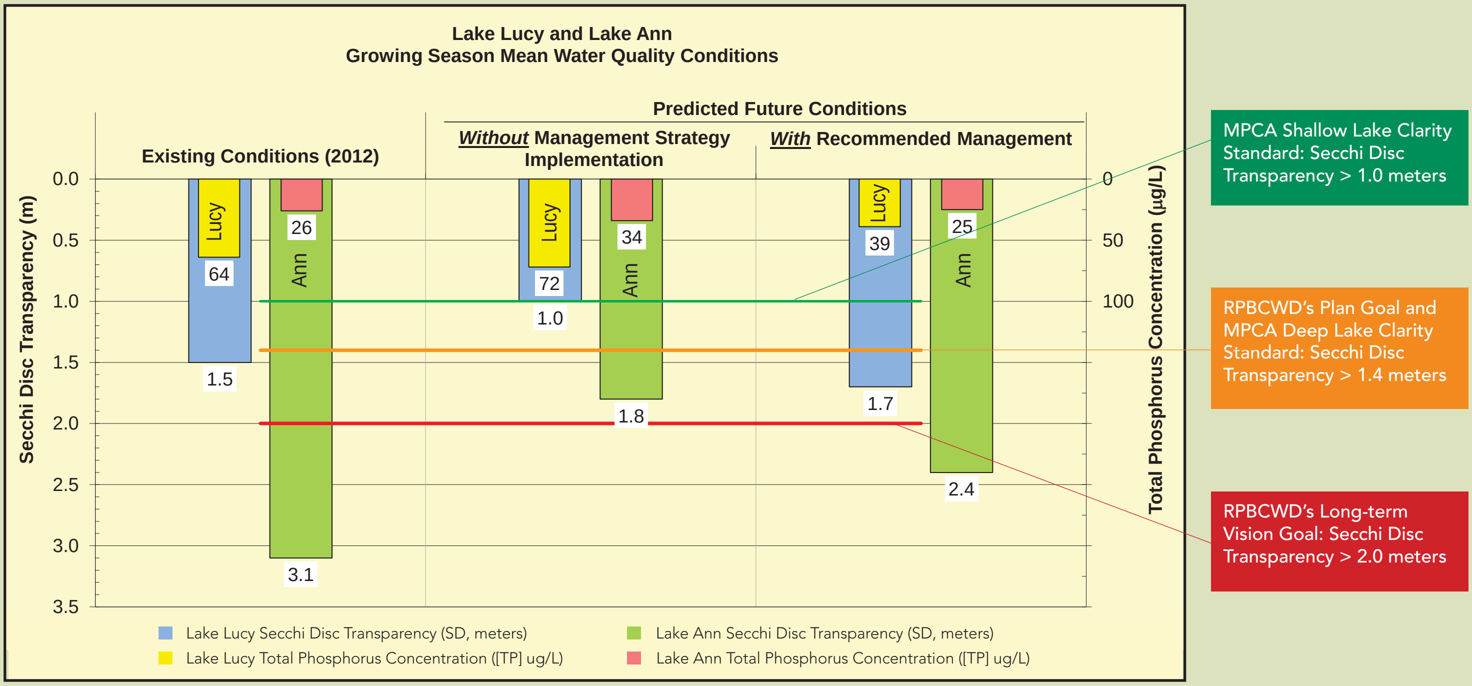
One strategy for both lakes is to implement stormwater volume abstraction rules as portions of the watershed develop or redevelop. In addition, it is very important to maximize the treatment of watershed runoff prior to implementing any in-lake phosphorus management practices to increase the longevity of in-lake measures. Therefore, watershed management strategies include construction of stormwater BMPs to remove soluble phosphorus at locations where there is land available and/or where significant portions of the runoff to Lake Lucy can be treated. In-lake practices to manage internal phosphorus loading have also been identified.

The evaluated practices included:

- Stormwater volume abstraction rules for development and redevelopment based on the MPCA's Minimal Impact Design Standards (MIDS)
- Iron-enhanced sand filtration (IESF) to remove soluble phosphorus
- Spent lime treatment to remove soluble phosphorus
- Alum treatment to reduce release of phosphorus from lake bottom sediments
- Curlyleaf pondweed management

Strategies were evaluated based on phosphorus removal effectiveness, resulting lake water quality improvements, cost, and feasibility. The figure on the back page compares the improvements in water quality of Lake Lucy and Lake Ann, respectively, through implementation of the evaluated management strategies.

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



Recommendations

The table below summarizes the major components (and opinions of cost) of the water quality improvement strategy for Lake Lucy and protection strategy for Lake Ann. Since the water quality in Lake Ann is directly influenced by the quality of the water leaving Lake Lucy, **the critical management option for protecting Lake Ann is to improve the water quality in Lake Lucy.**

Water quality management strategy component	Planning-level opinion of cost[1]	Annualized cost per pound of phosphorus removed[2]
Recommended management strategies		
Stormwater volume abstraction rule	N/A	N/A
Iron-enhanced sand filtration in subwatershed LU-A1.10c	$350,000	$1,023
Spent lime treatment system in subwatershed LU-A3.4	$190,000	$1,064
Whole-lake alum treatment of Lake Lucy[3]	$320,000	$724
Other potential management strategies		
Lake Lucy outlet channel modifications[4]	Permission to access site needed[4]	Permission to access site needed[4]
Five-year Curlyleaf pondweed management in Lake Lucy	$470,000	$892
Retrofit existing ponds with iron-enhanced filtration benches	Requires site specific assessment	Requires site specific assessment
Whole-lake alum treatment of Lake Ann[3]	$290,000	$499

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 35-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 reflect a single treatment while the annualized costs assume treatments occur every 10 years over a 35-year period.*
4. *A site assessment of potential BMPs at the Lake Lucy outlet channel was not possible because the channel is located on private property.*

Lake Lucy and Lake Ann Use Attainability Analysis Update

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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 (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, and
- Regulatory recommendations necessary for municipal, county, and state authorities to sustain the achieved conditions.

Lake Lucy and Lake Ann are identified in the Plan as important recreational resources for the RPBCWD with lake specific water quality goals. Lake Ann is one of the primary recreational resources in the RPBCWD that is used for swimming, boating, and fishing while Lake Lucy is primarily used for fishing and canoeing. There is a public boat access in Lake Ann Park, two swimming beaches located on the lake, and a fishing pier on Lake Ann while there is not a public boat access on Lake Lucy, people can carry-in boats and canoes or access Lake Lucy via a small channel connection to Lake Ann.

As part of the RPBCWD's continued efforts to achieve the District's vision for these valuable recreational resources, the RPBCWD undertook this update to the original 1999 *Lake Lucy and Lake Ann Use Attainability Analysis.* A Use Attainability Analysis (UAA) is a scientific assessment that uses an outcome-based evaluation and planning process in order 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 Lake Lucy, Lake Ann, 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 Lake Lucy and Lake Ann based on more recent physical, chemical, and biological data, improve the understanding of current water quality concerns in the lakes, minimize the likelihood of Lake Lucy being listed on the Minnesota Pollution Control Agency's (MPCA) impaired waters list for excess nutrients, 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 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 that have been prepared related to Lake Lucy, Lake Ann, and their watersheds:

- *Lake Lucy and Lake Ann Use Attainability Analysis* (Barr, July 1999
- *In situ Measurement of Sediment Oxygen Demand Lake Lucy, Lake Susan, Lake Riley, Lake Ann* ($HydrO_2$, Inc for CH2M Hill, November 2009)
- *Susan, Ann, and Lucy Subwatershed: Stormwater Retrofit Assessment* (Carver SWCD, 2011)
- *Stormwater Pond Protocols and Prioritization Report: 2011* (CH2M Hill, January 2012)
- *Lake Ann Basis of Design* (CH2M Hill, October 2012)
- *Lake Lucy Ice Preserving Aeration System* (CH2M Hill, October 2012)
- *Lake Lucy IPAS 2013 Update* (CH2M Hill, May 2013)
- *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)

1.3 Watershed Characteristics

Lake Lucy and Lake Ann, both located entirely within the City of Chanhassen, form the headwaters of Riley Creek. The Lake Lucy watershed, located immediately upstream of Lake Ann, is approximately 909 acres, not including the surface area of the lake. Lake Ann's contributing watershed is much smaller, only 131 acres, not including the surface area of the lake. Riley Creek begins at the outlet of Lake Ann and ultimately discharges to the Minnesota River. Figure 1 shows the major watersheds, subwatersheds, and flow direction for the Lake Lucy and Lake Ann watersheds.

1.3.1 Drainage Patterns

The Lake Lucy stormwater conveyance systems are comprised of a network of storm sewers, constructed stomwater detention ponds, and natural wetlands within the watershed tributary to the lake. There are ten (10) major drainage areas within the Lake Lucy watershed that ultimately contribute surface runoff to the lake, along with the direct drainage area around Lake Lucy (see Figure 1). Each major drainage area is named after the terminating watershed in each network.

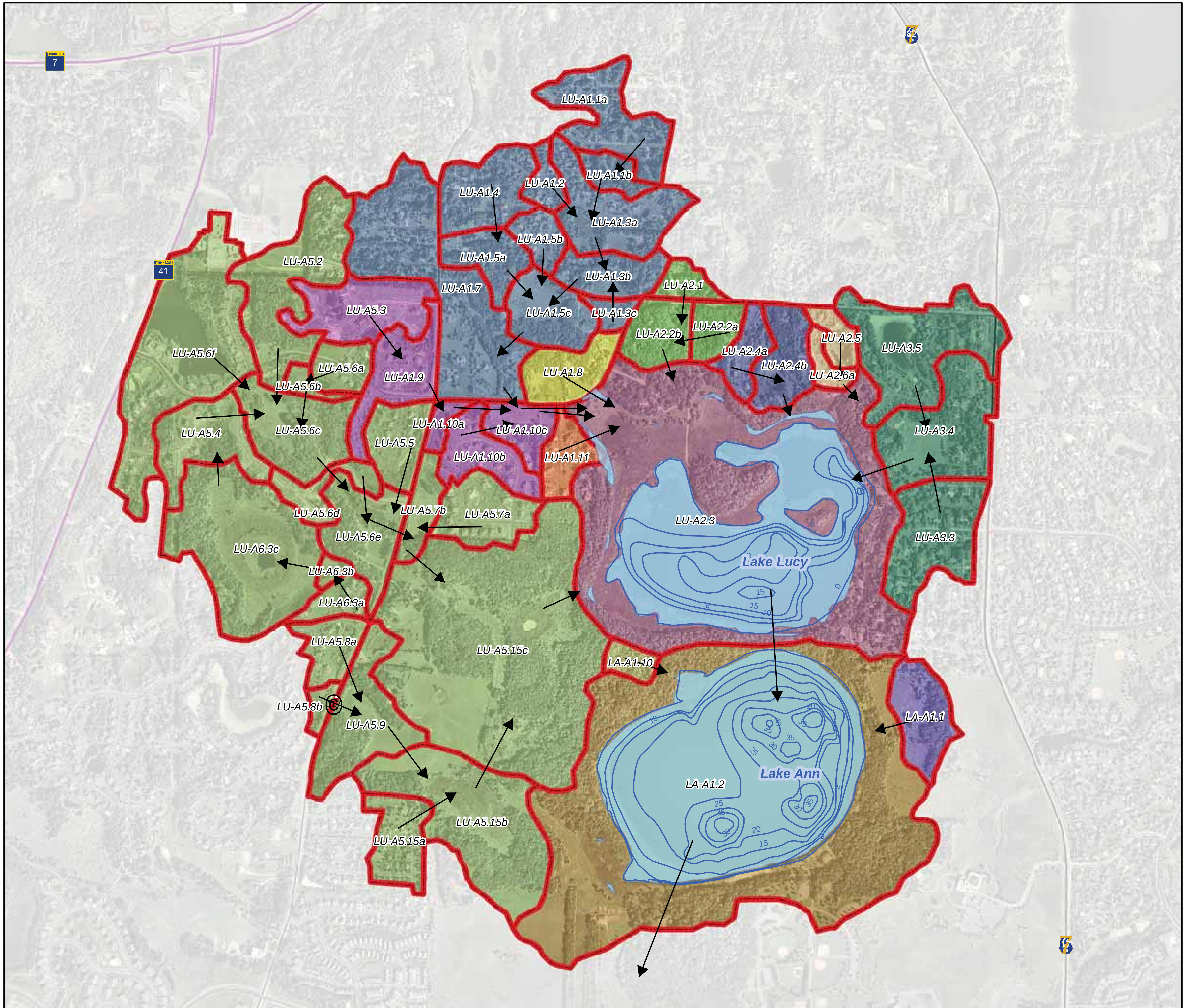


Figure 1
DRAINAGE PATTERNS, MAJOR DRAINAGE AREAS,
SUBWATERSHEDS, AND LAKE BATHYMETRY
Lake Lucy and Ann UAA Update
RPBCWD

The updated subwatersheds and drainage pattern are based on the subwatershed divides from the original UAA and the RPBCWD Riley Creek XP-SWMM modeling project (Barr Engineering, 2007). The subwatershed divides from these past studies were update using more recent topographic data (MDNR, 2011), storm sewer data and other information from the City of Chanhassen, and 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 Lake Lucy watershed 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 Lake Lucy watershed whereby the normal water levels are located below the outlet structure or overflow elevations based on the *City of Chanhassen Surface Water Management Plan* (SEH, 2006), the most recent topographic information, or communications with City of Chanhassen staff. This means that during dry climatic conditions or low flows, these areas might not discharge and could occasionally act as land-locked areas. These areas include:

- LU-A6.3c (Harrison Lake)
- LU-A2.2b
- LU-A5.6f
- LU-A6.3b

There are no perennial streams or rivers in the Lake Lucy watershed that convey flows to the lake. Also, there are no public ditch systems within the Lake Lucy watershed.

The natural inflow to Lake Ann is comprised largely of outflow from Lake Lucy with the remaining inflow being from stormwater runoff from Lake Ann's direct watershed and precipitation directly onto the lake surface. There are three (3) major drainage areas within the Lake Ann watershed. Like the Lake Lucy watershed, there are no perennial streams or public ditch systems within the Lake Ann watershed. However, Lake Lucy and Lake Ann are the headwaters to Riley Creek, which ultimately flows to the Minnesota River.

1.3.2 Land Use

Land use practices within a lake's watershed can impact the lake and its water quality. Impacts result from the export of sediment and nutrients, primarily phosphorus, to a lake from its watershed. Each land use contributes a different quantity of phosphorus to the lake, due 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 surfaces and expected change in imperviousness for each watershed was based on information from the Metropolitan Council and modified using the existing and future land use data from the City of Chanhassen and recent aerial photography. 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 Lake Lucy watershed is fully-developed with only a few areas expected to have changes in landuse in the future, mostly in the southwestern portion of the watershed. The existing land use within the Lake Lucy watershed is primarily low and medium density residential areas with some undeveloped parcels, open space, and agricultural areas. In the future, these areas are expected to develop as low density residential.

The existing land use conditions in the Lake Ann watershed is primarily in open space and natural land uses, including some developed parkland (Lake Ann Park). Under future conditions, the southwestern portion of the Lake Ann watershed is expected to change from agricultural and open space to low-density residential.

Figure 2 shows the existing conditions land uses in the Lake Lucy and Lake Ann watersheds. Figure 3 shows the future conditions land uses in the Lake Lucy and Lake Ann watersheds, as well as the areas where there are expected changes in land use between existing and future conditions.

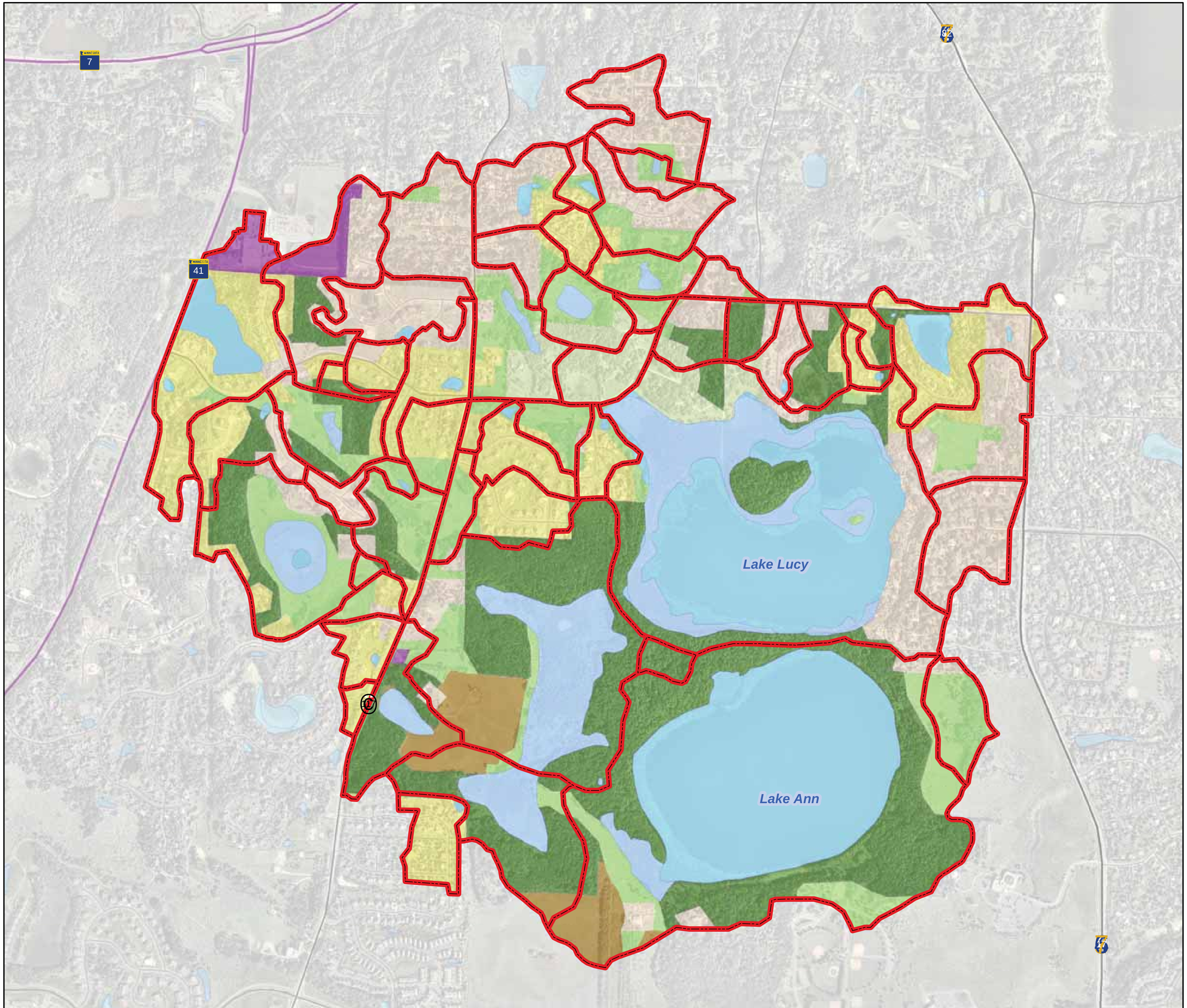
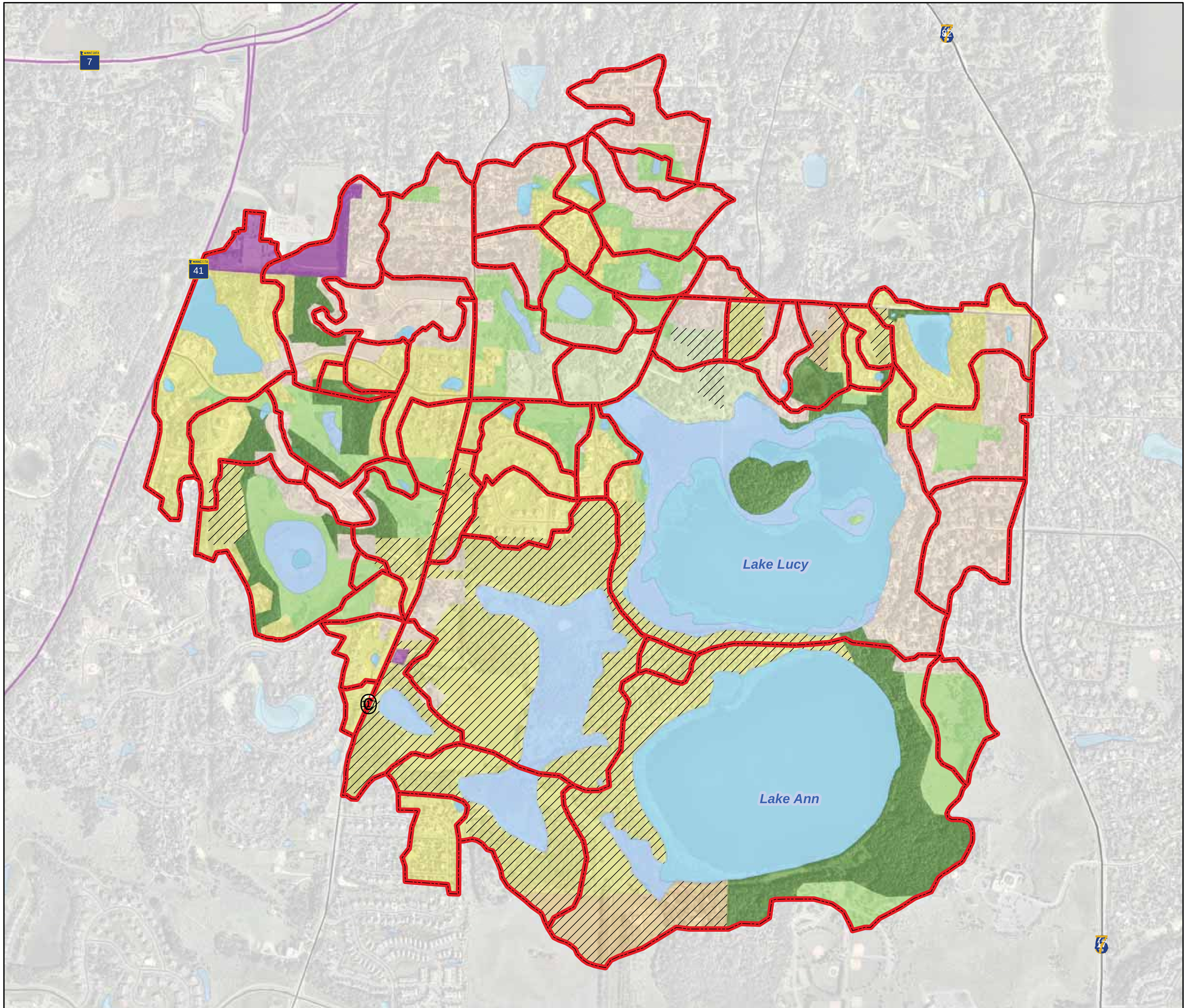


Figure 2
EXISTING LAND USE (2010)
Lake Lucy and Ann UAA Update
RPBCWD



Subwatersheds

Future Land Use[1]

- Agricultural
- Commercial
- Forest
- High Density Residential
- Highway
- Industrial/Office
- Institutional
- Low Density Residential
- Medium Density Residential
- Natural/Park/Open
- Open Water
- Suburban Low Density Res
- Very Low Density Residential
- Wetland
- Areas of Expected Land Use Change

1-Based on land use data from Met Council and the City of Chanhassen

Feet

500 0 500 1,000

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Figure 3
FUTURE LAND USE (2030)
Lake Lucy and Ann UAA Update
RPBCWD

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 Carver County Digital Soils map based on the Natural Resource Conservation Service (NRCS) Soil Survey, the underlying soils in the Lake Lucy and Lake Ann watersheds are predominantly classified as hydrologic soil group (HSG) B with moderate infiltration rates. Soils in the area around the lakes and around the wetland areas are typically A/D and B/D soils with low infiltration capacities.

1.4 Lake Characteristics

1.4.1 Physical Characteristics

Lake Lucy has a surface area of roughly 88.0 acres, maximum depth of approximately 20 feet, and a mean depth of 6.5 feet at a water surface elevation 955.5 (NGVD29), the surveyed saddle point in the channel connecting Lake Lucy to Lake Ann. The estimated littoral zone (shallow area typically less than 15-feet deep where light can penetrate and promote the growth of macrophytes) is estimated to be about 86 acres according to the Minnesota Department of Natural Resources (MDNR), or about 98 percent of the lake. Because of its depth and coverage by macrophytes, the MPCA classifies Lake Lucy as a shallow lake (Pam Anderson - MPCA, email communication, 5/14/2013). Review of temperature profile data along the depth of the lake indicates that Lake Lucy typically thermally stratifies during the summer, indicating that it is a dimictic system. The outlet from Lake Lucy is a natural channel located on the southeast side of the lake and the discharge passes directly to Lake Ann.

Lake Ann has a surface area of about 119 acres at a water surface elevation of 956 ft MSL (NGVD29), the approximate control elevation based on the most current topographic information (MDNR, 2011). The lake has a maximum depth of approximately 40 feet and a mean depth of 16.8 feet at the estimate control elevation. The estimated littoral area of Lake Ann is 45 acres according to the MDNR, or about 38 percent of the lake. Lake Ann is classified as a deep lake by the MPCA. Review of temperature profile data along the depth of the lake indicates that Lake Ann thermally stratify during the summer, indicating that it is a dimictic system. The outlet from Lake Ann is a natural, vegetated channel located on the southwest side of the lake. This channel forms the headwaters of Riley Creek and passes under 78th Street and Highway 5 just downstream of Lake Ann.

Because the outlet control elevation in Lake Ann appears to be higher than the outlet control elevation of the upstream Lake Lucy (roughly 0.6 feet higher), the discharge rate from Lake Lucy is highly dependent on the lake levels in Lake Ann. As a result, Lake Lucy and Lake Ann essentially function together as one hydraulic unit.

A summary of the physical parameters for Lake Lucy and Lake Ann are summarized in Table 1. Also, the bathymetric information for both lakes is shown on Figure 1.

Table 1 Lake Lucy and Lake Ann Physical Parameters

Lake Characteristic	Lake Lucy	Lake Ann
Lake MDNR ID	10-0007	10-0012
MPCA Lake Classification	Shallow	Deep
Water Level Control Elevation (ft MSL)	955.5 / Approx 956[1,2]	Approx 956[2]
Surface Area (acres)	88	119
Mean Depth (feet)	6.5	16.8
Maximum Depth (feet)	20	40
Littoral Area (acres)	86	45
Volume (below the control elevation) (acre-feet)	558 / 617	2005
Thermal Stratification Pattern	Dimicitic	Dimictic
Estimated Residence Time (years) – 2012 Climatic Conditions	5.6	11.4
Estimated Residence Time (years) – 2005 Climatic Conditions	2.7	7.1
Watershed Area (acres)[3]	997	250[4]
Trophic Status Based on Past 10-Years of Growing Season Average Water Quality Data	Eutrophic	Mesotrophic

1 – Two water level control elevations are listed for Lake Lucy as the outlet elevation from Lake Ann (located downstream of Lake Lucy) is higher than the outlet channel elevation from Lucy.
2 – The water level control elevation from Lake Ann based on channel elevation determined from MDNR LiDAR data (2011)
3 – Watershed area includes surface area of lake
4 – Does not include Lake Lucy watershed

1.4.2 Ecosystems Data

The term ecosystem describes the community of living things and their interaction with the environment in which they live with each other. The ecosystem includes all the organisms associated with the lake's food chain including: phytoplankton (algae), macrophytes (aquatic weeds), zooplankton (which prey upon algae), and the fisheries (which includes the smaller planktivores (small fish that feed on zooplankton) and predator fish (larger fish that feed on the planktivores)). A less visible component of the food chain, the decomposers, 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

The phytoplankton (algae) species in Lake Lucy and Lake Ann form the base of the lake's food web and directly impact the lake's fish production. 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 Lake Lucy for numerous years including: 1975, 1981, 1984, 1988, 1990, 1994, 1997, 2004, and 2011. Additionally, phycocyanin (cyanobacteria (blue green algae) pigment) readings have been collected from 2010 through 2012 in Lake Lucy.

Lake Lucy phytoplankton surveys indicate cyanobacteria (blue-green) and green algae were generally the dominant types of phytoplankton observed in Lake Lucy during much of the growing season, although cyanobacteria were especially dominant in the later summer. The more recent phycocyanin data collected in Lake Lucy indicates that cyanobacteria were present through the water profile of the lake in 2010 through 2012. The estimated number of cyanobacteria cells per mL (based on the phycocyanin measurements) at the surface of Lake Lucy typically fall within the World Health Organization relatively low risk of adverse health effects (WHO, 2003).

RPBCWD has collected phytoplankton data in Lake Ann for several years including: 1975, 1978, 1981, 1988, 1990, 1994, 1997, and 2004. More recent data phytoplankton data has been collected in Lake Ann by the RPBCWD in 2008 and 2009. Similar to Lake Lucy, phycocyanin (cyanobacteria (blue green algae) pigment) readings have been collected from 2008 through 2010 in Lake Ann.

Based on review the 2004 phytoplankton data in Lake Ann, cyanobacteria and green algae were generally the dominant types of phytoplankton early in the growing season. However, during the middle of the growing season, the number of green algae declined, and the lake was dominated by cyanobacteria and other phytoplankton species that are typically associated with eutrophic systems. Green algae numbers increased later in the summer, and the lake primarily had a mix of green and cyanobacteria and other phytoplankton species.

More recent phytoplankton and phycocyanin data collected in Lake Ann indicates that cyanobacteria (*Aphanizomenon flosaquae* and *Ocillatoria*) have been present in the metalimnion (typically at depths of 6-8 meters) of the lake in 2008, 2009, and 2010. At the surface of Lake Ann, the estimated number of cyanobacteria cells per mL (based on the phycocyanin measurements) typically fall within the World Health Organization relatively low risk of adverse health effects (WHO, 2003; CH2M Hill, 2009), although there were a few dates later summer that exceed the low risk threshold.

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.

Zooplankton data has been collected by RPBCWD and the University of Minnesota in Lake Lucy for the following years: 1981, 1984, 1988, 1990, 1994, 1997, 2004, 2010, 2011, and 2012. Zooplankton data for Lake Ann was collected by RPBCWD and the University of Minnesota for the following years: 1981, 1984, 1988, 1990, 1994, 1997, 2004, 2008, 2010, and 2011.

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 Lake Lucy that spans the entire growing season (2010), the cladocera were the most abundant zooplankton in the spring and early summer along with the copepods. Zooplankton numbers declined significantly in mid-summer (July), potentially due to grazing by fish such as bluegills and sunfish. The cladocera numbers rebounded in late summer, being the most abundant zooplankton in the lake.

In the most recent zooplankton data for Lake Ann that spans the entire growing season (2011), in spring the cladocera numbers were low and the copepods comprised the most significant numbers of zooplankton in the spring. Cladocera numbers increased in June and July, while the numbers of other zooplankton decreased. In late July and August, zooplankton numbers declined overall in Lake Ann, remaining low until fall, likely after the fall turnover. This decline in numbers 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 Lake Lucy and Lake Ann, 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. The RPBCWD has collected macrophyte data on Lake Lucy in the following years: 1994, 1997, and 2004. The RPBCWD has collected macrophyte data on Lake Ann in the following years: 1994, 1997, and 2004.

More recently, the University of Minnesota collected macrophyte data in both Lake Lucy and Lake Ann. The data collected included point intercept survey data, biomass sampling, Curlyleaf pondweed turion sampling, and milfoil herbivore abundance sampling. The University of Minnesota collected macrophyte data in Lake Lucy and Lake Ann in 2010, 2011, and 2012. The following is a summary of the 2011 macrophyte data collected by the University of Minnesota. The complete *Aquatic Plant Community of Lakes Ann, Lucy, Susan, Riley, and Staring: 2011 Summary of Results* (Knopik and Newman, 2012) can be found in Appendix B.

In Lake Lucy, point intercept surveys were completed on June 18, 2011 and August 17, 2011. The U of MN report indicates the macrophyte community was moderately diverse, with 15 submerged and aquatic plant species present. Native plants accounted for the vast majority of the plant biomass collected in 2011. Rooted vegetation was present to a depth of 4.1 meters. The most common macrophyte in both survey dates was coontail (*Ceratophyllum demersum*, a native species), occurring at 55 percent and 65 percent of the sampled sites in June and August, respectively. Eurasian watermilfoil (*Myriophyllum spicatum*, an exotic species) was found at one location in Lake Lucy. Curlyleaf pondweed (*Potamogeton crispus)* was observed at 40.6 percent of the littoral sites in June, although the plants were small and had very little biomass. This limited biomass could have been due to herbicide treatments by riparian landowners in early June 2011, prior to the macrophyte survey. In general, the Curlyleaf pondweed turion density in the lake sediments was low to moderate, lake-wide, with considerable variability across the lake.

In Lake Ann, point intercept surveys were completed on July 6, 2011 and August 16, 2011. The U of MN report indicates the macrophyte community was relatively stable and healthy community of macrophytes with 25 species present. The most common macrophyte on both survey dates was Eurasian watermilfoil (*Myriophyllum spicatum*, an exotic species) occurring at 57 percent of the sampled sites in July and August. Additionally, the number of milfoil herbivores (weevils) found on the Eurasian watermilfoil was at a low density, likely an insufficient population to effectively control the milfoil. The second most common macrophyte in both survey dates was coontail (*Ceratophyllum demersum*, a native species). Curlyleaf pondweed (*Potamogeton crispus)* was observed in Lake Ann; however, it does not appear to occur frequently or account for a significant portion of the macrophyte biomass in the lake.

1.4.2.4 Fishery

During 1992, the MDNR classified Lake Lucy and other 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, Lake Lucy is a Class 42 lake, which signifies a lake that may be better suited for wildlife than for fish (Schupp, 1992).

The most recent MDNR fishery survey of Lake Lucy was completed in 2006. The status of the Lake Lucy fishery is that it is a small, productive, and shallow lake system that have been to periodic partial winterkills (1955-56, 1963-64, 1975-75, 1977-78, 1988-89). As a result of these periodic winterkills, the fish populations have tended to fluctuate dramatically over time. The following is a summary of the 2006 MDNR fishery survey on Lake Lucy: Northern pike and largemouth bass were sampled at levels above average for a lake like Lucy Lake; however, the size of the pike could be due to the special regulation on pike in Lake Ann. Bluegills were the most sampled fish in Lucy Lake, representing 65 percent of the total catch. Yellow perch, pumpkinseed and hybrid sunfish were all present in below average rates for a lake in this lake class, with a total of 6.6 percent of the total catch. Black crappie only accounted for 3 percent of the total catch at Lucy Lake. Yellow, black and brown bullheads were all present in Lucy Lake and accounted for about 14 percent of the total catch, with yellow and black bullhead levels being higher than expected.

The most recent MDNR fishery survey of Lake Ann was completed in 2006. The following is a summary of the 2006 MDNR fishery survey on Lake Ann: Northern pike numbers have increased since the previous fishery survey. Additionally, largemouth bass, bluegills, black crappie, black bullhead, hybrid sunfish, pumpkinseed, yellow bullhead, and yellow perch were sampled during this survey. The following boating and fishing restrictions are in effect for Lake Ann: boats are restricted to electric trolling motors, and largemouth bass fishing is limited to catch-and-release only.

More recently, the University of Minnesota collected fishery data, focusing on carp, in several of the lakes within RPBCWD, including both Lake Lucy and Lake Ann. Fishery data were collected (using trapnets) in 2010 and 2011 for Lake Lucy. Since the trapnets typically do not target adult carp, the trapnet survey was conducted to target small carp (yearlings and age 1) to evaluate if the carp are able to successfully reproduce in the lake. According to the U of MN the absence of small carp shows that carp are not able to successfully reproduce in Lake Lucy, which is likely the result of an abundant native fish population that forage on carp eggs and larvae. Additionally, in 2010, the Lake Lucy carp population was estimated using the mark-and-recapture analysis. This analysis showed that Lake Lucy was inhabited by approximately 800 carp that were predominantly large and old. The biomass of carp in 2010 was approximately 70 kg/ha, a relatively low biomass level (Przemyslaw Bajer, email communication, April 15, 2013; and Bajer et. al., 2011). Additionally, in the research of the lakes in the Riley Creek watershed, there was no observation of movement of carp from the Lake Lucy/Lake Ann system downstream to Lake Susan.

Despite the low biomass of carp in Lake Lucy, carp were removed from the lake because they formed a tight winter aggregation that could be easily targeted with a net. Carp seining occurred in Lake

Lucy two times in the past years. The first seining occurred on January 24, 2010. The second seining occurred on January 13, 2011. It was estimated that approximately 3/4 of the carp population was removed from Lake Lucy in one seine haul. The estimates suggest that Lake Lucy is currently inhabited by approximately 100 carp and that the biomass is currently less than 20 kg/ha (a very low biomass level) (Przemyslaw Bajer, University of Minnesota, email communication, April 15, 2013; Bajer et. al., 2011).

According to Dr. Peter Sorensen of the U of MN, Lake Lucy experienced a winter kill in March of 2011, following the carp seining. To prevent the carp in Lake Ann from moving into Lake Lucy during the spawning season, a temporary fish barrier was installed in the channel between Lake Lucy and Lake Ann that would prevent the movement of large carp between the systems while still allowing for the movement of game and pan fish species. This helped prevent carp from reproducing while also providing the opportunity for the pan and game fish species to reestablish in Lake Lucy following the winter kill (Dr. Peter Sorensen, University of Minnesota, phone conversation, June 19, 2013). The temporary barrier was removed after the 2011 spawning season.

Lake Ann, the University of Minnesota conducted electrofishing suveys in 2009 and 2010. The data suggested that the density of carp in Lake Ann was less than half of that in Lake Lucy and the carp that have been caught have been adults. Additionally, the mark-and-recapture method could not be used as the density of carp in Lake Ann was so low that they could not capture enough fish to mark to get an appropriate mark-and-recapture estimate. As a result of this low carp population, no carp management activities have been performed in Lake Ann (Przemyslaw Bajer, email communication, April 15, 2013).

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 the fresh water lake systems is phosphorus, as it often acts as the limit 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 fill 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 weeds (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, it has been 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 decrease by reducing these external loads 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), its 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 > 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 depending 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. 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 (the fourth of July).

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. Additionally, they 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 as well (Dr. Peter 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 hypoliminion 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, "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, "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 Lake Lucy and Lake Ann

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 Lake Lucy and Lake Ann, 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).

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 Lake Lucy and Lake Ann; therefore, both methods were used to estimate the background phosphorus concentrations for each of the lakes.

For Lake Lucy, the Vighi and Chiaudani relationship using conductivity predicted phosphorus concentration from natural, background loadings to be 18 µg/L (ranging from 10 µg/L to 27 µg/L). The expected total phosphorus concentration in Lake Lucy based upon the average alkalinity over the period of record was 23 µg/L. Both methods indicated that historically, Lake Lucy was mesotrophic lake.

For Lake Ann, the Vighi and Chiaudani relationship using conductivity predicted phosphorus concentration from natural, background loadings to be 13 µg/L (ranging from 8 µg/L to 17 µg/L). The expected total phosphorus concentration in Lake Ann based upon the average alkalinity over the period of record was 16 µg/L. Both methods indicated that historically, Lake Lucy was 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 done in the past to identify Minnesota lakes which may be in better or worse condition that 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 Lake Lucy, the predicted total phosphorus concentration was estimated to be 55 µg/L (with a range of 37 µg/L to 73 µg/L). The estimated chlorophyll *a* concentration was estimated to be 23 µg/L (with a range of 9 µg/L to 37 µg/L). The estimated Secchi depth for Lake Lucy was 1.2 meters (with a range of 0.7 meters to 1.7 meters). These estimates would place Lake Lucy in the eutrophic classification. For all water quality parameters, the actual water quality data observed in Lake Lucy falls within the range of a minimally-impacted lake with similar characteristics to Lake Lucy.

In Lake Ann, the predicted total phosphorus concentration was estimated to be 20 µg/L (with a range of 11 µg/L to 29 µg/L). The estimated chlorophyll *a* concentration was estimated to be 5 µg/L (with a range of 2 µg/L to 9 µg/L). The estimated Secchi depth for Lake Ann was 2.9 meters (with a range of 1.6 meters to 4.2 meters). These estimates would place Lake Ann in the eutrophic classification. For all water quality parameters, the actual water quality data falls within the range of a minimally-impacted lake with similar characteristics to Lake Ann.

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 any water quality data collected in the depth range of 0-2 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.

Lake Lucy and Lake Ann are located within the North Central Hardwood Forest ecoregion of the state. Lake Lucy is considered a shallow lake by the MPCA (Pam Anderson - MPCA, email communication, 5/14/2013), while Lake Ann is a deep lake.

As part of the Plan (CH2M Hill, February, 2011), the RPBCWD adopted national and state goals for the water resources within the watershed, including the MPCA lake water quality standards. However, in the Plan, both Lake Lucy and Lake Ann were classified as deep lakes, establishing the MPCA deep lake water quality standards as the minimum requirement for each lake. Additionally, as part of the RPBCWD vision, an additional long-term goal is to have all lakes achieve water clarity of 2 meters or more. Table 2 summarizes the MPCA and RPBCWD water quality goals and standards as would be applied to Lake Lucy and Lake Ann.

Table 2 Water Quality Goals and Standards for Lake Lucy and Lake Ann

Agency	Parameter	Lake Lucy	Lake Ann
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	TP ≤ 40 µg/L
	Chlorophyll *a*	Chl-*a* ≤ 14 µg/L	Chl-*a* ≤ 14 µg/L
	Secchi Disc Transparency	SD ≥ 1.4 m	SD ≥ 1.4 m
	Goal for all Lakes	SD ≥ 2.0 m	SD ≥ 2.0 m

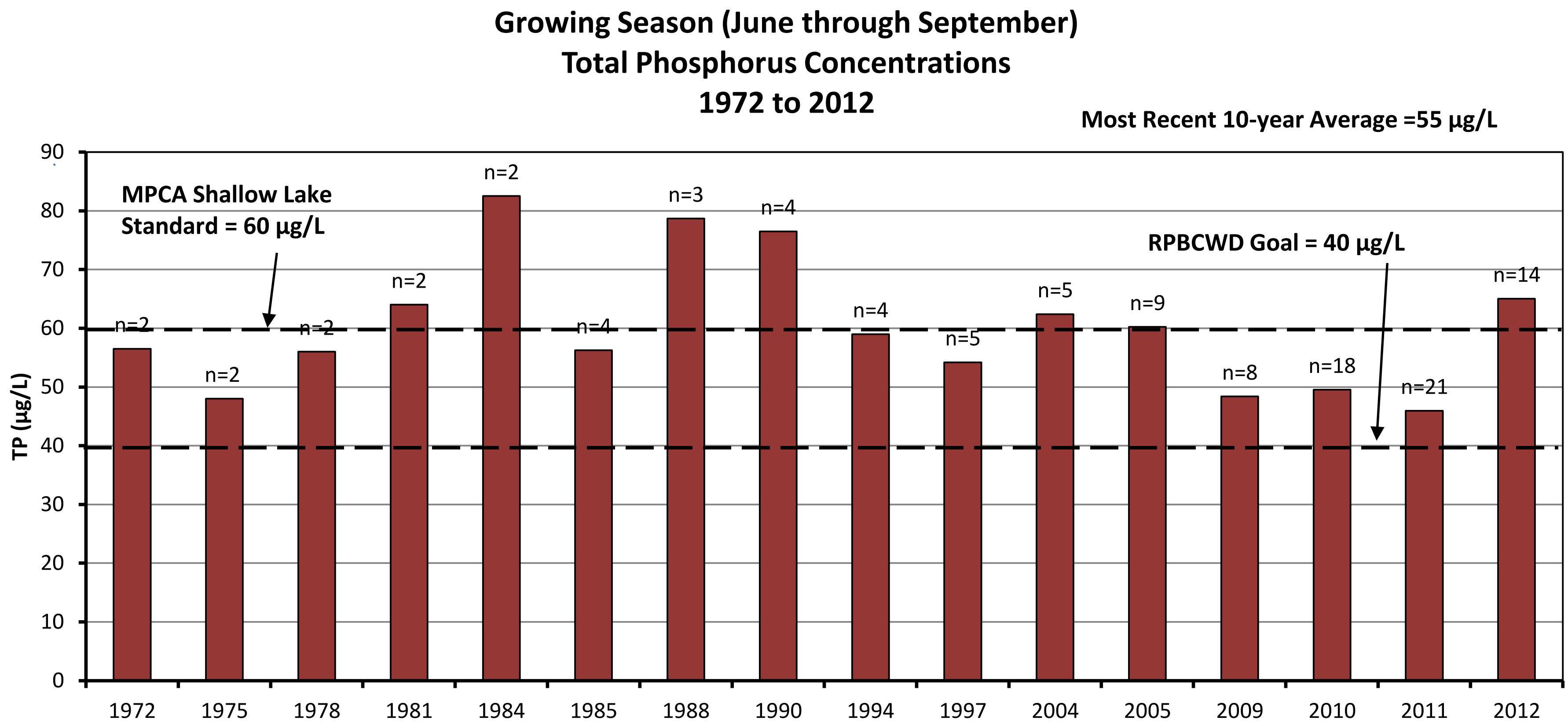
2.4 Water Quality Monitoring Program

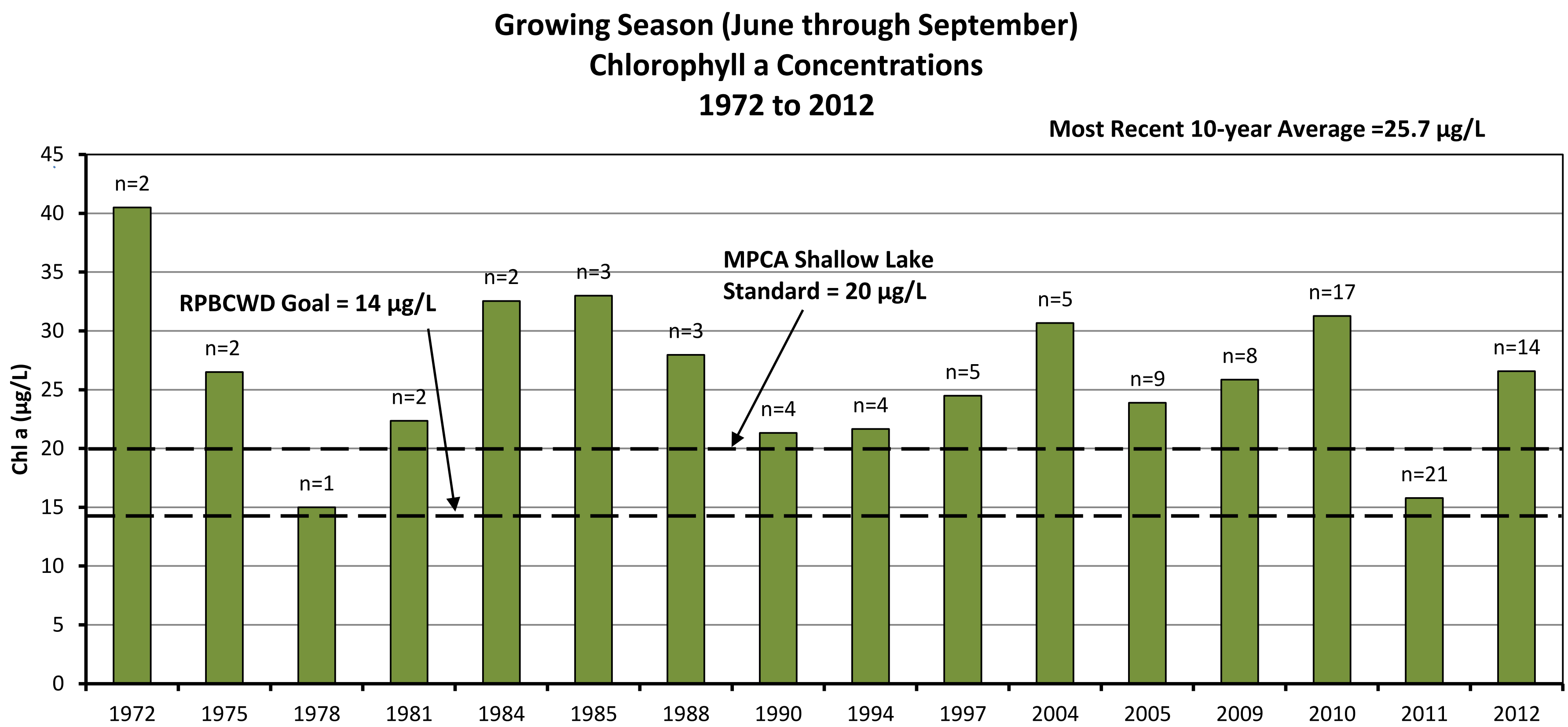
The water quality in Lake Lucy has historically been monitored by the RPBCWD, the Metropolitan Council as part of the Citizen-Assisted Monitoring Program (CAMP), the MDNR Citizen Lake Monitoring Program (CLMP), and more recently by the University of Minnesota. For the three typical water quality parameters, there is historical total phosphorus and chlorophyll *a* water quality data available for 1972, 1975, 1978, 1981, 1984, 1985, 1988, 1990, 1994, 1997, 2004, 2005, and 2009-2012. For Secchi disc transparency, there is data from 1972, 1975, 1978, 1981, 1984, 1985, 1988, 1990-2012.

The water quality in Lake Ann 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, 1981, 1984, 1985, 1988, 1989, 1990, 1994, 1997, 2002, 2004, 2005, and 2008-2012. For Secchi disc transparency, there is data from 1972, 1975, 1978, 1981, 1984, 1985, 1988-1990, 1994, 1997, 2002, 2004, 2005, 2007-2012.

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 Lake Lucy and Lake Ann are presented in Figures 4 and 5. Also shown on 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 10 years of water quality monitoring data (2003-2012).





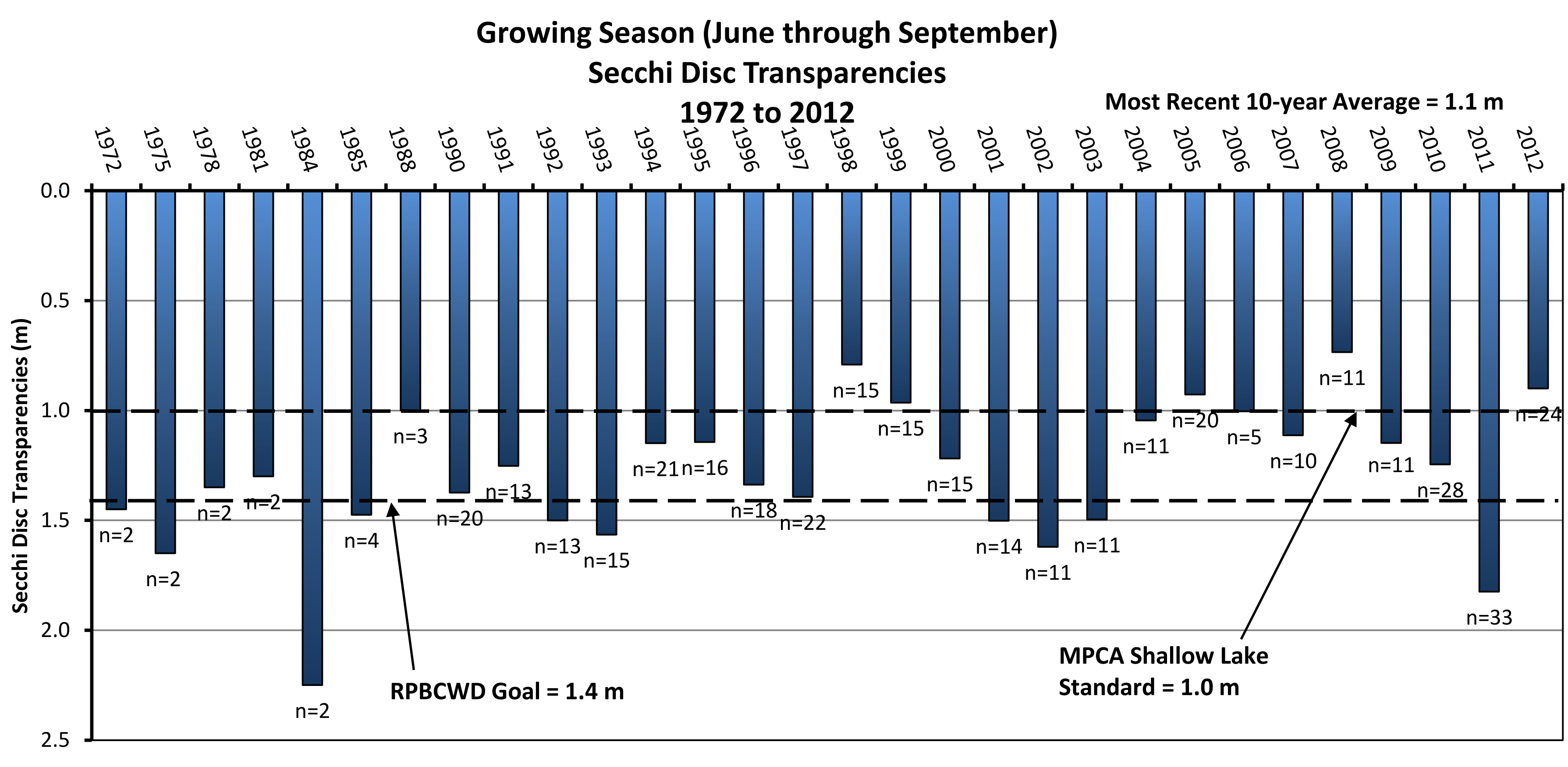
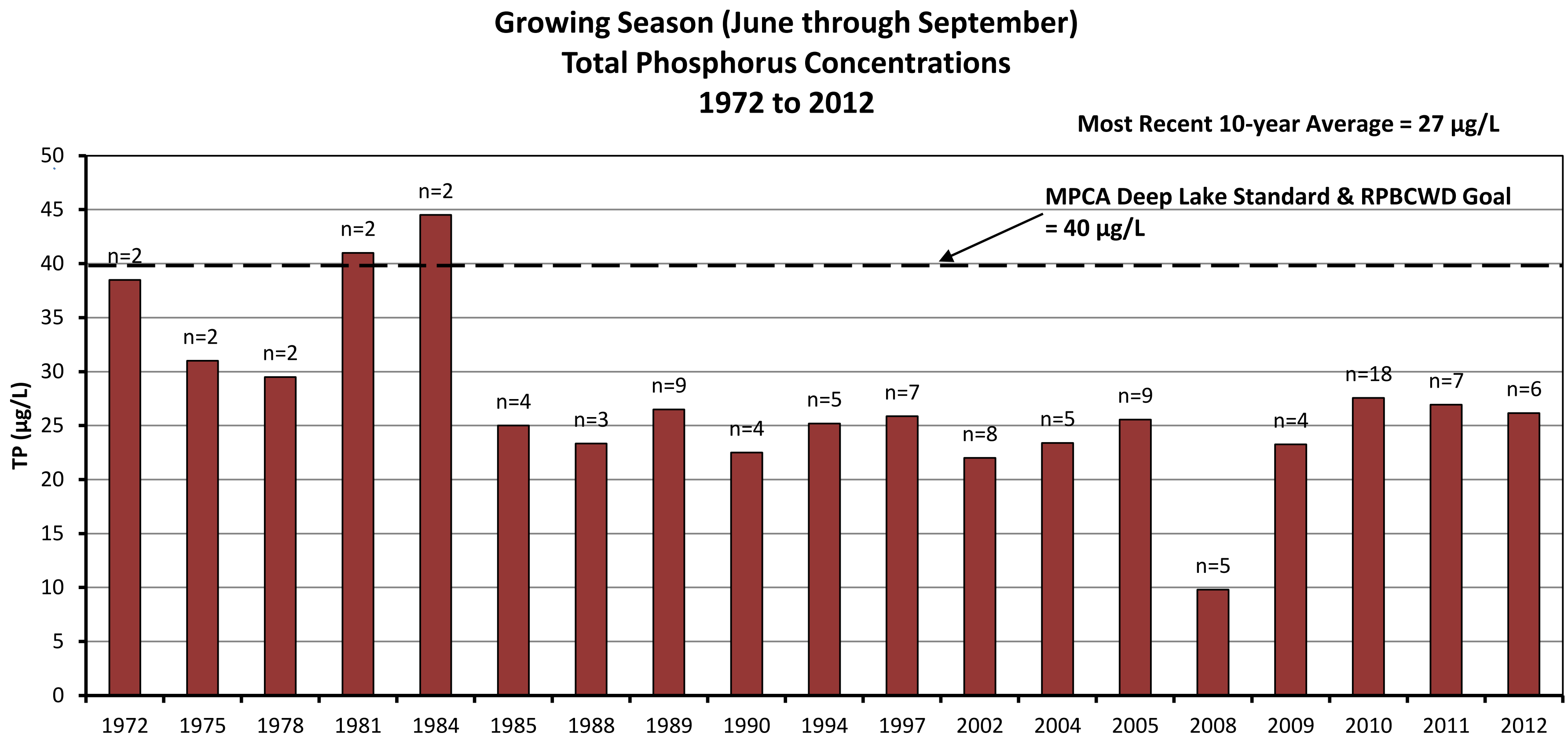
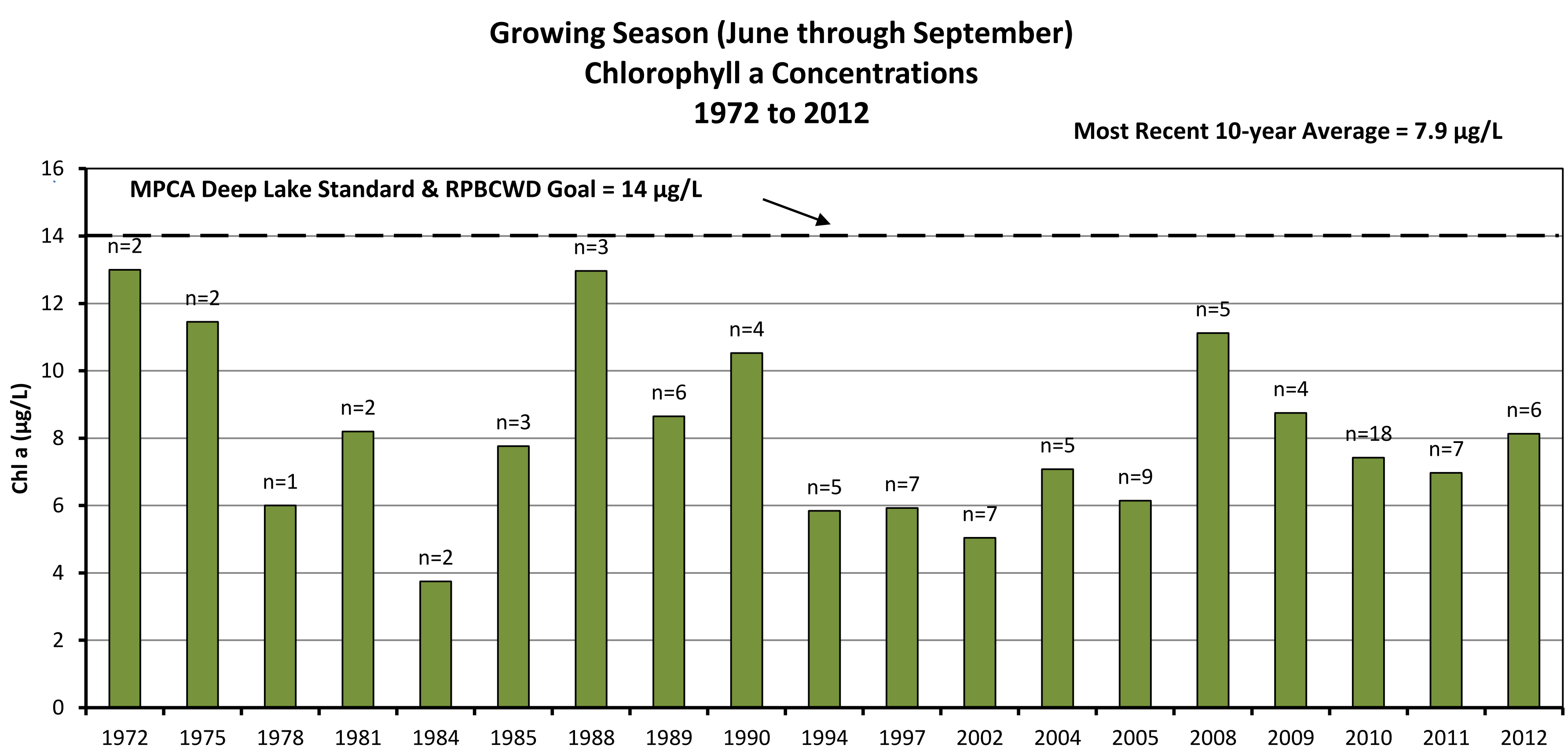


Figure 4
Lake Lucy
Historic Growing Season Water Quality
Total Phosphorus, Chlorophyll-a, and Secchi Disc Transparency





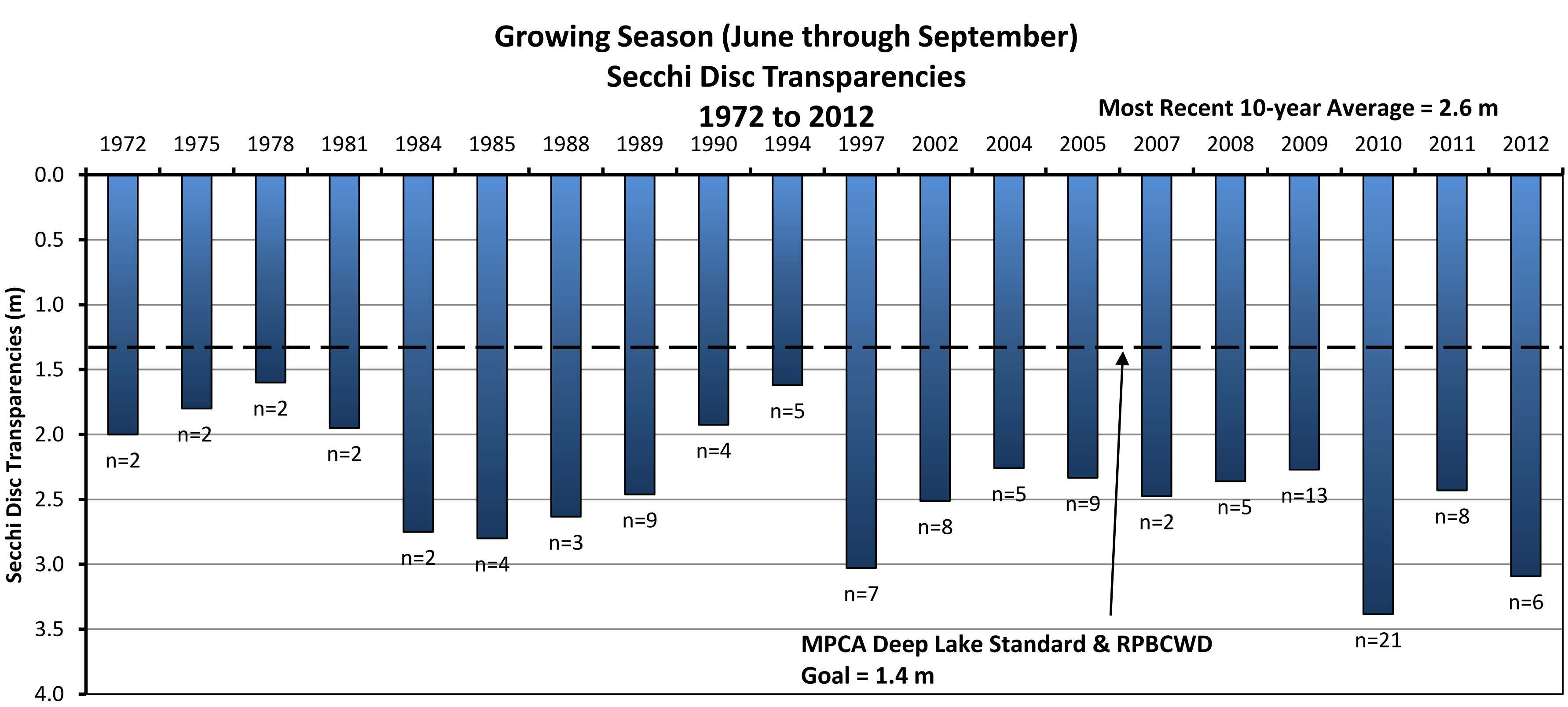


Figure 5
Lake Ann
Historic Growing Season Water Quality
Total Phosphorus, Chlorophyll-a, and Secchi Disc Transparency

2.5.1 Water Quality Relationships

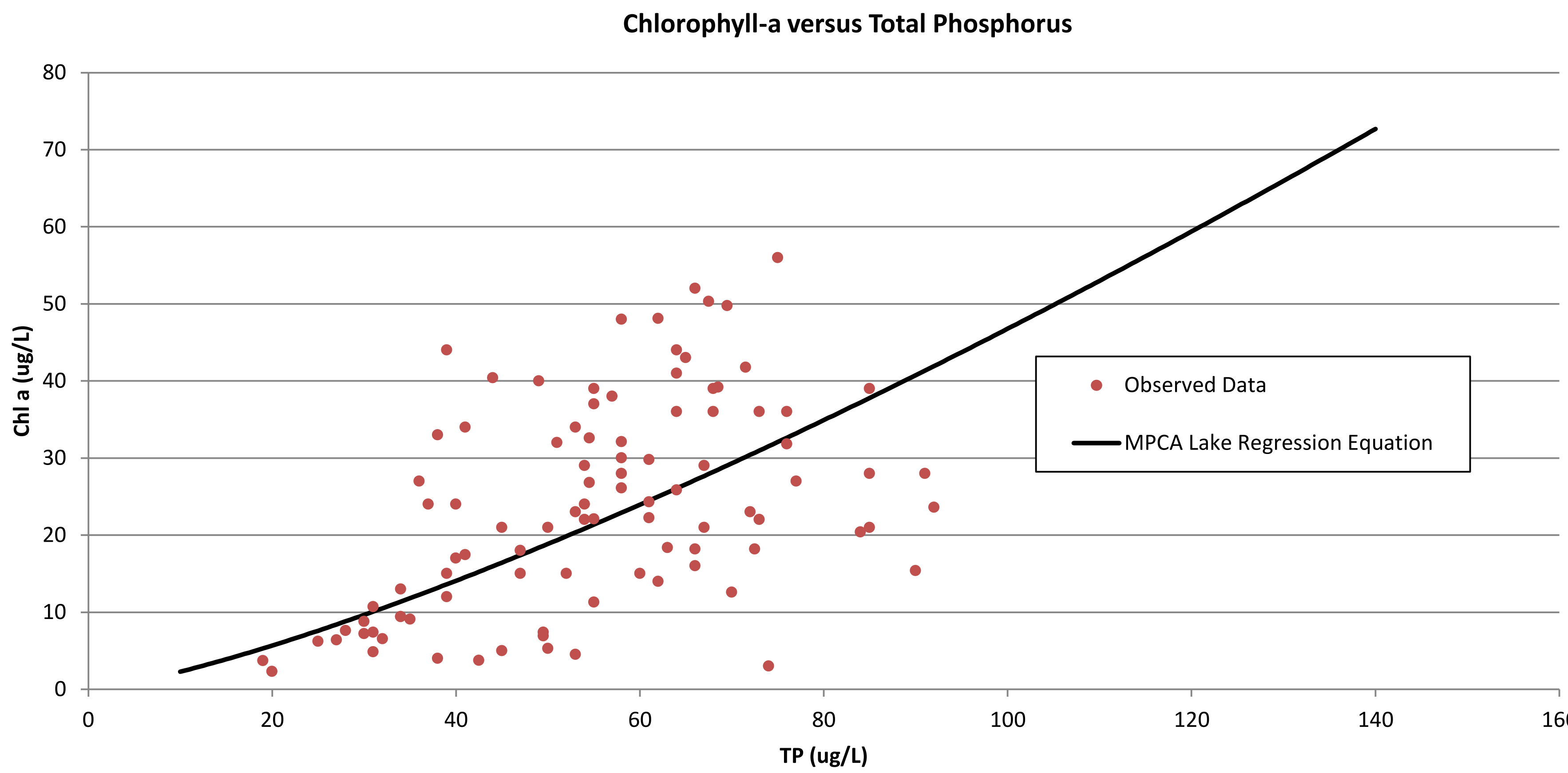
The compiled data for the water quality variables from Lake Lucy and Lake Ann were analyzed to develop relationships between the water quality parameters: total phosphorus, chlorophyll *a*, and Secchi depth. Relationships were evaluated based on individual sampling dates and based on the growing season 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. However, the relationships between the various water quality parameters based on actual data did not indicate a significant correlation. Therefore, 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 both Lake Lucy and Lake Ann. Figures 6 and 7 show the individual water quality data points for Lake Lucy and Lake Ann respectively, along with plots of the MPCA statewide regression equations.

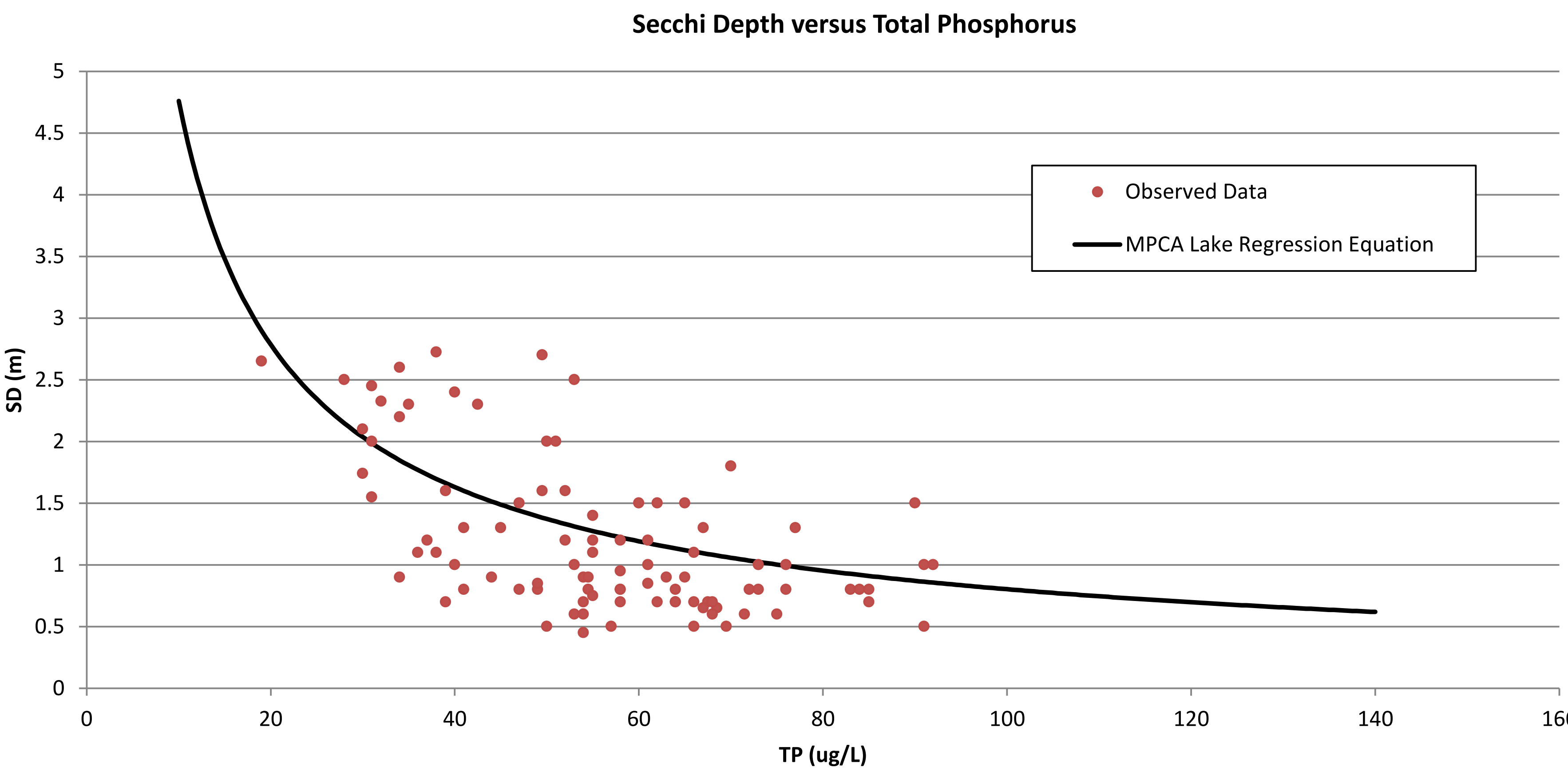
The statewide regression equations developed by the MPCA are summarized below:

$$\text{Log}_{10}\ \text{Chl}a = 1.31\ \text{Log}_{10}\ \text{TP} - 0.95$$

$$\text{Log}_{10}\ \text{Secchi} = -0.59\ \text{Log}_{10}\ \text{Chl}a + 0.89$$

$$\text{Log}_{10}\ \text{Secchi} = -0.81\ \text{Log}_{10}\ \text{TP} + 1.51$$





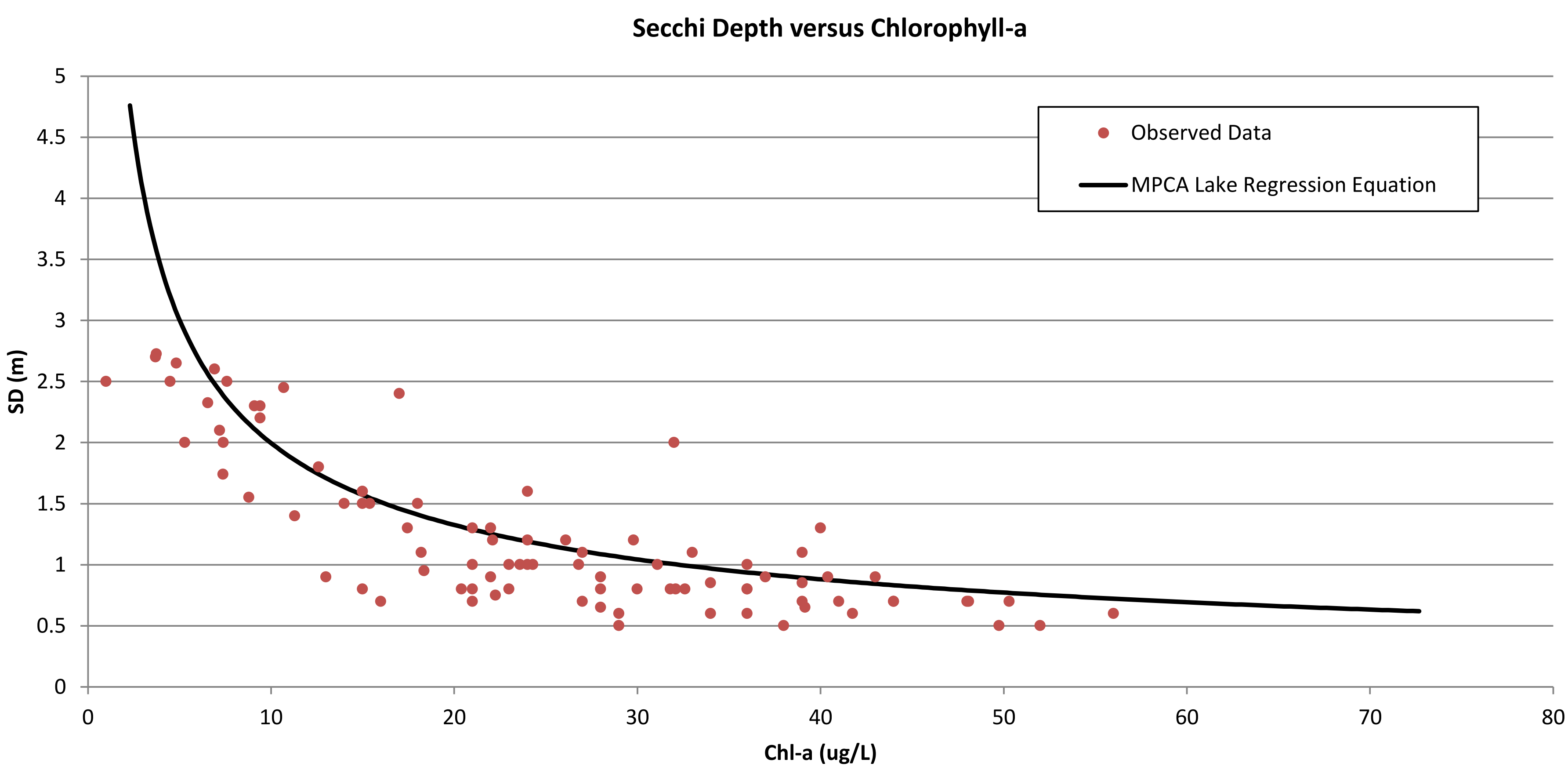
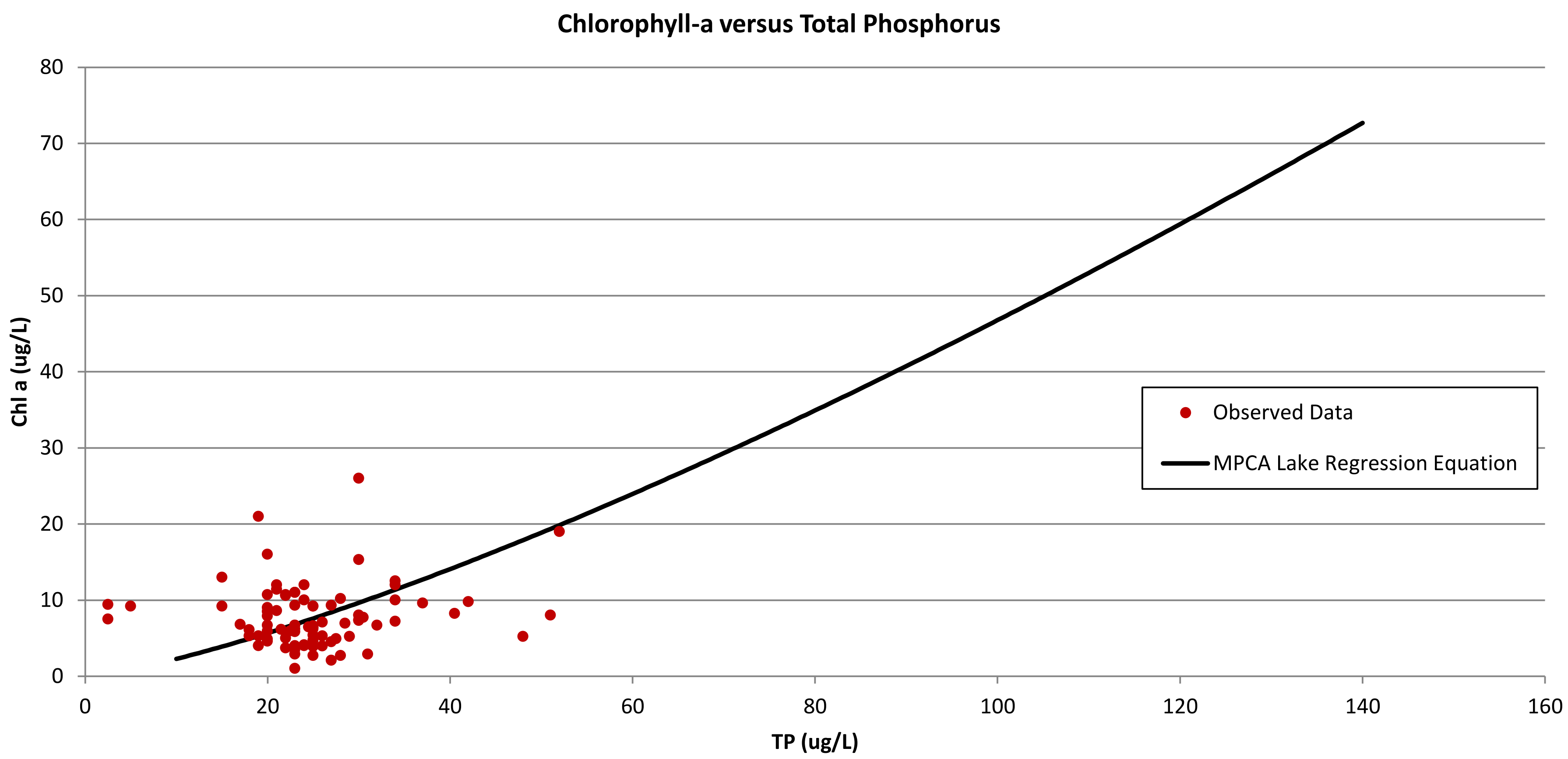
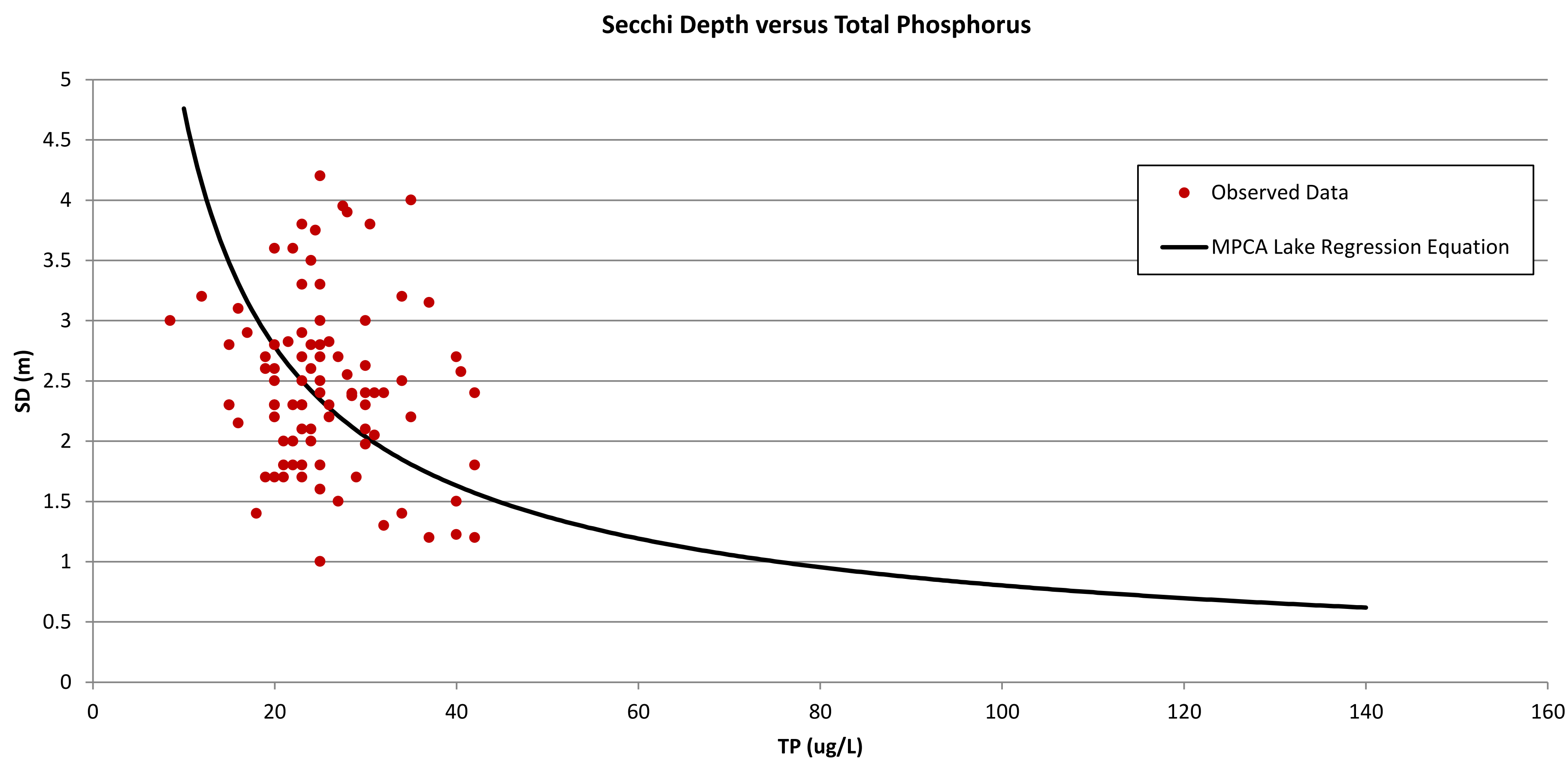


Figure 6
Lake Lucy
Water Quality Parameter
Regression Relationships





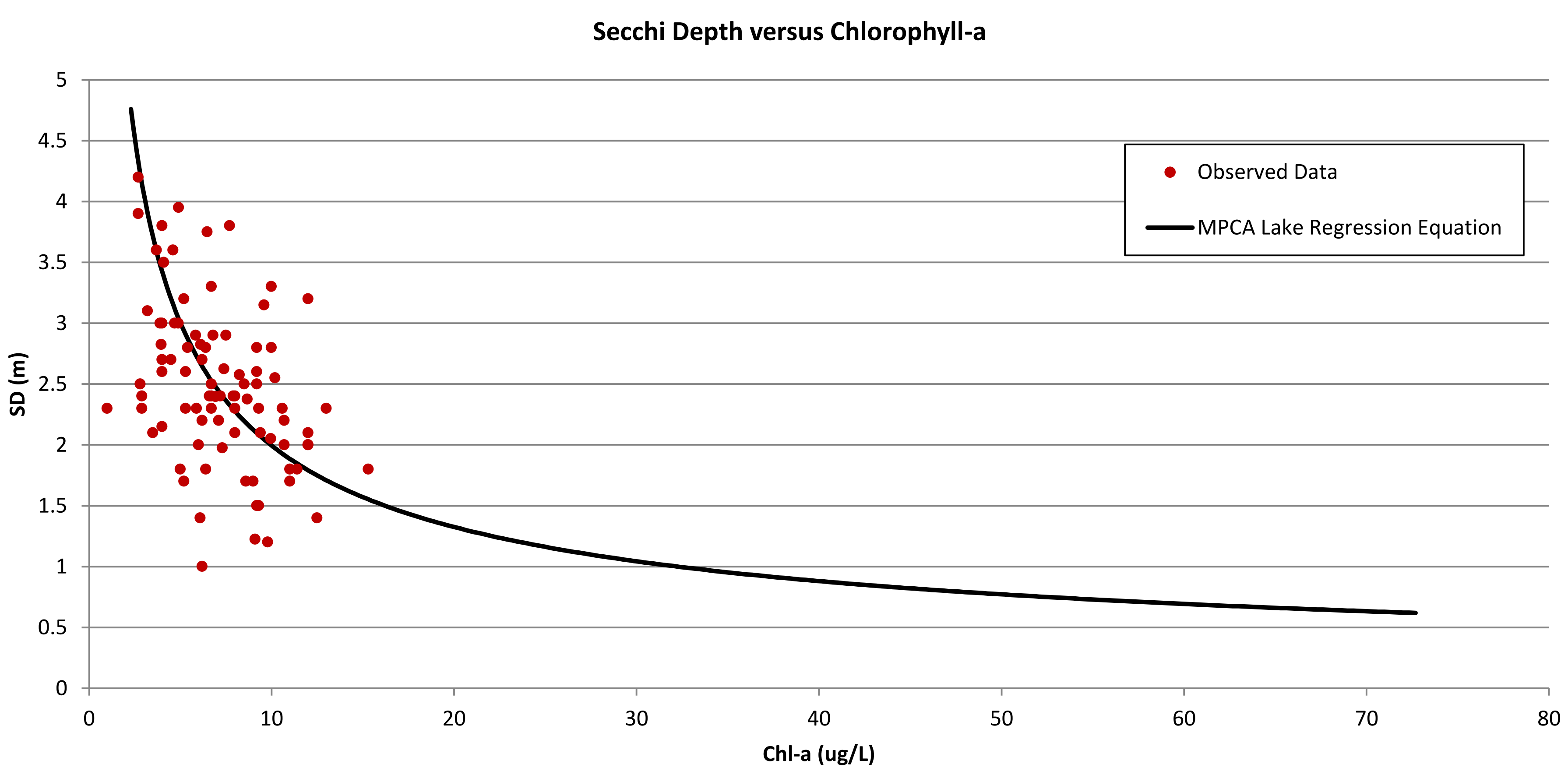


Figure 7
Lake Ann
Water Quality Parameter
Regression Relationships

2.5.3 Methylmercury In Fish Tissues

According to the MDNR and the Minnesota Department of Health (MDH), both Lake Lucy and Lake Ann have fish consumption advisories due to elevated levels of mercury in the fish tissues. Additionally, both lakes have been included as part of the statewide mercury impairment TMDL. To be considered impaired for mercury, more than 10% of a fish species in a lake or river have a mercury concentration in fillets that exceeds 0.2 parts per million (MPCA, 2013a).

In 2010, the RPBCWD collected methylmercury samples along the bottom sediments of Lake Ann. During the monitoring period, the levels of methylmercury increased throughout the summer, with the highest concentrations being observed in late September and early October, with peak concentrations of methylmercury around 0.58 ng/L. The average methylmercury concentration in Lake Ann over the entire sampling period was 0.37 ng/L. The increase in methylmercury appears to be correlated with the anoxic conditions and the reduced oxidation reduction potential observed in the hypolimnion of the lake.

The production of methylmercury in a lake can be influenced by a number of factors including the following: location compared to potential point sources of mercury, dissolved oxygen, temperature, sulfate concentrations, the total mercury in the system, dissolved organic carbon, and low (acidic) pH of the system (EPA, 2001; MPCA, 2007).

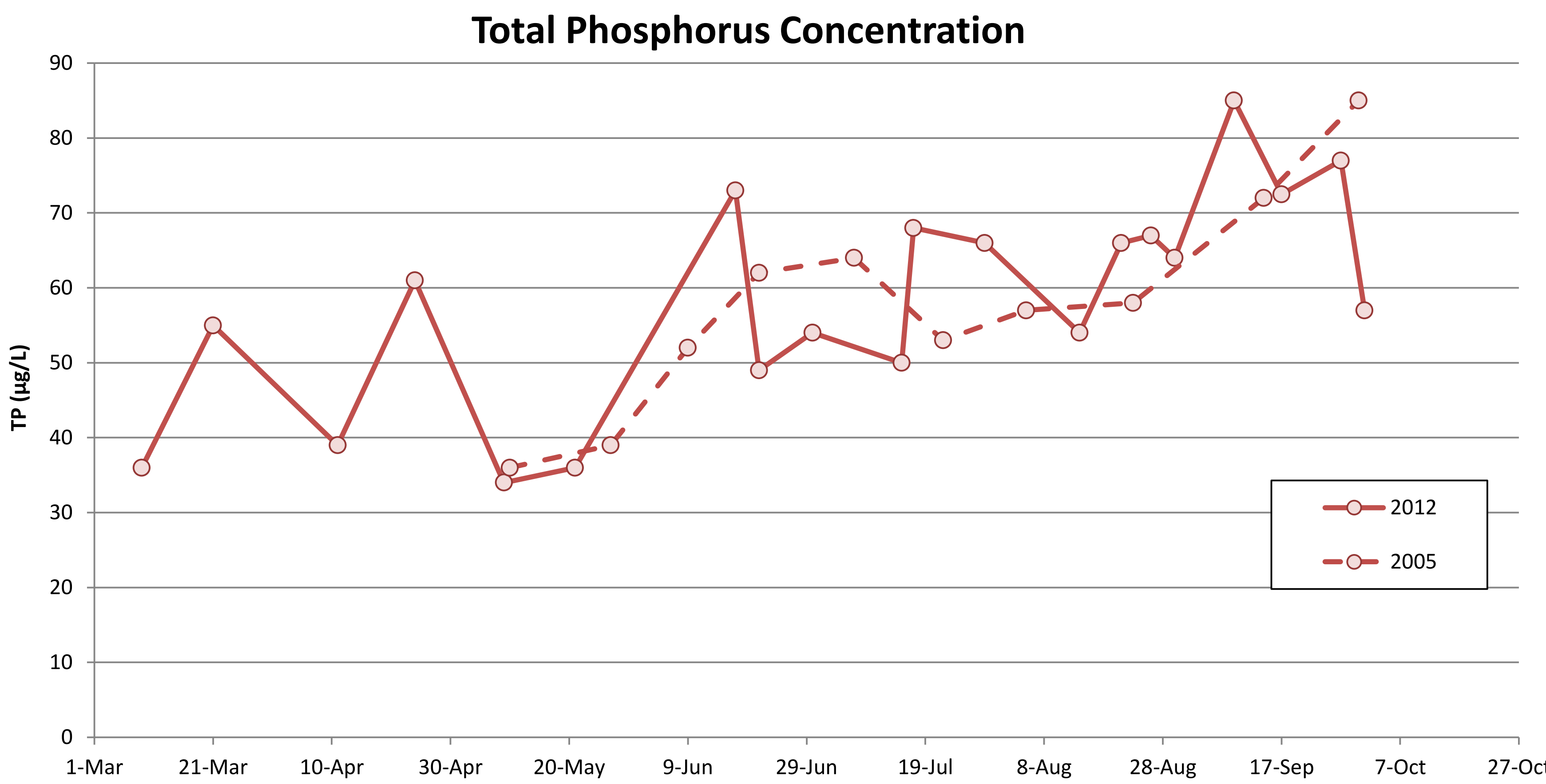
2.6 Water Quality Modeling Analysis

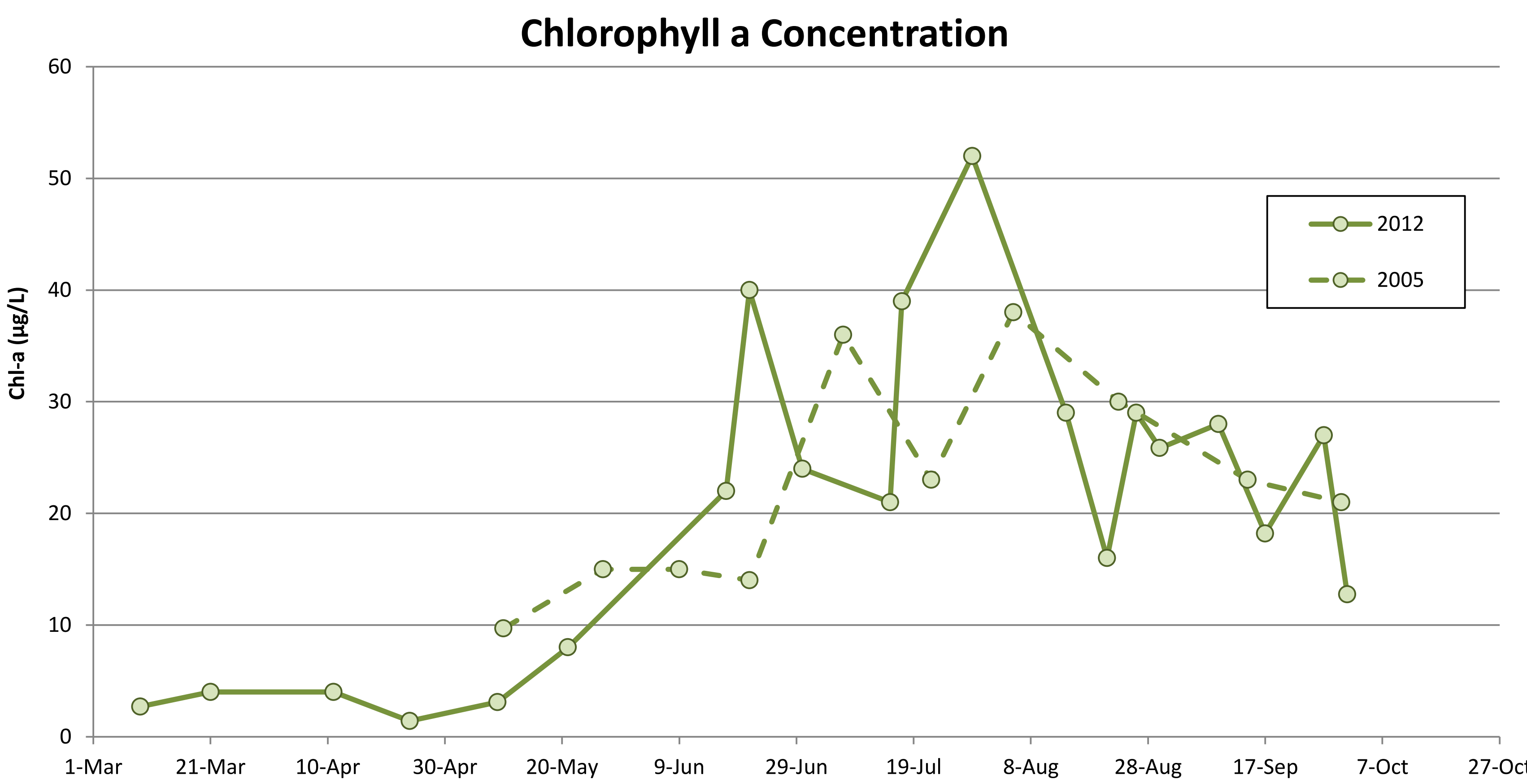
Two different years were selected to evaluate the water quality in Lake Lucy and Lake Ann, including 2005 and 2012. These years were selected because there was both water quality and lake level data available for both Lake Lucy and Lake Ann. Additionally, these years reflected different climatic conditions influencing water quality in these lakes.

2.6.1 Seasonal Patterns in the 2005 and 2012 Water Quality Conditions

The following section includes discussion of the seasonal patterns observed in the water quality during 2005 and 2012 in both Lake Lucy and Lake Ann. The focus of the discussion will primarily be on total phosphorus, chlorophyll *a*, and Secchi disc transparency.

Figure 8 and 9 shows the total phosphorus, chlorophyll *a*, and Secchi disc transparency for 2005 and 2012 in Lake Lucy and Lake Ann, respectively.





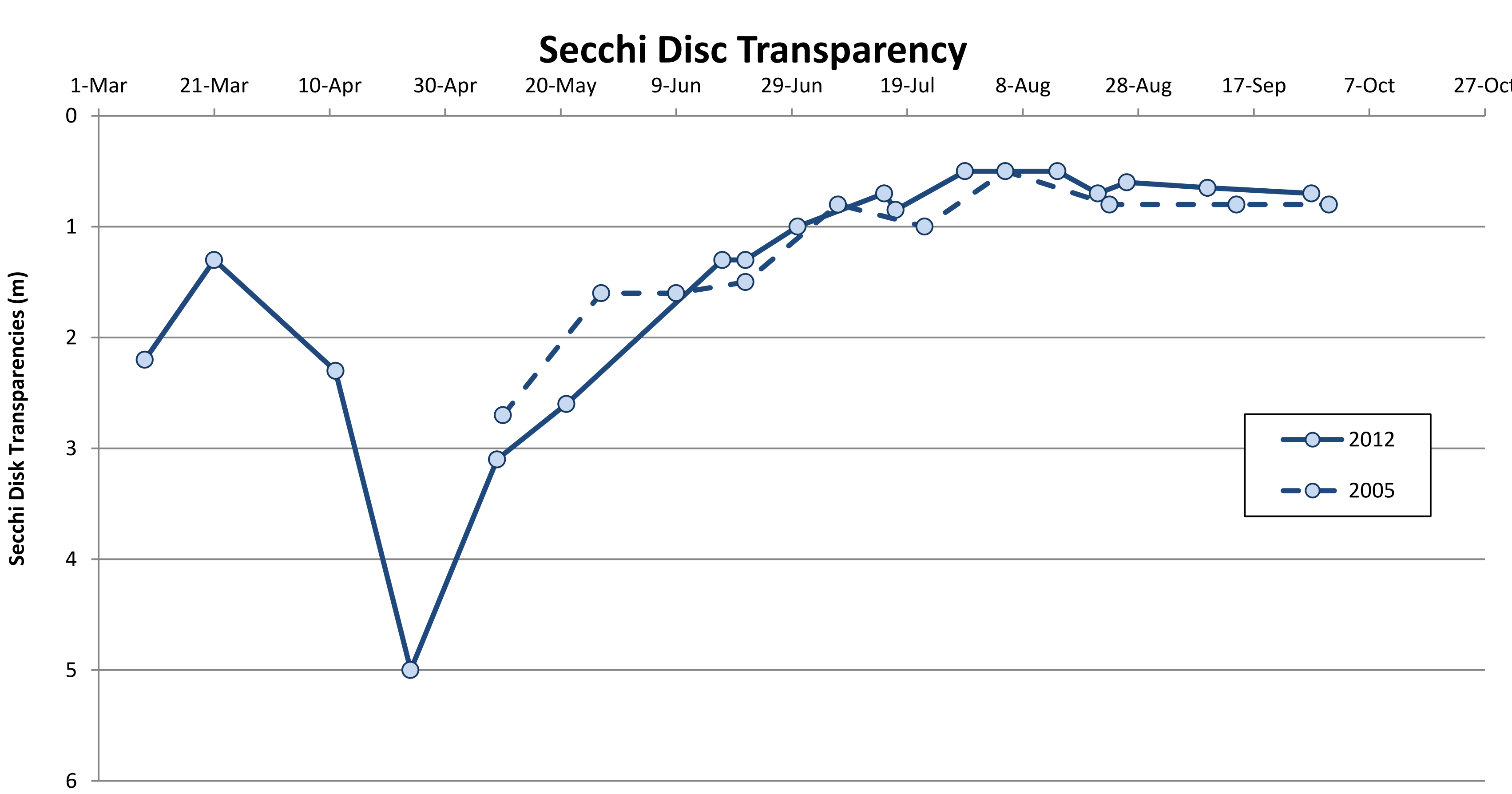
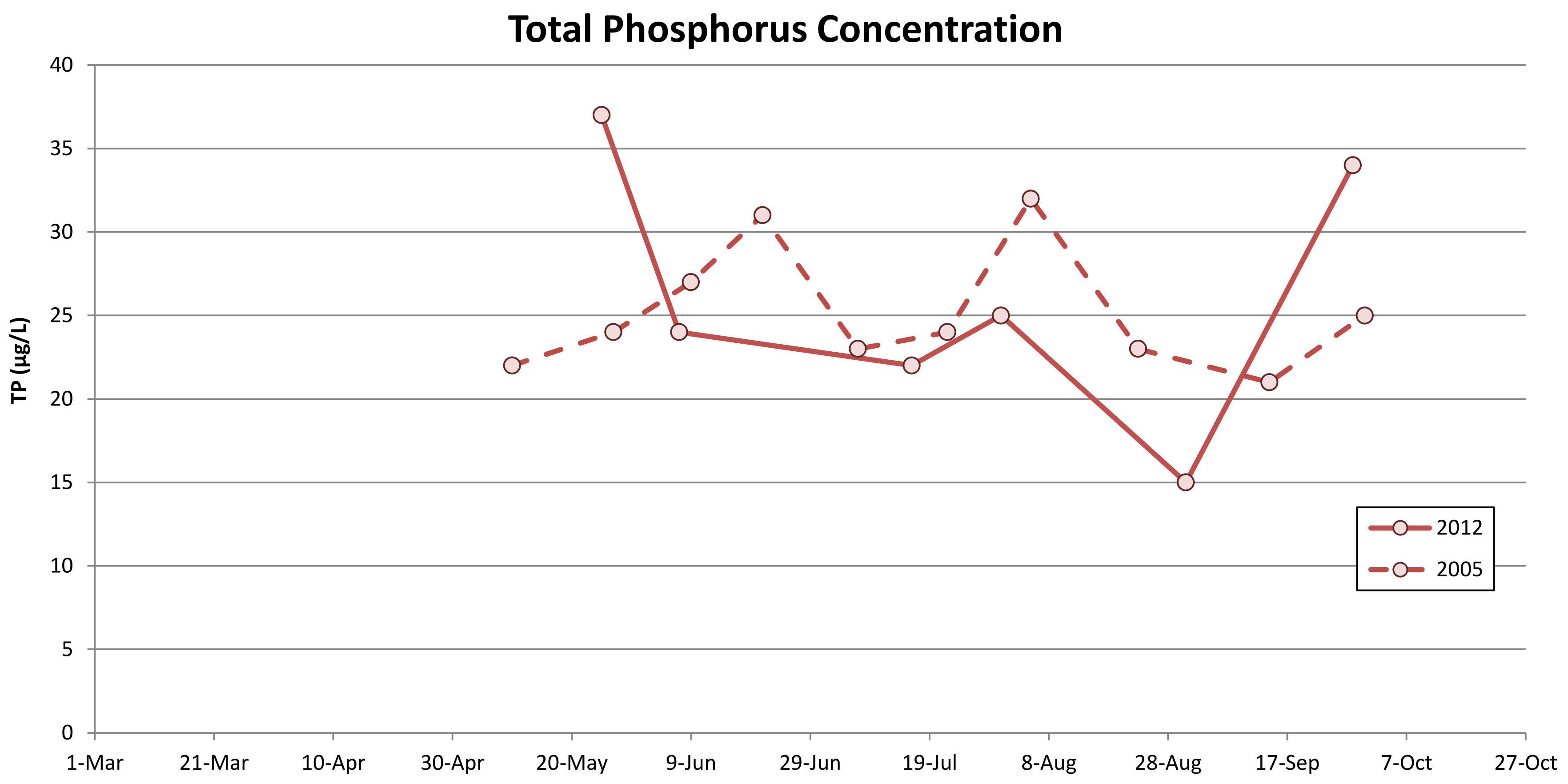
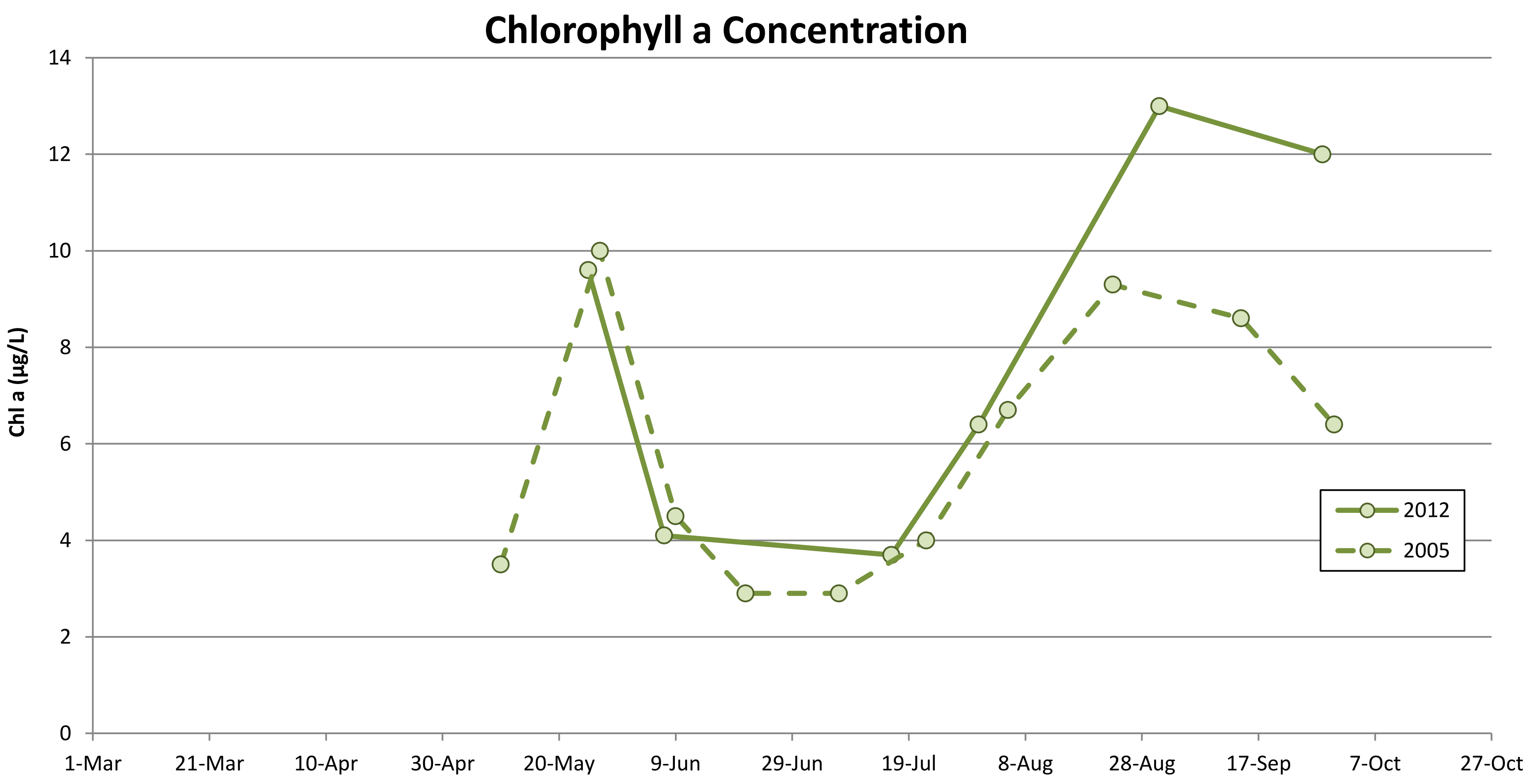


Figure 8
Lake Lucy 2005 and 2012
Seasonal Water Quality





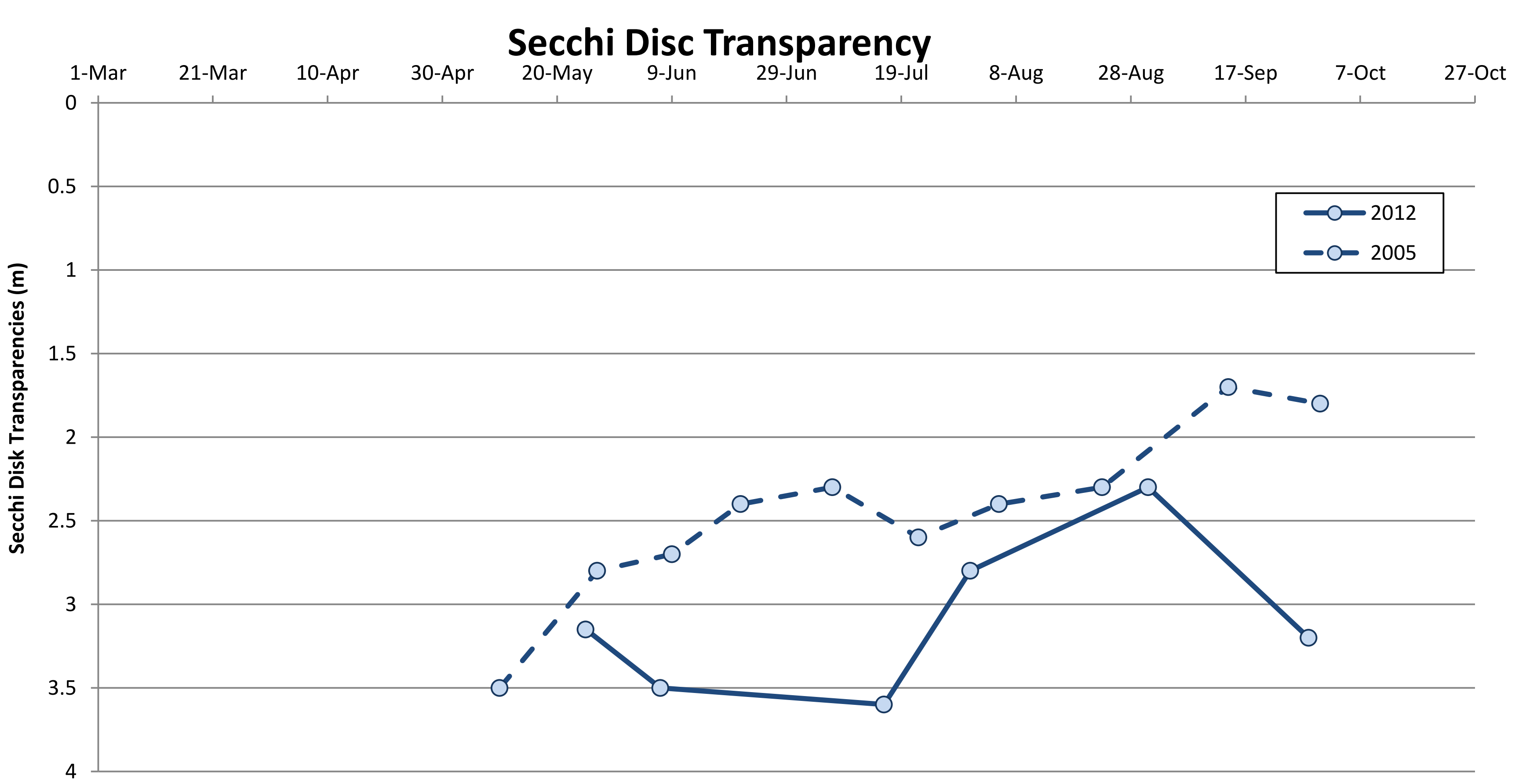


Figure 9
Lake Ann 2005 and 2012
Seasonal Water Quality

2.6.1.1 Total Phosphorus

In Lake Lucy, the total phosphorus concentrations at the beginning of the growing season in both 2005 and 2012 began in early May at 36 µg/L and 34 µg/L, respectively. These early season concentrations are typically the lowest concentration during the growing season. In both 2005 and 2012, the total phosphorus concentrations steadily increase over the growing season, with the peak phosphorus concentrations observed later in the growing season in early to mid-September, prior to the fall turnover. In both 2005 and 2012, the peak phosphorus concentration observed in Lake Lucy was 85 µg/L. These gradual increases in concentration over the season can often be associated with internal loading. Although the phosphorus concentrations generally increase over the growing season, in 2005, a smaller peak was observed in early July which can often be associated with the die back of Curlyleaf pondweed, which is present in the lake. In 2012, a similar peak was observed in early June, potentially associated with Curlyleaf pondweed. Although the timing is not typical of Curlyleaf pondweed die back, the 2012 season was unusually warm early in the year and may have resulted in an earlier die back. In general, the phosphorus concentrations in Lake Lucy would 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 Lake Lucy in 2005 was 63 µg/L while in 2012 the growing season average was 64 µg/L.

In Lake Ann, the total phosphorus concentrations at the beginning of the growing season in 2005 began around 22 µg/L in early May. In 2005, there were two peaks in the phosphorus concentrations in Lake Ann, the first peak in the end of June (31 µg/L) and a second peak in early August (32 µg/L). Curlyleaf pondweed is present in Lake Ann and may have contributed to the first peak in the end of June. The growing season average total phosphorus concentration in Lake Ann was 26 µg/L. In 2012, the first total phosphorus sample of the season was collected at the end of May with a concentration of 37 µg/L. This was also the highest phosphorus concentration during the season. During much of the 2012 growing season, the phosphorus levels dropped to concentrations below 25 µg/L, until a second peak was observed at the end of September (34 µg/L). The growing season average in 2012 was 26 µg/L.

2.6.1.2 Chlorophyll *a*

In Lake Lucy, the chlorophyll *a* concentrations at the beginning of the growing season (early May) in both 2005 and 2012 were 9.7 µg/L and 3.1 µg/L, respectively. These early season concentrations are typically the lowest concentration during the growing season. In both 2005 and 2012, the chlorophyll *a* concentrations peaked in mid-summer (late July/early August), with concentrations dropping off in later summer (late August/early September). In 2012, the peak chlorophyll *a* concentration was 38 µg/L with the summer average being 26.6 µg/L. In 2005, the peak chlorophyll *a* concentration was 52 µg/L with the summer average being 23.9 µg/L.

In Lake Ann, the chlorophyll *a* concentrations at the beginning of the growing season in 2005 began around 3.5 µg/L in early May. In 2005, there were two peaks in the chlorophyll *a* concentrations in Lake Ann, the first peak in the end of May (10 µg/L) and a second peak in mid-August (9.3 µg/L). The growing season average chlorophyll *a* concentration in Lake Ann was 6.1 µg/L. In 2012, the first chlorophyll *a* sample of the season was collected at the end of May with a concentration of 9.6 µg/L.

During much of the 2012 growing season, the chlorophyll *a* levels dropped through mid-July, when the concentrations began to increase until, until a second peak was observed at the end of August (13 μg/L). The growing season average in 2012 was 8.1 μg/L.

2.6.1.3 Secchi Disc Transparencies

In Lake Lucy, the Secchi disc transparencies began the 2012 growing season around 3.1 meters. However, data collected prior to May indicates that after the spring turnover, the Secchi disc transparency reached 5 meters in mid-April. The Secchi disc transparency gradually declined throughout the growing season, with transparencies less than 1 meter after the end of June. The 2012 growing season average transparency was 0.9 meters. A very similar trend in Secchi disc transparency was observed during the 2005 growing season, with a transparency of 2.7 meters at the beginning of May to transparencies of less than 1 meter by the end of June. The 2005 growing season average transparency was 1.0 meters.

In Lake Ann, the first Secchi disc transparencies measured in 2012 were greater than 3 meters. Transparency began to decline in July, with the worst transparency happening at the end of August. This decline in transparency correlates well with the increase in chlorophyll *a* concentrations during the same period. The 2012 growing season average Secchi disc transparency was 3.1 meters. In 2005, the transparency began at 3.5 meters at the beginning of the growing season, and a gradual decline in transparency was observed throughout the growing season. At the end of the season (September), the transparency was less than 2 meters. The 2005 growing season average Secchi disc transparency was 2.3 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 Lake Lucy and Lake Ann watersheds, to the lakes. P8 is a useful diagnostic tool for evaluating and designing watershed improvements and Best Management Practices (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

To update the Lake Lucy and Lake Ann P8 watershed model to reflect the current watershed conditions, the subwatershed divides and drainage patterns were updated using more recent topographic data (MDNR, 2011), storm sewer data, record drawings, and other information from the City of Chanhassen, and development plans submitted as part of the RPBCWD permit review process for projects implemented after the original UAA was completed through 2006. New watershed inputs were developed using more recent land use data (based on information provided by the City of Chanhassen) in combinations with soils data for the area.

Inputs for the ponds and wetlands included in the watershed model developed for the original UAA were maintained. For new ponds and wetland areas included in the updated P8 model of the Lake Lucy and Lake Ann watersheds, the dimensions and outlet information were developed based on the following sources: RPBCWD Riley Creek XP-SWMM modeling project (Barr Engineering, 2007), development plans submitted as part of the RPBCWD permit review process, drawings and storm sewer information provided by the City of Chanhassen, and the *City of Chanhassen 2nd Generation Surface Water Management Plan* (August 2006).

Stormwater runoff monitoring was not done as part of the UAA update, so the original pollutant loading assumptions from the original Lake Lucy and Lake Ann watershed model were preserved.

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 upon 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 two different climatic scenarios.

- 2005 climatic conditions: May 2004- September 2005

2012 climatic conditions: May 2011- September 2012The watershed model requires hourly precipitation and daily temperature data for each of the modeled time periods. For the 2005 climatic conditions, the hourly data from the Minneapolis-St. Paul International Airport NWS stations (MSP) was used and adjusted based on comparison of the precipitation amounts at MSP to the data collected at the Chanhassen NWS station. For 2012 climatic conditions, a continuous hourly precipitation file was developed based on local data collected by the RPBCWD at Lake Susan (2011) and Lake Lucy (2012). 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.

The water year precipitation (October – September) and the growing season (June – September) precipitation for 2005 and 2012 are summarized in Table 3.

Table 3 Summary of 2012 and 2005 Precipitation Conditions

Year	Water Year Precipitation (inches)	Growing Season Precipitation (inches)
2005	36.9	22.1
2012	28.6	10.3

For both the 2005 and 2012 climatic conditions, the daily temperature data was obtained from the NWS station at the Minneapolis-St. Paul International Airport station.

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, 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 that can then be compared to observed lake levels, which can be used to estimate groundwater exchange and verify the estimated watershed model runoff volumes.

For Lake Lucy and Lake Ann, 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 estimated based on the monthly pan evaporation values collected at the University of Minnesota St. Paul Campus Climatological Observatory, applying a pan coefficient of 0.7 and converted to a daily value. The pan evaporation data are typically available from mid-April through mid-October. For the months of November through March, evaporation was assumed to be zero.

Table 4 summarizes the stage-storage-discharge relationship developed for Lake Lucy based on basin bathymetry data (see Figure 1) and outlet characteristics. Table 5 summarizes the stage-storage-discharge relationship developed for Lake Ann based on basin bathymetry data (see Figure 1) and outlet characteristics. As previously discussed, due to the fact that the outlet elevation from Lake Lucy is lower than the outlet elevation from Lake Ann (located downstream), discharge from Lake Lucy is dependent on the water levels in Lake Ann. Therefore, actual lake level data for Lake Ann were used to determine which rating curve was applied to estimate discharge from Lake Lucy. Because Lake Lucy is located immediately upstream of Lake Ann, the estimated daily discharge volumes from Lake Lucy were used as an input to Lake Ann water balance model.

Table 4 Stage-Storage-Discharge for Lake Lucy

Elevation	Water Surface Area (acres)	Cumulative Storage Volume (acre-feet)	Discharge, Lake Ann < 955.5 ft MSL (cfs)	Discharge, 955.5 ft MSL < Lake Ann < 956.1 ft MSL (cfs)	Discharge, Lake Ann > 956.1 ft MSL (cfs)
935.3	0.0	0.0	0.0	0.0	0.0
955.5	88	558	0.0	0.0	0.0
956.0	93	607	0.4	0.2	0.0
956.1	95	617	0.6	0.3	0.0
957.0	106	707	8	5	1
958.0	119	817	33	33	33

Table 5 Stage-Storage-Discharge for Lake Ann

Elevation	Water Surface Area (acres)	Cumulative Storage Volume (acre-feet)	Discharge (cfs)
916.4	0.6	0.0	0.0
956.1	119	2005	0.0
957.0	122	2114	6
958.0	127	2237	27

The lake level data used for the calibration period (May 1, 2011 through September 30, 2012) was 15-minute data collected by the RPBCWD, converted to daily average lake levels. For Lake Lucy, the data were available for 2012. For Lake Ann, the data were collected in 2010, 2011, and 2012. Because lake level data was available for both Lake Lucy and Lake Ann in 2012, a correlation was developed between the daily average lake level datasets ($r^2 = 0.93$). This relationship was used to estimate the 2011 lake levels in Lake Lucy for use in the water balance modeling.

To verify the 2012 water balance model calibration, a water balance was also developed for 2005 and the model results compared to the lake level data available for that year as well.

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.

To evaluate the lake's response to external and internal loads of phosphorus under a range of precipitation conditions, in-lake water quality models were created to route the watershed model phosphorus loads through the lake for the following time periods:

- 2005 climatic conditions: May 2004- September 2005

2012 climatic conditions: May 2011 - September 2012 Water quality data has been collected in both Lake Lucy and Lake Ann since the early 1970s. For the initial calibration of the in-lake water quality models, the 2012 water quality data was used. The 2011 macrophyte survey data from the University of Minnesota was used to estimate the coverage and density of Curlyleaf pondweed in each lake. Additionally, in-lake water quality model was calibrated to 2005 water quality data as well.

For the two climatic scenarios, the 2011 point-intercept macrophyte survey data from the University of Minnesota was used to estimate the coverage and density of Curlyleaf pondweed and coontail in each lake. Watershed runoff loads as predicted by P8 were developed specifically for each year being evaluated.

The in-lake water quality modeling methodology used for the update to the Lake Lucy and Lake Ann UAA is two-fold: First, the spring concentration is estimated with a steady-state, annual empirical lake model. Second, a spreadsheet mass balance model based on Dillon and Rigler (1974) is used that starts with the estimated spring concentration (from the empirical model) and routes external and internal phosphorous loads through the lake over many time steps throughout the summer season (May through September).

The method described in the following sections was used for existing land use conditions under the two climatic conditions to estimate the internal loading rates and groundwater exchange and to understand the variability in the sources of phosphorus to the lakes. Once calibrated, the models could be used predictively to evaluate the lake phosphorus concentrations under a variety scenarios, including future land use conditions and following the implementation of different watershed BMP and in-lake management strategies.

2.6.3.2.1 *Predicting Springtime Concentrations in Lake Lucy and Lake Ann*

Water quality monitoring data from Lake Lucy was used to determine the empirical model that could best predict the spring concentration in the lake. For Lake Lucy, the Dillon and Rigler model with a phosphorus retention term based on Chapra (1975) was used to predict the spring total phosphorus concentration.

$$P_{SPRING} = \frac{L(1-R)}{z\rho}$$

where:

P_{SPRING} = spring total phosphorus concentration (µg/L)
L = areal total phosphorus loading rate (mg/m²/yr)
R = retention coefficient as based on Chapra (1975)
= $v_s/(v_s + q_s)$, where v_s = 3.5 m/yr
q_s = annual areal water outflow load (m/yr)
= Q/A
z = lake mean depth (m)
ρ = hydraulic flushing rate (1/yr)
= 1/(hydraulic residence time) = 1/(V/Q)
Q = annual outflow (m^3/yr)
V = lake volume (m^3)
A = lake surface area (m^2)

Water quality monitoring data from Lake Ann was used to determine the empirical model that could best predict the spring concentration in the lake. For Lake Ann, the Dillon and Rigler model with a phosphorus retention term from Larsen and Mercier (1976) was used to predict the spring total phosphorus concentration.

$$P_{SPRING} = \frac{L(1-R)}{z\rho}$$

where:

P_{SPRING}	=	spring total phosphorus concentration (μg/L)
L	=	areal total phosphorus loading rate ($mg/m^2/yr$)
R	=	retention coefficient as defined by Larsen and Mercier (1976)
	=	$1/(1+\rho^{(1/2)})$
z	=	lake mean depth (m)
ρ	=	hydraulic flushing rate (1/yr)
	=	1/(hydraulic residence time) = 1/(V/Q)
Q	=	annual outflow (m^3/yr)
V	=	lake volume (m^3)

Early summer, summer-average and fall overturn concentrations, however, are often not well represented in steady state empirical models such as Dillon and Rigler. Most empirical phosphorus models assume that the lake to be modeled is well mixed, meaning that the phosphorus concentrations within the lake are uniform. This assumption is useful in providing a general prediction of lake conditions (especially for springtime concentrations), but it accounts for neither the seasonal changes in phosphorus concentrations nor the effect of internal phosphorus load that can occur in a lake throughout the summer and fall. Therefore, mass balance models are needed that look at the effect of the total phosphorus loads at different times throughout the year to provide reasonable predictions of summer-average epilimnetic lake phosphorus concentrations.

Historical water quality data for Lake Lucy and Lake Ann show that the phosphorus concentrations vary significantly during the summer as a result of additional watershed runoff and internal loading of phosphorus. For this reason, the Dillon and Rigler equation was used to calculate a spring concentration in the lake, but a mass balance model that builds off of this predicted spring concentration was used to calculate the in lake phosphorus concentrations at various times throughout the growing season.

2.6.3.2.2 Accounting for Seasonal Variation in External and Internal Loads in the In-Lake Water Quality Mass Balance Models for Lake Lucy and Lake Ann

As previously mentioned, a spreadsheet mass balance model based on Dillon and Rigler (1974) was used to reconcile phosphorus loadings from the watershed with phosphorus concentrations observed in the lake. The in-lake mass balance model routes external and internal phosphorous loads through the lake over the summer season (from May 1 through September 30).

In the mass balance model, internal load from the lake sediments was calculated by deduction, using the following equation, calculated at time intervals varying from a few days to two weeks (dependent on the frequency of the water quality sampling):

Internal P = Observed P + Outflow P + Coontail Uptake P – Watershed Runoff P - Internal Load P from Upstream Ponds – P from Curlyleaf Pondweed - Atmospheric P – Upstream Lakes P – P Initial ± Groundwater P

Although in-situ measurements of sediment oxygen demand were measured in Lake Lucy and Lake Ann in 2009 (HydrO_2, Inc, 2009), sediment core data have not been collected and analyzed for mobile phosphorus (mobile P) in Lake Lucy and Lake Ann. Mobile phosphorus (mobile P) measures the maximum potential for internal loading rate of phosphorus from the lake sediments. However, the internal loading rates from the sediments could be estimated from the models for each lake and were compared and compared to the range of mobile P maximum release rates determined for other lakes in the Twin Cities metropolitan area to help verify that the estimated internal loads are reasonable (Huser et al., 2009; Pilgrim et al., 2007).

Internal load from Curlyleaf pondweed was calculated within the mass balance model, using an estimated stem density (based on the coverage and density estimated from the recent macrophyte surveys), an estimated grams dry weight per stem, and an estimated phosphorus content per dry weight (these values were measured as a part of a study of Big Lake in Wisconsin (Barr, 2001)).

Uptake of phosphorus by coontail was also estimated in the model, using average daily uptake rates from Lombardo and Cooke (2003). The biomass density measurements were related to wet weight based on data by Newman, 2004.

2.7 Summary of Water Quality Modeling and Phosphorus Source Assessment

2.7.1 Discussion of External Loads

The following section discusses the results of the watershed and in-lake water quality modeling, summarizing the external loading sources to Lake Ann and Lake Lucy.

2.7.1.1 Atmospheric Deposition

Phosphorus loading from atmospheric deposition onto the lake surface was estimated assuming a 0.2615 kg/ha/yr rate (Barr, 2005). For Lake Lucy, this loading rate was applied to the surface area of the lake resulting in an annual TP load of 21 pounds. For Lake Ann, this loading rate was applied to the surface area of the lake resulting in an annual TP load of 28 pounds.

2.7.1.2 Watershed Loads

The watershed model was used to estimate the surface runoff to the lakes from the direct watershed (not passing through upstream lakes) based on actual observed climatic data (precipitation and temperature) for Lake Lucy and Lake Ann. The estimated water and phosphorus loads to each lake from the direct watershed are summarized for 2005 and 2012 in Table 6. Figure 10 shows the relative contributions of the annual watershed phosphorus (as a percentage) from each major drainage area to Lake Lucy and Lake Ann.

Table 6 Watershed Load Summary for Lake Lucy and Lake Ann

Lake	Parameter	2005 Water Year (10/1/2004 – 9/30/2005)	2012 Water Year (10/1/2011 – 9/30/2012)
Lake Lucy	Watershed Runoff Water Load (acre-ft)	186	221
	Watershed Runoff Total Phosphorus Load (lbs)	133	148
Lake Ann	Watershed Runoff Water Load (acre-ft)	11	20
	Watershed Runoff Total Phosphorus Load (lbs)	29	42

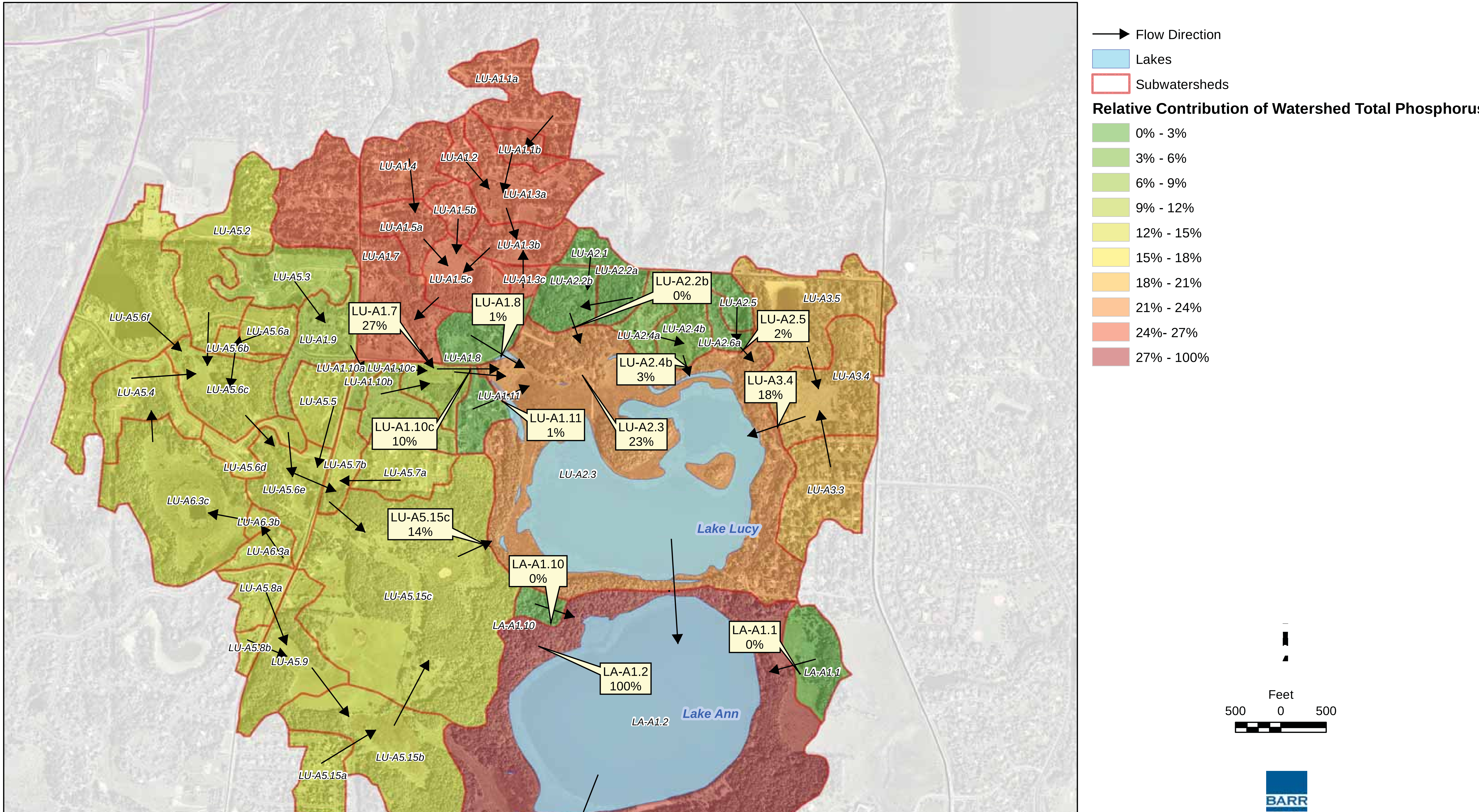


Figure 10
RELATIVE CONTRIBUTION (AS A %) OF EACH MAJOR DRAINAGE AREA TO THE ANNUAL WATERSHED PHOSPHORUS LOAD
Lake Lucy and Ann UAA Update
RPBCWD

2.7.1.3 Surficial Groundwater

Based on the water balance modeling for each lake, it appears that there were surficial groundwater inflows into Lake Lucy and Lake Ann. The estimated total phosphorus concentration for the surficial groundwater inflows was assumed to be 25 μg/L which is typical in groundwater in the Twin Cities metropolitan area (USGS, 2005). Table 7 summarizes the estimated surficial groundwater contributions to Lake Lucy and Lake Ann.

Table 7 Surficial Groundwater Load Summary for Lake Lucy and Lake Ann

Lake	Parameter	2005 Water Year (10/1/2004 – 9/30/2005)	2012 Water Year (10/1/2011 – 9/30/2012)
Lake Lucy	Surficial Groundwater Load (acre-ft)	63	53
	Surficial Groundwater Total Phosphorus Load (lbs)	6	5
Lake Ann	Surficial Groundwater Load (acre-ft)	58	51
	Surficial Groundwater Total Phosphorus Load (lbs)	4	3

2.7.1.4 Upstream Lakes

The mass balance modeling accounts for the water and phosphorus loads from upstream water bodies (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. For Lake Lucy, there are no upstream water bodies and the watershed runoff generated by the watershed model accounts for the entire watershed to the lake. For Lake Ann, Lake Lucy is located immediately upstream. Water and phosphorus loads from Lake Lucy to Lake Ann were estimated based on the Lake Lucy water balance model and the measured water quality data during the growing season. Table 8 summarizes the estimated loads from Lake Lucy to Lake Ann.

Table 8 Upstream Water Body Load Summary to Lake Ann

Parameter	2005 Water Year (10/1/2004 – 9/30/2005)	2012 Water Year (10/1/2011 – 9/30/2012)
Lake Lucy Water Load (acre-ft)	272	252
Lake Lucy Total Phosphorus Load (lbs)	59	38

2.7.1.5 Internal Loads from Upstream Ponds and Wetlands

The RPBCWD collected monitoring data (total phosphorus) from two ponds/wetlands in the Lake Lucy watershed collected in August 2012 indicated that one of the water bodies may potentially be acting as a source of phosphorus to Lake Lucy (LU-A1.9) while the other pond (LU-A1.11) had phosphorus levels typical of a stormwater pond (and likely is not acting as a source of phosphorus).

The watershed model is not able to predict the potential for internal loading from ponds or wetlands in a watershed, so to estimate the impact of the additional loading from pond LU-A1.9 the monitored total phosphorus concentration in the pond was compared to the discharge total phosphorus concentration as estimated by the watershed model during the storm events in August 2012. The difference between the predicted concentration and the monitored concentration was then applied to the estimated discharge volume to estimate the additional phosphorus load from pond LU-A1.9. The watershed modeling indicated that pond LU-A1.9 only discharged downstream during one precipitation event during August 2012.

The estimated load from pond LU-A1.9 was only 0.2 lbs, contributing less than 1 percent of the total phosphorus load to Lake Lucy.

Table 9 Estimated Internal Loads from Upstream Ponds and Wetlands to Lake Lucy

Pond/Wetland	Parameter	2012 Water Year (10/1/2011 – 9/30/2012)
LU-A1.9	Additional Total Phosphorus Load due to Internal Loading (lbs)[1]	0.2

1 – Monitoring data from Pond LU-A1.9 not available in 2005 and was assumed to be zero

2.7.2 Discussion of Internal Loads

The following section discusses the results of the in-lake water quality modeling, summarizing the internal loading sources to Lake Ann and Lake Lucy.

2.7.2.1 Curlyleaf Pondweed

For the 2012 in-lake model, the 2011 point-intercept macrophyte survey data collected by the University of Minnesota was used to estimate the coverage and density of Curlyleaf pondweed in both Lake Lucy and Lake Ann and estimate the potential phosphorus loading associated with the senescence of Curlyleaf pondweed in each of these systems. It was assumed that the macrophyte coverage and density measured in 2011 would be the same in 2012. In Lake Lucy, it was assumed that approximately 40 percent of the lake surface area was covered with low density, non-nuisance Curlyleaf pondweed. In Lake Ann, the 2011 macrophyte surveys indicated that Curlyleaf pondweed was present but not a significant macrophyte in the lake. It was assumed that approximately 1 percent of the Lake Ann surface area was covered with low density, non-nuisance Curlyleaf pondweed.

For the 2005 in-lake models, the 2004 surveys provided a general estimate of relative coverage and density of macrophytes observed in the lake. In Lake Lucy, the June 2004 survey indicated that Curlyleaf pondweed covered about 30-40 percent of Lake Lucy at a low to moderate density. In Lake Ann, the June 2004 survey indicated that Curlyleaf pondweed was present at a low density at a few sites around the lake. Because the relative coverage and density of Curlyleaf pondweed observed in 2004 in Lake Lucy and Lake Ann were similar to what was observed in 2011, the assumptions used in the 2012 models were also used in the 2005 models for Lake Lucy and Lake Ann. Table 10 summarizes the estimated contributions of Curlyleaf pondweed to the phosphorus budgets of Lake Lucy and Lake Ann.

Table 10 Curlyleaf Pondweed Phosphorus Loads to Lake Lucy and Lake Ann

Lake	Parameter	2005 Water Year (10/1/2004 – 9/30/2005)	2012 Water Year (10/1/2011 – 9/30/2012)
Lake Lucy	Curlyleaf Pondweed Total Phosphorus Load (lbs)	27	35
Lake Ann	Curlyleaf Pondweed Total Phosphorus Load (lbs)	1	1

2.7.2.2 Benthivorous Fish Activity

Although carp and other rough fish (e.g., bullheads) have historically been present in Lake Lucy and Lake Ann, the relative carp densities estimated in each lake would suggest that carp activity does not have a significant impact on the observed water quality in the lakes. The biomass of carp in Lake Lucy in 2010 was approximately 70 kg/ha, a relatively low biomass level. After the carp seining in January 2011, the biomass of carp is currently less than 20 kg/ha, a very low level. Based on electrofish surveys in 2009 and 2010 in Lake Ann, it was estimated that carp densities in Lake Ann were half of that is Lake Lucy (also very low).

As a result, we assumed that the activities of carp and other benthivorous fish are not a significant source of phosphorus in the Lake Lucy and Lake Ann systems and were not quantified as part of the in-lake water quality modeling in 2005 or 2012.

2.7.2.3 Sediment Release

For both Lake Lucy and Lake Ann, internal loading appears to be a significant source of phosphorus to each of the lakes during the growing season. Table 11 summarizes the estimated internal sediment loads and the average release rate over the entire surface area of the lake to Lake Lucy and Lake Ann, based on the water quality modeling.

Review of dissolved oxygen and total phosphorus depth profiles (available in 1985, 1997, 2004, 2010, and 2012) indicate that in Lake Lucy can experience significant internal loading from the sediments. Lake Lucy does thermally stratify for periods during the growing season. Based on the in-situ measurements of the sediment oxygen demand ($HydrO_2$, Inc, 2009), the mean sediment oxygen demand in Lake Lucy is 1.87 g $O_2/m^2/d$. The bottom sediments are often under anoxic conditions for much of the growing season and elevated phosphorus levels are observed in the hypolimnion. Additionally, the model inferred average rate of phosphorus release from the sediments in Lake Lucy (over the entire lake area) based on the 2005 and 2012 in-lake modeling ranged from 1.3 to

1.6 mg/m^2/d. These rates fall within the range that has been observed in several Twin Cities metropolitan area lakes (Huser et al., 2009; Pilgrim et al., 2007).

Review of dissolved oxygen and total phosphorus depth profiles (available in 1985, 1989, 1997, 2004, 2008, 2009, 2010, and 2012) indicate that in Lake Ann can experience significant internal loading from the sediments. Based on the in-situ measurements of the sediment oxygen demand (HydrO$_2$, Inc, 2009), the mean sediment oxygen demand in Lake Ann is 2.44 g O_2/m^2/d. The bottom sediments are often under anoxic conditions for much of the growing season and elevated phosphorus levels are observed in the hypolimnion. Additionally, the model inferred rate of phosphorus release from the sediments in Lake Ann (over the entire lake area) based on the 2005 and 2012 modeling ranged from 1.4 to 1.6 mg/m^2/d. These rates fall within the range that has been observed in several Twin Cities metropolitan area lakes.

Table 11 Phosphorus Loads from the Internal Release of Sediments to Lake Lucy and Lake Ann

Lake	Parameter	2005 Water Year (10/1/2004 – 9/30/2005)		2012 Water Year (10/1/2011 – 9/30/2012)	
		Estimated Internal Sediment Phosphorus Load (lbs)	Estimated Release Rate (mg/m^2/d)[1]	Estimated Internal Sediment Phosphorus Load (lbs)	Estimated Release Rate (mg/m^2/d)[1]
Lake Lucy	Internal Sediment Release Total Phosphorus Load	121	1.3	104	1.6
Lake Ann	Internal Sediment Release Total Phosphorus Load	146	1.4	135	1.6

1 – Estimated average release rate over the entire surface area of the lake.

2.7.3 Summary of Existing Conditions Phosphorus Sources to Lake Lucy and Lake Ann

Table 12 and Table 13 summarize the annual water and phosphorus budgets for Lake Lucy and Lake Ann for 2005 and 2012, respectively. The following figures (Figure 11 and Figure 12) summarize the 2012 existing conditions annual water and phosphorus budgets for Lake Lucy and Lake Ann, including the relative contributions of the internal and external phosphorus loads. These budgets help to understand the sources of phosphorus to each of the lakes and help direct the implementation strategies selected for each lake.

The phosphorus budgets for both 2005 and 2012 climatic conditions tell a similar story for Lake Lucy. The major sources of phosphorus to the lake are from watershed runoff (43-47 percent) internal sediment loads (33-39 percent), and Curlyleaf pondweed (9-11 percent). The remainder of the phosphorus load is from direct atmospheric deposition and groundwater inflows.

The 2005 and 2012 annual phosphorus budgets for Lake Ann indicated that the major source of phosphorus to Lake Ann is from internal sediment release (55 percent). External loads from the watershed and from upstream Lake Lucy make up 11-17 percent and 15-22 percent of the phosphorus load to the lake, respectively.

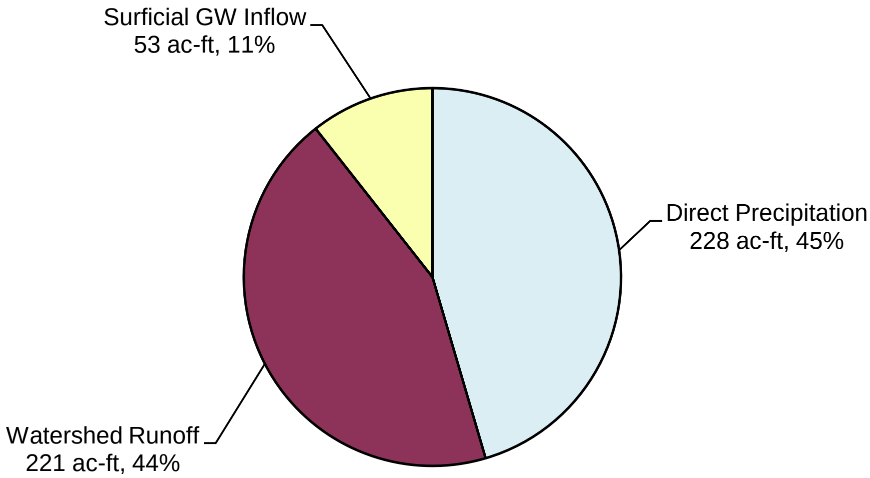
Table 12 Summary of 2005 Annual Water and Phosphorus Budgets to Lake Lucy and Lake Ann

Source	Lake Lucy		Lake Ann	
	2005 Annual Load	% of Total Annual Load	2005 Annual Load	% of Total Annual Load
Water Load Summary				
Direct Precipitation (ac-ft)	290	54	366	52
Watershed Runoff (acre-ft)	186	35	11	2
Surficial Groundwater (acre-ft)	63	12	58	8
Upstream Lakes (acre-ft)	--	--	272	42
Total Annual Water Load (acre-ft)	539	100	708	100
Phosphorus Load Summary				
External Phosphorus Sources				
Atmospheric Deposition (lbs)	21	7	28	10
Watershed Runoff (lbs)	133	43	29	11
Surficial Groundwater (lbs)	6	2	4	1
Upstream Lakes (lbs)	--	--	59	22
Internal Load from Upstream Ponds/Wetlands (lbs)	--	--	--	--
Internal Phosphorus Sources				
Curlyleaf Pondweed (lbs)	26	9	1	<1
Sediment Release (lbs)	121	39	146	55
Total Phosphorus Load (lbs)	**308**	**100**	**267**	**100**
Resulting Growing Season Average Water Quality				
Observed Total Phosphorus (µg/L)	63		26	
Model Predicted Total Phosphorus (µg/L)	63		26	

Table 13 Summary of 2012 Annual Water and Phosphorus Budgets to Lake Lucy and Lake Ann

Source	Lake Lucy		Lake Ann	
	2012 Annual Load	% of Total Annual Load	2012 Annual Load	% of Total Annual Load
Water Load Summary				
Direct Precipitation (ac-ft)	228	45	283	47
Watershed Runoff (acre-ft)	221	44	20	3
Surficial Groundwater (acre-ft)	53	11	51	8
Upstream Lakes (acre-ft)	--	--	252	42
Total Annual Water Load (acre-ft)	503	100	606	100
Phosphorus Load Summary				
External Phosphorus Sources				
Atmospheric Deposition (lbs)	21	7	28	11
Watershed Runoff (lbs)	148	47	29	17
Surficial Groundwater (lbs)	5	2	4	1
Upstream Lakes (lbs)	--	--	59	15
Internal Load from Upstream Ponds/Wetlands (lbs)	0.2	<1	--	--
Internal Phosphorus Sources				
Curlyleaf Pondweed (lbs)	35	11	1	<1
Sediment Release (lbs)	104	33	146	55
Total Phosphorus Load (lbs)	**313**	**100**	**267**	**100**
Resulting Growing Season Average Water Quality				
Observed Total Phosphorus (µg/L)	64		26	
Model Predicted Total Phosphorus (µg/L)	64		26	

Estimated Water Budget (503 ac-ft) for Lake Lucy
Water Year 2012 (October 1, 2011 - September 30, 2012)



Estimated Phosphorus Budget (313 lbs) for Lake Lucy
Water Year 2012 (October 1, 2011 - September 30, 2012)

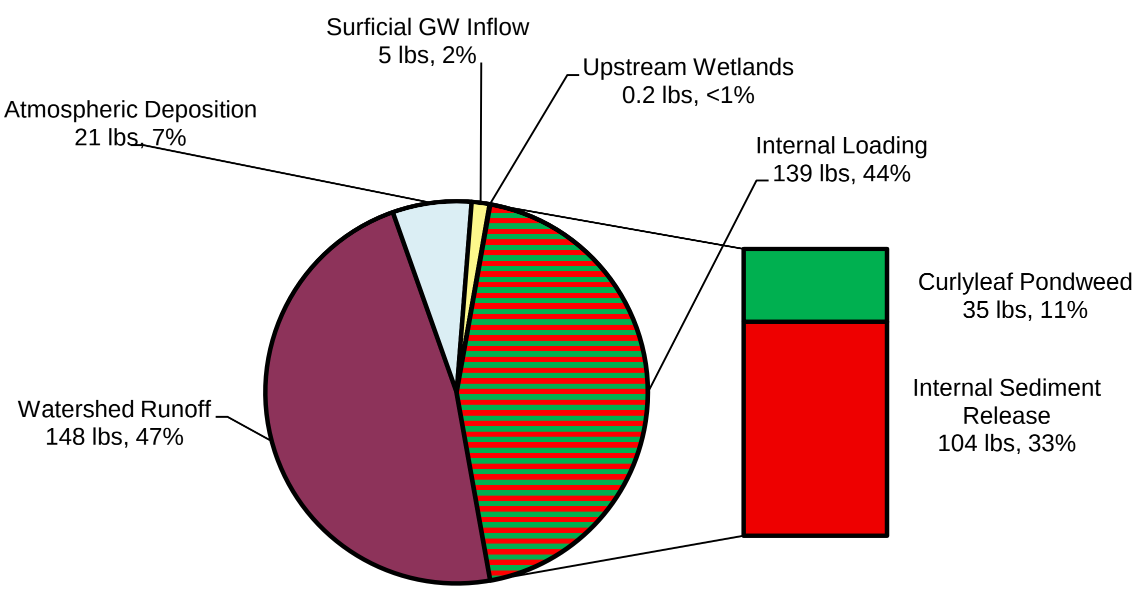
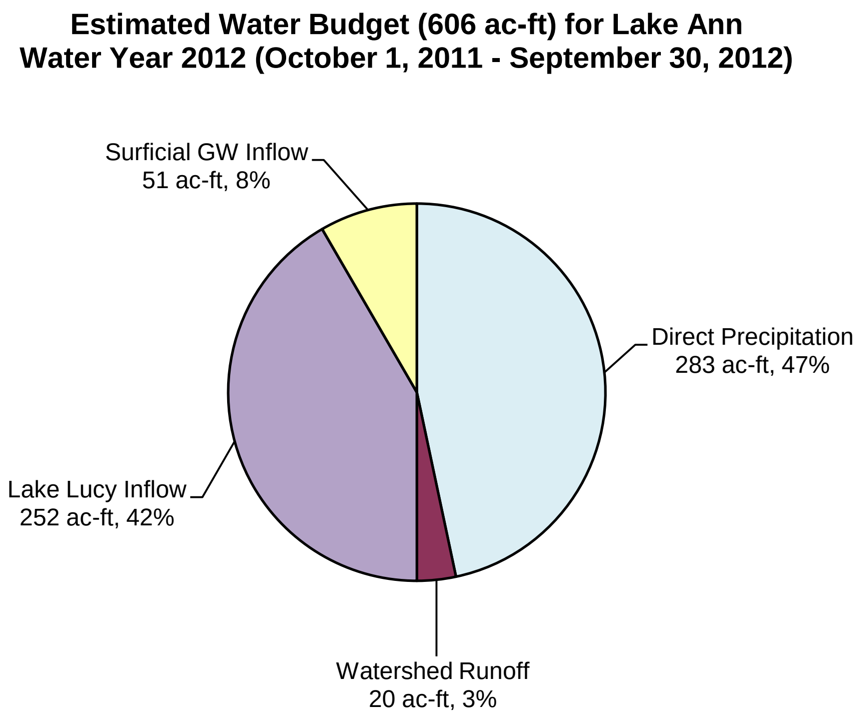


Figure 11
Lake Lucy Water and Total Phosphorus Budget
2012 Existing Conditions



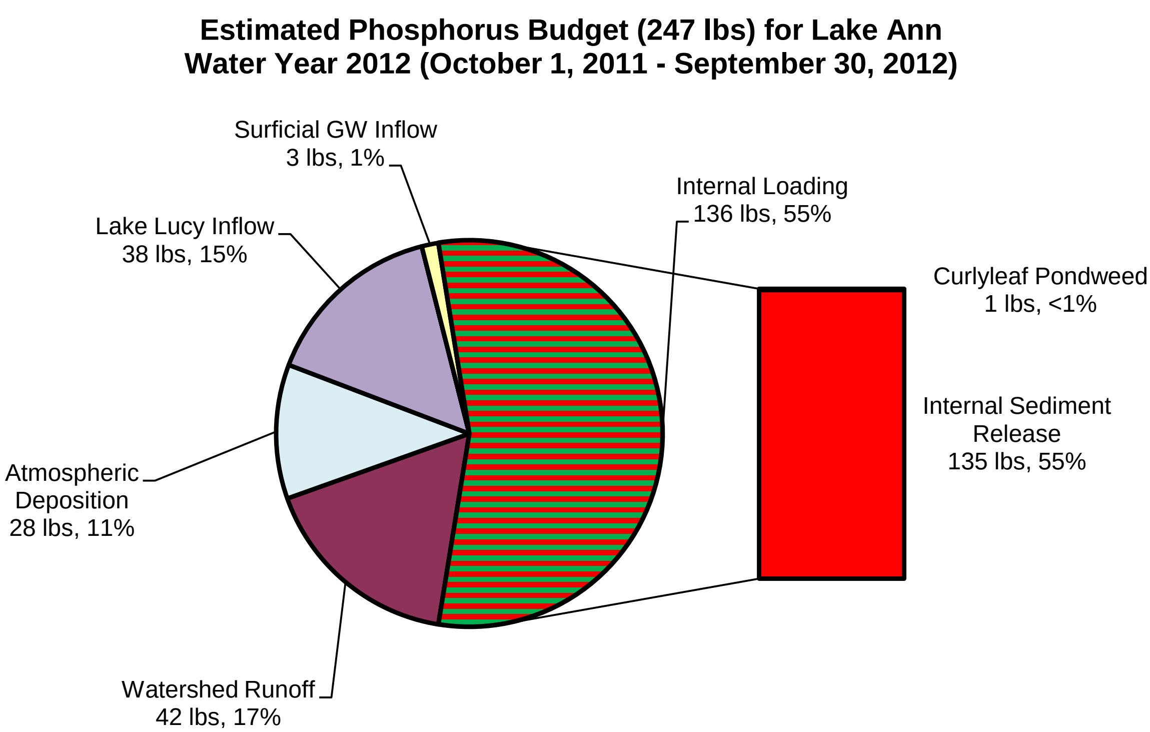


Figure 12
Lake Ann Water and Total Phosphorus Budget
2012 Existing Conditions

2.7.4 Summary of Future Conditions on Lake Lucy and Lake Ann

Although much of the Lake Lucy watershed is developed, there are still areas of the watershed that are expected to change. This is also true of the Lake Ann watershed, which is primarily undeveloped and parkland. Figure 3 shows the future land use within the Lake Lucy and Lake Ann 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 2012 climatic conditions. Table 14 summarizes the growing season average total phosphorus and chlorophyll a concentrations and Secchi disc transparencies in Lake Lucy and Lake Ann for existing, future, and future conditions assuming stormwater volume abstraction rules are applied to the areas expected to develop.

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 southwest and western portion of the Lake Lucy and Lake Ann watersheds.

Based on the modeling results, development and redevelopment in the watershed is expected to degrade the water quality in both Lake Lucy and Lake Ann. Based on the 2012 climatic year, the growing season average total phosphorus concentration in Lake Lucy will increase from 64 ug/L to 71 ug/L, a 12 percent increase. In Lake Ann, the growing season average total phosphorus concentration is expected to increase from 26 ug/L to 34 ug/L, a 34 percent increase. Note that this scenario assumes land use change only and that no additional stormwater BMPs will be implemented.

2.7.4.2 Future Conditions with Stormwater Rules Aligned with MIDS

The MPCA has recently developed statewide Minimal Impact Design Standards (MIDS) to promote low impact development (LID) and reduce runoff volumes to levels that mimic natural hydrology. The MIDS performance goal for new developments indicates that for sites creating more than one acre of new impervious surface, stormwater runoff volumes will be controlled and the post-construction runoff volume shall be retained on site for 1.1 inches of runoff from impervious surfaces statewide (MPCA, 2013b).

The RPBCWD and the cities are currently in the process of developing stormwater management rules, and it is anticipated that their rules will require abstraction of stormwater volume similar to the MIDS performance goal for new development. Given this, we have assumed that stormwater runoff from the impervious surfaces of future development and redevelopment would be managed in accordance with the MIDS performance goals, abstracting 1.1 inches of runoff from the impervious surfaces.

Model results demonstrate that the implementation of stormwater rules that align with the MIDS performance goal will help reduce the expected impact of future changes in the watershed on the water quality in Lake Lucy and Lake Ann. Based on the 2012 climatic year, the growing season average total phosphorus concentration in Lake Lucy is expected to increase from 64 ug/L to 67 ug/L, versus 71 ug/L without stormwater rules. In Lake Ann, the growing season average total phosphorus concentration in Lake Ann is expected to increase from 26 ug/L to 27 ug/L, versus 34 ug/L without stormwater rules.

This future conditions scenario with the implementation of stormwater rules similar to MIDS has been used as the baseline condition for the evaluation of the various implementation strategies to protect and improve the water quality in Lake Lucy and Lake Ann.

Table 14 Summary of Existing, Future, and Future Conditions with MIDS on Lake Lucy and Lake Ann Total Phosphorus (TP), Chlorophyll *a* (Chl *a*), and Secchi Disc Transparency (SD)

Lake	2012 Observed Water Quality Conditions (Existing Conditions)[1]			Future Conditions[1]			Future Conditions with MIDS[1]		
	TP (µg/L)	Chl *a* (µg/L)	SD (m)	TP (µg/L)	Chl *a* (µg/L)[2]	SD (m)[2]	TP (µg/L)	Chl *a* (µg/L)[2]	SD (m)[2]
Lake Lucy	64	15.7	1.5	71	30.5	1.0	67	27.7	1.1
Lake Ann	26	8.1	3.1	34	11.4	1.8	27	8.5	2.2

1 – Model predictions based on 2012 climatic conditions
2 – Chl *a* concentration and Secchi disc transparency for future conditioned determined using MCPA statewide regression equation

2.8 Summary of Diagnostic Findings

Table 15 provides a summary of the key water quality findings for Lake Lucy and Lake Ann. Additional discussion of the diagnostic findings in relation to the sources of phosphorus and water quality of Lake Lucy and Lake Ann 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 Lake Lucy and Lake Ann water quality (see Section 3.0).

Table 15 Summary of Diagnostic Findings for Lake Lucy and Lake Ann

Topic	Lake Lucy	Lake Ann
Water Quality Standards and Goals	- Meets MPCA Shallow Lake Standards - Does not meet RPBCWD goals or long term vision	- Meets MPCA Deep Lake Standards - Meets RPBCWD goals or long term vision
Baseline Water Quality	- Water quality as expected for a minimally impacted lake	- Water quality as expected for a minimally impacted lake
Water Quality Trends	- Stable, neither improving nor degrading	- Stable, neither improving nor degrading
Watershed Runoff	- Represents 43-47% of annual phosphorus load - Receives significant removal of particulate phosphorus in existing ponds and wetlands	- Represents 11-17% of annual phosphorus load - Majority of direct watershed is in a fairly undeveloped state including developed park and wetlands
Future Conditions	- Expected water quality degradation with future land use changes	- Expected water quality degradation with future land use changes
Internal Loading in Watershed Ponds and Wetlands	- 2012 data suggests that internal loading may be an issues with some of the ponds and wetlands within the Lake Lucy watershed although additional monitoring data is necessary to understand the extent and magnitude	- N/A
Macrophyte Status	- Moderately diverse macrophyte community with 15 plant species, primarily native plants - Curlyleaf pondweed was present at many sampling sites; the plants were typically small and did not account for much of the aquatic plant biomass	- Healthy macrophyte community with 25 plant species, primarily native plants - Eurasian watermilfoil was the most frequently occurring species - Curlyleaf pondweed was present but in very low amounts.
Fishery Status	- Carp population very low	- Carp population very low
Cyanobacteria (blue green algae)	- Has historically experienced cyanobacteria blooms during the summer	- Has historically experienced cyanobacteria blooms during the summer - Blooms typically occur in the metalimnion
Internal Loading from sediments	- Thermally stratifies with anoxic conditions along bottom sediment - Internal loading from sediment estimated to be 33-39% of annual phosphorus load	- Thermally stratifies with anoxic conditions along bottom sediment - Internal loading from sediment estimated to be 55% of annual phosphorus load
Methylmercury in Fish Tissues	- Listed as impaired by mercury on the Minnesota statewide mercury impairment list - Fish consumption advisories from MDNR and MDH	- 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 Lake Lucy

- Correspondence with MPCA staff indicates that they will classify Lake Lucy as a shallow lake due to the amount of littoral area within the lake (Pam Anderson, email communication, 5/14/2013) and therefore the MPCA shallow lake standards will apply.

- Lake Lucy is not listed on the MPCA 303(d) impaired waters list for excess nutrients. A review of historic water quality for Lake Lucy indicates the lake is currently meeting MPCA shallow lake water quality standards. Lake Lucy does not meet the RPBCWD water quality goals or the RPBCWD long term water clarity vision (2 m). However, the water quality in Lake Lucy is as would be expected for a "minimally impacted lake" with similar characteristics in the north central hardwood forest ecoregion. Additionally, the trend analyses performed on the water quality data for the past 10-years indicate that the water quality in Lake Lucy is stable and is neither improving nor degrading.

- Watershed runoff receives a significant amount of treatment prior to entering Lake Lucy due to the number of water bodies 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 majority of phosphorus in the watershed runoff is in a soluble form or associated with very small particles that are difficult to settle. Therefore, watershed BMPs should target the soluble (non-settleable) 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 Lake Lucy. The direct watershed to Lake Lucy contributes 23 percent of the watershed phosphorus load to the lake.

- The watershed phosphorous load to Lake Lucy typically represents 43-47 percent of the total annual phosphorus budget to the lake. Internal loading represents 44-48 percent of the total annual phosphorus budget (see Tables 12 and 13).

- Water quality data collected along the depth profile of Lake Lucy 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 Lake Lucy.

- Based on future land use changes, water quality degradation in Lake Lucy is expected if additional stormwater management is not incorporated into the watershed as the area is developed or redeveloped.

- Figure 10 shows the estimated phosphorus loading from the major drainage basins in the Lake Lucy watershed as a percentage of the total watershed load. The watershed modeling suggests that 45 percent of the watershed load to Lake Lucy passes through the LU-A1.7 and

LU-A3.4 major drainage areas. These drainage areas appear to provide the best opportunity for the implementation of additional watershed BMPs, or modifications to existing BMPs.

- Monitoring data from two ponds/wetlands in the Lake Lucy watershed collected in August 2012 indicate that one of the water bodies may potentially be acting as a source of phosphorus to Lake Lucy (LU-A1.9) while the other pond (LU-A1.11) had phosphorus levels typical of a stormwater pond (and likely is not acting as a source of phosphorus). The watershed modeling indicates that the pond with the elevated phosphorus levels only discharged downstream during one precipitation event during the monitoring period, with this additional loading contributing less than one percent of the total phosphorus load to Lake Lucy. The 2012 monitoring data did not distinguish if the phosphorus was in the soluble or particulate form. However, if the elevated phosphorus levels in the wetland were due to release from the sediments or the decomposition of organic material, it is likely to be in the soluble form.

- Based on the 2010 and 2011 macrophyte data collected by the U of MN, Lake Lucy is dominated by a moderately diverse macrophyte community with 15 plant species, primarily native plants. Eurasian watermilfoil was only found at one location in 2011 and was not found at any sites in 2010. Although Curlyleaf pondweed is present at many sampling sites, the plants were typically small and did not account for much of the aquatic plant biomass. It is unknown if the relatively low abundance of curlyleaf was natural or due to effective control by the riparian owners or natural lake dynamics and climatic conditions.

- Prior to the carp seining in 2010 and 2011, the carp densities in Lake Lucy were low. After the carp harvesting, the carp densities in the lake are currently very low. Most of the carp in the Lake Lucy were fairly large, adult carp. Additionally, review of the carp age and recruitment data indicate low- moderate recruitment across years with a small peak in 2002. This peak does not correlate with any known winterkill events, suggesting that winterkill is not a significant threat to carp production in Lake Lucy (Dr. Peter Sorensen, University of Minnesota, unpublished data via email communication, June 22, 2013). Additionally, although carp do move from Lake Ann to Lake Lucy to spawn, the data collected on the carp populations indicates that carp do not move between Lake Ann and Lake Susan downstream (Dr. Peter Sorensen, University of Minnesota, phone conversation, June 19, 2013).

- Both historic and recent phytoplankton surveys indicate that Lake Lucy experiences blue-green algae blooms during the growing season. The more recent estimates of the number of cyanobacteria cells per mL typically fall within the World Health Organization relatively low risk of adverse health effects.

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

2.8.2 Diagnostic Findings for Lake Ann

- Based on review of historic water quality for Lake Ann, the lake is currently meeting MPCA deep lake water quality standards and is not listed on the MPCA 303(d) impaired waters list. Additionally, Lake Ann meets the RPBCWD water quality goals and the RPBCWD long term water clarity vision (2 m). The water quality in Lake Ann is similar to 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 Ann is stable and is neither improving nor degrading.

- Lake Ann thermally-stratifies throughout the growing season. Water quality data collected along the depth profile of Lake Ann 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 2005 and 2012 water quality modeling, the watershed phosphorous load to Lake Ann typically represents 11-17 percent of the total annual phosphorus budget to the lake. Discharge from Lake Lucy represents 15-22 percent of the phosphorous load. Internal loading represents about 55 percent of the total annual phosphorus budget (see Tables 12 and 13).

- Lake Ann has a small watershed and much of the watershed is either undeveloped or parkland. Therefore, the majority of the existing watershed is “untreated” (does not pass through a wetland or pond prior to entering the lake), but also, currently has very little impervious coverage.

- Based on future land use changes, water quality degradation in Lake Ann is expected if additional stormwater management is not incorporated into the watershed as the area is developed or redeveloped.

- Based on the 2010 and 2011 macrophyte data collected by the U of MN, Lake Ann has a relatively healthy macrophyte community with 25 plant species, primarily native plants. However, non-native Eurasian watermilfoil was the most frequently occurring species. Curlyleaf pondweed is also present in the lake but in very low amounts.

- Carp densities in Lake Ann have historically been very low, and as a result, carp management has not been necessary in Lake Ann. Additionally, the 2010 and 2011 carp seining in Lake Lucy will help to maintain a controlled carp population in both lakes.

- Both historic and recent phytoplankton surveys indicate that Lake Ann experiences blue-green algae blooms during the growing season. The more recent phytoplankton data collected in Lake Ann indicates that filamentous blue green algae (*Ocillatoria*) have been present in the metalimnion of the lake in 2008, 2009, and 2010, likely feeding on the elevated phosphorus levels in the hypolimnion. The estimated number of cyanobacteria cells per mL at the surface of Lake Ann typically fall within the World Health Organization relatively low risk of adverse health effects, although there were a few dates in later summer that exceed the low risk threshold.

- Lake Ann is included on the Minnesota statewide list of mercury impaired water bodies. Additionally, there are fish consumption advisories for Lake Ann from the MDNR and the MDH. Methylmercury measurements in the hypolimnion of Lake Ann show a gradual increase over the growing season that appears to be correlated with the anoxic conditions and the reduced oxidation reduction potential observed in the hypolimnion of the lake.

3.0 Water Quality Goal Attainment and Implementation Strategies

3.1 Typical Stormwater Management Strategies

This section discusses improvement options and general Best Management Practices (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 16. 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 to improve removal of not only the pollutants associated with particulates, but to 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
- Infiltration basins or trenches
- Sand filters
- Iron-enhanced sand filters
- Vegetative buffer strips
- Oil and grit separators
- Alum treatment plants
- Spent lime treatment

The general effectiveness of each of the BMPs is summarized in Table 16.

Table 16 General Effectiveness of Stormwater BMPs at Removing Phosphorus from Runoff

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

Source: Adapted from the Minnesota Stormwater Manual (MPCA, 2005)

[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-Wasthington Metro Watershed District

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. Several examples of in-lake management practices intended to reduce phosphorus loading to the lake are listed below:

- Removal of benthivorous (bottom-feeding) fish, including carp,
- Application of alum (aluminum sulfate),
- Application of herbicides to control nonnative macrophyte species such as Curlyleaf pondweed and Eurasian watermilfoil,
- Mechanical harvesting of lake macrophytes,
- Hypolimnetic withdrawl,
- Hypolimnetic aeration, and
- Iron salt applications

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, and
- Deterrence of waterfowl

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 Lake Lucy and Lake Ann.

3.2.1 1999 UAA Implementation Strategy

A summary of the implementation strategy from the original UAAs developed for Lake Lucy and Lake Ann (Barr Engineering, 1999) is presented below:

For Lake Lucy:

- Preservation of all existing wetlands in the Lake Lucy watershed.
- Upgrading two ponds in the Lake Lucy watershed to provide more wet detention for stormwater treatment.
- Addition of seven ponds in the Lake Lucy watershed in areas that contribute significant particulate phosphorus loads to the lake.
- Providing infiltration basins throughout the Lake Lucy watershed in areas that experience a significant change in impervious area between existing and future land use conditions.
- Managing the fisheries by restocking sport fish after winterkills, employing commercial anglers to remove rough fish, and installing a fishing pier.
- Managing the lake's macrophytes by continuing to survey communities to detect nuisance, non-native growths.

For Lake Ann:

- Protection/improvement of Lake Lucy.
- Preservation of all existing wetlands in the Lake Ann watershed.
- Addition of five ponds in the Lake Ann watershed in areas that contribute significant particulate phosphorus loads to the lake.
- Providing infiltration basins throughout the Lake Ann watershed in areas that experience a significant change in impervious area between existing and future land use conditions.
- Managing the lake's macrophytes by continuing to survey communities to detect nuisance, non-native growths.

3.2.2 Lake Lucy Carp Seining – January 2010 and 2011

As part of the research conducted by the University of Minnesota within the RPBCWD, it was determined that during the winter, carp in Lake Lucy form a tight aggregation in the lake that could be easily targeted with a net (Bajer *et. al.*, 2011). Carp seining occurred in Lake Lucy twice in the past years. The first seining occurred on January 24, 2010. The second seining occurred on January 13, 2011. It was estimated that approximately 3/4 of the carp population was removed from Lake Lucy in one seine haul. The estimates suggest that Lake Lucy is currently inhabited by approximately 100 carp and that the biomass is currently less than 20 kg/ha (a very low biomass level). At these levels, the activity of carp is not expected to have an impact on total phosphorus levels in the lake.

3.2.3 Lake Lucy Ice Preserving Aeration System – Winter 2011-2012 and 2012-2013

The fishery in Lake Lucy is prone to periodic winterkills, with historic fishkills documented every 5 to 10 years. Following the carp harvesting in Lake Lucy in January 2010 and 2011, the RPBCWD installed an aeration system to help prevent winterkills of the Lake Lucy fishery to maintain a low carp population. The secondary intent of the winter aeration is to reduce internal phosphorus loads during the winter (CH2M Hill, 2012b).

The RPBCWD installed an ice preserving aeration system (IPAS) on Lake Lucy on December 8, 2011. The system was sized to aerate the areas in Lake Lucy greater than 10 feet deep, or approximately 22 acres with a goal of creating an area of at least 16 acres with a minimum dissolved oxygen level of 2 mg/L. The system was operated continuously through March 21, 2012. The summary report on the first season of operation, prepared by CH2M Hill (2012b), concluded the following:

- Dissolved oxygen levels in the hypolimnion of Lake Lucy stayed elevated (near saturation) for the winter; however, it was not clear if this was entirely the result of the IPAS system or if the limited snowpack during the winter of 2011-2012 resulted in enough light penetration into the lake to provide for sufficient photosynthesis.
- The total phosphorus concentrations in the hypolimnion of Lake Lucy during the winter were observed at lower concentrations than during the winter of the previous year. However, this trend was also observed in similar lakes without aeration systems in operation. The lower

total phosphorus concentrations in the hypolimnion during the winter of 2011-2012 and at spring turnover, did not seem to have a significant impact on the water quality observed in Lake Lucy during the following growing season.
- The IPAS system prevented winter thermal stratification.

The IPAS system in Lake Lucy was operated a second season, beginning on December 21, 2012, and was operated continuously through the end of April 2013. Review of the technical memorandum prepared by CH2M Hill (2013b) regarding the second season of operation concluded the following:

- The dissolved oxygen levels in the hypolimnion of Lake Lucy stayed elevated for much of the winter. The dissolved oxygen levels in the deep hole dropped to less than 1 mg/L during February and March, corresponding to an accumulation of approximately 25 inches of snow on the ice, reducing light penetration into the lake and reducing under-ice photosynthesis.
- The total phosphorus concentrations in the hypolimnion of Lake Lucy during the winter were similar to what was observed in the first year of operation.
- The IPAS system prevented winter thermal stratification.

3.2.4 Lake Ann Oxygenation Basis of Design Report – October 2012

This report (CH2M Hill, 2012c; CH2M Hill, 2013a) summarizes the potential pilot oxygenation project intended to protect water quality in Lake Ann by using pure oxygen to prevent the release of phosphorus from the anoxic bottom sediments into the hypolimnion. Based on the report, the purposes of the proposed system are to:

- Prevent further degradation of Lake Ann water quality,
- Reduce mercury concentrations from Lake Ann fish populations by suppressing mercury methylation within the hypolimnion,
- Reduce potentially toxic filamentous blue-green algae blooms in the metalimnion
- Create an oxygenated cold water fisheries habitat in Lake Ann during the summer

The recommended project was a full-lift oxygenation system with a capital cost of $289,000 and an annual operation and maintenance cost of $33,000. The pilot project was not implemented as the RPBCWD determined the project to be cost prohibitive (CH2M Hill, 2013a).

3.2.5 Lake Lucy Mechanical Harvesting of Curlyleaf Pondweed/Herbicide Treatment by Riparian Owners and RPBCWD

Shoreline residents (Lake Lucy Homeowner Association) have been historically managing macrophytes in localized areas around Lake Lucy. In 2009, the Lake Lucy Homeowner Association mechanically harvested 130 tons of macrophytes, including Curlyleaf pondweed, from Lake Lucy (CH2M Hill phone conversation record, 4/1/2010). Although the RPBCWD has not historically been involved with the management and harvesting of macrophytes in the Lake Lucy and Lake Ann systems, in 2010, the RPBCWD began harvesting macrophytes on Lake Lucy as part of the Plan (Lake Lucy Homeowners Association Aquatic Plan Control Letter to the MDNR, March 2, 2010). In

2010, Lake Lucy residents obtained a permit for mechanical harvesting of submerged vegetation for 19.1 acres on the east side of Lake Lucy.

3.2.6 RPBCWD Stormwater Pond Study (2010-2012)

Due to concerns that stormwater ponds that collect sediments and organic materials from runoff can act as phosphorus sources to downstream water resources, rather than as phosphorus sinks that remove total phosphorus from runoff, the RPBCWD conducted a pond study. In 2010 and 2011, water quality data was collected on several stormwater ponds and wetlands through the RPBCWD to begin understanding which ponds might have elevated phosphorus concentrations. This data was used to develop a Rapid Assessment Protocol (RAP) intended to be used as a means of screening the worst-performing ponds for remediation.

In 2012, the RPBCWD continued to monitor select stormwater ponds and wetlands within the watershed. Two ponds in the Lake Lucy watershed were monitored in 2012 (LU-A1.9 and LU-A1.11). Three samples were collected in LU-A1.9 on dates between early August and early September. Four samples were collected in LU-A1.11 on dates between mid-July and early September. The results of this monitoring indicated that the phosphorus concentrations in LU-A1.9 were higher than would typically be expected from a stormwater pond, ranging from 240 μg/L to 880 μg/L. A typical value for a stormwater pond would be approximately 150 μg/L. This suggests that LU-A1.9 might be acting as a phosphorus source to Lake Lucy. The phosphorus concentrations in LU-A1.11 were as expected in a stormwater pond, ranging from 78 μg/L to 130 μg/L.

3.2.7 Susan, Ann, and Lucy Subwatershed: Stormwater Retrofit Assessment (2011)

In 2011, the Carver Soil and Water Conservation District completed the *Susan, Ann, and Lucy Subwatershed: Stormwater Retrofit Assessment* (SALSA). This report detailed a subwatershed stormwater retrofit assessment to prioritize and recommend catchments for the placement of stormwater BMP retrofits to help address the goals of the various local agencies. Three subcatchments within the Lake Lucy watershed were evaluated as part of the assessment. The report ranked projects based on the following criteria: treatment of previously untreated areas, cost-benefit of projects in terms of cost per pound of total phosphorus per year, and total project costs.

For the Lake Lucy watershed, the SALSA report recommended that existing stormwater ponds in two subcatchments be retrofit with iron-enhanced sand filtration trenches. For the third subcatchment, it was recommended that rainwater gardens be constructed during upcoming street reconstruction.

3.3 Implementation Strategies

The following implementation plan outlines strategies to protect (and improve) the water quality in Lake Lucy and Lake Ann to prevent water quality degradation and keep the lake from inclusion on the MPCA 303(d) Impaired Waters List in the future.

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 City of Chanhassen and/or other local, regional, or state agencies) can implement if funding or opportunities arise.

Because much of the runoff from the Lake Lucy watershed 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.

Since the water quality in Lake Ann is directly influenced by the quality of the water leaving Lake Lucy the focus for many implementation strategies is on the improvement in Lake Lucy water quality as a means of protecting the water quality in Lake Ann, which currently meets the MPCA water quality standards and the RPBCWD goals.

Planning level opinions of probable cost have been developed for the various management strategies based on conceptual designs of the BMPs evaluated. However, there is cost uncertainty and risk associated with this concept level of design opinion of probably cost. The costs reported for the BMPs are point estimates and include engineering and design (30 percent), contingencies (30 percent), and estimated land acquisition/easement costs (if applicable). 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. We have utilized industry resources for cost estimating (*AACE International Recommended Practice No. 18R-97* and *ASTM E 2516-06 Standard Classification for Cost Estimate Classification System*) to provide guidance on cost uncertainty. Based on the current level of design the cost range varies by +40 percent to -20 percent from the point opinion of probable cost. Additional details about the estimated costs can be found in Appendix D.

The annual BMP cost per pound phosphorus removed per year (cost-benefit) was estimated to provide a comparison of the various practices and the overall cost effectiveness of the proposed BMPs. The annualized costs are based on the point opinion of probably cost combined with the annual estimated operation and maintenance costs over the life span of the various BMPs. We have assumed an interest rate of 4 percent to annualize the capital costs.

Table 17 summarizes the estimated impact of the various management strategies (if applicable) on the in-lake water quality in Lake Lucy and Lake Ann. Table 18 summarizes the estimated capital costs, maintenance costs, lifespan, and annual cost-benefit of the various practices evaluated. Figure 13 shows the locations of the various BMPs evaluated as part of this study. Figures 14 and 15 shows the impact of the various strategies on Lake Lucy and Lake Ann water quality in comparison to the current MPCA standards and RPBCWD goals.

Table 17 Summary of Potential Water Quality Management Projects on Lake Lucy and Lake Ann Total Phosphorus (TP) and Chlorophyll *a* (Chl *a*) Concentrations and Secchi Disc Transparencies (SD)

Water Quality Management Strategy		Lake Lucy					Lake Ann				
		Estimated Annual Total Phosphorus Load (lbs)	Estimated Reduction in Annual Total Phosphorus Load (lbs)[1]	Growing Season			Estimated Annual Total Phosphorus Load (lbs)	Estimated Reduction in Annual Total Phosphorus Load (lbs)[1]	Growing Season		
				TP (µg/L)	Chl *a* (µg/L)[2]	SD (µg/L)[2]			TP (µg/L)	Chl *a* (µg/L)[2]	SD (µg/L)[2]
Baseline Conditions	Existing Conditions - 2012	313	--	64	15.7	1.5	247	--	26	8.1	3.1
	Future Conditions - No Stormwater Rules Implemented	350	--	72	30.5	1.0	287	--	34	11.4	1.8
	Future Conditions - Stormwater Rules (MIDS) Applied to Development Areas	327	--	67	27.7	1.1	249	--	27	8.5	2.2
Implementation Strategies	Iron Enhanced Sand Filtration Located in LU-A1.10c	307	19	62	25.0	1.2	244	4	26	7.9	2.3
	Spent Lime Treatment Located in LU-A3.4	316	11	64	26.0	1.1	246	3	26	8.1	2.3
	Lake Lucy Alum Treatment	244	83[3]	43	15.6	1.5	245	4	25	7.5	2.4
	Lake Ann Alum Treatment	327	0	67	27.7	1.1	140	109	18	5.0	3.0
	Iron Enhanced Sand Filtration Located in LU-A1.10c and Spent Lime Treatment Located in LU-A3.4	297	30	59	23.3	1.2	242	7	25	7.5	2.4
	Iron Enhanced Sand Filtration Located in LU-A1.10c, Spent Lime Treatment Located in LU-A3.4, and Lake Lucy Alum Treatment	214	113	39	13.7	1.7	240	8	25	7.5	2.4
	Iron Enhanced Sand Filtration Located in LU-A1.10c, Spent Lime Treatment Located in LU-A3.4, and Lakes Lucy and Ann Alum Treatments	214	113	39	13.7	1.7	131	117	17	4.5	3.2

1 – Future Conditions with MIDS Stormwater Rules serves as the baseline conditions for evaluation of all other implementation strategies.
2 – For Existing Conditions, observed 2012 water quality; For Future Conditions and BMP Strategies, Chl *a* concentrations and Secchi Disc Transparencies estimated using the MPCA regression equations
3 – Does not include whole-lake management of Curlyleaf pondweed in conjunction with the Lake Lucy alum treatment.

Table 18 Summary of Water Quality Management Projects Costs and Annual Cost per Pound of Phosphorus Removed

Water Quality Management Strategy	Estimated Annual TP Reduction (lbs)[1]	Planning Level Opinion of Cost[2]	Annual Maintenance Costs	Estimated Life Span (yrs)	Annual Cost per Pound TP Removed[4]
Iron Enhanced Sand Filtration Located in LU-A1.10c	19	$350,000 ($280,000 - $490,000)	$1,000	35	$1,023
Spent Lime Treatment Located in LU-A3.4	11	$190,000 ($160,000 - $270,000)	$1,000	35	$1,064
Lake Lucy Alum Treatment	83	$320,000 ($260,000 - $450,000)	$0	35[3]	$724
Lake Lucy Alum Treatment w/ Curlyleaf Pondweed Management	111	$790,000 ($640,000 - $1,110,000)	$0	35[3]	$767
Lake Ann Alum Treatment	109	$290,000 ($240,000 - $410,000)	$0	35[3]	$499
Iron Enhanced Sand Filtration Located in LU-A1.10c and Spent Lime Treatment Located in LU-A3.4	30	$540,000 ($440,000 - $760,000)	$2,000	35	$1,037
Iron Enhanced Sand Filtration Located in LU-A1.10c, Spent Lime Treatment Located in LU-A3.4, and Lake Lucy Alum Treatment[5]	113	$860,000 ($700,000 - $1,210,000)	$2,000	35[3]	$807
Iron Enhanced Sand Filtration Located in LU-A1.10c, Spent Lime Treatment Located in LU-A3.4, and Lakes Lucy and Ann Alum Treatments[5]	222	$1,150,000 ($940,000 - $1,620,000)	$2,000	35[3]	$656

1 Based on comparison to Future Conditions with MIDS Stormwater Rules
2 Planning level opinions of probable cost point estimates with range of costs provided toreflect the level of uncertainty, unknowns, and risk due to concept design
3 The lifespan of an alum treatment is typically 7-10 years. Future alum treatment may be necessary; however, the necessity of additional alum treatments would be evaluated a future time. The 35 year life span for the alum treatment assumes treatment every 10-years.
4 Annualized costs based on factors associated with a 4% interest rate
5 Assumes that Curlyleaf pondweed management is not necessary for the alum treatment in Lake Lucy

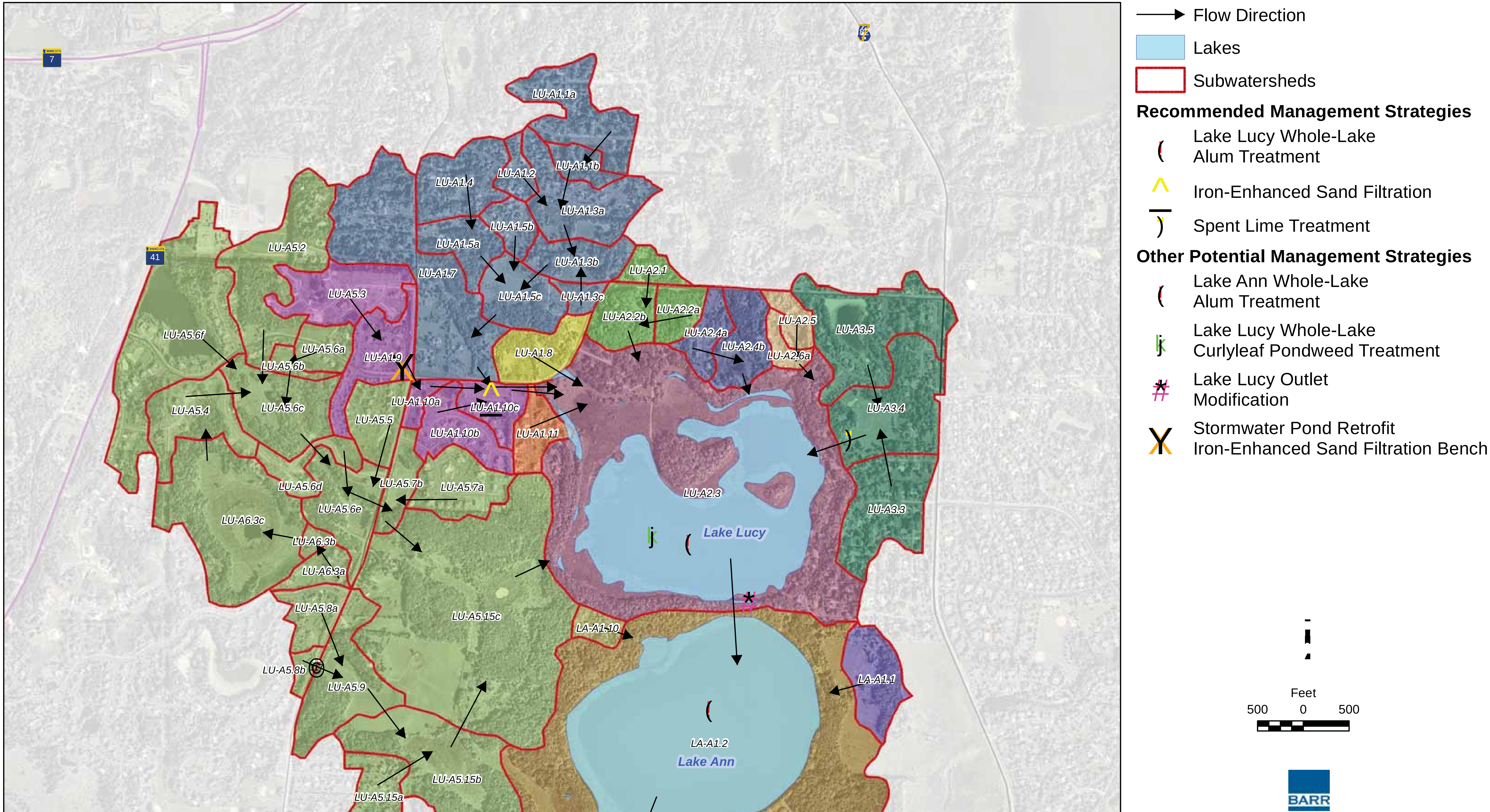


Figure 13
SUMMARY OF LAKE LUCY AND LAKE ANN
WATER QUALITY MANAGEMENT STRATEGIES
Lake Lucy and Ann UAA Update
RPBCWD

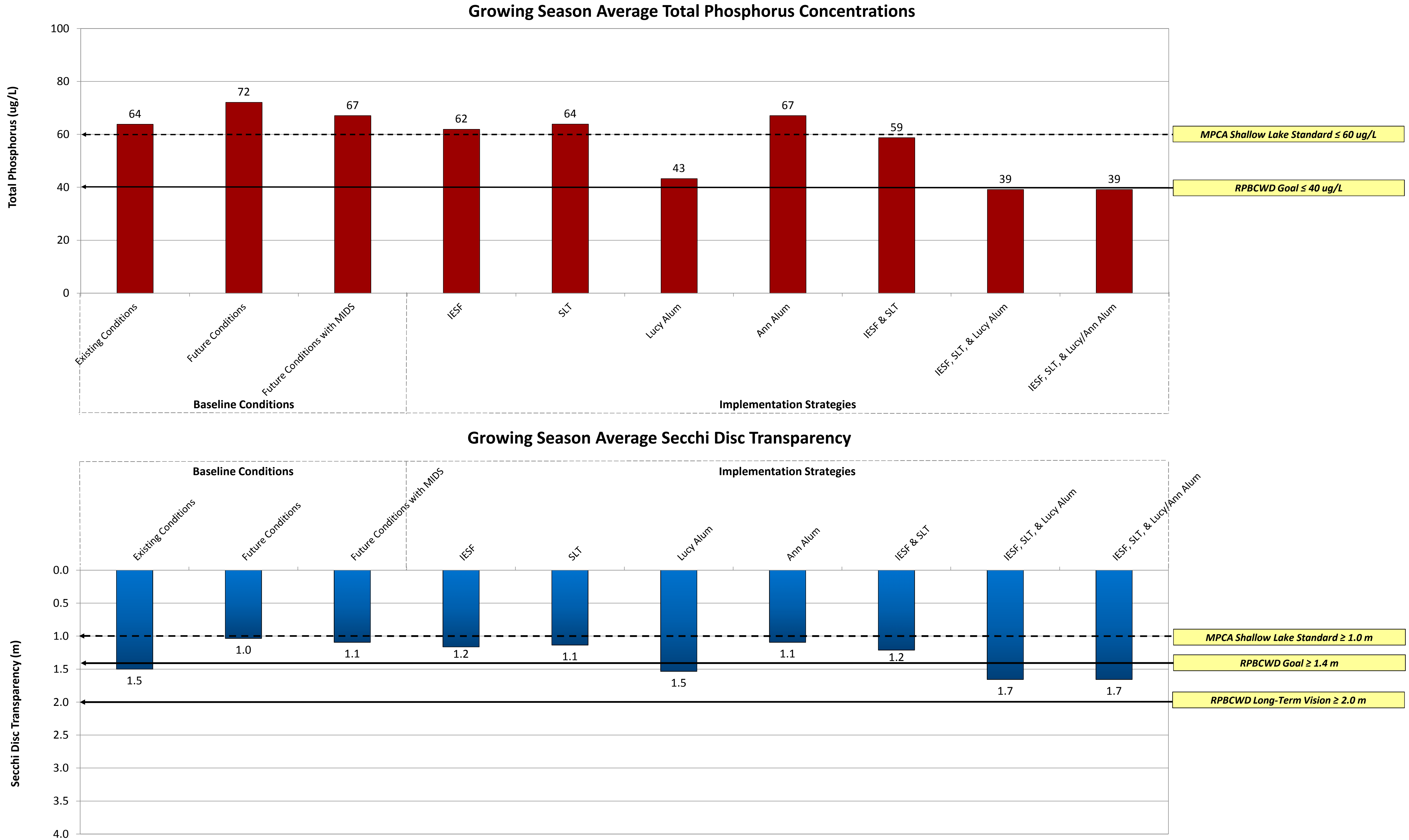


Figure 14
Summary of the Impact of Water Quality BMPs on Lake Lucy Total Phosphorus Concentrations and Secchi Disc Transparencies

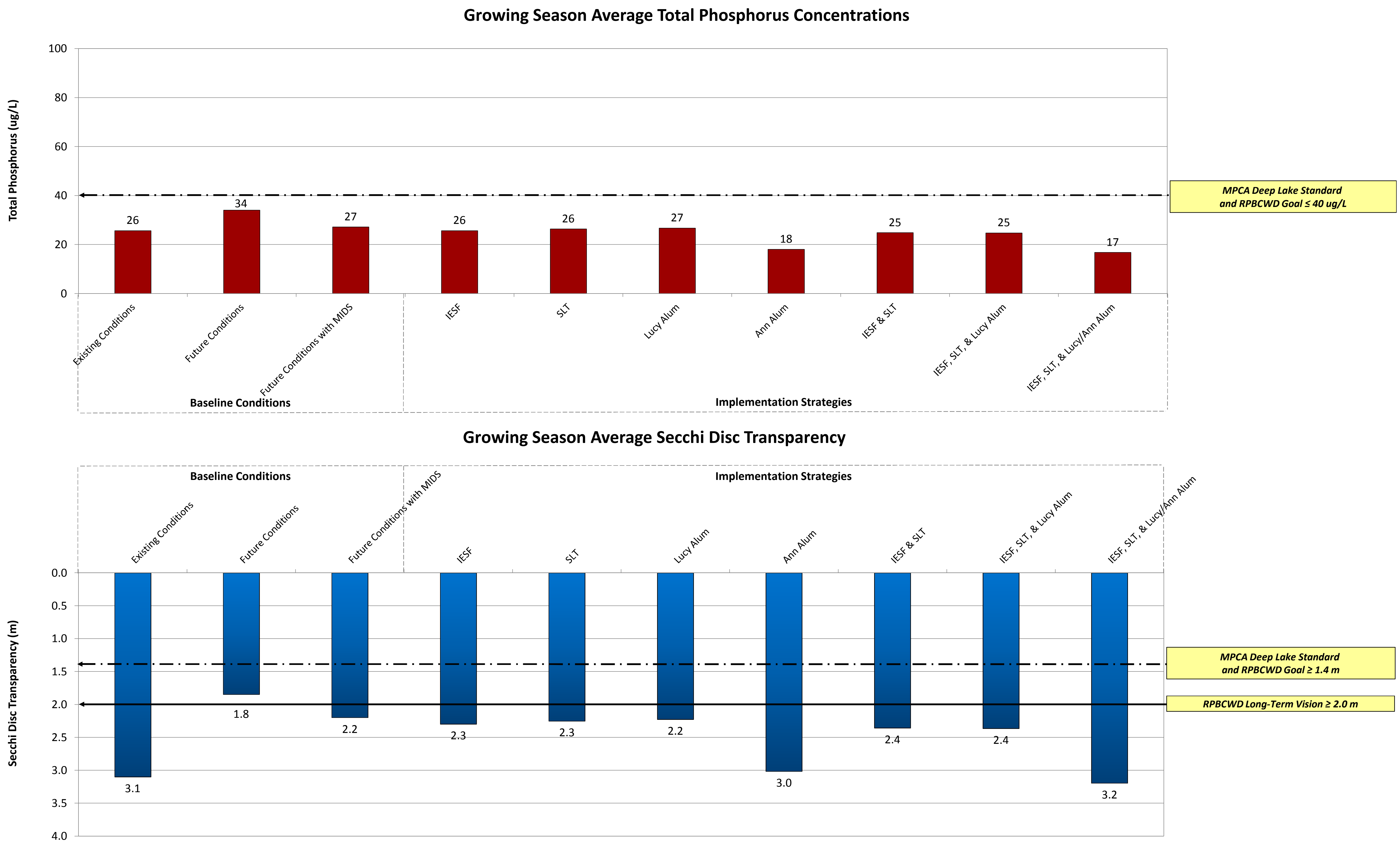


Figure 15
Summary of the Impact of Water Quality BMPs on Lake Ann Total Phosphorus Concentrations and Secchi Disc Transparencies

3.3.1 Implementation of Stormwater Rules Aligned with MIDS

The watershed and in-lake water quality modeling demonstrated that the expected land use changes from existing (2010) to future (2030) conditions would result in degradation of the water quality in Lake Lucy and Lake Ann, assuming no new stormwater BMPs are implemented in the watershed. However, implementation of stormwater rules that align with the MIDS performance goal will help reduce the expected impact of future changes in the watershed on the water quality in Lake Lucy and Lake Ann.

This future conditions scenario with the implementation of stormwater rules similar to MIDS has been used as the baseline condition for the evaluation of the various implementation strategies to protect and improve the water quality in Lake Lucy and Lake Ann. The cost of implementation of stormwater rules, such as the MIDS performance standards, will typically be the responsibility of the developers, with the exception of programmatic costs to implement the regulatory program.

3.3.2 Iron-Enhanced Sand Filtration in Subwatershed LU-A1.10c

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).

Construction of an iron-enhanced sand filter is proposed in subwatershed LU-A1.10c, located on the outlot of the Ashling Meadows development, just south of Lake Lucy Road. Discharge from subwatershed LU-A1.7 and its tributary watershed will be diverted to the 0.25 acre iron-enhanced sand filter. Due to the proximity of the proposed sand filter to the adjacent wetland, an impermeable liner and underdrain have been included in the concept design to minimize the impact of high groundwater and/or high water levels.

Under existing conditions, the watershed draining to LU-A1.7 contributes 27 percent of the total watershed phosphorus load to Lake Lucy. Assuming removal of 80 percent of the soluble fraction of phosphorus, this BMP is expected to remove 19 lbs of phosphorus per year. In-lake modeling suggests this reduction in phosphorus loading could reduce the growing season average in-lake phosphorus concentration in Lake Lucy from 67 μg/L to 62 μg/L (an 8 percent reduction), based on 2012 climatic conditions. This BMP is expected to improve the growing season average phosphorus concentrations in Lake Ann from 27 μg/L to 26 μg/L (a 6 percent reduction) based on 2012 climatic conditions.

The estimated cost of the construction of the iron-enhanced sand filter south of Lake Lucy Road is $350,000 ($280,000-$490,000). The cost includes engineering, design, and administration, purchase a 0.3 acre easement, and the capital construction cost. The estimated annual maintenance of the iron-enhanced system should include inspection of the filter surface, inlet, outlet, and underdrains for clogging and for standing water. Additionally, vegetated side slopes above the filter should be inspected for erosion and gaps in vegetation, and managed similarly to other landscaped areas. Ultimately, the filter media will need to be replaced when the maximum phosphorus retention has been achieved. Laboratory column tests suggest a life span of 35 years (Erikson, et. al. 2012), but this had not been verified in the field. Based on a 35 year life span, the estimated annual cost per pound of phosphorus removed is $1,023.

3.3.3 Spent Lime Treatment in Subwatershed LU-A3.4

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 storm water, thus remaining within the treatment system.

The use of spent lime in stormwater management is still an experimental concept. Currently, Ramsey-Washington Metro Watershed District has constructed a test spent lime system in Maplewood on the south side of Wakefield Lake (an impaired water) which has been operated and monitored for only one year (2012). In the Wakefield Lake system, stormwater runoff is conveyed to a treatment cell with several feet of spent lime material at the bottom of the cell. When stormwater enter the cell, stormwater fills all of the air spaces and contacts the lime material, removing the dissolved phosphorus. Treated runoff then flows to the downstream waterbody via a draintile installed under the spent lime material. Unlike a sand filter, the spent lime treatment cell does not significantly filter solids or particulate phosphorus. However, monitoring data from the treatment cell in Maplewood has shown that dissolved phosphorus is removed to levels below analytical detection.

Because of the identified need to target soluble phosphorus removal, we propose consideration of this experimental BMP in the Lake Lucy watershed. A spent lime treatment system is proposed in subwatershed LU-A3.4 to treat flows from the wetland system and upstream subwatersheds, which contribute 18 percent of the total watershed phosphorus load to Lake Lucy under existing land use conditions. While the location offers a good opportunity to treat a significant portion of runoff to Lake Lucy, the properties on both the east and west sides of Utica Terrace are privately owned, which presents challenges in citing and designing stormwater BMPs that will be functional and aesthetically-acceptable to residents.

To minimize impacts to the adjacent property owners, the spent lime treatment system is proposed to be located within the city right-of-way just east of Utica Terrace. Low flows from the upstream wetland will be diverted to a subsurface, linear box culvert system (approximately 50 feet long) partially filled with the spent lime material and an underdrain system to help facilitate drainage through the system. Access manholes will be included for inspection and maintenance activities.

Assuming removal 80 percent of the soluble fraction of phosphorus from the treated runoff, the proposed spent lime treatment system is expected to remove 11 lbs of phosphorus per year. Modeling indicates that the reduced watershed loading could reduce the growing season average in-lake phosphorus concentration in Lake Lucy from 67 μg/L to 64 μg/L (a 5 percent reduction). This BMP is expected to improve the growing season average in-lake phosphorus concentration in Lake Ann from 27 μg/L to 26 μg/L (a 3 percent reduction) based on 2012 climatic conditions.

The estimated cost of the construction of the spent lime treatment system east of Utica Terrace is $190,000 ($160,000 - $270,000). The cost includes the engineering and design and the capital cost of the BMP construction. The cost assumes that the spent lime material can be obtained for no cost from the water treatment plan (as is the case with the system operating in Ramsey Washington Metro Watershed District) and the only associated cost is to haul the material. The estimated annual maintenance of the system should include inspection of the spent lime surface, inlet, outlet, and underdrains for clogging and for standing water. Typical maintenance involves annual removal of debris that accumulates on the cell surface and manual or mechanical mixing of the cell material. Mixing can be done by hand with a compost-type aeration tool. Ultimately, the spent lime will need to be replaced when the maximum phosphorus retention has been achieved. Assuming a 35 year life span, the estimated annual cost per pound of phosphorus removed is $1,064.

3.3.4 Whole-Lake Alum Treatment of the Lake Lucy 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 problem in Lake Lucy and contributes to the lake water quality degradation during the growing season. The water quality modeling suggests that 33-39 percent of the total phosphorus load to Lake Lucy is from the bottom sediments. To address this internal load, the application of an aluminum sulfate (alum) treatment 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 an alum treatment of Lake Lucy, which was assumed to decrease the internal phosphorus load from the sediment by 80 percent based on literature would reduce the growing season average phosphorus in the Lake Lucy by 35 percent. Modeling suggests an alum treatment would remove 83 lbs of phosphorus per year from the Lake Lucy system, reducing the growing season average in-lake phosphorus concentration from 67 μg/L to 43 μg/L, based on 2012 climatic conditions. This phosphorus concentration will meet the MPCA water quality standards but will not meet the RPBCWD goal for Lake Lucy. This BMP is expected to improve the growing season average phosphorus concentrations in Lake Ann from 27 μg/L to 27 μg/L (an 2 percent reduction) based on 2012 climatic conditions.

The estimated capital cost of one in-lake alum application in Lake Lucy is $320,000 ($260,000-$450,000), based on average alum dosing rates for several lakes across the Twin Cities metro area and the assumption that access to the lake for the alum treatment will be difficult because of lack of a public water access. In addition, the collection and analysis of sediment cores is needed to appropriately estimate the alum dosing rate for the lake. Therefore, the estimated cost includes the collection and analysis of sediment cores in Lake Lucy to appropriately dose the lake. 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 7-10 years (Welch and Cook, 1999).

Because alum treatments have longevity of approximately 10 years, to convert to a 35 year lifespan to compare all management strategies, it was assumed that the alum treatment would need to 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 35 year lifespan, cost-benefit of an alum treatment is $724 per pound of phosphorus per year.

It is expected that alum treatment of Lake Lucy will result in reduced phosphorus concentrations and improved clarity in the water. Because Lake Lucy is a macrophyte dominated system that also has Curlyleaf pondweed present at approximately 40 percent of the littoral area in the lake, there is concern that the increase in clarity may result in significant growth and expansion of Curlyleaf pondweed rather than the other native macrophytes in the system. Given this, it may be necessary to manage Curlyleaf pondweed prior to the treatment of Lake Lucy with alum. The alum treatment costs listed above do not include Curlyleaf pondweed management.

The management of Curlyleaf pondweed can be done by herbicide treatments applied by boat or barge, or by mechanical harvesting. Herbicide treatments are more effective than mechanical harvesting in controlling the plant, but MDNR regulations limit the extent of the lake that can be treated in any year. Effective management typically requires treatment of the entire lake surface; however, currently the MDNR will only allow for herbicide treatment of up to 15 percent of the lake surface without an approved variance. The timing of the treatment of Curlyleaf pondweed is extremely important and should occur early in the spring when water temperatures are between 50-60 degrees F to minimize impact on native plants. Examples of two aquatic herbicides that have been used in controlling the growth of Curlyleaf pondweed in lakes are Reward (active ingredient = Diquat) and Aquathol-K (active ingredient = Endothall).

Recent research and experience indicates that several years of intensive whole-lake herbicide treatment is required to successfully manage the growth of Curlyleaf pondweed as Curlyleaf pondweed turions (seedpods) remain viable for at least five years, potentially more. Additionally, the management typically requires treatment of the entire lake surface (currently the MDNR will only allow for herbicide treatment of up to 15 percent of the lake surface).

At a minimum, lake-wide management of Curlyleaf pondweed will require obtaining a MDNR permit and letter of variance (to treat the entire lake surface), obtaining letters of permission from all shoreline property owners to treat within 150 feet of the shoreline, 5-years of herbicide treatments of the entire lake surface shortly after ice out to target the Curlyleaf pondweed, and 5-years of monitoring, analysis, and reporting. The estimated cost to intensively manage Curlyleaf pondweed for the five years prior to the alum treatment is $470,000 ($380,000-$660,000).

It was estimated that Curlyleaf pondweed contributes from 9-11 percent of the total phosphorus load to Lake Lucy. It is expected that if Curlyleaf pondweed is managed as part of the alum treatment alternative, there could be additional improvements in Lake Lucy water quality, especially in late June and early July when the die-back of Curlyleaf pondweed typically happens. Whole-lake management of Curlyleaf pondweed has the potential to reduce the total annual phosphorus load to Lake Lucy by approximately 28 pounds per year, assuming 80 percent treatment effectiveness.

3.3.5 Whole-Lake Alum Treatment of the Lake Ann Bottom Sediments

Water quality monitoring data and in-lake water quality modeling indicate that internal phosphorus loading from the lake bottom sediments is also a problem in Lake Ann. The water quality modeling suggests that 55 percent of the total phosphorus load to Lake Ann is from the bottom sediments. To address this internal load, we proposed the application of an aluminum sulfate (alum) treatment to the lake sediments. Alum is commonly used in lakes to bind with phosphorus in lake sediments and prevent its release into the water column.

An alum treatment of Lake Ann, 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 Ann by 34 percent. We estimated that an alum treatment would remove 109 lbs of phosphorus per year from the Lake Ann system, reducing the growing season average in-lake phosphorus concentration in Lake Ann from 27 μg/L to 18 μg/L based on 2012 climatic conditions. Because Lake Lucy is located upstream of Lake Ann, an alum treatment in Lake Ann would have no impact on the Lake Lucy water quality.

The estimated capital cost of one in-lake alum application in Lake Ann is $290,000 ($240,000-$410,000), based on average alum dosing rates for several lakes across the Twin Cities metro area and access via the boat launch in Lake Ann Park. Since sediment cores have not been collected in Lake Ann to estimate the actual dosing required for the lake, we would recommend the collection and analysis of sediment cores to appropriately estimate the dosing for the lake. The estimated cost includes the collection and analysis of sediment cores in Lake Ann

Because alum treatments have longevity of approximately 10 years, to convert to a 35 year lifespan to compare all management strategies, it was assumed that the alum treatment would need to 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 35 year lifespan, cost-benefit of an alum treatment is $499 per pound of phosphorus per year in Lake Ann.

3.3.6 Combined Strategy: Iron-Enhanced Sand Filtration and Spent Lime Treatment

This strategy includes the incorporation of both the iron-enhanced sand filtration into subwatershed LU-A1.10c and the spent lime treatment system into subwatershed LU-A3.4 in the Lake Lucy watershed. This proposed combination of BMPs will reduce the growing season average in-lake phosphorus concentration in Lake Lucy from 67 μg/L to 59 μg/L (a 12 percent reduction). This phosphorus concentration will meet the MPCA water quality standards but will not meet the

RPBCWD goal for Lake Lucy. This combination of management practices is expected to improve the growing season average in-lake phosphorus concentration in Lake Ann from 27 µg/L to 25 µg/L (a 9 percent reduction) based on 2012 climatic conditions.

The estimated combined cost of the construction of the iron-enhanced sand filter south of Lake Lucy Road and the spent lime treatment system at Utica Terrace is $540,000 ($440,000-$760,000). Assuming a 35 year life span, the estimated annual cost per pound of phosphorus removed is $1,037.

3.3.7 Combined Strategy: Iron-Enhanced Sand Filtration, Spent Lime Treatment, and Lake Lucy Alum Treatment

This strategy includes the incorporation of both the iron-enhanced sand filtration into subwatershed LU-A1.10c and the spent lime treatment system into subwatershed LU-A3.4 in the Lake Lucy watershed, and the alum treatment of Lake Lucy. This proposed combination of BMPs will reduce the growing season average in-lake phosphorus concentration in Lake Lucy from 67 µg/L to 39 µg/L (an 42 percent reduction). This phosphorus concentration will meet both the MPCA water quality standards and the RPBCWD goal. This combination of management practices is expected to improve the growing season average in-lake phosphorus concentration in Lake Ann from 27 µg/L to 25 µg/L (an 9 percent reduction).

The estimated combined cost of the construction of the iron-enhanced sand filter south of Lake Lucy Road, the spent lime treatment system east of Utica Terrace, and the alum treatment of Lake Lucy is $860,000 ($700,000-$1,210,000). Assuming a 35 year life span for the watershed BMPs and the Lake Lucy alum treatment (see Section 3.3.4 for a discussion of the methodology), the estimated annual cost per pound of phosphorus removed is $2,062.

3.3.8 Combined Strategy: Iron-Enhanced Sand Filtration, Spent Lime Treatment, Lake Lucy Alum Treatment, and Lake Ann Alum Treatment

This strategy includes the incorporation of both the iron-enhanced sand filtration into subwatershed LU-A1.10c, the spent lime treatment system into subwatershed LU-A3.4 in the Lake Lucy watershed, and the alum treatment of both Lake Lucy and Lake Ann. This proposed combination of management practices will reduce the growing season average in-lake phosphorus concentration in Lake Lucy from 67 µg/L to 39 µg/L (a 42 percent reduction). The resulting phosphorus concentration will meet both the MPCA water quality standards and the RPBCWD goal. This combination of management practices is expected to improve the growing season average in-lake phosphorus concentration in Lake Ann from 27 µg/L to 17 µg/L (an 38 percent reduction).

The estimated combined cost of the construction of the iron-enhanced sand filter south of Lake Lucy Road, the spent lime treatment system east of Utica Terrace, and the alum treatment of Lake Lucy and Lake Ann is $1,150,000 ($940,000-$1,620,000). Assuming a 35 year life span for both the watershed BMPs and the Lake Lucy and Lake Ann alum treatments (see Section 3.3.4 and 3.3.5 for a discussion of the methodology), the estimated annual cost per pound of phosphorus removed is $656.

3.3.9 Additional Treatment Opportunities

The following are more general, localized BMPs and/or stormwater management opportunities that should be considered for the protection of the water quality in Lake Lucy and Lake Ann, but have not been evaluated in detail as part of this UAA.

3.3.9.1 "As Opportunities Arise" in the Watershed

It is recommended that RPBCWD and City of Chanhassen staff continue to work together to identify and evaluate opportunities to implement additional stormwater management as changes occur within the watershed (beyond what may be required by current and future stormwater management rules). Opportunities could include incorporation of stormwater BMPs in areas slated for road reconstruction or for redevelopment. For example, in the *Susan, Ann, and Lucy Subwatershed: Stormwater Retrofit Assessment* (Carver SWCD, 2001), the roads within the watersheds contributing to the LU-A3.4 discharge were identified as being slated for reconstruction in the near future. Complete reconstruction of roads can provide the opportunity to incorporate linear stormwater management features within the right right-of-way that can provide localized stormwater treatment. However, the study did note that the soils in this area are tight clays and may not be conducive to infiltration alone.

Runoff from the direct watersheds to Lake Lucy and Lake Ann currently receives limited stormwater treatment before discharging to the lakes. There may be opportunities within these watersheds to educate residents about stormwater runoff management and incorporate stormwater treatment and/or shoreline and vegetation management on their properties. For Lake Lucy and Lake Ann, the land along the west shorelines is fairly undeveloped and currently under private ownership. However, as future changes occur within the direct watersheds to Lake Lucy and Lake Ann, preserving the land along the shoreline as undeveloped or parkland will help further protect the water quality in both lakes.

Additionally, as new BMPs and water quality improvement technologies are developed, it is recommended that they be considered for implementation in the Lake Lucy and Lake Ann watersheds if determined to be reasonable, practicable, and cost effective.

3.3.9.2 Retrofits to Existing Stormwater Ponds and Wetlands

The *Susan, Ann, and Lucy Subwatershed: Stormwater Retrofit Assessment* (Carver SWCD, 2011), it recommends that existing stormwater ponds in the Lake Lucy watershed be retrofitted with iron-enhanced sand filtration benches to help reduce the soluble fraction of phosphorus from leaving the system.

Based on our more detailed modeling of the watershed, we have identified the following specific locations to potentially retrofit existing ponds with iron-enhanced benches within the Lake Lucy watershed:

- Stormwater pond in subwatershed LU-A1.9: The watershed passing through the stormwater pond in LU-A1.9 contributes approximately 5 percent of the estimated watershed phosphorus load to Lake Lucy. Additionally, this pond was monitored by the RPBCWD in 2012 and was identified to have elevated phosphorus concentrations (potentially due to internal loading). However, the pond is located on private property, and there is limited space to incorporate an iron-enhanced sand filtration bench near the outlet.

- Wetland LU-A1.15c – The watershed passing through the wetland in LU-A1.15c contributes approximately 14 percent of the estimated watershed phosphorus load to Lake Lucy. However, the water body is a mapped wetland and is located on private land. Based on conversations with City and RPBCWD staff, it is likely that implementation on a stormwater BMP on this site will not happen under the current ownership. However, the RPBCWD and the City of Chanhassen should continue to track future opportunities in this area.
- In 2013 the RPBCWD is monitoring phosphorus concentrations in other ponds and wetlands within the Lake Lucy watershed. The results of this monitoring may help identify other ponds that could be retrofitted with iron-enhanced benches to help reduce the soluble phosphorus loads to Lake Lucy.

3.3.9.3 Lake Lucy Outlet Modifications

A cursory evaluation of opportunities to remove soluble phosphorus at the outlet channel from Lake Lucy to Lake Ann, such as an iron-enhanced sand filtration system, was conducted. However, a detailed site assessment of potential BMPs was not feasible because the channel is located on private property and was not accessible during this study nor is it expected to be accessible in the near future.

In addition to not having access permission, fluctuating water levels within the channel may limit the potential for effective performance of an iron-enhanced sand filtration system. For an iron-enhanced sand filtration system to effectively remove soluble phosphorus, the water that is treated by the system needs to draw down between each storm event so that the iron-enhanced sand filter media stays oxygenated (and does not release the phosphorus bound to the iron in the media). The challenge of the outlet channel between Lake Lucy and Lake Ann is that due to the elevations of the Lake Lucy and Lake Ann outlets (the elevation of the Lake Ann outlet channel is higher than the Lake Lucy outlet channel), the Lake Lucy outlet channel is often submerged with water. This means that an iron-enhanced sand filter within the channel would be submerged much of the time and may not function effectively. In addition, sufficient head (change in elevation) is often required to force water through the filter media for treatment.

Monitoring of oxygen levels in the channel over the growing season is necessary to understand the conditions at the site and if the oxygen levels would allow an iron-enhanced sand filter to function properly. There is also concern that including an iron-enhanced sand filter in the channel between Lake Lucy and Lake Ann would accumulate organics in the filter that could eventually start to decay, using oxygen and potentially releasing phosphorus. Sedimentation may also occur in the channel, reducing the system's ability to function properly. Finally, any modifications to this channel would need to allow for fish passage between Lake Lucy and Lake Ann.

An alternative would be to install a treatment system that would pump a portion of water from Lake Lucy to an above ground treatment system, such as an iron-enhanced sand filtration system or a spent lime treatment system. The system could be located at an elevation higher than Lake Lucy and Lake Ann in Greenwood Shores Park on the southwest side of Lake Lucy, as the area between Lake Lucy and Lake Ann is on private property and it is unlikely the implementation of a stormwater BMP on the property will happen under the current ownership. Pumping water to a treatment system located at a higher elevation would provide the required elevation changed needed to force water through the filtration system and would prevent the concerns with the iron-enhanced filter media releasing phosphorus under anoxic conditions. The discharge from the treatment system could be discharged directly to Lake Ann.

Whether the treatment of the discharge from Lake Lucy were installed in the outlet channel or in a separate system in the Greenwood Shores Park, the system will have no impact on the observed water quality in Lake Lucy; however, there is some expected improvement in the Lake Ann water quality due to the improvement in the discharge from Lake Lucy. Based on the future conditions with MIDS under the 2012 climatic conditions baseline scenario that has been used to evaluate the various implementation strategies, the estimated annual phosphorus load from Lake Lucy to Lake Ann is approximately 44 pounds. If a system were designed to treat all flows from Lake Lucy to Lake Ann, the maximum annual phosphorus removal would be about 35 pounds of phosphorus (assuming 80 percent phosphorus removal). This would reduce the annual phosphorus load to Lake Ann by about 14 percent.

4.0 Lake Lucy and Lake Ann 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 not only protect but also improve water quality in Lake Lucy and Lake Ann.

The following is a summary of the recommendations for the management of water quality in Lake Lucy and Lake Ann.

- **Implementation of stormwater management rules that align with the MIDS performance goals** to help minimize degradation of water quality in Lake Lucy and Lake Ann as future development occurs within the watersheds.
- Implementation of BMPs at targeted locations within the Lake Lucy 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 subwatershed LU-A1.10c** and the **spent lime treatment system in subwatershed LU-A3.4**.
- Continued evaluation of **opportunities to work with landowners in the direct watersheds** to Lake Lucy and Lake Ann that currently do not receive any water quality treatment prior to discharging to the lakes. These efforts should focus on the implementation of stormwater BMPs on private parcels and to educate about shoreline/vegetation management (if applicable). The RPBCWD could target **the promotion of their new cost-share program to residents in the direct watersheds to Lake Lucy and Lake Ann**. Additionally this could also include **preservation of the currently undeveloped shorelines** on the west sides of both Lake Lucy and Lake Ann.
- **Continue to work with the City of Chanhassen 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 LU-A1.9)** should be pursued as opportunities arise. Other stormwater ponds maybe identified as good candidates for **pond retrofits with iron-enhanced sand filtration benches upon completion of the 2013 pond water quality monitoring** by the RPBCWD.
- **Monitoring of dissolved oxygen levels in the Lake Lucy outlet channel should be performed for a growing season** if permission to access the site is obtained to determine if the site is a potential candidate to retrofit iron-enhanced filtration treatment. If the oxygen levels would support that the channel could be modified to incorporate treatment, additional feasibility study would be required including site visits.
- Once the watershed loads to Lake Lucy have been reduced, the RPBCWD should consider performing an **alum treatment of the internal sediment loading in Lake Lucy**. However, this may also require management of Curlyleaf pondweed prior to the alum treatment to prevent the expansion of this non-native species should the water clarity increase

significantly. **Prior to the alum treatment, we would recommend collection of an early spring (shortly after ice out) survey of macrophytes in Lake Lucy**, before to any macrophyte treatments are done by shoreline residents. This data, in combination with the point-intercept survey data collected by the University of Minnesota from 2010 through 2012 should be reviewed. Using this data, the necessity of whole-lake Curlyleaf pondweed management prior to an alum treatment can be determined, and if so, a vegetation management plan can be developed for Lake Lucy.

- **Continued 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, macrophyte surveys should be conducted 1-2 times per year in both Lake Lucy and Lake Ann, in early June to capture the Curlyleaf pondweed and again in late summer.
    - Additionally, because macrophyte management is being performed by private residents on Lake Lucy, the RPBCWD should try to document the magnitude and extent of this private management in the future.
    - In Lake Lucy and Ann, the RPBCWD should continue to monitor cyanobacteria levels within the lake.
    - Water quality monitoring in select ponds and wetlands throughout the watershed to determine if they are potentially sources of phosphorus to the lakes.
    - Sediment cores to evaluate the sediment for mobile-phosphorus, to help understand the potential magnitude of internal loading from the bottom sediments and to help with the dosing of future alum treatments.
- Based on review of the water quality monitoring data during the system operation and follow up discussions with the University of Minnesota researchers about the carp populations, the RPBCWD should consider **discontinuing operation of the Lake Lucy ice preserving aeration system during the winter**.
    - The primary reason for the aeration system was to prevent winterkill in Lake Lucy to preserve the sunfish populations to help control the carp populations. Recent discussions with U of MN researchers about winterkill frequency (every 5- 10 years), carp recruitment, and carp age data indicate that there is a low risk of carp reestablishing in Lake Lucy. Review of the carp age data collected on Lake Lucy indicated that the most recent peak of carp recruitment in the system (2002) did not occur after a known winterkill event (Bajer and Sorensen, University of Minnesota, unpublished data, email communication, 6/25/2013).
    - The secondary reason for the aeration system was to reduce the release of phosphorus into the hypolimnion during the winter. Although monitoring data indicates that the system does keep the dissolved oxygen levels elevated in the hypolimnion and the phosphorus levels low during the winter, the aeration system seems to have little impact on the spring or the growing season average phosphorus concentrations. Lake water quality standards are typically based on the growing season management period.

- Because Lake Ann currently meets the MPCA water quality standards and the RPBCWD goals, we do not recommend an alum treatment of the Lake Ann bottom sediments to help achieve the water quality goals at this time. However, as previously mentioned, RPBCWD should continue to monitor the cyanobacteria levels in Lake Ann. **If the cyanobacteria levels become a significant public health risk, an alum treatment of the Lake Ann bottom sediments will help reduce the cyanobacteria levels in the lake.**
- **The RPBCWD should continue to follow any developments by the MPCA related to management of mercury impairments** to aid in addressing methylmercury concerns in Lake Ann after more scientific data and remedial measures become available at some point in the future.

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Appendix A

P8 Model Parameter Selection

P8 Model Parameter Selection

During the development of the original UAA P8 watershed model (which was used as the basis for the UAA update), there was no monitoring of stormwater inflows for Lake Lucy and Lake Ann; this limited the amount of P8 calibration that could be performed. At the time the original Lake Lucy and Lake Ann P8 model was developed, a P8 model was being developed and calibrated for nearby Round Lake and the calibrated parameters from Round Lake were used in the Lake Lucy and Lake Ann models.

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) = 10. 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.

- Snowmelt Melt Coef (Inches/Day-Deg-F) = 0.03. The P8 model predicts snowmelt runoff beginning and ending earlier than observed snowmelt. The lowest coefficient of the recommended range was selected to minimize the disparity between observed and predicted snowmelt (i.e., the coefficient minimizes the number of inches of snow melted per day and maximizes the number of snowmelt runoff days). Preserved from the original UAA P8 model.

- 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 Round Lake P8 model calibration. Preserved from the original UAA P8 model.

- Growing Season Antecedent Moisture Conditions AMC II = .05 and AMC III = 100. 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 II 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 was selected and modeled water volumes exceeded observed volumes when Antecedent Moisture Condition III was selected. The selected parameters tell the model to only use Antecedent Moisture Condition I when less than 0.05 inches of rainfall occur during the five days prior to a rainfall event and to only use Antecedent Moisture Condition III if more than 100 inches of rainfall occur within five days prior to a rainfall event. Preserved from the original UAA P8 model.

- Particle Scale Factor for TP = 1.45. The particle scale factor determines the total phosphorus load generated by the particles predicted by the model in watershed runoff. Preserved from the original UAA P8 model.

- 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 = LakeLucy_LakeAnn_P8Precip_01-12.pcp. For 2012 climatic conditions, a continuous hourly precipitation file was developed based on local data collected by the RPBCWD at Lake Susan (2011) and Lake Lucy (2012). 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. For the 2005 climatic conditions, the hourly data from the Minneapolis-St. Paul International Airport NWS stations (MSP) was used and adjusted based on comparison of the precipitation amounts at MSP to the data collected at the Chanhassen NWS station.

- Air Temperature File Selection msp4912.tmp. The temperature file was comprised of temperature data from the Minneapolis St. Paul International airport during the period 1949 through 2012.

- 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, 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 Factorσ: 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 Hennepin County Soils Survey 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. The table below summarizes the impervious coverage assumptions by land use category.

Table 1 Impervious Assumption by Land Use

LANDUSE	Total Impervious (%)	Directly-Connected Impervious (%)
Agricultural	5	1
Airport	85	80
Commercial	86	85
Golf Course	6	4
High Density Residential	68	50
Highway	25	25
Industrial/Office	62	61
Institutional	49	40
Institutional - High Impervious	75	70
Low Density Residential	39	24
Medium Density Residential	59	37
Suburban Low Density Residential	32	17
Natural/Park/Open	5	3
Forest	0	0
Other	60	55
Very Low Density Residential	12	10

- Impervious Depression Storage = 0.05 Preserved from the original UAA P8 model.

- Impervious Runoff Coefficient = 0.92 Preserved from the original UAA P8 model.

- Passes Thru Storm File = 5. 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.

Appendix B

Aquatic Plant Community of Lakes Ann, Lucy, Susan, Riley, and Staring: 2011 Summary of Results

Knopik and Newman, University of Minnesota

Aquatic Plant Community of

Lakes Ann, Lucy, Susan, Riley and Staring,

Riley Purgatory Creek Watershed

Chanhassen, MN:

2011 Summary of Results

Annual Report to the Riley Purgatory Bluff Creek Watershed District

Joshua M. Knopik
and
Raymond M. Newman,

University of Minnesota

23 January 2012

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I. Introduction

Lakes Lucy, Ann, Susan and Riley are small lakes connected by Riley Creek within the cities of Chanhassen and Eden Prairie, Minnesota. Lake Staring, also in Eden Prairie, is along the Purgatory Creek. These lakes are part of the Riley-Purgatory Bluff Creek Watershed District. Aquatic vegetation surveys were performed on the lakes between May and October 2010 and 2011. These surveys were conducted to evaluate the response of aquatic plant communities of the lakes to management actions. There are several goals of the project, but the main purpose of our research was to quantify the aquatic plant community response to the removal of common carp (*Cyprinus carpio*) from the lakes. Carp were removed (by the Sorensen lab) from Lake Susan in winter 2009 and its plant community was surveyed in summer 2009, 2010 and 2011. Carp were also removed from Lucy in January 2010 and plants were surveyed in 2010 and 2011. Carp were removed from Lake Riley in March 2010 and plant surveys were done in summer 2011. By repeating these surveys after carp removal, we can assess the change in the aquatic plant community. A secondary goal of the project was to enhance the recovery of native plants and minimize the dominance of aquatic invasive species. The hypothesis is that removal of carp will lead to a decrease in rooting of aquatic plants and an increase in water clarity. This will in turn increase the light available to aquatic plants, which will benefit both native and exotic species (Hanson and Butler, 1994). However, invasive species such as Eurasian watermilfoil (*Myriophyllum spicatum*) and curlyleaf pondweed (*Potamogeton crispus*) are already established in the lakes, and due to their natural aggressive recruitment, there is concern the invasive species will expand at a faster rate than native species. Techniques to reduce the dominance of the invasive species and enhance native plant communities are also being evaluated. This report presents data and preliminary results from 2011 and relates these to results from 2009 (Newman 2009) and 2010 (Newman and Knopik 2011).

II. Methods

Plant communities were surveyed for species occurrence and diversity (point intercept surveys), biomass, curlyleaf pondweed turion densities, and herbivore abundance in all the lakes to assess response to carp removal and develop approaches to enhance native plant communities. The success of several approaches to transplanting native submersed plants was also assessed in Lake Susan to determine if transplanting might be used to hasten establishment of diverse native plant communities.

Point Intercept Survey:

A point intercept survey approach modeled from the methods described by Madsen (1999) was used to define sampling points to assess the plant community in each lake. Using Arcmap GIS, survey points were generated following a systematic square grid. Grid spacing ranged from 35m to 40m to ensure at least 120 points within the littoral zone (≤4.6m depth) of each lake. The sampling points were loaded into a Garmin GPS 76 and a boat was navigated to each sampling point. A weighted double headed rake (0.3m wide) attached to a rope was then tossed into the lake, allowed to sink and retrieved along the lake bottom for approximately four meters, thus sampling approximately one square meter. The vegetation collected was identified and a semi-quantitative density rating (0 to 5) was visually estimated. Frequency of occurrence was determined for each species within the littoral zone and for native and invasive plants. Mean species richness was determined from the total number of taxa present at each site and total number of species found in each lake was also determined. Samples were taken in depths up to 6m to determine the maximum depth of rooted vegetation. Arcmap GIS was used to generate maps to assist in visualizing taxa locations, depth of growth, and richness at sites.

Biomass Sampling:

Plant biomass (g dry/m^2) was sampled using methods described by Johnson and Newman (2011). Forty sampling sites were randomly selected from the point intercept survey points on each lake. At each site, all the plants in a 0.3m^2 area were collected with a long handled garden rake that was lowered to the lake bottom, rotated three times to ensure uprooting of all plants, and pulled to the surface (Johnson and Newman 2011). The samples were placed in plastic bags, and taken to a lab where the plants were sorted by species. The samples were dried at 105˚C for >48 hr and weighed. Mean dry biomass was calculated for each species based on all samples taken within the littoral zone.

Curlyleaf Pondweed Turion Sampling:

The invasive species curlyleaf pondweed (CLP) is found in many lakes in Minnesota including Lakes Lucy, Ann, and Susan. One of the most common ways CLP reproduces is by forming over-wintering structures called turions (Madsen and Crowell 2002). To better understand the CLP population dynamics in the lakes we assessed the Turion bank in the sediment. Forty sampling sites in the littoral zone (≤ 4.6m depth) were randomly selected from the full set of point intercept sites. The coordinates were entered into a GPS, and a boat was navigated to each point. At each point a petite ponar (225 cm^2 basal area, sample depth ~10 cm) was used to take a sediment sample. Sampling depth and substrate type was noted. The sediment sample was then passed through a 1mm mesh sieve to remove fine sediment. The remaining sample was returned to the lab and turions were enumerated. The turions that had sprouted in the field (plants or sprouts collected with turions attached) were discarded. The remaining turions were stored in transparent freezer bags and placed in a dark refrigerator at 5^{o}C. Every 7 to 10 days the samples were examined for sprouting, and sprouted turions were counted and removed. After several weeks, the rate of cold sprouting turions had declined. At this point the samples were placed at room temperature (21^{o}C) under natural spectrum lighting for 12 hours per day. Samples were examined every 7-10 days and sprouted turions were removed and recorded. Turion viability (proportion) was calculated taking the ratio of the number of sprouted turions per site (including the turions that were sprouted when collected) to the total number of turions collected per site. The total number of turions collected at each site and number of viable (sprouted) turions was expressed as number of turions per square meter.

Milfoil Herbivore Abundance:

Surveys were conducted to evaluate the abundance of milfoil herbivores. The milfoil weevil, *Euhrychiopsis lecontei*, is a native weevil found in many lakes in North America. Much of the weevil's life cycle is dependent on the milfoil plant. Evidence suggests the milfoil weevil can be effective in controlling population of Eurasian watermilfoil (*Myriophyllum spicatum*) (Newman 2004). One survey was conducted on Lake Ann and Lake Lucy in 2010 and 2011 and on Lake Riley in 2011 to determine if milfoil weevils were present or abundant. Weevil surveys were not conducted on Lake Staring due to lack of plants. On Lake Susan, repeated surveys were conducted every two to three weeks to quantify and monitor the population throughout the summer in 2010 and 2011. To sample milfoil herbivores, transects perpendicular to the shoreline were predetermined and geographically spread around the lake. Three sampling points were established on each transect, one at shallow depth (<0.75m), one at an intermittent depth (0.75 to 1.5m), and one at deeper depth (>1.5m). At each sampling point the top 0.5m of eight stems of EWM were collected and placed in a sealable bag with water. In a lab, each sample was examined with a 3x magnifying lens, plant meristems were counted, and all herbivores (lepidopterans and weevils) and weevil life stages (eggs, pupae, larvae, and adults) were counted and preserved in ethanol.

Water Quality:

Several indicators of water quality were measured periodically on all lakes. Water temperature and dissolved oxygen readings were recorded in 0.5m depth intervals using a YSI 50B electronic meter. Secchi depths were recorded to the nearest 0.1m.

II. Lake Lucy

Lake Lucy, Carver County (DOW-ID 10-000700) is the headwaters of the Riley Creek watershed. Lake Lucy has a surface area of about 35.5 hectares (87 acres), with about 35 hectares littoral (86 acres), and a maximum depth of 6.8m (MN DNR Lake finder 2011). The outlet of Lake Lucy goes directly into Lake Ann. In attempts to improve water quality, common carp were removed from Lake Lucy in January 2010 (Bajer and Sorenson, University of Minnesota, personal communication). Plant assessments were started in summer 2010.

Water Quality:

Summer Secchi depths indicate that Lake Lucy maintained greater clarity (>2.5m) throughout much of July 2011 as compared to 2010 (Bajer and Sorenson, unpublished data, Figure 1). Clarity then decreased quickly from 2.5m in late July to <1.0m in September 2011. Lake Lucy temperature and dissolved oxygen profiles show an anoxic hypolimnion below 2.5 to 3m (Figure 1).

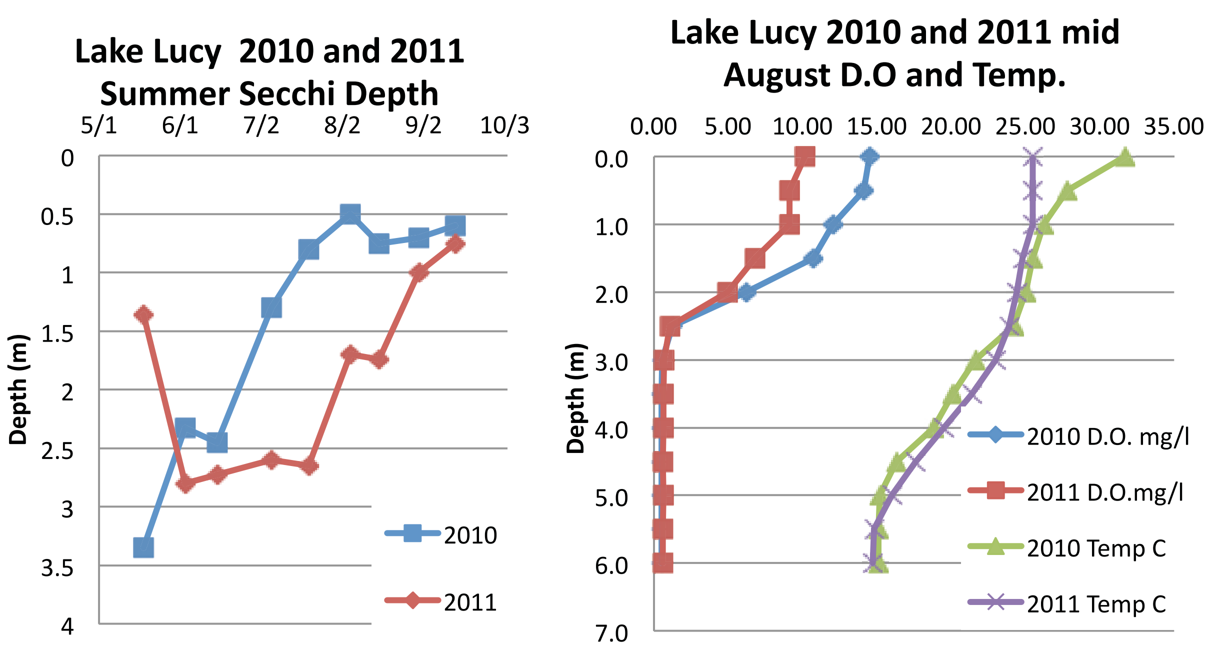


Figure 1. Comparison of 2010 and 2011 Secchi depth (Bajer and Sorenson, unpublished data), temperature, and dissolved oxygen profiles for Lake Lucy 2010 and 2011.

Vegetation Survey:

Point intercept surveys were performed on Lake Lucy on 18 June and 17 August 2011 following the procedures previously mentioned. Overall there was a moderately diverse plant community with 15 submerged and floating aquatic plant species present (Table 1) in 2011. The maximum depth of rooted vegetation was 4.1m (August). Maximum species richness per sample increased from six species present at a few sampling sites in 2010 to seven species per site in several locations in 2011 (Figure 2). Plants were noted in 84% (June) and 72% (August) of sites shallower than 4.6m. The most frequently occurring species was coontail (*Ceratophyllum demersum*), found in 55% of the sampled sites in June and 65% of the sampled sites in August. The free-floating species star duckweed (*Lemna trisulca)* was also very common, occurring in 48% and 42% of the sites in June and August respectively. The native northern watermilfoil (*Myriophyllum sibiricum*) was noted in 13% of sites in June and 10% of the sites in August (Figure 3). Although *Chara sp*. was only found in 20% of the sites in June, it was growing in relatively small but dense patches. Curlyleaf pondweed was noted in 40.6% of the littoral sites in June and only 3% of sites in the August survey, which is to be expected because of its life cycle.

Coontail had a consistently high dry plant biomass with 205g/m^2 in June and 152g/m^2 August (Figure 4). *Chara sp.* also had a relatively high biomass with 414g/m^2 in June but only 13g/m^2 in August. Lake Lucy has had abundant curlyleaf pondweed in the past.

Comparing the differences in aquatic plant community between august 2010 and 2011 (Figure 3 bottom), there are few differences in frequency of occurrence. The exotic species, Eurasian watermilfoil was found at only one location in Lake Lucy 2011; it was not found at any sites in 2010. There were slight increases in frequency of occurrence in *Chara sp.* and northern milfoil. Native plants accounted for the vast majority of total dry plant biomass in both June and August 2011 with coontail making up most of the biomass. This was also noted in 2010 (Table 2).

Although curlyleaf pondweed was found in many of the sites in June, the plants were small and accounted for very little biomass (2.1g/m^2 in 2010, and 16.4 g/m^2 in 2011) (Figure 4). It was noted that nearly all the biomass collected (16.1 g/m^2) in June 2011 were from plants that appeared to be dead and showing early signs of decay. This was surprising because by mid June curlyleaf should be at or near peak growth. It was later discovered this was probably due to herbicide treatments for curlyleaf done by riparian owners in early June 2010 and 2011 (personal communication with lake home owner). Thus it is difficult to know if the relatively low abundance of curlyleaf was natural or due to effective control efforts by riparian owners.

Curlyleaf pondweed turions survey:

A curlyleaf pondweed turion survey was conducted in October 2010 and 2011, as turions tend to sprout naturally in the fall (Kunii 1982). Forty sites were randomly sampled with a ponar to collect substrate. Lake Lucy had a low to moderate lake-wide density of turions in the sediment (Table 3). Turion densities in 2011 (306 per m^2) and 2010 (362 per m^2) were low and similar. However there is still considerable variability, with a few sites having very high densities (1000-2500 turions/m^2) in both 2010 and 2011.

Table 1. Aquatic plant species found in Lake Lucy in 2011.

Common Name	Scientific Name	Abbreviation
Emergent		
Cattail	*Typha spp.*	Typh
Submerged species		
Coontail	*Ceratophyllum demersum*	Cdem
Chara	*Chara spp.*	Char
Canada waterweed	*Elodea canadensis*	Ecan
Eurasian watermilfoil	*Myriophyllum spicatum*	EWM
Northern milfoil	*Myriophyllum sibiricum*	Msib
Curlyleaf pondweed	*Potamogeton crispus*	Pcri
Sago pondweed	*Stuckenia pectinata*	Spec
Greater bladderwort	*Utricularia vulgaris*	Uvul
Water Stargrass	*Zosterella dubia*	Zdub
Floating-leaf Species		
Star Duckweed	*Lemna trisulca*	Ltri
Lesser Duckweed	*Lemna minor*	Lmin
White lily	*Nymphaea odorata*	Nodo
Yellow lily	*Nuphar variegata*	Nvar
Watermeal	*Wolffia columbiana*	Wcol
Greater duckweed	*Spirodela polyrhiza*	Spol

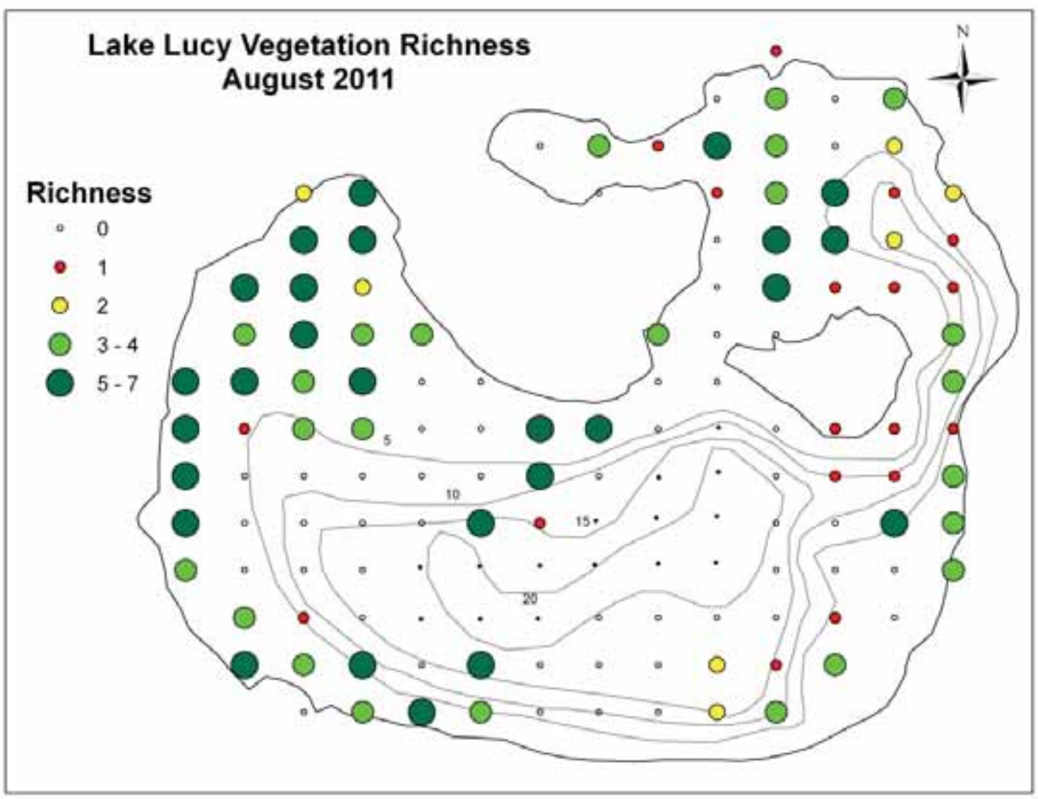


Figure 2. Sampling point locations and the number of species found per site in August 2011.

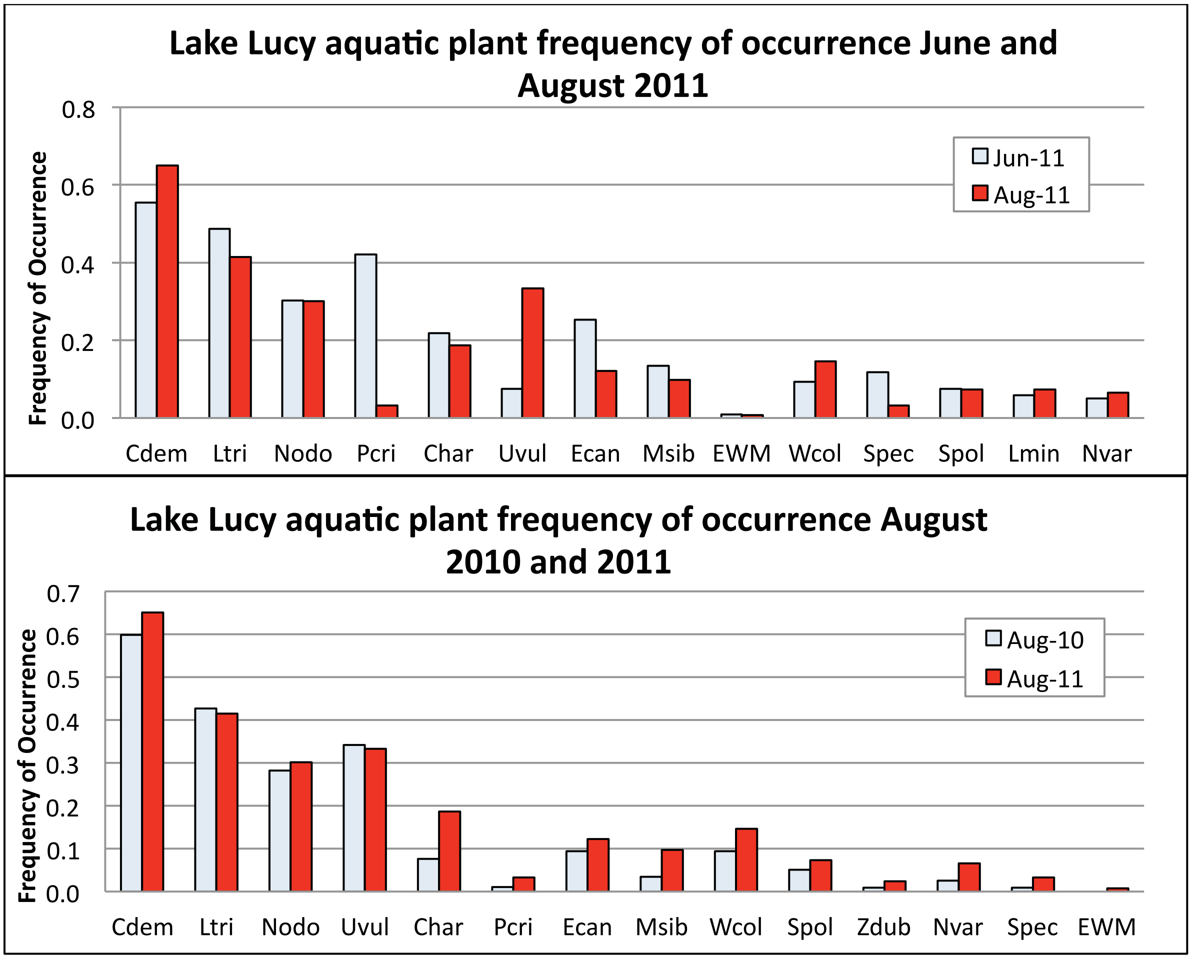


Figure 3. Comparison of frequency of occurrence by species of aquatic plants found in Lake Lucy during surveys done June and August 2011(top), August 2010 and August 2011(bottom). See Table 1 for abbreviation legend.

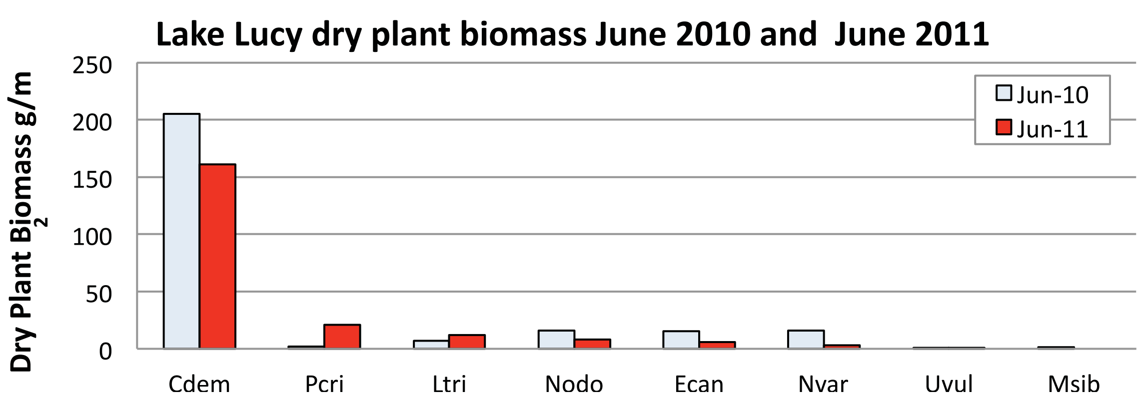


Figure 4. Dry plant biomass (g/m^2) for the most common species found in Lake Lucy in June 2010 and 2011. See Table 1 for abbreviation legend.

Table 2. A comparison of dry plant biomass between native and exotic species in Lake Lucy, June and 2010 and 2011.

		Native	Exotic
Jun-10	Mean/m^2	235.7	0.7
	2 se	298.9	0.8
Jun-11	Mean/m^2	155.6	0.2
	2 se	93.5	0.2

Table 3. Comparison of curlyleaf pondweed turion densities in 2010 and 2011.

	Oct-10	Oct-11
Turions/m^2	362	306
2se	173	165
Viability	85%	78%

Milfoil Herbivore Population:

A survey was performed in August 2011 to quantify abundance of milfoil weevils and other herbivores. Because Eurasian watermilfoil had not been noted in Lake Lucy at the time of survey, only northern milfoil was collected. Following the procedures listed above, 36 sites were sampled. Due to the general low abundances of northern milfoil in Lake Lucy, samples were only found in 12 of the pre determined sampling sites. There was an average of 0.34 weevils per stem, and no lepidoptera found on northern watermilfoil. This is a low to moderate density of weevils and considerably higher than that found in August 2010 when no milfoil weevils were collected.

Recommendations for Lake Lucy:

With improved water clarity in 2011, Lake Lucy continued to support a fairly diverse community of plants. It is not clear that transplanting, proposed in our original proposal, would benefit the lake as 6 species of native rooted plants occur in 10% or more of the littoral and 9 native taxa are present. Currently, curlyleaf pondweed is contained; however it should be monitored for expansion. Control by homeowners may be controlling curlyleaf, though care is needed to not damage the native plant community. Eurasian watermilfoil is present but uncommon and milfoil weevils are present.

Intensive management does not appear to be needed at present. The extent of shore owners vegetation control should be determined and the plant and herbivore communities should be assessed once or twice per year. If Eurasian watermilfoil or curlyleaf pondweed begin to expand substantially, June and early July water clarity declines, or native plants fail to continue to increase, then additional attention and management is warranted.

2012 Plans for Lake Lucy:

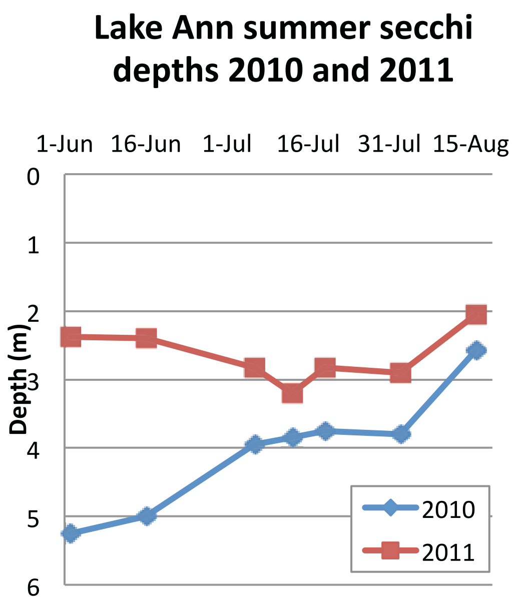
- Monitor aquatic plant community with June and August surveys
- Monitor milfoil herbivore population with two surveys

IV. Lake Ann

Lake Ann (DOW ID 10-001200) is just south of Lake Lucy and connected by a short channel. Lake Ann has a surface area of 45 hectares (110 acres), with a littoral zone of 18 hectares (45 acres), and a maximum depth of about 14m (45ft) (MN DNR Lakefinder 2011).

Water Quality:

Depth profiles of dissolved oxygen (DO) and temperature were taken periodically. Lake Ann had good mid-summer water clarity with Secchi depths of 2.5 to 4m in 2010 and 2.5m to 3m in 2011 (Bajer and Sorenson unpublished data). The DO values show an anoxic hypolimnion at depths ≥ 7m in June and ≥ 4.5m in August (Figure 5).



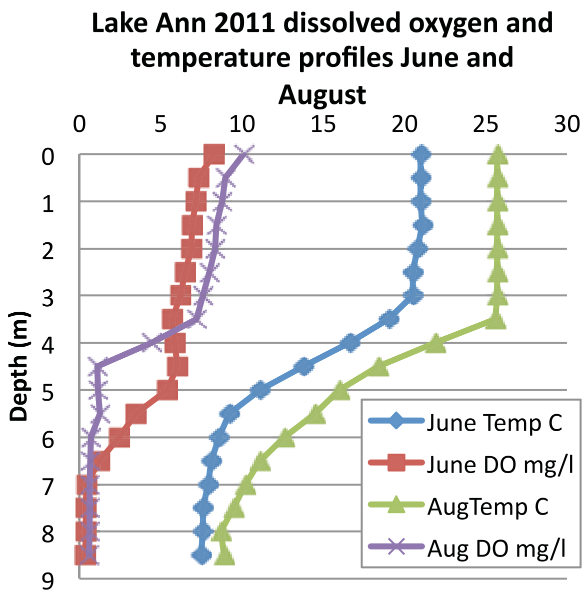


Figure 5. Midsummer Secchi depths for Lake Ann in 2010 and 2011, and temperature (^{o}C) and dissolved oxygen (mg/l) profiles taken on Lake Ann 14 June and 16 August 2011.

Aquatic Vegetation Survey:

Point intercept vegetation surveys were performed on Lake Ann on 6 July and 16 August 2011, using the same 142 sampling points used in the 2010 surveys. Overall Lake Ann had a relatively healthy community of aquatic plants with 25 species found (Table 4) in 2011. The maximum depth of rooted vegetation was 4.7m (July). There was very good species richness with several survey sites (in shallow water) having up to 12 different species (Figure 6). Plants were found at 69% (July) and 72% (August) of the sites shallower than 4.6m in depth. The invasive species Eurasian watermilfoil, EWM, was the most frequently occurring species in both surveys; it was noted at 57% of surveyed sites in July and August (Figure 7 top). Coontail was the second most frequently occurring species, noted in 53% and 62% of sites respectively.

Other common species include flat-stem pondweed (*Potamogeton zosterformis)* occurring in 38% and 29% of the sites; floating leaf pondweed (*Potamogeton natans)* occurring in 13% and 14% of the sites; white water lily, in 22% and 28% of the sites; and yellow water lily (*Nuphar variegatum)* occurring in 15% and 18% of the sites respectively (Figure 7 top).

There were few changes in frequency of occurrence of aquatic plant species between August 2010 and 2011 (Figure 7 bottom). Flatstem pondweed showed a higher occurrence in 2011, and floating leaf pondweed showed a decrease. But overall there was relatively little change to the aquatic plant communities' frequency of occurrence in Lake Ann between 2010 and 2011. This would suggest the aquatic plant community in Lake Ann is stable with typical annual variation.

Table 4. Aquatic plants found in all surveys performed on Lake Ann in 2011.

Aquatic Plants Found in Lake Ann 2011

Common Name	Scientific Name	Abbreviation
Emergent species		
Cattail	*Typha spp.*	Typh
Hardstem bulrush	*Scirpus acuts*	Sacu
Submerged species		
Coontail	*Ceratophyllum demersum*	Cdem
Chara	*Chara spp.*	Char
Canada waterweed	*Elodea canadensis*	Ecan
Eurasian Milfoil	*Myriophyllum spicatum*	EWM
Northern Milfoil	*Myriophyllum sibiricum*	Msib
Bushy Pondweed	*Najas flexilis*	Nfle
Arrowhead, grassy	*Sagittaria graminea*	Sgra
Large leaf pondweed	*Potamogeton amplifolius*	Pamp
Curlyleaf pondweed	*Potamogeton crispus*	Pcri
Illinois pondweed	*Potamogeton illinoensis*	Pill
Narrow leaf pondweed	*Potamogeton pusillus*	Ppus
Flat-stem Pondweed	*Potamogeton zosterformis*	Pzos
White water buttercup	*Ranunculus aquatilis*	Rlon
Sago pondweed	*Stuckenia pectinata*	Spec
Lesser bladderwort	*Utricularia vulgaris*	Umin
Greater bladderwort	*Utricularia vulgaris*	Uvul
Wild celery	*Vallisneria americana*	Vame
Water stargrass	*Zosterella dubia*	Zdub
Floating-leaf species		
Star Duckweed	*Lemna trisulca*	Ltri
White lily	*Nymphaea odorata*	Nodo
Yellow lily	*Nuphar variegata*	Nvar
Floating-leaf Pondweed	*Potamogeton natans*	Pnat
Long-leaf Pondweed	*Potamogeton nodosus*	Pnod

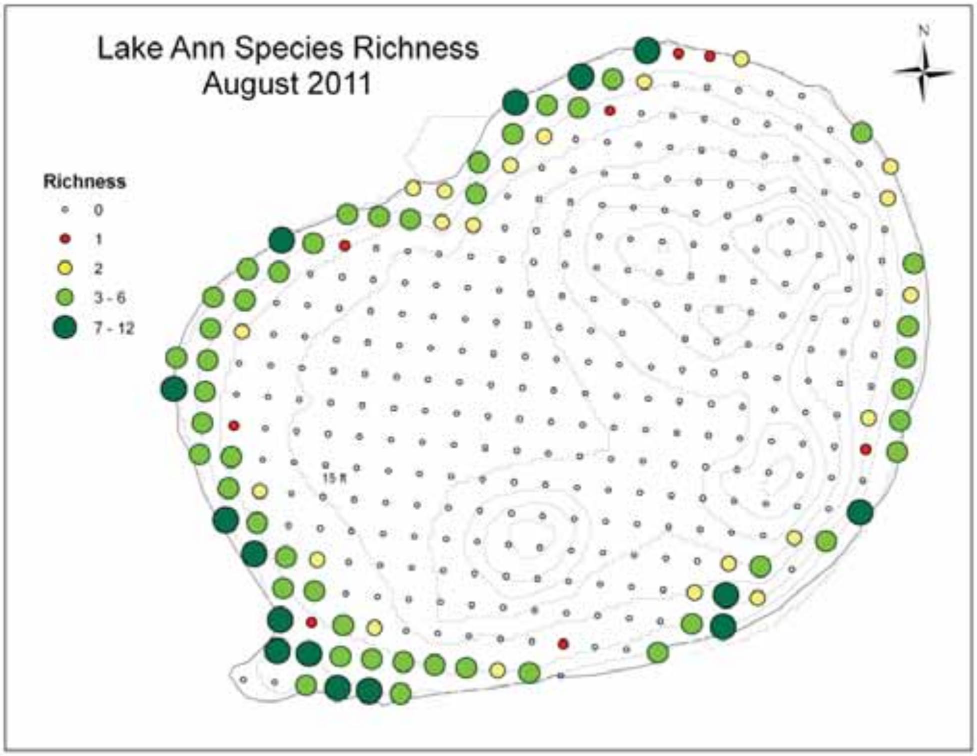
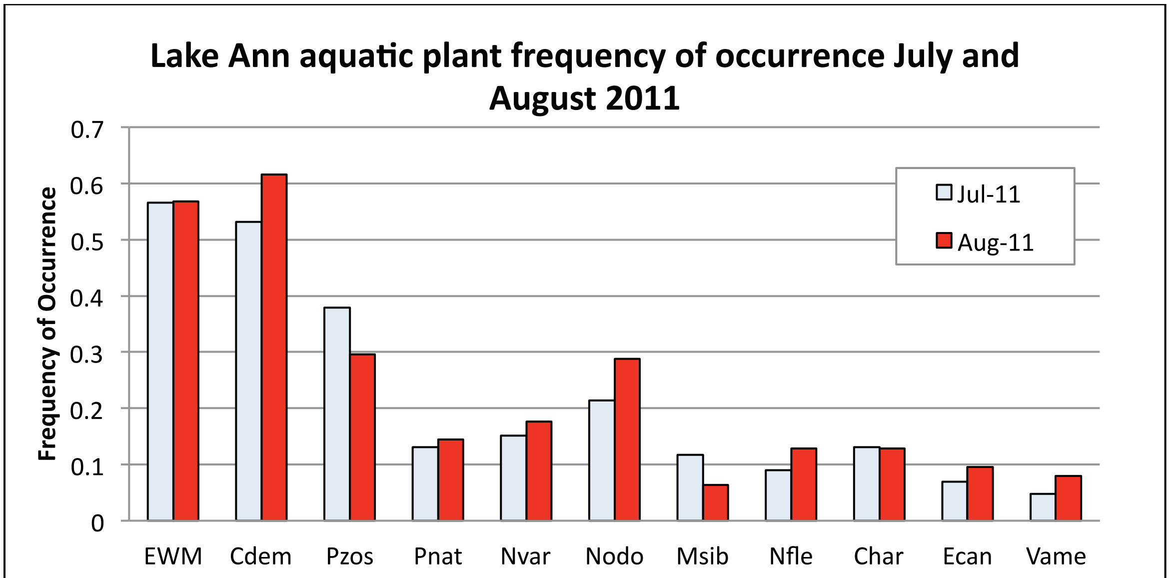


Figure 6. The number of aquatic plant species present at each site in Lake Ann, August 2011.



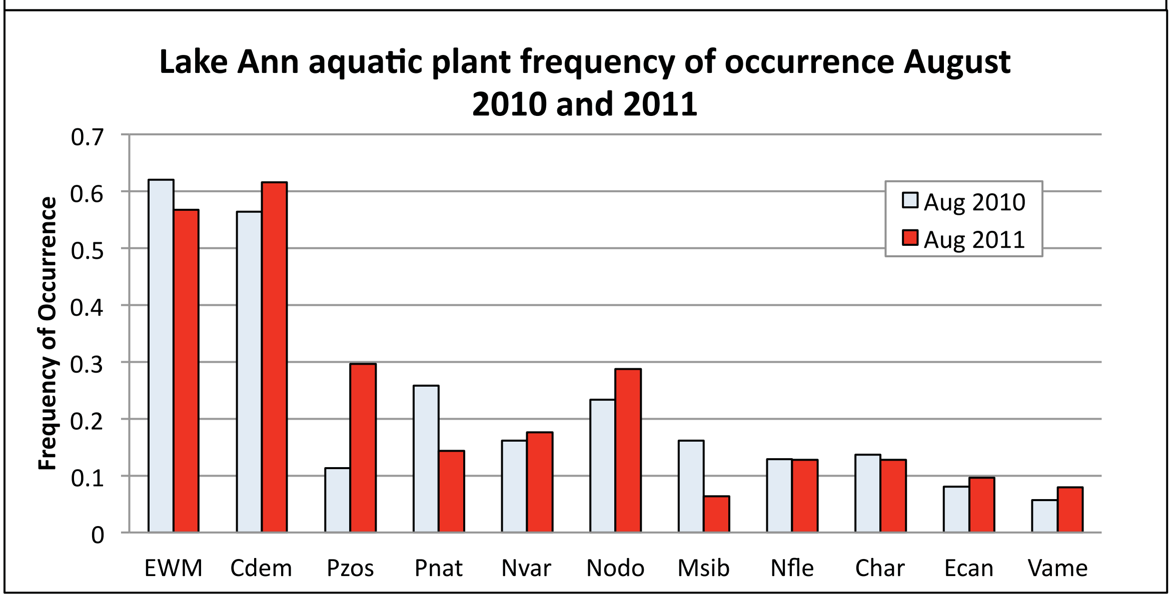


Figure 7. A comparison of the frequency of occurrence of the most common aquatic plants found in Lake Ann during surveys done July 2011 and August 2011 (top), and August 2010 and August 2011 (bottom). See Table 4 for abbreviations.

The distribution of biomass followed a similar pattern to the frequency of occurrence of species, with coontail and Eurasian watermilfoil having the greatest biomass. Overall there was a greater mass of native species (Table 5) than exotic species in both July and August of 2011. Coontail had the highest biomass with 467 g/m^2 in August, followed by Eurasian watermilfoil with 165 g/m^2 (Figure 8).

Comparing biomass values between 2010 and 2011, Eurasian watermilfoil, chara, and bushy pondweed showed a decrease in biomass, whereas coontail and flatstem pondweed showed an increase in biomass (Figure 10).

Table 5. Mean dry biomass (g/m^2) of total native species and exotic species (curlyleaf pondweed and Eurasian watermilfoil) in August Lake Ann 2010 and 2011.

		Native	Exotic
Aug-10	g/m^2	635.5	397.5
	S.E.	817.0	286.0
Aug-11	g/m^2	623.4	165.0
	S.E.	166.2	117.1

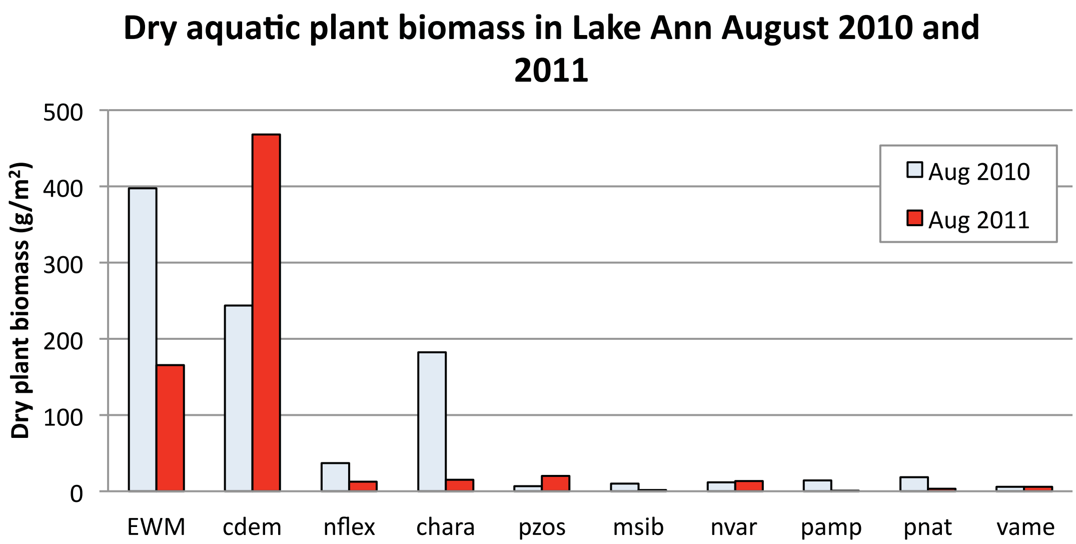


Figure 8. Dry plant biomass (g/m^2) of the most common species found in Lake Ann in August 2010 and August 2011. See Table 4 for abbreviations.

The high frequency of Eurasian watermilfoil is potentially worrisome; anecdotal information suggests there was more widespread EWM in 2010 and 2011 as compared to 2009. However comparing 2010 to 2011, EWM showed a decrease in mean biomass, but little change in frequency. Comparing the mean biomass at different depth ranges, the EWM was most dense in the 1.5m to 2.5m range in 2011, but had higher density in 2.5m to 3.5m in 2010 (Figure 9). This decrease in biomass at the deeper range explains much of the overall decrease seen in 2011. It is possible the lower Secchi depths noted in 2011 may have contributed to the lower biomass of EWM in depths greater the 2.5m. Although annual variation is common, further evaluation should be done to monitor trends and consider appropriate management options.

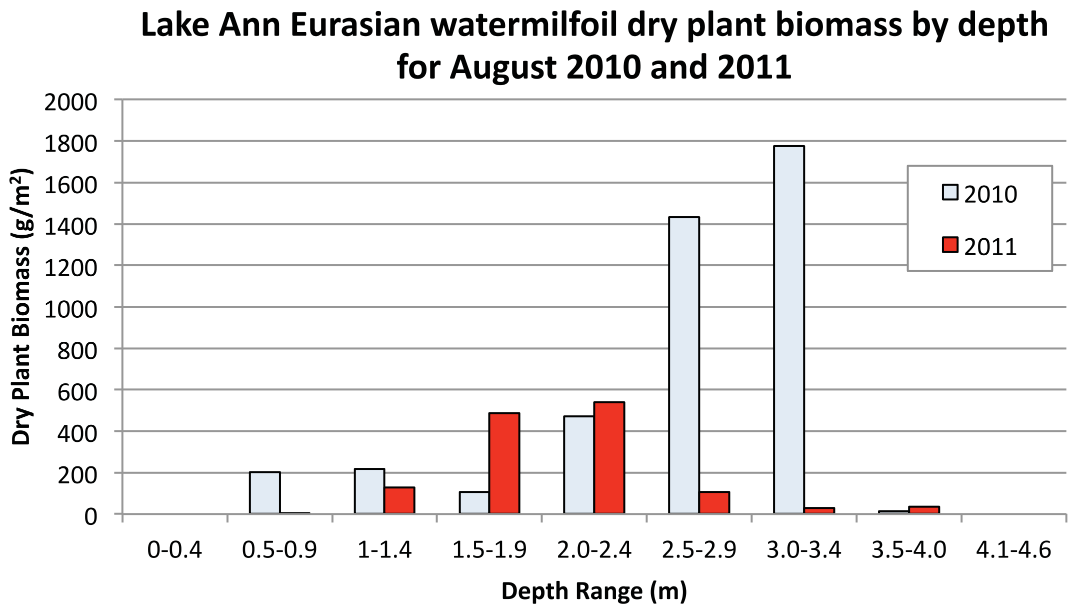


Figure 9. Mean dry plant biomass for Eurasian watermilfoil, categorized by 0.5m depth range, in Lake Ann surveyed August 2010 and 2011.

Milfoil Herbivore Population:

A survey was performed on 21 July 2011 to quantify abundance of milfoil weevils and other herbivores, on both Eurasian and northern watermilfoil. To evaluate the presence of herbivores, samples of EWM from 36 sites were collected following the established methods. Because northern milfoil was primarily found in the shallower depths (<1m) only the shallowest site was sampled per transect for northern watermilfoil (12 samples total). There were no lepidoptera found in Lake Ann in 2011. There was an average of 0.13 weevils per stem found on EWM. On northern watermilfoil there were 0.07 weevils per stem. This is a low density of weevils and very similar to that found on 01 August 2010. While there was a fair amount of damage to some plants, there doesn't appear to be a sufficient population of weevils to effectively control the milfoil. Ward and Newman (2006) suggest high sunfish densities can control the weevil and DNR surveys indicate a high density of sunfish in Lake Ann (MNDNR 2011). There may be potential management options to increase the weevil populations, thus controlling the EWM.

Recommendations for Lake Ann:

We will conduct one mid-summer plant survey and one herbivore assessment in Ann in 2012 to monitor for changes in native plants and Eurasian watermilfoil. Because Ann currently supports a good diverse native plant community additional management is not urgent, however there is concern that Eurasian watermilfoil will expand, particularly if water clarity declines. A longer-term plan to control or contain Eurasian watermilfoil would be useful. Herbivore densities are low, likely due to high sunfish densities. Lake Ann would be a good candidate for sunfish removal and herbivore enhancement and will be considered if funding for such a project is obtained. Continued monitoring will be useful to help maintain the diverse plant community.

2012 plans for Lake Ann:

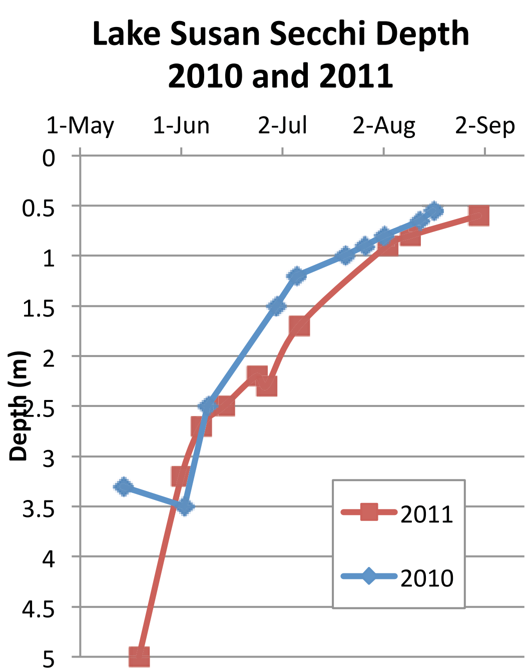
- Monitor native vegetation and Eurasian milfoil and herbivore population with one survey in July.

V. Lake Susan

Lake Susan (DOW ID 10-001300) is a small kettle lake about two kilometers southeast of Lake Ann, within Chanhassen city limits. Lake Susan covers about 38 hectares (93 acres), with approximately 30 hectares littoral (75 acres) and maximum depth about 5.2m (17ft) (MNDNR).

Water Quality Profiles:

Lake Susan Secchi depths show that springtime water clarity improved in 2011 as compared to 2010 (Figure 10). Secchi depths started at 5m in May, stayed deeper than 2m through June, dropped to 1m the end of July, and decreased to 0.6m in mid August (Bajer and Sorenson). The Dissolved oxygen profile from mid August 2011 shows an anoxic hypolimnion below 3.5m



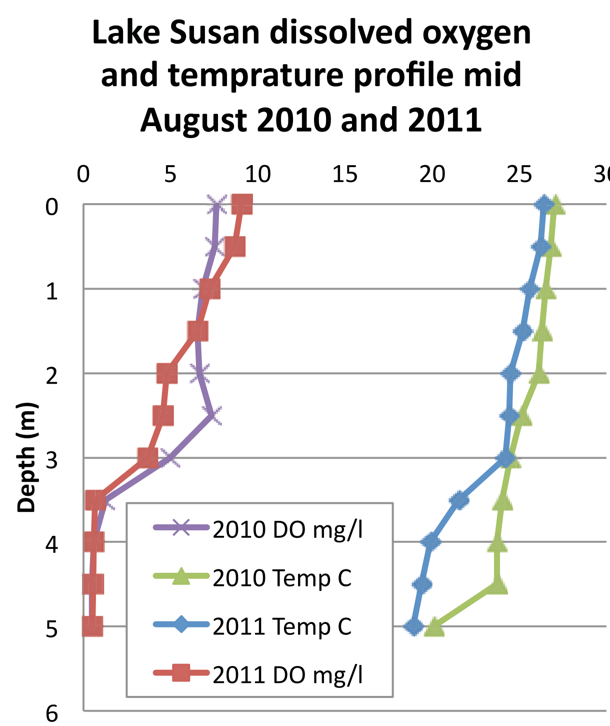


Figure 10. Secchi depth of Lake Susan throughout the summer of 2010 and 2011 and dissolved oxygen and temperature profiles from 10 August 2011.

Aquatic Vegetation Community:

Point intercept surveys were conducted in Lake Susan on 24 May, 27 June and 10 August 2011, using the same 146 survey points used in 2009 and 2010. Lake Susan had low plant diversity with 10 submerged and floating species documented in each survey (Table 6). The maximum depth of rooted vegetation was 4.5m (June). There was generally poor species richness although several survey sites had five different species present (Figure 11). Of the sites less then 4.6m deep, 52% were vegetated in May, 68% in June, and 46% in August. Part of the decrease in vegetated sites in August was due to the high frequency of curlyleaf pondweed in June, when it occurred in 41% of the sites. Curlyleaf pondweed dropped to only 7% of the sites in August (Figure 12 top). Curlyleaf pondweed also often grew at deeper zones in the lake (1.5-2.5m), leaving those areas un-vegetated after senescence. Coontail was the most frequently occurring species, occurring in 53% of the sites in June 2011, and 39% in August 2011. Narrow-leaf pondweed (*P. pusillus*) was the second most frequent species found in 35% of the sites in June and 31% in August. Eurasian watermilfoil was also present, occurring in 14% of the sites in June and 10% in August.

The greatest change in the aquatic plant community in Lake Susan between 2010 and 2011 was the dramatic increase in Canada waterweed (*Elodea canadensis*), which increased from 4% in June 2010 to 27% in 2011. Curly leaf pondweed also appeared have increased in June from 28% in 2010 to 41% in 2011 (Figure 12 bottom).

The amount of dry plant biomass in 2010 and 2011 showed a similar pattern as frequency of occurrence. Coontail had the highest dry plant biomass in both June and August 2011 (Figure 13), although lower biomass than 2010. Canada waterweed showed a large increase in biomass in both June and August 2011, becoming the second densest species in August 2011. Narrow-leaf pondweed also showed an increase in biomass between August 2010 and 2011 as did yellow waterlily (*Nuphar variegata*) (Figure 13).

Table 6. Aquatic plants found in Lake Susan during all surveys in 2011.

Common Name	Scientific Name	Abbreviation
Emergent species		
Cattail	*Typha spp.*	Typh
Hardstem bulrush	*Scirpus acuts*	Sacu
Submerged species		
Coontail	*Ceratophyllum demersum*	Cdem
Canada waterweed	*Elodea canadensis*	Ecan
Eurasian watermilfoil	*Myriophyllum spicatum*	EWM
Curlyleaf pondweed	*Potamogeton crispus*	Pcri
Narrow leaf pondweed	*Potamogeton pusillus*	Ppus
Sago pondweed	*Stuckenia pectinata*	Spec
Floating-leaf Species		
Lesser duckweed	*Lemna Minor*	Lmin
Water Lotus	*Nelumbo lutea*	Ltri
White lily	*Nymphaea odorata*	Nodo
Yellow lily	*Nuphar variegata*	Nvar

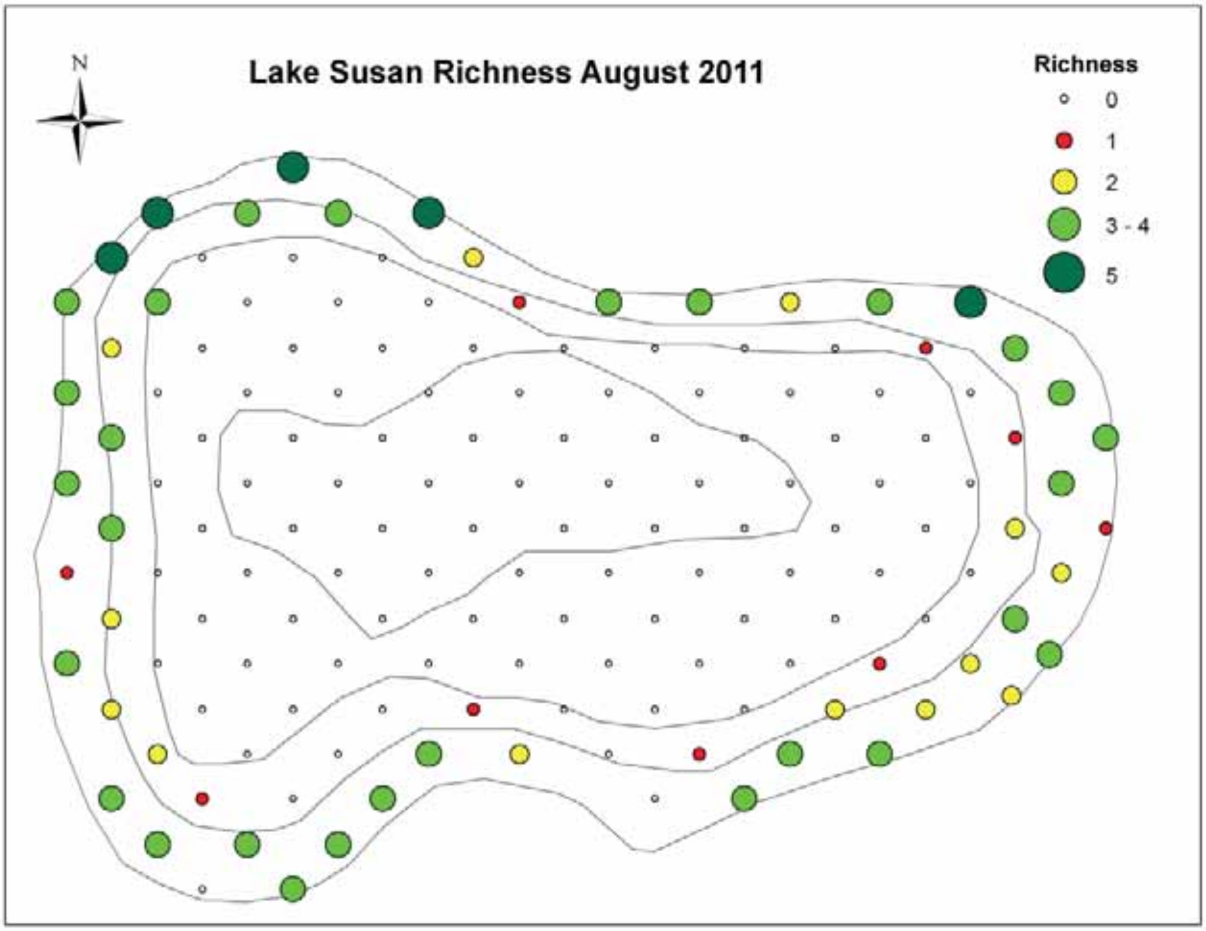


Figure 11. The number of aquatic plant species present at each site in Lake Susan, August 2011.

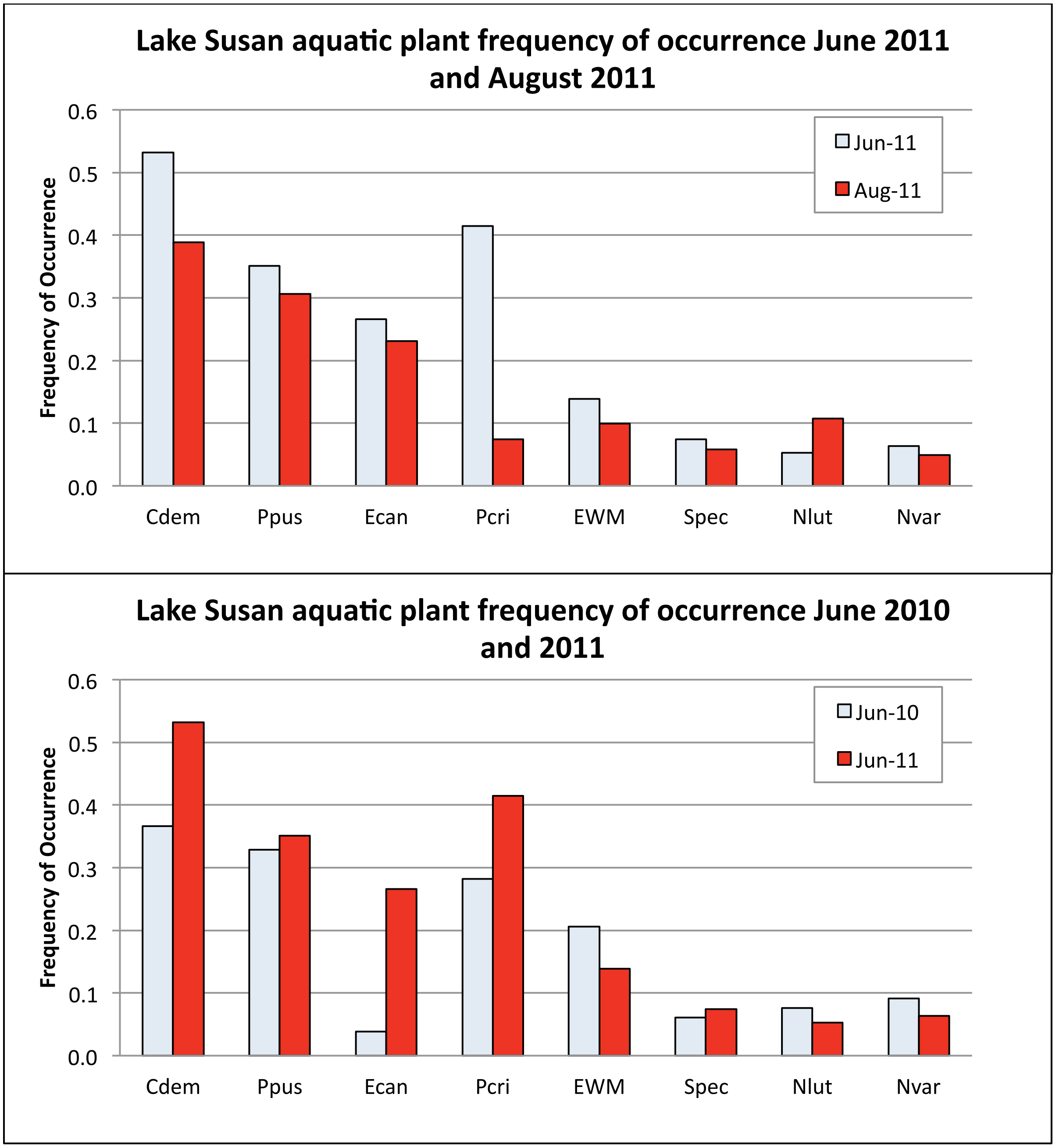


Figure 12. A comparison of the frequency of occurrence by species found in Lake Susan in June 2011 to August 2011 (top), and June 2010 to June 2011 (bottom). See Table 6 for abbreviations.

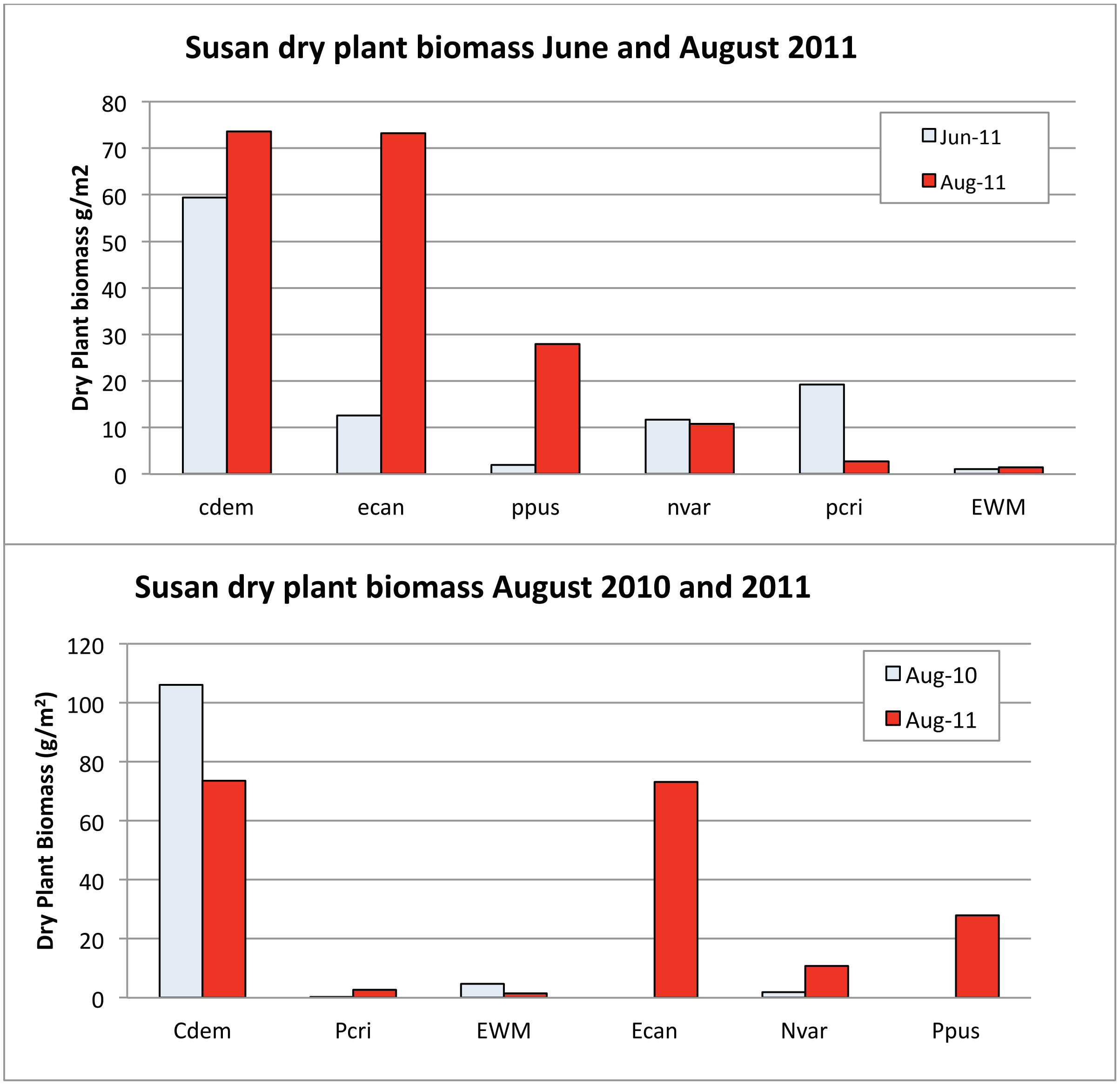


Figure 13. Comparison of dry plant biomass (g/m^2) of the most common species in Lake Susan for June 2011 to August 2011 (top), and August 2010 to August 2011 (bottom). See Table 6 for abbreviations.

Curlyleaf Pondweed Turion Survey:

A curlyleaf pondweed turion survey was conducted on 20 October 2011. To provide more consistency in comparing differences between years the same randomly selected points that were used in the 2010 were also used in the 2011 survey. At each point a petite ponar was used to sample the substrate. Lake Susan had a low lake-wide density of turions in the sediment, with an average of 50 turions per m^2 in October 2011, compared to 24 turions per m^2 found in October 2010. The turions collected in October 2011 had a 98% viability rate and turions collected in 2010 had a 90% viability rate. Maximum viability includes turions sprouted naturally in field as well as sprouted in lab. There was not an even distribution of curlyleaf in Lake Susan in June. Because of this, seven additional sites were sampled in October to better evaluate turion density within the area of the denser curlyleaf stands. Within just these non-randomly selected sites, there was an average turion density of 280 turions per m^2, with an 88% viability of the turions. These same sites were sampled in 2010 and found to have an average of 148 turions per m^2. This turion pool is still lower than many lakes with high curlyleaf density (Johnson 2010), but does suggest the turion pool may be increasing.

Table 7. Lake Susan curlyleaf pondweed turion summary for surveys done October 2010 and 2011.

		2010	2011
Lakewide	mean/m2	24	51
	2se	27	47
	Viability	90%	98%
selected	mean/m2	148	280
	2se	161	220
	Viability	99%	88%

Milfoil Herbivore Survey:

Milfoil herbivore surveys were conducted approximately every 3 weeks throughout the summer in 2011. There were very few lepidoptera found (0.002/stem) in the lake in 2011. The weevil population started fairly low in June with an average of 0.22 weevils per stem, increased to very high densities in July at 1.78 weevils/stem and declined to 0.54 weevils per stem by early September (Figure 14). Weevils were likely a factor in controlling the Eurasian milfoil population in Lake Susan. By late-July, it was difficult to collect enough Eurasian milfoil stems to analyze in many areas. This followed a similar pattern that was seen in 2010. The point intercept vegetation survey showed that the frequency of occurrence of Eurasian milfoil remained fairly constant and low throughout the summer, occurring in 10-14% of the sites. Also noted were scattered stems of Eurasian milfoil, rather than large monotypic stands.

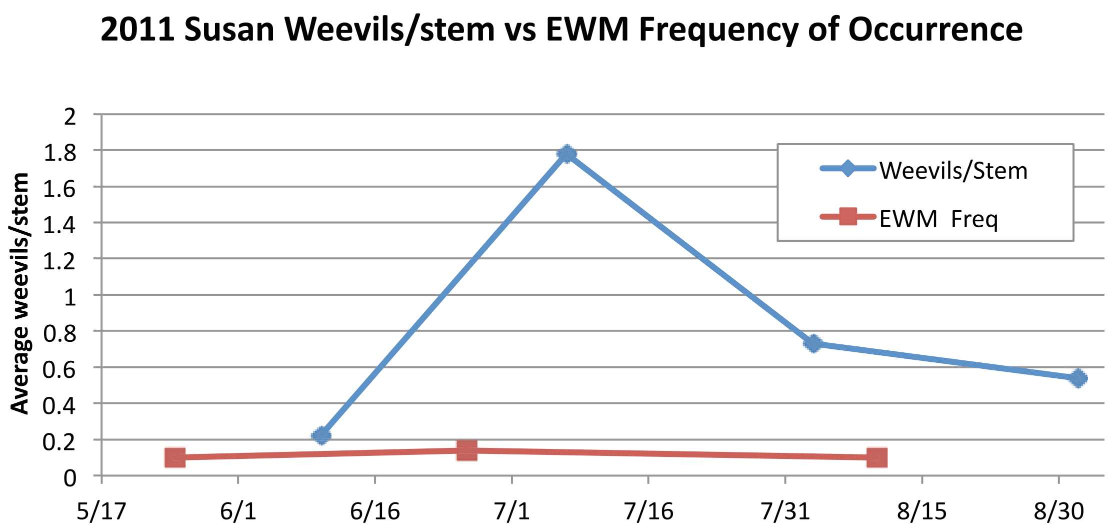


Figure 14. Abundance of weevils of any life stage per stem (blue), and the frequency of occurrence of Eurasian watermilfoil (red) in Lake Susan, 2011.

Aquatic Plant Transplants:

To promote the growth and expansion of healthy native macrophytes after the removal of carp, six taxa of native species were transplanted from nearby Lake Ann into Lake Susan. Species selection was done by assessing species desirability (Smart et al. 1998) of abundant species in the source lake (Lake Ann).

2009 Transplants:

In August 2009 four shallow plots were located along undeveloped reaches of shoreline in Lake Susan (Figure 15), two on the western shore and two on the eastern shore in water depths of 0.3 to 0.8m. Each plot contained five transplant sites and five control sites.

Transplants were collected from Lake Ann by gently uprooting nearly mature plants (0.5m to 0.75m height) and storing them in lake water overnight. The next day they were transplanted into lake Susan by placing them in a small hole in the sediment pinning them with iron sod staples to hold the roots in place, and covering with sediment. Each site was marked with a small PVC pipe and marked by GPS to aid in locating sites for future monitoring. One plot on the western and one on the eastern end of the lake were enclosed with wire fencing to prevent herbivore access. At each site four stems of one of five taxa were planted. The five species were *Chara sp.,* water stargrass (*Zosterella dubia),* northern watermilfoil *(M. sibiricum),* bushy pondweed (*Najas flexilis),* and wild celery (*Vallisnaria americana)*. Control sites were established about 1 meter from each of the transplant sites to determine taxa naturally recruiting (Newman and Johnson, unpublished data 2009). Plant height was measured about every three weeks during the growing season of 2009, 2010, and 2011 to monitor plant growth and quantify success (survival) rate. Coverage was calculated by measuring area of homogenous growth (cm^2) as well as the area of influence. The area of influence was defined as the area in which the species was present, but not dominant (Figure 16).

In these 2009 plots, wild celery showed the highest success rate, with plants found 88% of the time in the original planted locations (Table 8). Water stargrass also showed a high success rate being found 81% of the times. Chara had some success being noted in 56% of the time. Bushy pondweed showed low success being noted only 6% of the originally planted locations. Similar to 2010, northern milfoil was not found in or near any of the originally planted sites and appears to have failed to establish at these sites.

In these 2009 shallow plots, water stargrass showed the greatest growth rate with each site averaging nearly $36m^2$ in area with stargrass present (Table 8). Although Wild celery had a high survival rate, its average expansion rate was lower than water stargrass with each site averaging $16m^2$ in coverage. Although Bushy pondweed showed low survival success, it wasn't found in exactly the same locations as it was originally planted in 2009, 50% of the sites showed expansion outside of the originally planted area and averaged $8.3m^2$ in area of influence (surviving sites averaged $33m^2$). Chara showed some improvement compared to the results in 2010, with an increased success rate of 56%. This was a surprising finding, as chara appeared to have failed to establish in 2010. However expansion was very low averaging only $0.28m^2$ in area of influence (surviving sites averaged $0.5m^2$).

Table 8. Summary of August 2011 survival, height, and growth of species transplanted at shallow (≤0.7m) sites in August 2009. Mean height calculated with only successful sites, and mean area of influence calculated with all sites, successful and failed together.

	Survival	Mean Height (cm)	Mean Area of Influence(m^2)
Chara	56%	51.3	0.28
Northern milfoil	0%	0.0	0.0
Wild celery	88%	69.8	16.0
Bushy pondweed	6%	32.0	8.3
Water stargrass	81%	59.6	35.8

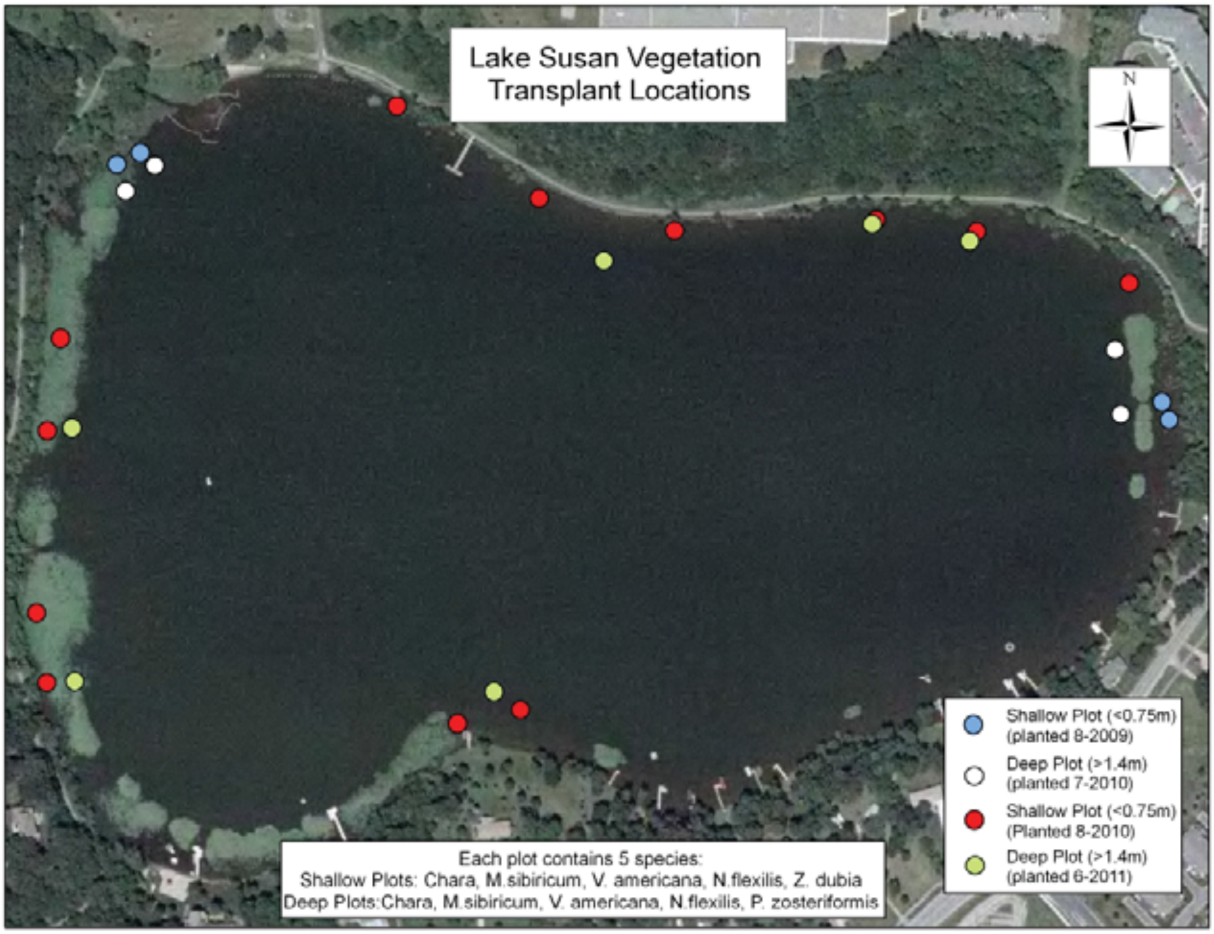


Figure 15. Locations of transplant plots in Lake Susan. Each plot contains five sites with one species planted at each site.

2010 Large-scale shallow transplants:

To increase the potential for the reintroduced native species to establish a greater distribution within the lake, 12 more plots of five taxa were transplanted to shallow (0.5m depth) locations in greater distribution around the lake on 1 August 2010 (Figure 15). The species planted were Chara, water stargrass, northern watermilfoil, bushy pondweed, and wild celery. Each site started off with 10 stems planted in a 0.25 square meter area. Chara was transplanted as 10 clusters approximately 500cm^3 each. To monitor the success of the transplanting, each site was assessed every three to four weeks during the growing season for average plant height and area of coverage.

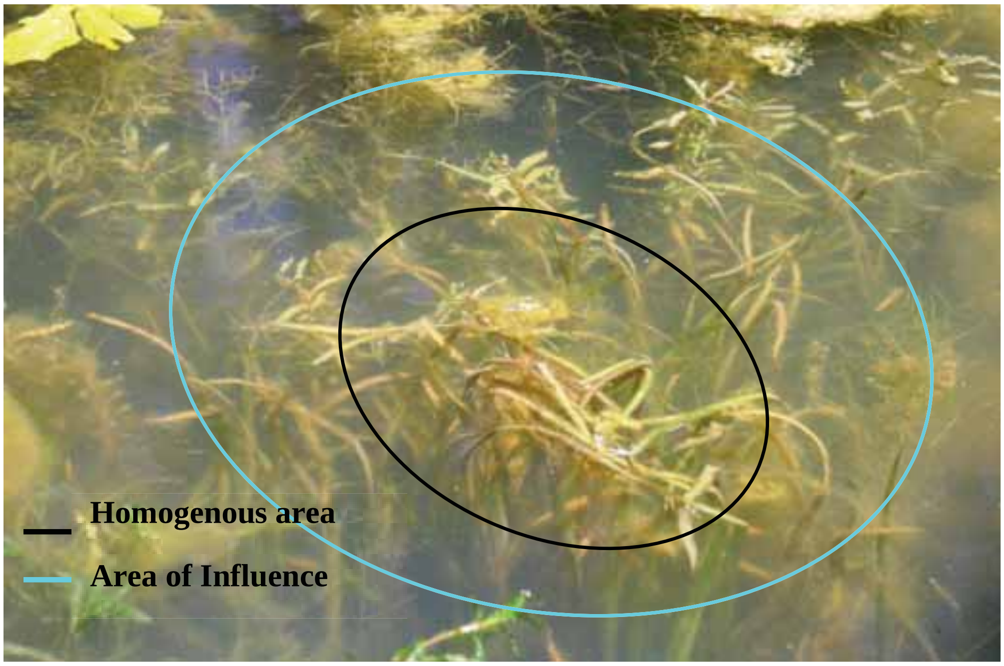


Figure 16. Example of plant growth assessment, wild celery (*Vallisneria americana*) at site 35

In these 2010 plots, Water stargrass showed the highest success rate, with plants found in 100% of the original planted locations (Figure I). wild celery and Bushy Pondweed also showed a high success rate each being found 92% of the sites. Chara had some success being noted in 58% of the time. Northern milfoil showed low success being noted only 50% of the originally planted locations. This was a considerable increase in survival success between transplants done in 2009 and 2010.

The expansion of plant species planted in shallow depths in 2010 followed a similar pattern to that of the 2009 transplants, with the exception of northern milfoil, which showed some success (Figure 17). Water stargrass and bushy pondweed showed the greatest amount of expansion with an area of influence covering 73m^2 and 62m^2 respectively (Table 9). Water celery also showed an increase in area of influence, averaging about 1m^2. Chara initially showed an increase in growth and expansion in early July, however decreased in both success rate and area of influence in August. This may have been due to decreased water clarity or crowding from other species such as coontail and Canada waterweed. Northern milfoil also showed expansion in area of influence with an average of 2.9m^2(surviving sites averaging 11m^2).

Table 9. Summary of August 2011 survival, height, and growth of species transplanted at shallow (0.7m) sites in June 2010. Mean height calculated with only successful sites, mean area of influence calculated with all sites, successful and failed together.

	Survival	Height (cm)	Area of Influence (m^2)
Chara	58%	22.3	0.1
Bushy Pondweed	92%	59.6	62.5
Wild celery	92%	64.2	1.1
Northern milfoil	50%	32.8	2.9
Water stargrass	100%	66.7	73.3

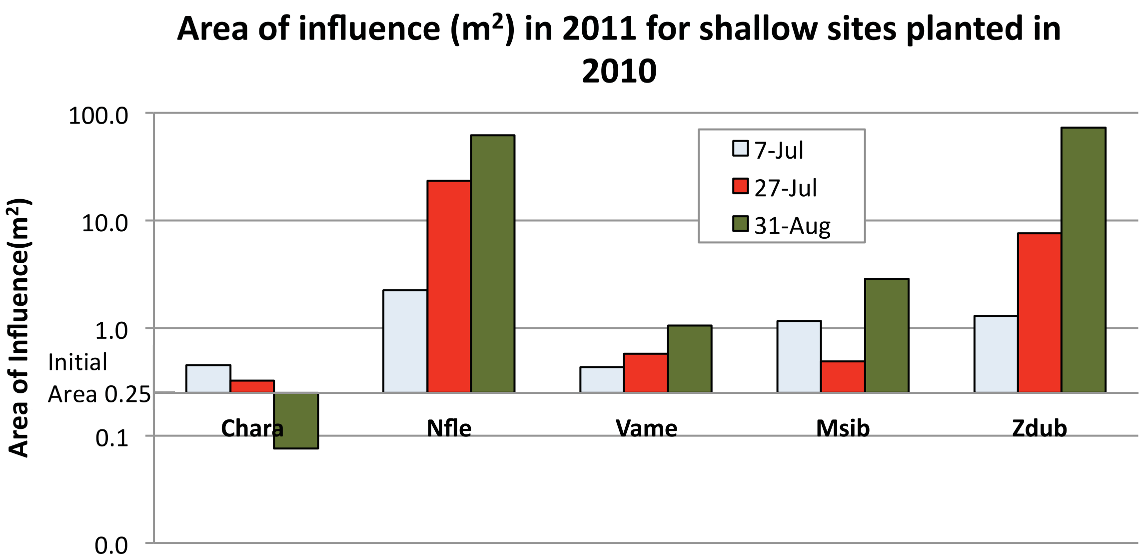


Figure 17. The mean area of influence (maximum expansion in 2011) of species transplanted in shallow water (0.5 to 1.0m) in summer 2010. Means calculated for all sites, including successful and failed sites. Note that each site started as covering $0.25m^2$ and the area scale is logarithmic. See Table 6 for abbreviations.

2010 Deeper transplants:

To determine if transplants would establish in deeper water, four plots of each of species (two plots per side of the lake) were transplanted in depths of 1.2 m to 1.6m on 22 July 2010 (Figure 15). The five species included Chara, flat-stem pondweed (*P. zosteriformis*), northern milfoil, bushy pondweed, and wild celery. The plots were monitored for growth approximately every three weeks. These plots failed to establish in 2010, most likely due to poor water clarity shortly after the time of planting. However, re-evaluation of these plots in August 2011 found a few single stems of flat-stem pondweed at three of the four sites, and wild celery at one of the sites. No other transplanted species were found (Table 10).

Table 10. Summary of August 2011 survival, height, and growth of species transplanted at deeper (1.3m) sites July 2010. Mean height calculated with only successful sites, mean area of influence calculated with all sites, successful and failed together.

	Survival	Height (cm)	Area of Influence (m^2)
Chara	0%	0.0	0.00
Northern milfoil	0%	0.0	0.00
Wild celery	0%	0.0	0.00
Bushy pondweed	0%	0.0	0.00
Flatstem pondweed	50%	0.5	0.03

2011 Deeper transplants:

To further assess the success of deeper transplants, six more plots of the same five taxa were transplanted June of 2011 in depths of 0.75m to 1.5m (Figure 15). Following the previously mentioned procedures, ten plants were planted in a $0.25m^2$ area at each site. The earlier planting was aimed to provide enough time for the plants to become established before water clarity decreased, thus increasing the rate of establishment. The June transplanting was timed to allow the plants to mature as long as possible in Lake Ann while providing at least two weeks of growth in Lake Susan before the water clarity was expected to decrease.

The 2011 deeper transplants followed the trend of the 2010 deeper transplants in failing to thrive (Table 11). Flat stem pondweed and wild celery both had a 66% survival rate, with at least one plant found in four of the six sites in August. It was noted that a few of the flat stem pondweed stems and some of the northern milfoil stems had shoot growth in early July. Although they were successful in surviving the summer, the average area of growth ($0.01m^2$ and $0.05m^2$ respectively) was less than that which was planted in June ($0.25m^2$). This suggests that while a few plants survived, most of them failed. Bushy pondweed failed to establish as it was noted in only one site and had less than a $0.01m^2$ growth area. Neither northern milfoil nor chara was not noted in any of the sites is August. The reasons for success in the shallow sites (mean depth 0.62m) and subsequent failure of the deeper sites (mean depth 1.30m) is likely due to poor water clarity and low light availability during the mid summer. The definitive test of survival of the deep plots planted in 2011 will be overwintering success. As was the case for some of the deeper sites planted in 2010, there is some potential for survival of some of the deeper plots, and this will be analyzed in 2012.

Table 11. Summary of August 2011 survival, height, and growth of species transplanted at deeper (1.3m) sites in June 2011. Mean height calculated with only successful sites, mean area of influence calculated with all sites, successful and failed together.

	Survival	Height (cm)	Area of Influence (m^2)
Chara	0%	0.0	0.000
Northern milfoil	0%	0.0	0.000
Wild celery	67%	43.5	0.049
Bushy pondweed	17%	8.3	0.003
Flatstem Pondweed	67%	53.3	0.006

Natural Recruitment:

Control sites were established in 2009 about one meter from each of the transplant locations to determine taxa naturally recruiting. Because the expansion of water stargrass, wild celery, and bushy pondweed was greater than one meter, they often grew into the control plots, especially during the second growing season. This resulted in biasing the results of frequency and species composition at those sites, nullifying this method. The lake wide point intercept data previously mentioned is a better predictor of the frequency and distribution of species that have recruited naturally. While there has been positive expansion of many of the transplanted species, the expansion hasn't been great enough to have been noted in the courser scale (40m) lake wide point intercept survey. Canada waterweed naturally recruited in Lake Susan in 2010 and lesser duckweed (*Lemna minor*), star duckweed *(Lemna trisulca*) and water buttercup (*Ranunculus* spp.) naturally recruited in Lake Susan in 2011.

Recommendations for Lake Susan:

Lake Susan has responded positively to carp removal. Native plant distribution and abundance has increased and invasive Eurasian watermilfoil and curlyleaf pondweed have not become problematic. We will complete a final year of transplanting and attempting to increase native plant abundance and will monitor Eurasian watermilfoil and its herbivores, which have been keeping the plant in check. Continued monitoring of curlyleaf pondweed plant and turions should be conducted and we will work with lakeshore owners to devise a plan to deal with curlyleaf should it continue to expand. It will be important to maintain and further improve the native plant community and will educate shoreline owners on the importance of maintaining a healthy plant community.

2012 Plans for Lake Susan:

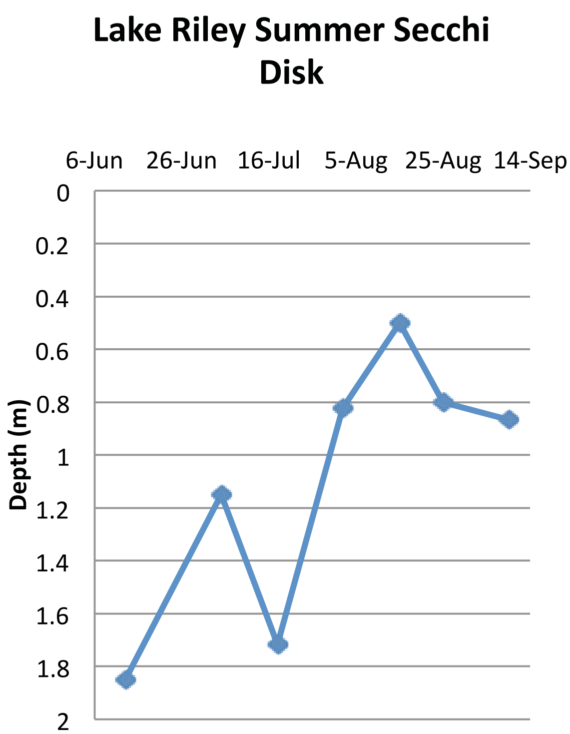
- Work with lakeshore owners on vegetation management plans.
- Monitor vegetation with two surveys and milfoil herbivore populations with 3 surveys.
- Monitor transplant growth and consider adding another set of extensive shallow transplants.

VI. Lake Riley

Lake Riley (10000200) is a eutrophic lake located about two km downstream of Lake Susan and sits along the Chanhassen and Eden Prairie city boundary. Rice Lake Marsh lies along Riley Creek between Lake Susan and Lake Riley. Lake Riley is about 120 hectares (300 acres) in size with a maximum depth of 15m (49 ft.).

Water Quality:

Lake Riley midsummer Secchi disk values decreased quickly from almost 2m in June to < 1.0m in August (Figure 18). Lake Riley temperature and dissolved oxygen profiles show an anoxic hypolimnion below 4m.



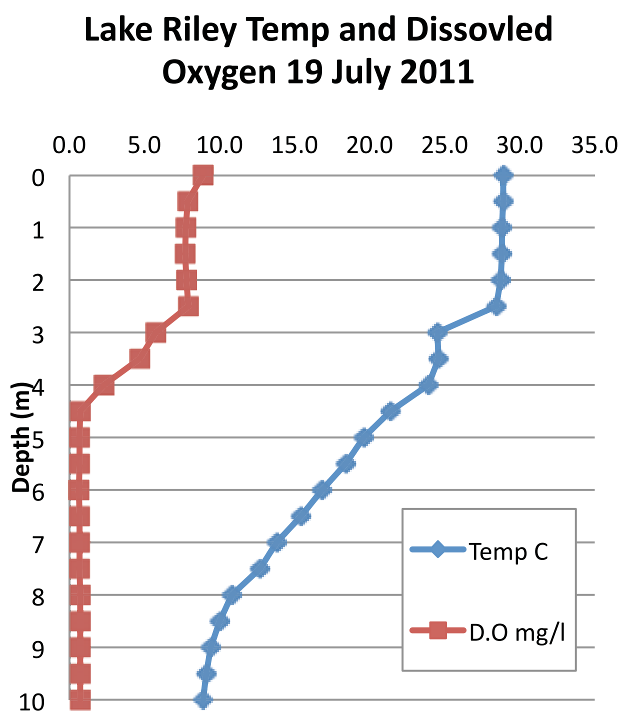


Figure 18. Lake Riley summer Secchi disk and typical summer temperature and dissolved oxygen profile from 2011.

Vegetation Survey:

Point intercept surveys were performed on Lake Riley 29 June and 26 August 2011 following the procedures previously mentioned. Overall the plant community has a low diversity with 7 submerged aquatic plant species present (Table 12). The maximum depth of rooted vegetation was 4.7m (June). The maximum species richness was four species noted in a few sites in June, and a few sites with three species in August. Plants were found in 86% (June) and 64% (August) of sites less then 4.6m in depth (Figure 19). The most frequently occurring species was coontail, found in 48% of the sampled sites in June and 45% of the sampled sites in August (Figure 20). Native species accounted for the majority of dry plant biomass in both June and August surveys (Table 13). Coontail accounted for nearly all of the native plant biomass in both surveys (Figure 21).

Table 12. Aquatic plants found in Lake Riley during all surveys in 2011.

Common Name	Scientific Name	Abbreviation
Submerged species		
Coontail	*Ceratophyllum demersum*	Cdem
Canada waterweed	*Elodea canadensis*	Ecan
Eurasian watermilfoil	*Myriophyllum spicatum*	EWM
Curlyleaf pondweed	*Potamogeton crispus*	Pcri
Narrow leaf pondweed	*Potamogeton pusillus*	Ppus
Sago pondweed	*Stuckenia pectinata*	Spec
Horned pondweed	*Zannichellia palustris*	Zpal
Floating-leaf Species		
White lily	*Nymphaea odorata*	Nodo

Table 13. Comparison of total dry plant biomass (g/m^2) of native and exotic (EWM and Pcri) plants in Lake Riley during 2011 sampling.

		Natives	Exotics
June	mean	32.9	21.4
	2se	19.8	14.0
August	mean	118.2	76.7
	2se	50.7	74.1

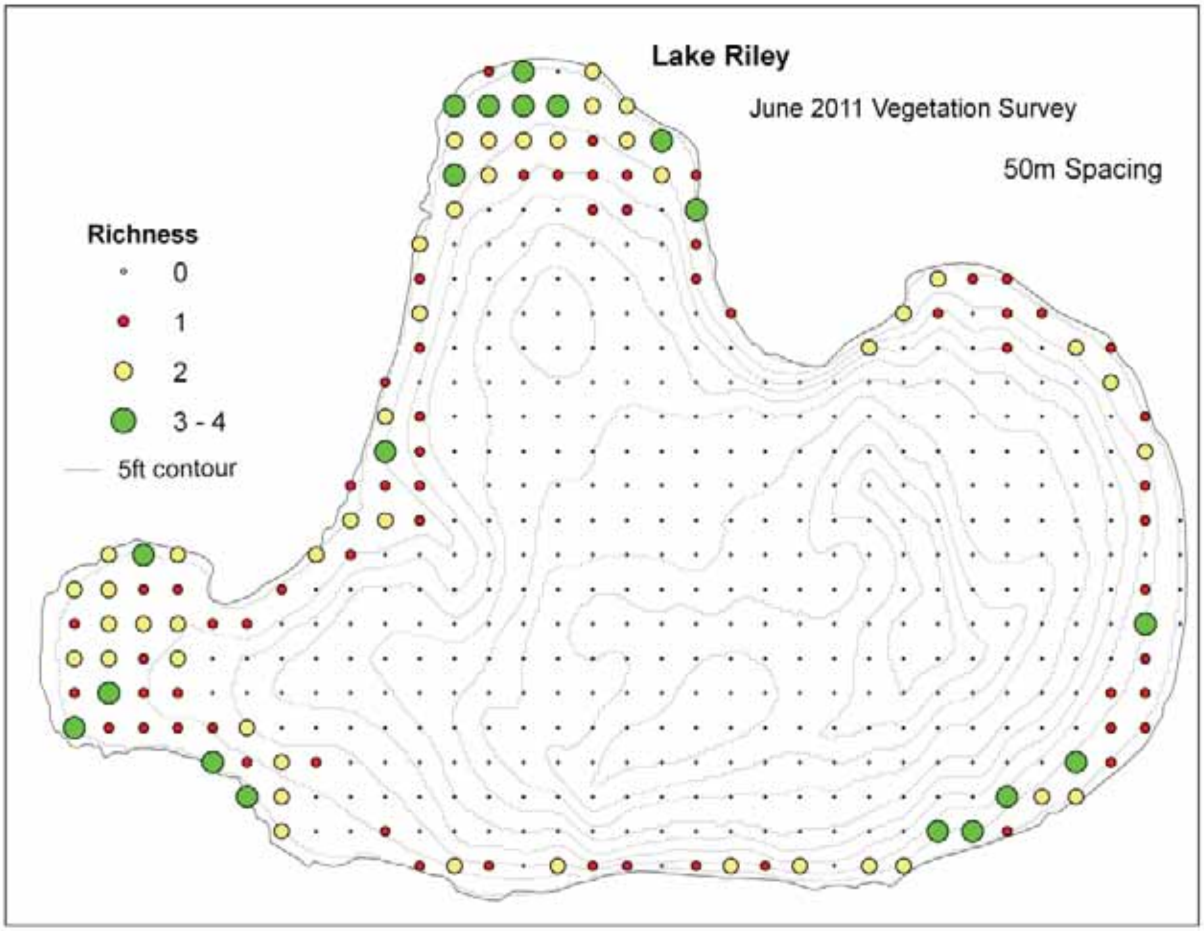


Figure 19. Sampling point locations and the number of species found per site in Lake Riley.

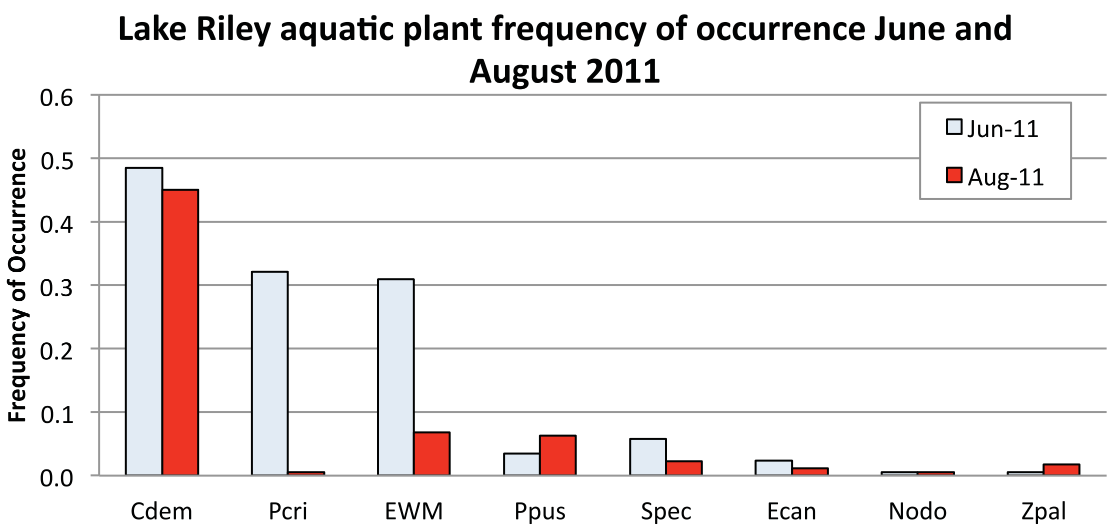


Figure 20. Frequency of occurrence of submerged aquatic plants in Lake Riley June and August 2011. See Table 12 for abbreviations.

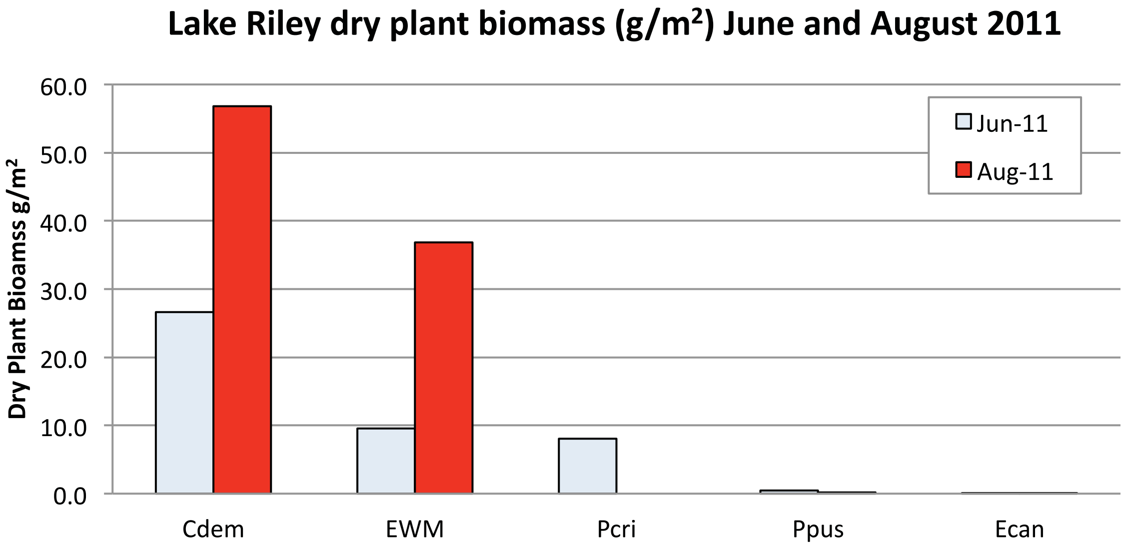


Figure 21. Dry plant biomass (g/m^2) for surveys conducted in Lake Riley June and August 2011. See Table 12 for abbreviations.

One noteworthy change in the aquatic vegetation community in Lake Riley is the decrease in aquatic plants throughout the course of the summer in frequency of occurrence and richness. This trend is counter to that shown in Lake Susan after carp removal. Although dry plant biomass increased in coontail and Eurasian watermilfoil in August (Figure 21), it decreased in all other species. Some lakeshore owners on Lake Riley have elected to control exotic Eurasian watermilfoil and curly leaf pondweed along some of their frontage. It has been speculated, though not proven, that herbicide treatments may potentially be partially responsible for the overall decrease in vegetation. Unfortunately the timing of the June survey was a few weeks after treatment, so pre treatment data are not available. Further research is required to determine the factors required to reestablish a healthy native plant community in Lake Riley

Curlyleaf pondweed turions survey:

A curlyleaf pondweed turion survey was conducted in Lake Riley on 24 October 2011. Forty sites in depths <4.6m were randomly sampled with a ponar to collect substrate. The majority of the substrate sampled consisted of sand. Lake Riley had a lake-wide mean density of 45 turions per m^2. This is a low density of turions in the sediment. As seen in other lakes, Lake Riley also has large variability in locations containing curlyleaf turions. Three individual sampling sites collectively accounted for 75% of the total turions collected. The density of turions in just these three sites averaged 444 turions per m^2. This clustered distribution of curlyleaf turions may be useful for more targeted management options.

Milfoil Herbivore Survey:

A milfoil herbivore survey was conducted on 19 July 2011. There were very few lepidopteron found (0.004/stem) in Lake Riley in 2011.The weevil population was found to be low with an average of 0.20 weevils of any stage per stem. A further breakdown of weevil life stage shows eggs made up the majority of life stage found (Table 14). Weevils were not likely a factor in controlling the Eurasian milfoil population in Lake Riley. There is a high abundance of small sunfish in the lake (Bajer and Sorenson, unpublished data) that is likely limiting herbivores. Also noted were scattered monotypic patches of Eurasian milfoil.

Table 14. Summary of the mean number of milfoil weevils present per life stage in Lake Riley July 2011.

	Eggs/Stem	Larvae/Stem	Pupae/Stem	Adults/Stem	Total/Stem
Mean	0.16	0.01	0.00	0.03	0.20
2SE	0.15	0.01	0.01	0.03	0.18

Lake Riley Recommendation:

Lake Riley appears to be in a typical eutrophic lake coontail/milfoil state. Management options are limited until water clarity is improved. Overreliance on chemical control may be contributing to the lack of other plants and poor water clarity. Efforts to improve the plant community are beyond the scope of our proposal. We will work with the lake association to discuss objectives and help develop a vegetation management plan. Biological control of Eurasian watermilfoil would first require restructuring of the sunfish population. Effective chemical control would require better water clarity to allow recruitment of native plants.

2012 plans for Lake Riley:

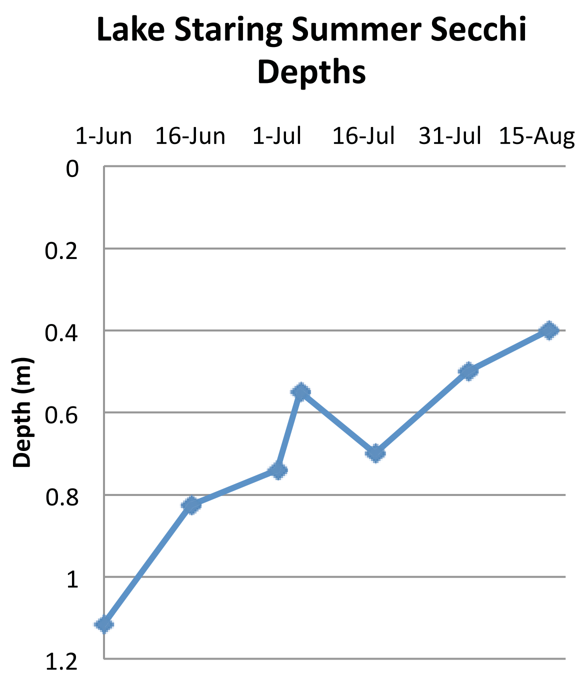
- Work with lake association on vegetation management.
- Conduct one vegetation and one herbivore survey in mid-summer.
- Provide guidance and recommendations on future management based on objectives and preferences of the lake association.

VII. Lake Staring

Lake Staring (27007800) is a hypereutrophic lake in the Purgatory Creek watershed. The lake is about 66 hectares (164 acres) in area, with a maximum depth of 4.9m (16ft). Lake Staring has a high population of carp (Bajer and Sorenson personal communication) and subsequently was algae-dominated with low water clarity.

Water Quality:

Lake Staring is algae dominated with few aquatic plants and high turbidity. Summer Secchi disk readings were consistently low, from 0.9m in June to 0.4m in August (Figure 22). A temperature profile taken 11 August 2011 shows the lack of a thermocline and the lake appears to be well mixed, however, dissolved oxygen profiles show an anoxic hypolimnion in depths >4.5m.



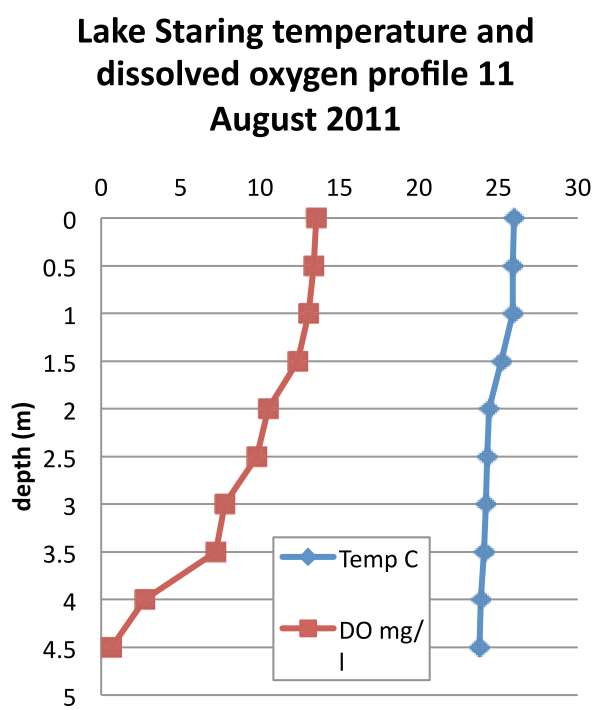


Figure 22. Summer Secchi disk, temperature and dissolved oxygen profiles for Lake Staring August 2011.

Aquatic vegetation Survey:

Point intercept surveys were conducted on Lake Staring 28 June and 11 August 2011. The overall vegetation community was very poor in with only 13% of sites vegetated in depths less than 4.6m. Lake Staring has a low plant diversity with only eight submerged species noted in the lake (Table 15) and only four species found in August. The maximum depth of rooted vegetation was only 1.7m with most of the vegetation found in the 0.8m to 1.2m depth range.

Mean species richness was also very low with only a maximum of three species per site in June (Figure 23) and only two species per site in August. Curly leaf pondweed was the most frequently occurring species in June, found in 7% of the sites; and yellow water lily was the most frequent species noted in August, being found in 3% of the sites. Plant biomass was also very low with curlyleaf pondweed having the greatest biomass with a lake-wide average of 0.67g/m^2 in June 2011 (Table 16). There were no plants found in the 40 randomly sampled biomass sites during the August survey. The same sampling sites (within 5m) were used in both the June and August survey.

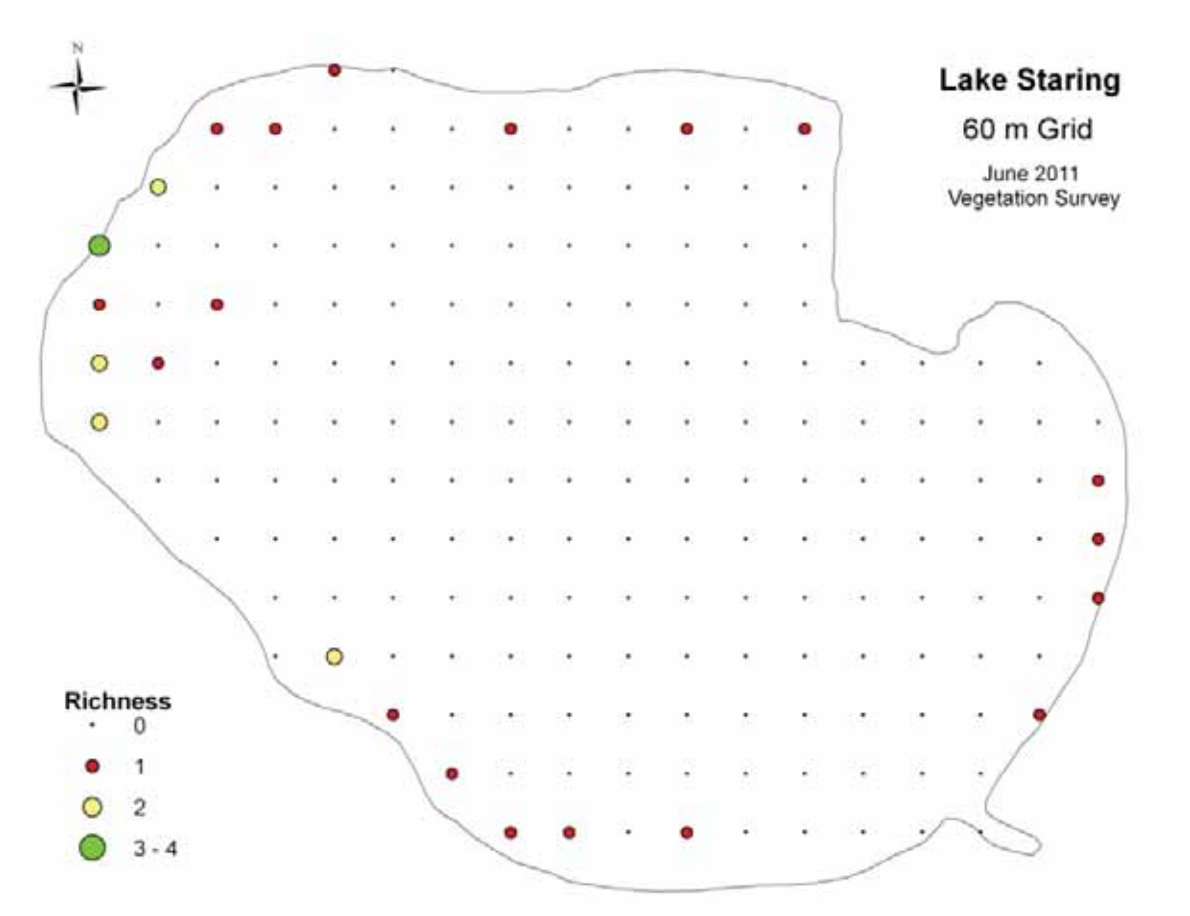


Figure 23. Sampling point locations and the number of species of aquatic plants found in Lake Staring June 2011.

Table 15. Aquatic plants found in Lake Susan during all surveys in 2011.

Common Name	Scientific Name	Abbreviation
Emergent species		
Cattail	*Typha spp.*	Typh
Submerged species		
Coontail	*Ceratophyllum demersum*	Cdem
Muskgrass	*Chara spp.*	Char
Curlyleaf pondweed	*Potamogeton crispus*	Pcri
Narrow leaf pondweed	*Potamogeton pusillus*	Ppus
Sago pondweed	*Stuckenia pectinata*	Spec
Horned pondweed	*Zannichellia palustris*	Zpal
Floating-leaf Species		
White lily	*Nymphaea odorata*	Nodo
Yellow lily	*Nuphar variegata*	Nvar

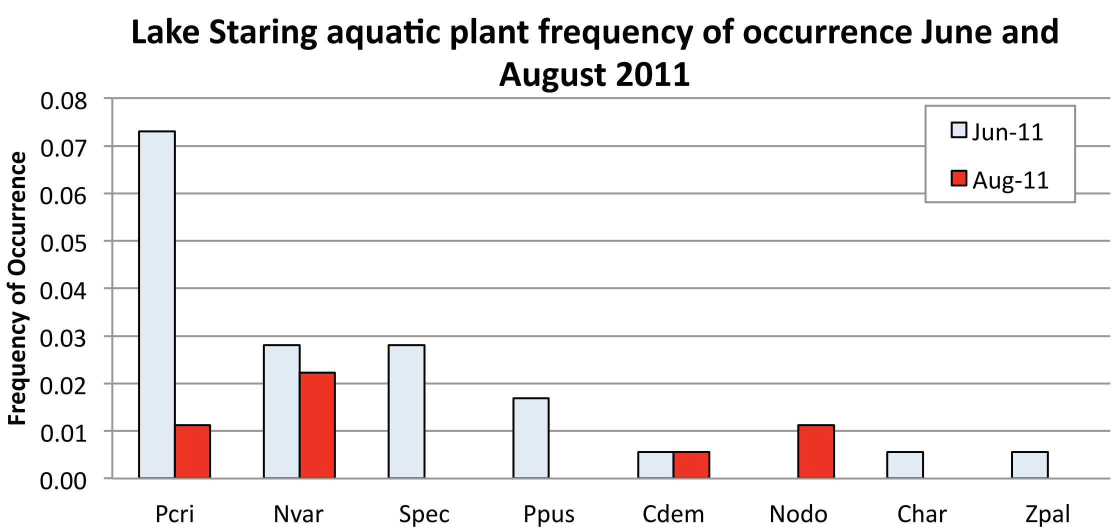


Figure 24. Frequency of occurrence of submerged aquatic plants in Lake Staring June and August 2011. Note the scale is considerably smaller than for other lakes. See Table 15 for abbreviations.

Table 16. Lake Staring dry plant biomass (g/m^2) in June 2011. No plants were found in August biomass samples.

	Curlyleaf pondweed	Chara	Narrowleaf pondweed
mean/m^2	0.67	0.57	0.02
2SE	1.01	1.13	0.05

Curlyleaf Pondweed Turion Sampling:

Sediment samples we collected on 25 October 2011 to quantify the number of curly leaf pondweed turions in the sediment bank. There were no turions found in the 40 randomly sampled sites >4.6m deep. The sediment consisted primarily of sand in depths <2m and consisted mostly of silty-muck in depths >2m. Although 7% of the sites sampled in June had curlyleaf present; there were only a few scattered stems noted, and no mats of curly leaf at the surface. The lack of curly leaf pondweed turion found in the sediments is not surprising considering the very low density of plants found in the lake.

2012 plans for Lake Staring:

- Monitor aquatic plant community after carp removal (proposed winter 2012).
- Develop method for restoration of healthy plant community and plan for transplanting in 2013.

Summary:

Lake Lucy:

Lake Lucy saw relatively minor changes in the aquatic plant community between 2010 and 2011. Overall species composition and distribution was similar between the years. Eurasian water milfoil was noted in 2011 and not noted in 2010. This is not a new infestation as it has been listed as infested waters by the MN DNR in 2006. There were considerably more milfoil weevils noted in Lucy in 2011 than 2010. There is some suggestion that the current curlyleaf pondweed management is effective. Transplants are not needed and only monitoring is recommended.

2012 Plans for Lake Lucy

- Monitor aquatic plant community with June and August surveys.
- Monitor milfoil herbivore population with two surveys.

Lake Ann:

The Aquatic plant community in Lake Ann is healthy and diverse. There is some concern over the high frequency and biomass of Eurasian watermilfoil. There were some differences in distribution of Eurasian watermilfoil between 2011 and 2010. The mean depth of densest growth of Eurasian watermilfoil was shallower in 2011 then 2010. This may be explained by the decreased summer Secchi disk values noted in 2011. If the water clarity and plant community continue to be good, no further management is needed. Plans to deal with Eurasian watermilfoil should be developed and this could range from sunfish control to enhance herbivores or possible use of selective herbicides. The focus should be on retaining clarity and the diverse native plant community.

2012 plans for Lake Ann:

- Monitor native vegetation and Eurasian milfoil and herbivore population with one survey in July.

Lake Susan:

An increase in aquatic plants after the removal of carp has been noted in Lake Susan and in Lake Lucy to a lesser degree. Lake Susan has a greatly improved aquatic plant community, however there are some concerns about potential invasive native and exotic species. The attempts at re-establishment of native species appear to be having some reasonable success in the shallower (<1.2m) depths, but establishing native plants in depths >1.2m is more challenging. Natural recruitment of new taxa is relatively slow with one to two new taxa noted each year post carp removal. We will add more, shallow transplant sites to further expand distribution of native plants. If a number of native plant species can be established around the lake they should fill in deeper areas if clarity increases. Contingency plans to control curlyleaf pondweed should be developed and maintaining a healthy herbivore population is key to keeping Eurasian watermilfoil at low density.

2012 Plans for Lake Susan

- Work with lakeshore owners on vegetation management plans.
- Monitor the vegetation with two surveys.
- Monitor milfoil herbivore populations with several surveys.
- Monitor transplant growth and consider adding another set of extensive shallow transplants.

Lake Riley:

The aquatic plant community in Lake Riley does not appear to be following the same trend as Lake Susan after the removal of carp. This is evident by the poor species richness and comparative lack of vegetation in the shallower zones. The dominance by invasive Eurasian watermilfoil may be a problem and the lack of herbivores indicates that biological control is likely limited by abundant sunfish. More research and attention to the aquatic plant management methods are needed for the reestablishment of a healthy plant community. After the lake association considers options a management plan should be developed. More resources will be needed to further manage the Lake Riley plant community.

2012 plans for Lake Riley:

- Work with lake association on vegetation management.
- Conduct one vegetation and one herbivore survey in mid-summer.
- Provide guidance and recommendations on future management based on objectives and preferences of the lake association.

Lake Staring:

The aquatic plant community in Lake Staring is very weak which is consistent with the very high density of carp in the lake. Carp removal is being considered for winter/spring 2012. Lake Staring is a good candidate for early re-vegetation options considering there is very little curlyleaf pondweed or Eurasian watermilfoil present. We will explore options for transplanting in 2012 but will likely hold off until 2013 after assessing that natural plant community response.

Plans for Lake Staring 2012:

- Monitor aquatic plant community after carp removal (proposed winter 2012).
- Develop method for restoration of healthy plant community and plan for transplanting in 2013.

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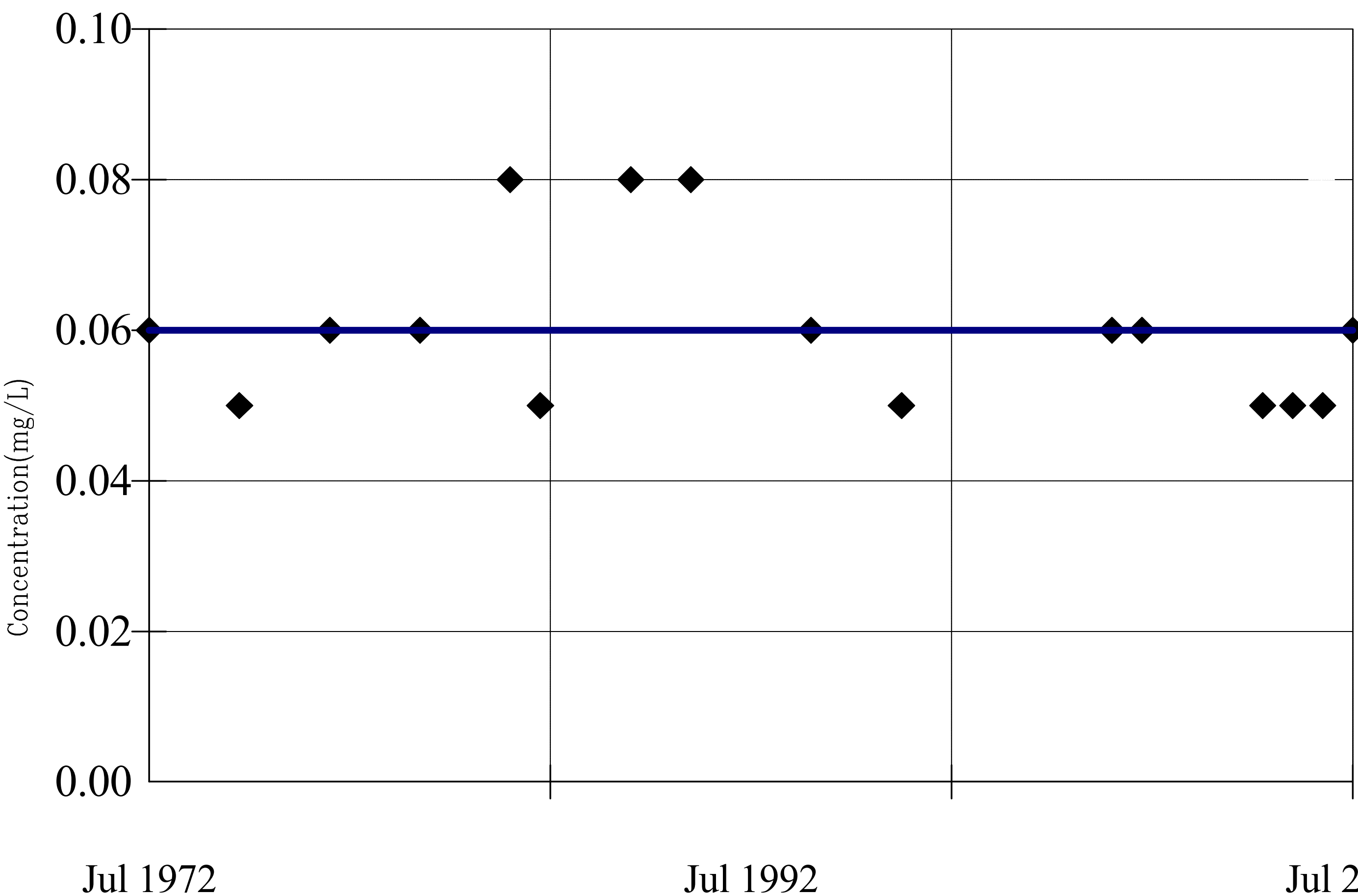
Appendix C

Lake Lucy and Lake Ann Trend Analyses

SEN'S SLOPE ESTIMATOR
LkLucy



Alpha	Critical	Signif.
0.01	-58	No
0.05	-45	No
0.1	-38	No
0.2	-30	No

Constituent: TP (mg/L)

Facility: Lake Trend Analysis

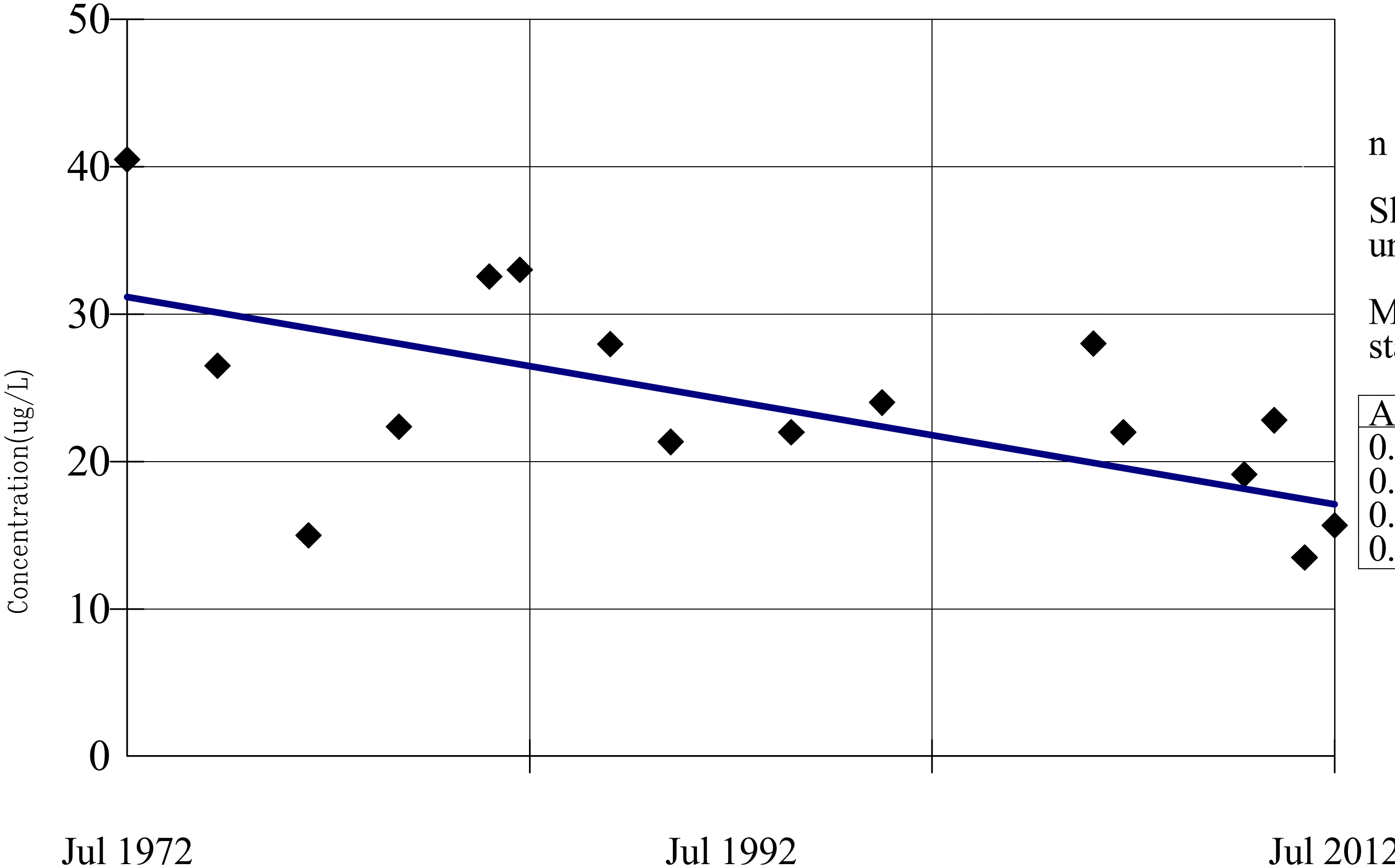
Data File: LKLUCY

Date: 6/13/13

Time: 9:25 AM

View: LkLUCY

SEN'S SLOPE ESTIMATOR
LkLucy



n = 16

Slope = -0.351
units per year.

Mann Kendall
statistic = -47

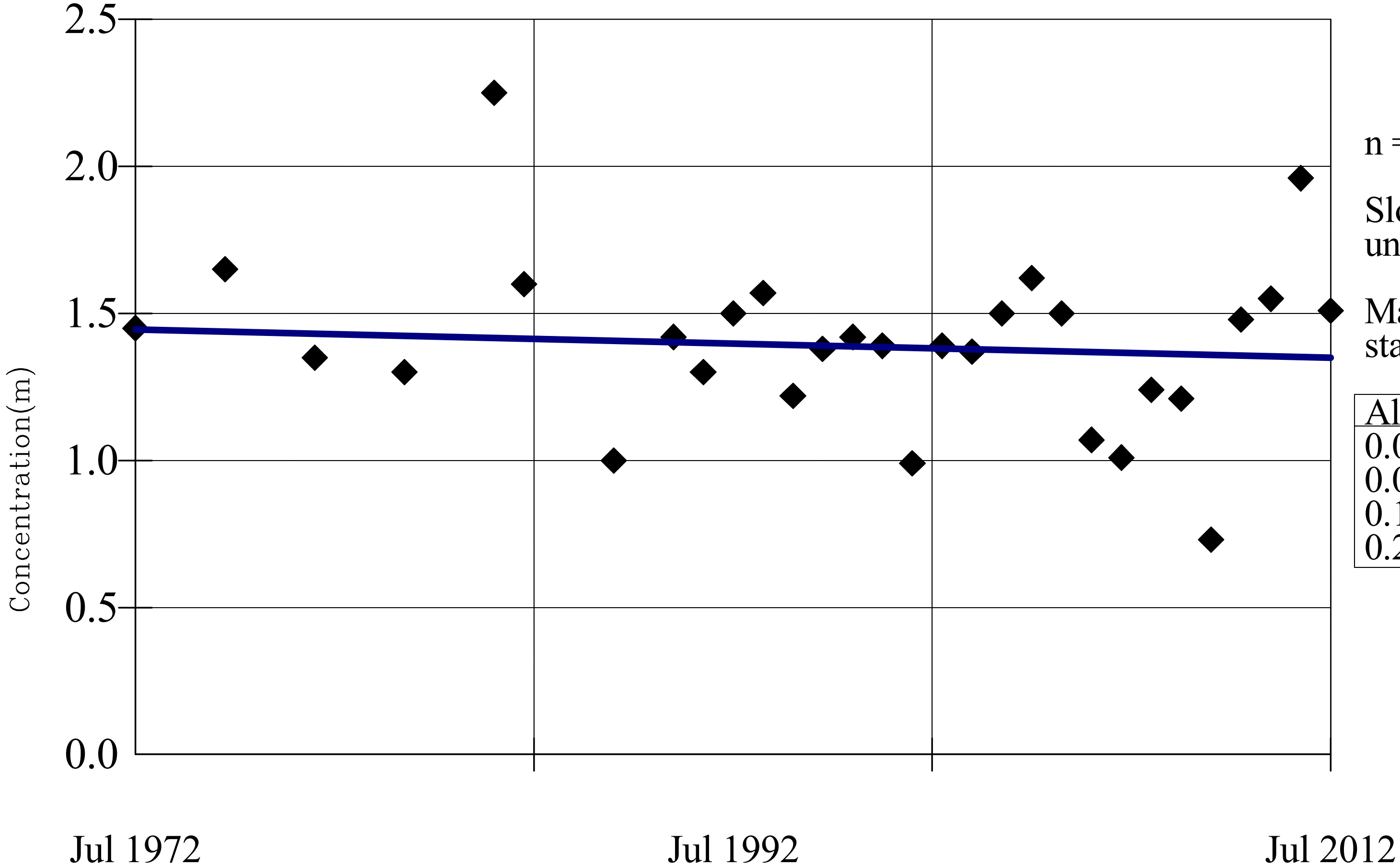
Alpha	Critical	Signif.
0.01	-58	No
0.05	-45	Down
0.1	-38	Down
0.2	-30	Down

Constituent: Chl a (ug/L)
Date: 6/13/13

Facility: Lake Trend Analysis
Time: 9:25 AM

Data File: LKLUCY
View: LkLUCY

SEN'S SLOPE ESTIMATOR
LkLucy



n = 30

Slope = -0.002 units per year.

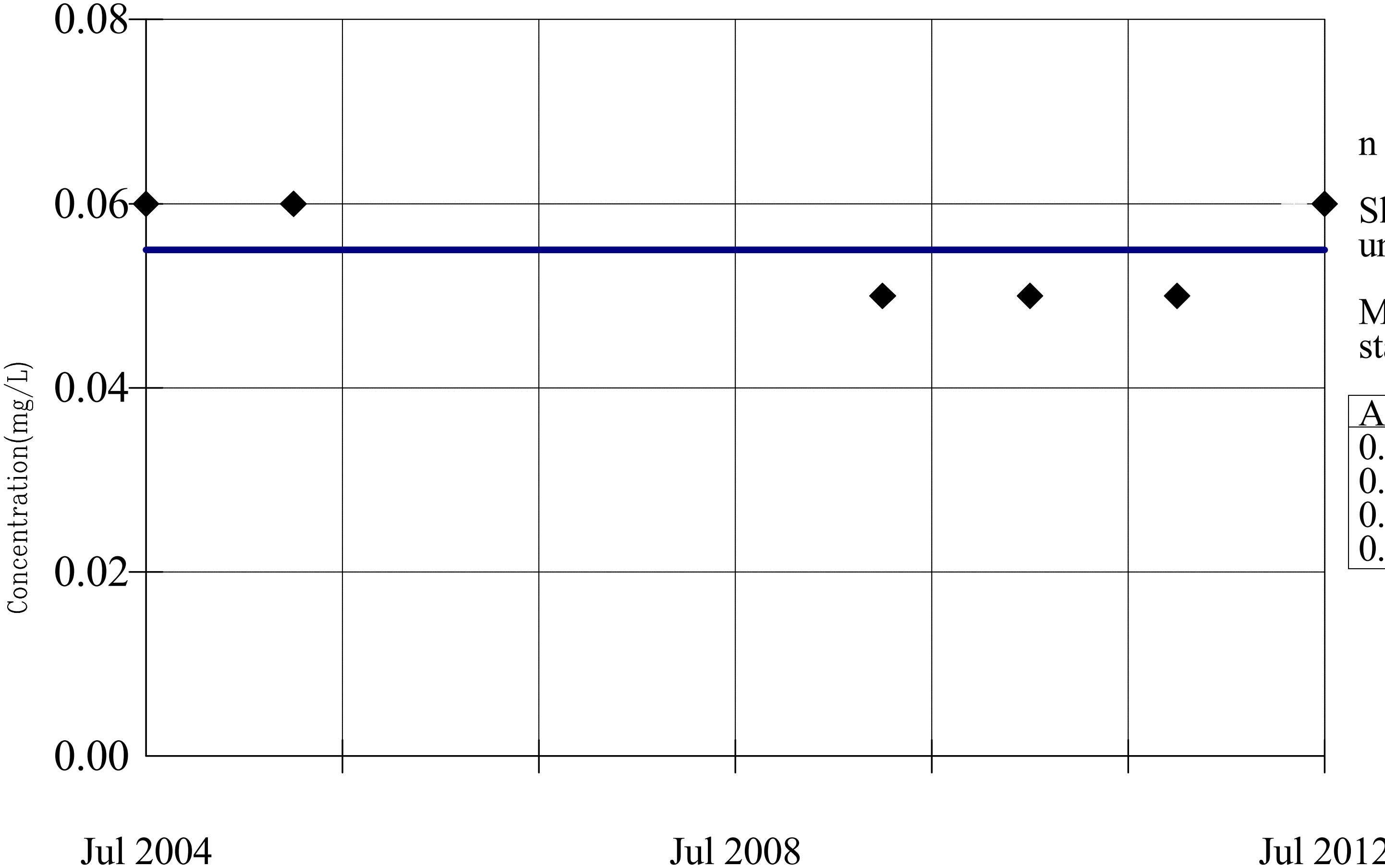
Mann Kendall statistic = -27

Alpha	Critical	Signif.
0.01	-146	No
0.05	-112	No
0.1	-94	No
0.2	-74	No

Constituent: SD (m) Facility: Lake Trend Analysis Data File: LKLUCY

Date: 6/13/13 Time: 9:23 AM View: LkLUCY

SEN'S SLOPE ESTIMATOR
LkLucy



n = 6

Slope = 0
units per year.

Mann Kendall
statistic = -3

Alpha	Critical	Signif.
0.01	-14	No
0.05	-12	No
0.1	-10	No
0.2	-9	No

Constituent: TP (mg/L)

Facility: Lake Trend Analysis

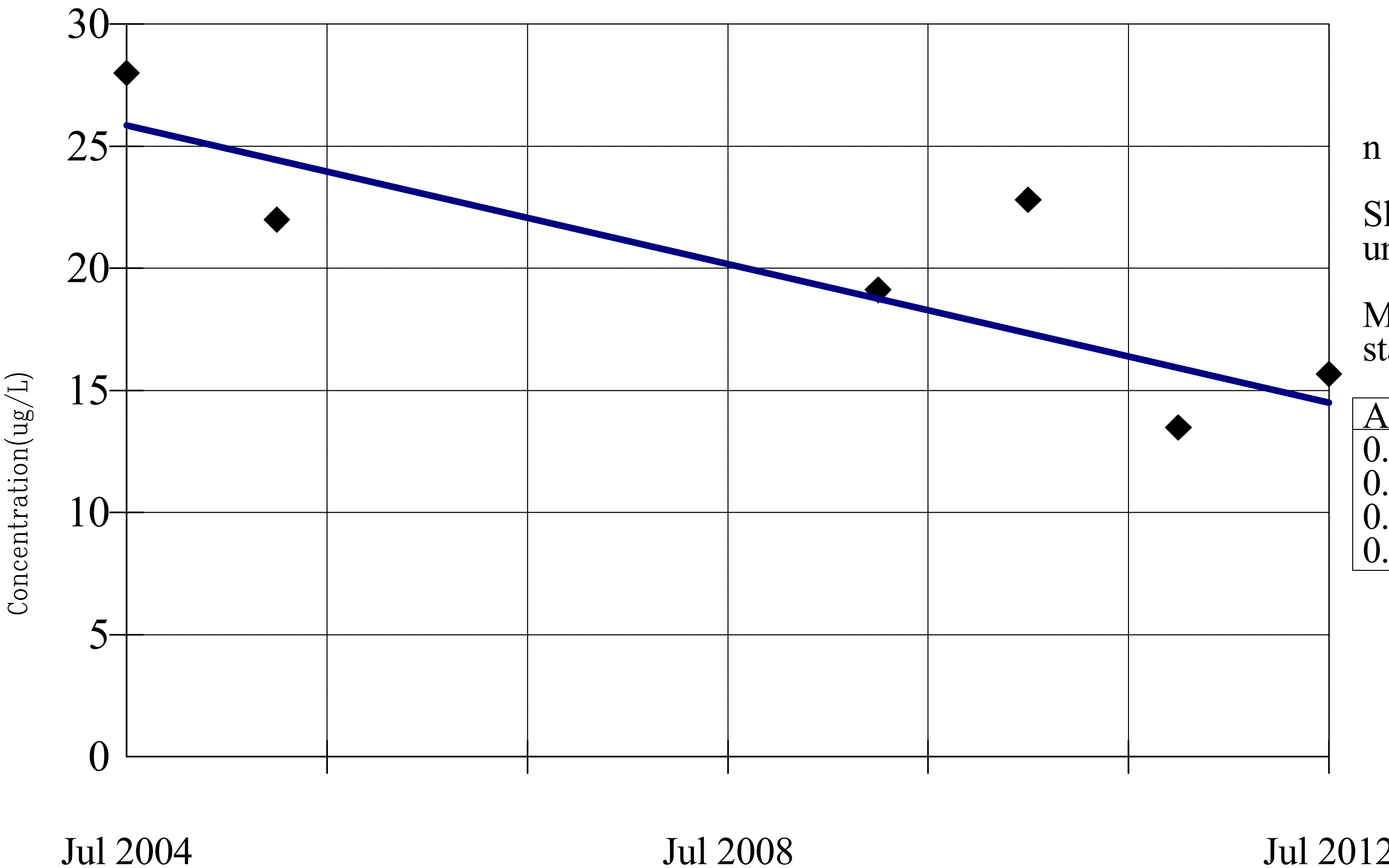
Data File: LKLUCY

Date: 6/13/13

Time: 9:32 AM

View: LkLUCY

SEN'S SLOPE ESTIMATOR
LkLucy



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Slope = -1.418
units per year.

Mann Kendall
statistic = -9

Alpha	Critical	Signif.
0.01	-14	No
0.05	-12	No
0.1	-10	No
0.2	-9	Down

Constituent: Chl a (ug/L)

Date: 6/13/13

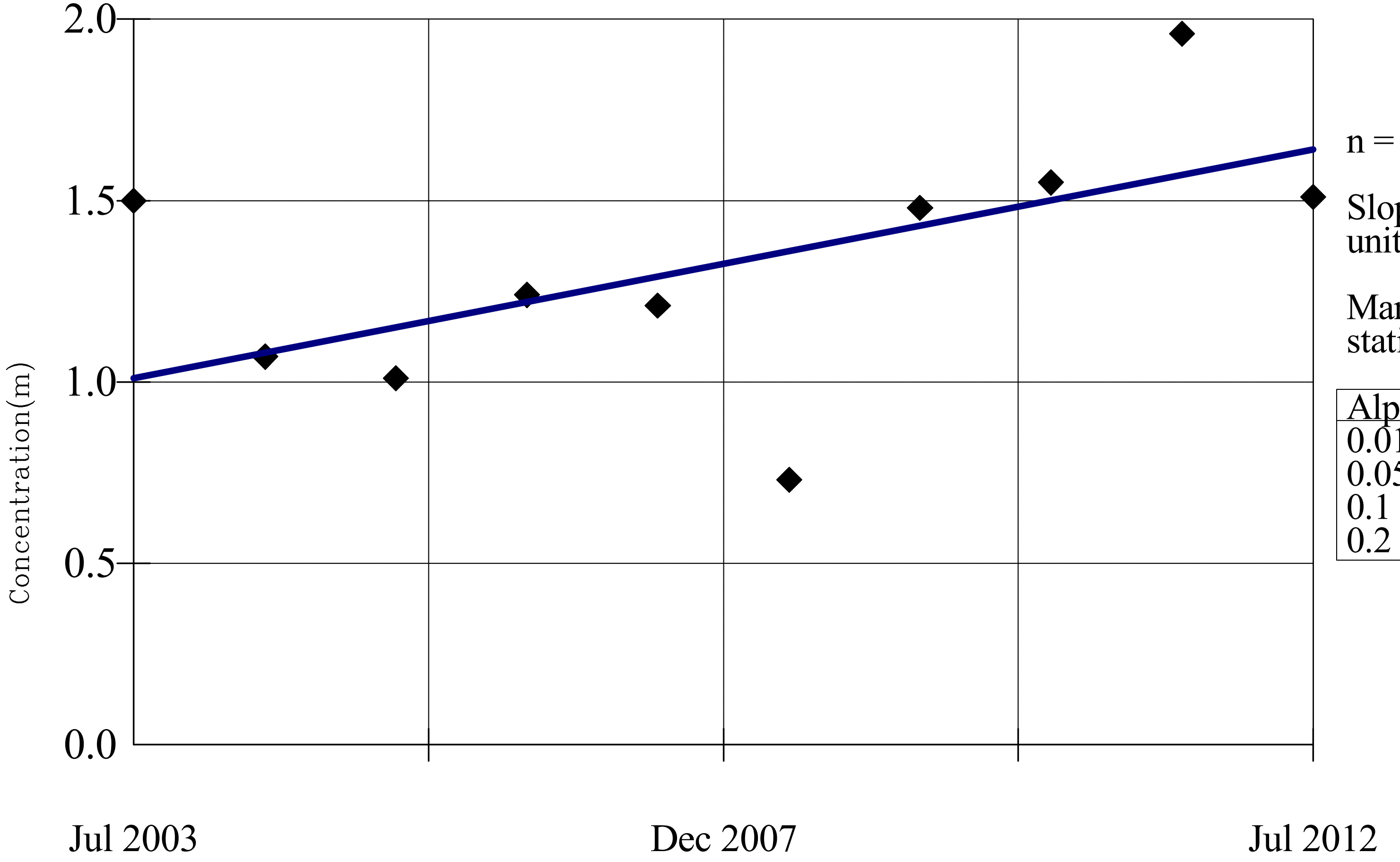
Facility: Lake Trend Analysis

Time: 9:32 AM

Data File: LKLUCY

View: LkLUCY

SEN'S SLOPE ESTIMATOR
LkLucy

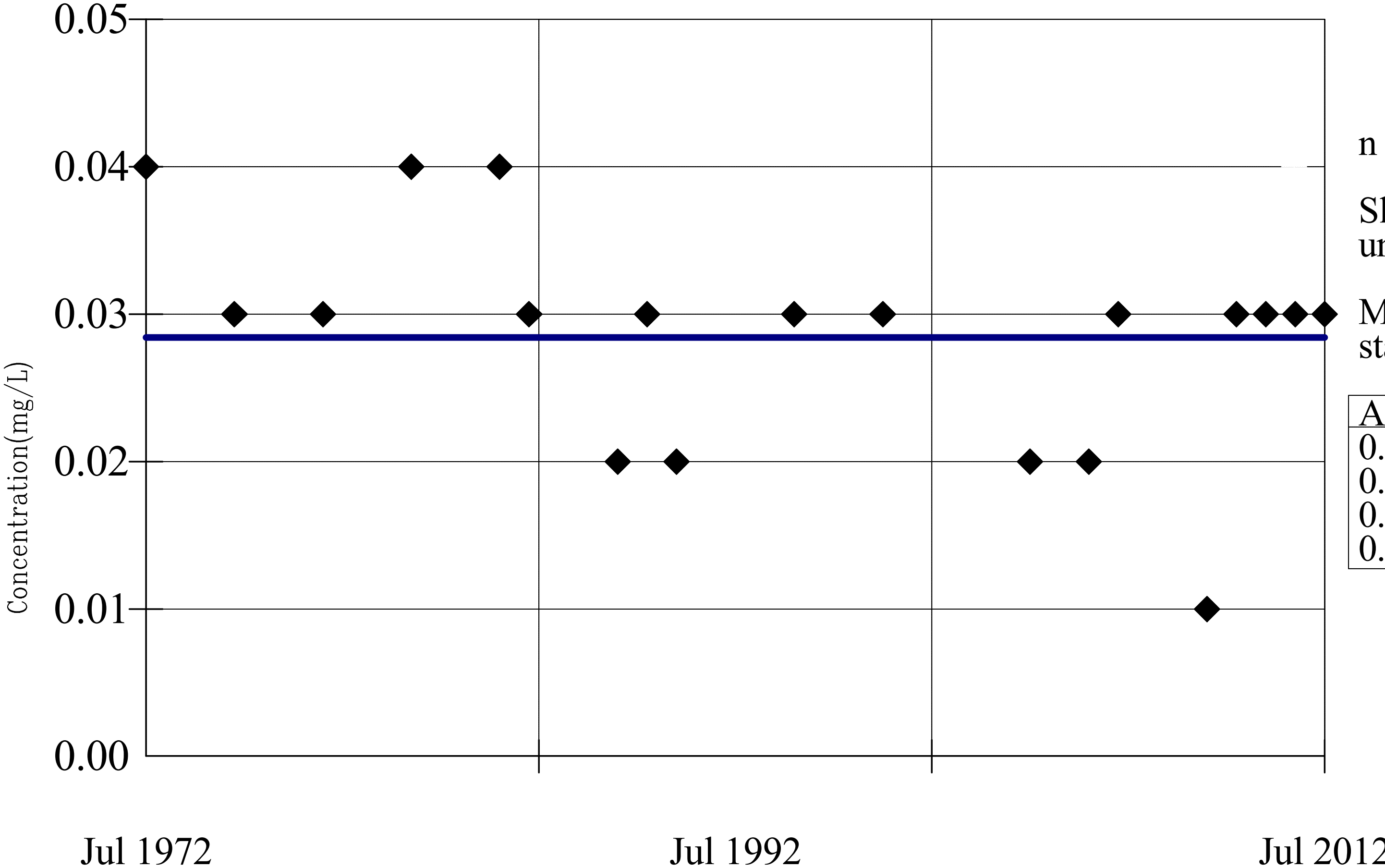


Alpha	Critical	Signif.
0.01	30	No
0.05	23	No
0.1	20	No
0.2	16	Up

Constituent: SD (m) Facility: Lake Trend Analysis Data File: LKLUCY

Date: 6/13/13 Time: 9:31 AM View: LkLUCY

SEN'S SLOPE ESTIMATOR
LkAnn



n = 19

Slope = 0
units per year.

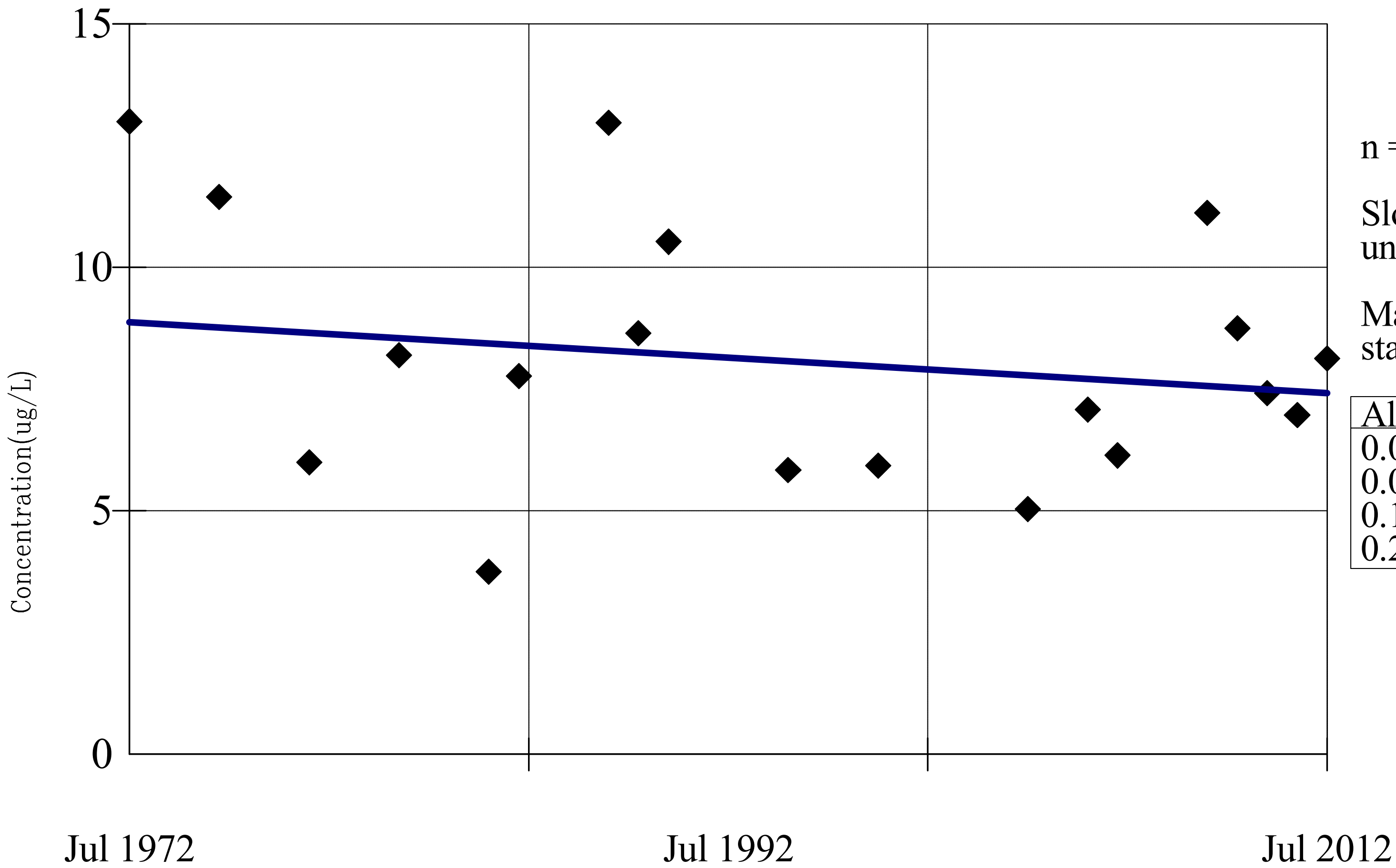
Mann Kendall
statistic = -41

Alpha	Critical	Signif.
0.01	-74	No
0.05	-58	No
0.1	-49	No
0.2	-38	Down

Constituent: TP (mg/L) Facility: Lake Trend Analysis Data File: LKANN

Date: 6/13/13 Time: 9:27 AM View: LkANN

SEN'S SLOPE ESTIMATOR
LkAnn



n = 19

Slope = -0.036
units per year.

Mann Kendall
statistic = -21

Alpha	Critical	Signif.
0.01	-74	No
0.05	-58	No
0.1	-49	No
0.2	-38	No

Constituent: Chl a (ug/L)

Date: 6/13/13

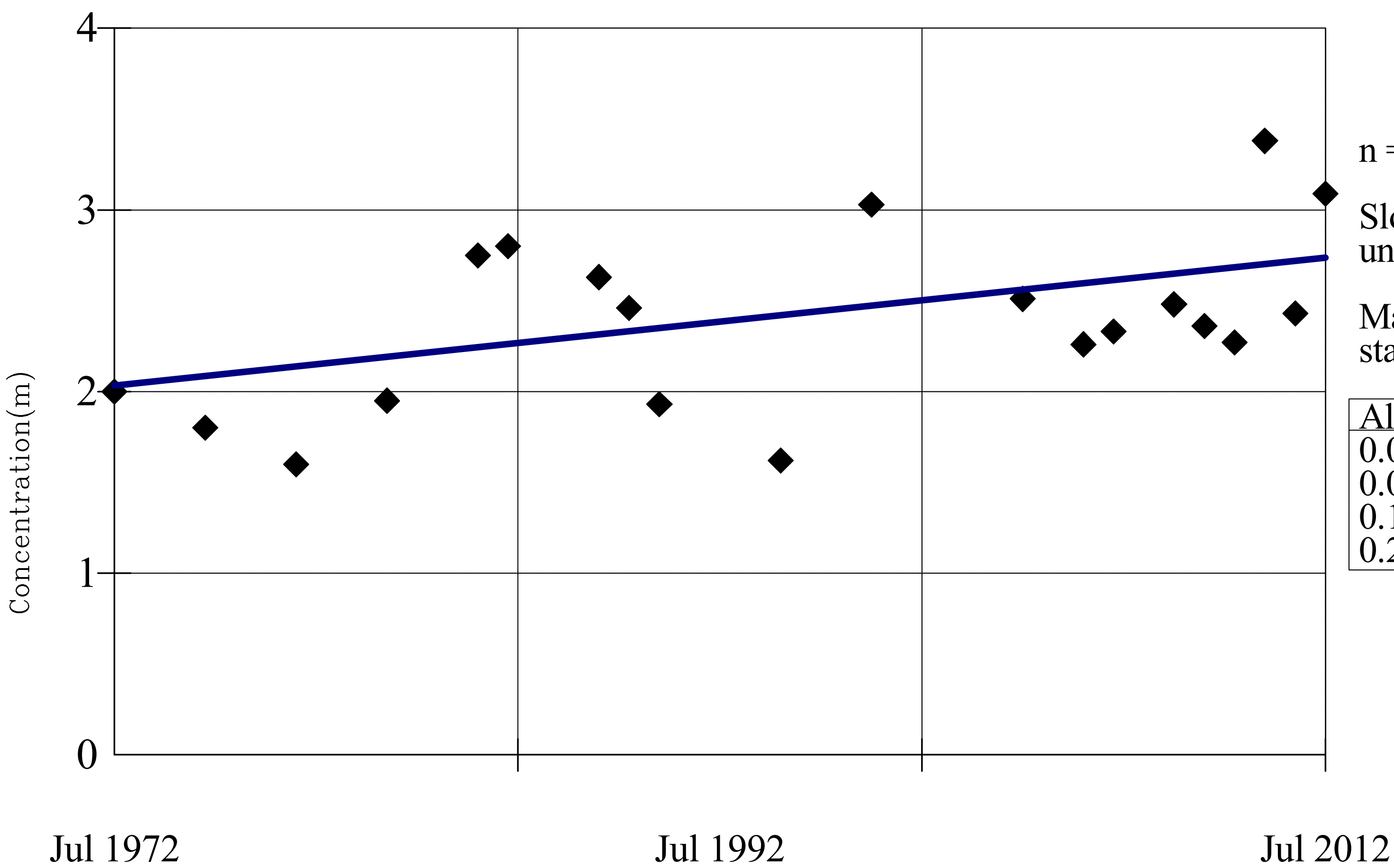
Facility: Lake Trend Analysis

Time: 9:28 AM

Data File: LKANN

View: LkANN

SEN'S SLOPE ESTIMATOR
LkAnn



n = 20

Slope = 0.018
units per year.

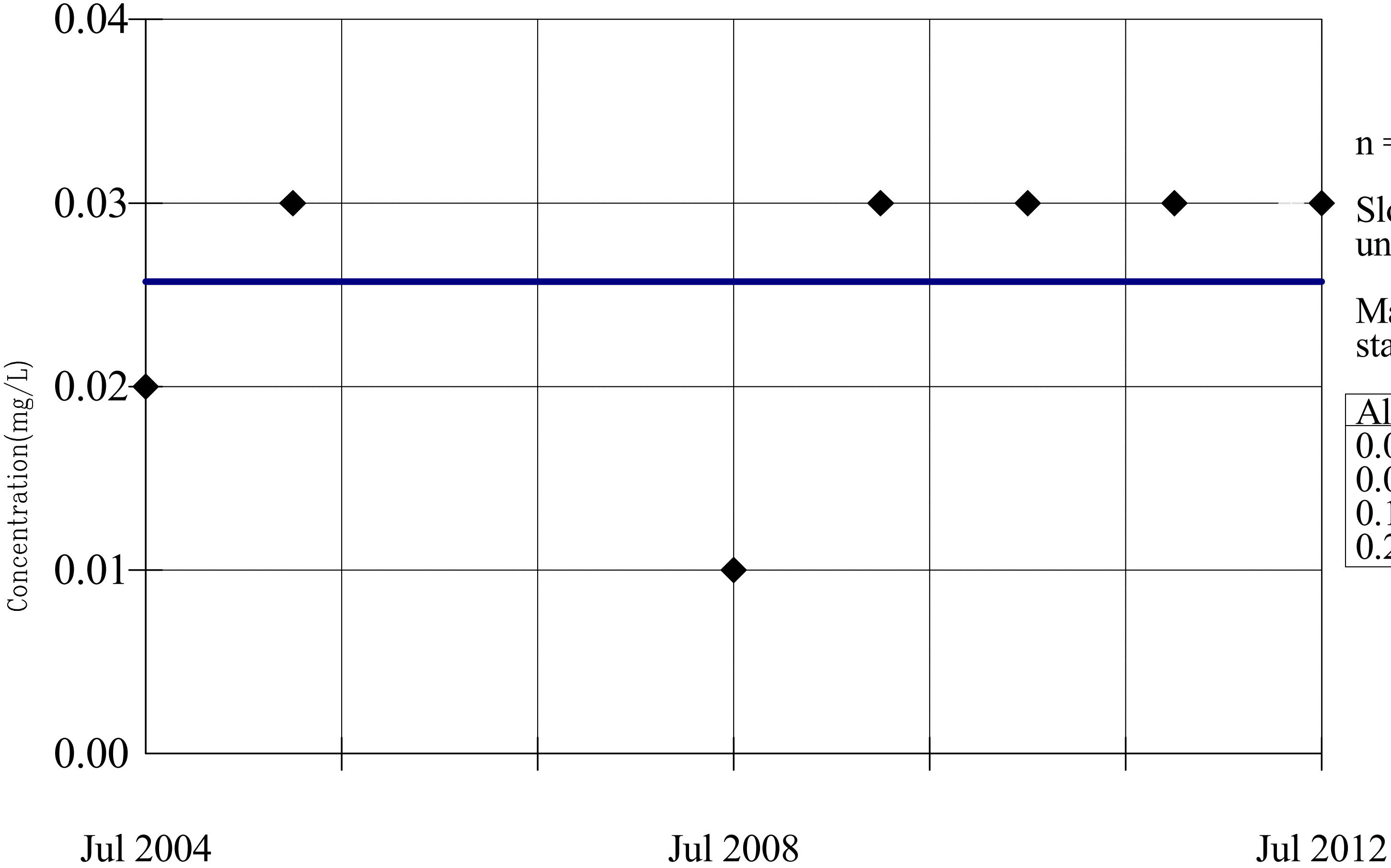
Mann Kendall
statistic = 52

Alpha	Critical	Signif.
0.01	81	No
0.05	62	No
0.1	52	Up
0.2	41	Up

Constituent: SD (m) Facility: Lake Trend Analysis Data File: LKANN

Date: 6/13/13 Time: 9:26 AM View: LkANN

SEN'S SLOPE ESTIMATOR
LkAnn



n = 7

Slope = 0
units per year.

Mann Kendall
statistic = 7

Alpha	Critical	Signif.
0.01	18	No
0.05	15	No
0.1	13	No
0.2	10	No

Constituent: TP (mg/L)

Date: 6/13/13

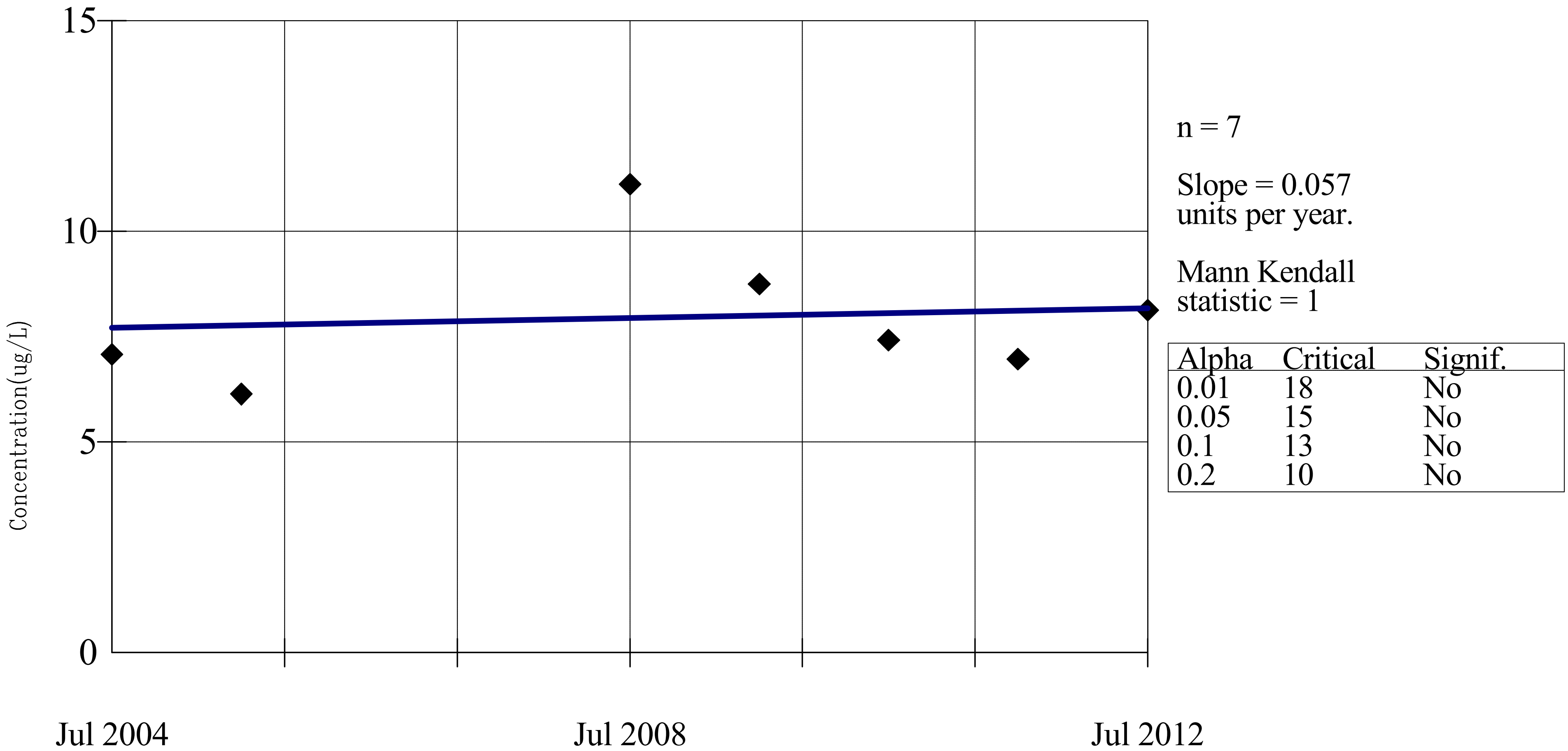
Facility: Lake Trend Analysis

Time: 9:34 AM

Data File: LKANN

View: LkANN

SEN'S SLOPE ESTIMATOR
LkAnn



Constituent: Chl a (ug/L)

Date: 6/13/13

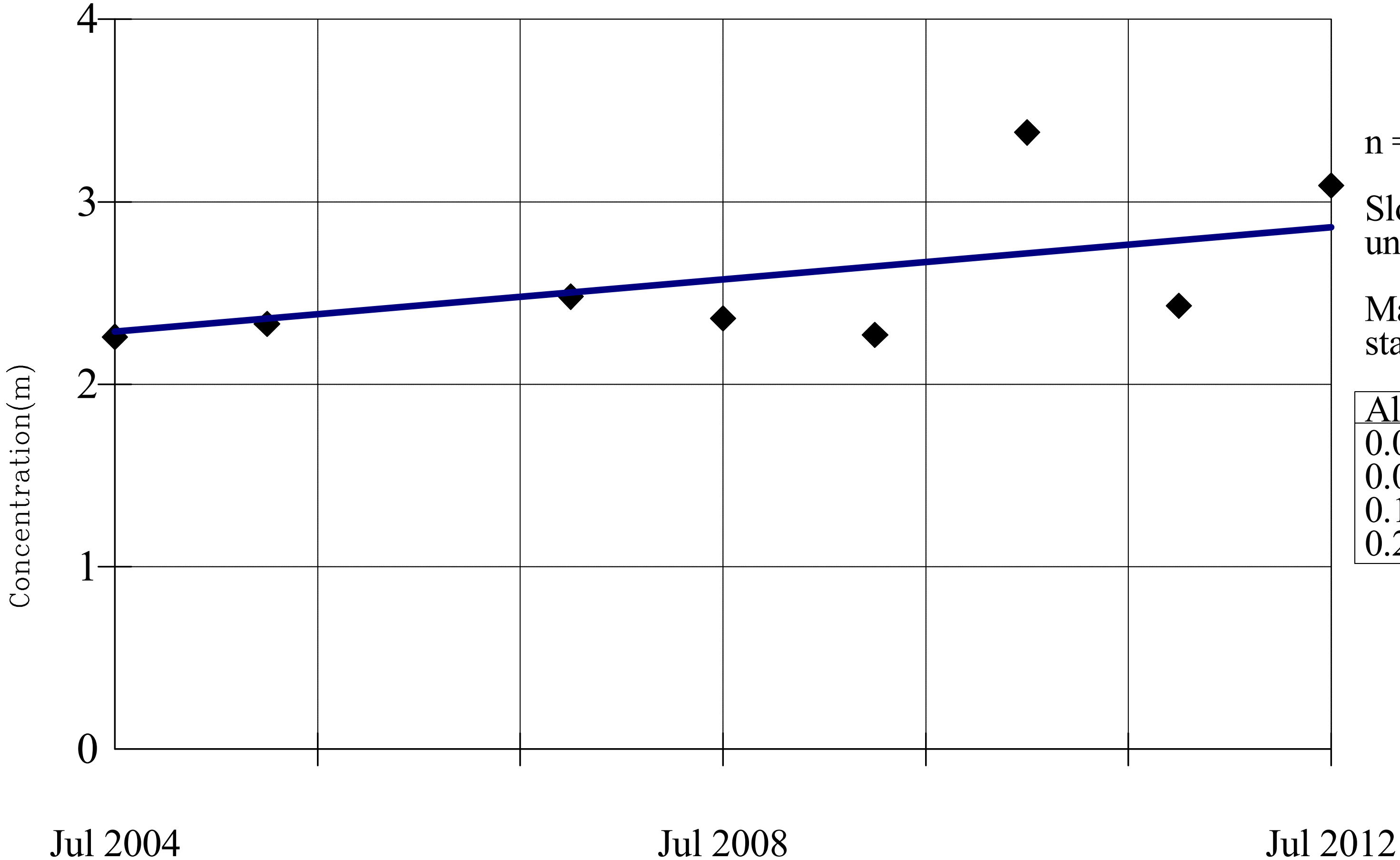
Facility: Lake Trend Analysis

Time: 9:34 AM

Data File: LKANN

View: LkANN

SEN'S SLOPE ESTIMATOR
LkAnn



n = 8

Slope = 0.072
units per year.

Mann Kendall
statistic = 14

Alpha	Critical	Signif.
0.01	21	No
0.05	17	No
0.1	15	No
0.2	12	Up

Constituent: SD (m)

Date: 6/13/13

Facility: Lake Trend Analysis

Time: 9:34 AM

Data File: LKANN

View: LkANN

Appendix D

Planning Level Opinion of Costs

Lucy/Ann BMP Cost Estimates
Planning Level Opinion of Cost
Prepared 6/24/2013

Enhanced Sand Filter

Description	Unit	Estimated Quantity	Unit Price	Extension		Assumptions
Easement	Ac	0.3	$16,000	$4,800		Based on easement costs estimated from recent VBWD easements
Mobilization/Demobilization (10%)	Lump Sum	1	$18,239	$18,239		
Erosion Control	Lump Sum	1	$500	$500		
Traffic and Pedestrian Safety	Lump Sum	1	$1,000	$1,000		
Clear and Grub Area	S.Y.	1250	$5	$6,250		From Maplewood Mall - for end islands
Excavate and Dispose of Soil	C.Y.	1500	$8	$12,000		Maplewood Mall/Living Streets
Catch Basin A - 120" with weir	Each	1	$15,000	$15,000		8' depth or less
Catch Basin B - 120"	Each	1	$10,500	$10,500		8' depth or less
Catch Basin C - 60"	Each	1	$5,500	$5,500		37th
Splash Block at Inlet Structure	Each	1	$2,000	$2,000		
30" RCP Pipe	L.F.	210	$65	$13,650		37th
4" Slotted CPEP Draintile	L.F.	650	$12	$7,800		Maplewood Mall
12" CPEP Pipe	L.F.	50	$25	$1,250		Maplewood Mall
Impervious Geomembrane Liner (EPDM)	S.Y.	1460	$25	$36,500		Maplewood Mall - Entrances
Clean Washed Sand	Ton	370	$55	$20,350		Maplewood Mall and CCLRT
Iron Aggregate	Ton	18.5	$1,700	$31,450		5% of sand by weight. Assumed sand=1.4 tons/CY, MM and CCLRT
Pea Rock	Ton	170	$40	$6,800		
Drain Gravel	Ton	145	$43	$6,235		1/4" chip and 3/4" chip granite prices from Maplewood Mall
Planting Soil	C.Y.	100	$35	$3,500		Assumed 6" planting soil, Maplewood Mall/Living Streets
Flexterra on Slope (Hydro applied seed, tacifier, and mulch)	S.Y.	600	$3.50	$2,100		Eagan Ponds
Subtotal				**$205,000**	**Subtotal**	
				$61,500	**Contingency (30%)**	
				$79,950	**Engineering and Design (30%)**	
				$350,000	**Total**	
920,00				$490,000.00	+40%	
				$280,000.00	-20%	

Description	Unit	Estimated Quantity	Unit Price	Extension	Assumptions
Annual Operation and Maintenance Costs	Lump Sum	1	$1,000.00	$1,000	based on actual O & M numbers from RWMWD Beam Avenue filter ($900/yr)

Lucy/Ann BMP Cost Estimates
Planning Level Opinion of Cost
Prepared 6/24/2013

Spent Lime Treatment Vault

Description	Unit	Estimated Quantity	Unit Price	Extension		Assumptions
Mobilization/Demobilization (10%)	Lump Sum	1	$9,885	$9,885		
Erosion Control	Lump Sum	1	$500	$500		
Traffic and Pedestrian Safety	Lump Sum	1	$1,000	$1,000		
Box Culvert 10'x12' (includes excavation, spent lime, and draintile)	L.F.	50	$1,500	$75,000		HERC 12'x7' average: $1,700/LF box only, 37th 12'x10' average: $1,010/LF box and excavation
Haul Spent Lime (St. Paul to Chanhassen)	C.Y.	47	$25	$1,175		
Diversion Structure	Each	1	$10,000	$10,000		
Directional Drill Outlet Pipe for Draintile	L.F.	50	$75	$3,750		
30" RCP Flared End Section	Each	1	$900	$900		Eagan
Remove 30" CMP and Replace with 30" RCP Pipe	L.F.	75	$80	$6,000		
Site Restoration	S.Y.	150	$3.50	$525		
Subtotal				**$109,000**	**Subtotal**	
				$32,700	**Contingency (30%)**	
				$42,510	**Engineering and Design (30%)**	
				$190,000	**Total**	ASSUMES CONSTRUCTION IN ROW, DOES NOT INCLUDE EASEMENT COSTS
				$270,000.00	+40%	
				$160,000.00	-20%	

Description	Unit	Estimated Quantity	Unit Price	Extension	Assumptions
Annual Operation and Maintenance Costs	Lump Sum	1	$1,000.00	$1,000	Raking of material annually

Lucy/Ann BMP Cost Estimates
Planning Level Opinion of Cost
Prepared 6/24/2013

Lake Lucy Alum Treatment

Description	Unit	Estimated Quantity	Unit Price	Extension		Assumptions
Sediment Core Analysis & Dosing Estimated	Lump Sum	1	$6,000	$6,000		Assumes 4 sediment cores collected, 50 hrs KDM, Expenses - Based on Lake Edith Estimate
Mobilization/Demobilization (10%)	Lump Sum	1	$17,016	$17,016		
Alum (Aluminum Sulfate)	gal	61600	$2.60	$160,160		Gallons of alum based on average application rate (gal/acre of lake surface) from Alum Treatment memo prepared for Prior Lake Spring Lake WD & 2012 Southwest Anderson Lake Alum Treatment; Based on costs from Rachel/Lake Restoration for Southwest Anderson Alum Treatment 2012 - unit cost assumes difficult access to Lake
Restoration/Assistance Work	Lump Sum	1	$10,000	$10,000		Based on restoration estimated from Rachel for Southwest Anderson Lake Alum Treatment - 2012
Subtotal				**$187,000**	**Subtotal**	
				$56,100	**Contingency (30%)**	
				$72,930	**Engineering and Design (30%)**	Monitoring and observation during application
				$320,000	**Total**	
				$450,000.00	+40%	
				$260,000.00	-20%	

Description	Unit	Estimated Quantity	Unit Price	Extension	Assumptions
Annual Operation and Maintenance Costs	Lump Sum	1		$0	

Engineer's Opinion of Probable Costs – Endothall Treatments in Lake Lucy to Control Curlyleaf Pondweed

Item	Unit	Estimated Quantity	Unit Price*	Extension Per Year*	Extension 5 Years*	Comments
Mobilization (10%)	L.S.	1	$3,000	$3,000.00	$15,000	
Endothall Application (CLPW & EWMF)	Gal	363	$92	$33,368	$166,842	Treatment of entire lake area
Subtotal				$36,368	$181,842	
Contingencies (30%)				$10,911	$54,553	
Engineering & Administration (30%) (One Time Cost)				$10,911	$10,911	
Total				$58,189	$247,305	

*2013 dollars

Engineer's Opinion of Probable Costs – Develop Lake Vegetation Management Plan and Obtain MDNR Treatment Permit and Letter of Variance and Letters of Permission to Treat Within 150 Feet of Riparian Property Boundaries

Item	Unit	Estimated Quantity	Unit Price*	Extension Per Year*	Extension 5 Years*	Comments
Obtain Letter of Variance	L.S.	1	$570	$570	$2,850	
Obtain Permit For Endothall Application	L.S	1	$2,870	$2,870	$14,350	
Obtain Permission Letters From Riparian Owners	L.S	1	$2,870	$2,870	$14,350	
Lake Vegetation Management Plan (One Time Cost)	L.S.	1	$17,220	$17,220	$17,220	
Total				$23,530	$48,770	

*2013 dollars

Engineer's Opinion of Probable Costs - Monitoring, Analysis, and Reporting Cost Estimate – Aquatic Plant, Biomass, Turion, and Herbicide Residue

Item	Unit	Estimated Quantity	Unit Price*	Extension Per Year*	Extension 5 Years*	Comments
Aquatic Plant Monitoring & Biomass Sampling	L.S.	3	$2,350	$7,050	$35,250	3 survey events per year (April, June, August) per MDNR requirements; Assumes subcontractor based on Anderson Lakes CLPW treatment costs - 2013; Assumes District staff will assist in aquatic plant and turion monitoring
Biomass Analysis	L.S	1	$4,000	$4,000	$20,000	Assumes subcontractor based on Anderson Lakes CLPW treatment costs - 2013
Turion Monitoring	L.S	1	$3,250	$3,250	$16,250	1 survey event per year; Assumes subcontractor based on Anderson Lakes CLPW treatment costs - 2013;Assumes District staff will assist in aquatic plant and turion monitoring
Herbicide Residue Monitoring	L.S.	1	$6,850	$6,850	$34,250	5 survey events at 1, 2, 7, 14, 21 days after treatment @ 2 survey locations
Subtotal				$21,150	$105,750	
Contingencies (30%)				$6,345	$31,725	
Engineering & Design (30%)				$6,345	$31,725	
Total				$33,840	$169,200	

*2013 dollars

TOTAL	**$120,000**	**$470,000**
+40%	$170,000.00	$660,000.00
-20%	$100,000.00	$380,000.00

Lucy/Ann BMP Cost Estimates
Planning Level Opinion of Cost
Prepared 6/24/2013

Lake Ann Alum Treatment

Description	Unit	Estimated Quantity	Unit Price	Extension		Assumptions
Sediment Core Analysis & Dosing Estimated	Lump Sum	1	$6,000	$6,000		Assumes 4 sediment cores collected, 50 hrs KDM, Expenses - Based on Lake Edith Estimate
Mobilization/Demobilization (10%)	Lump Sum	1	$15,161	$15,161		
Alum (Aluminum Sulfate)	gal	83300	$1.70	$141,610		Gallons of alum based on average application rate (gal/acre of lake surface) from Alum Treatment memo prepared for Prior Lake Spring Lake WD (Approx 700 gal/ac) & 2012 Southwest Anderson Lake Alum Treatment; Based on recent costs from Rachel/Lake Restoration for Southwest Anderson Alum Treatment 2012 and the Kohlman Lake Alum treatment
Restoration/Assistance Work	Lump Sum	1	$10,000	$10,000		Based on restoration estimated from Rachel for Southwest Anderson Lake Alum Treatment - 2012
Subtotal				**$167,000**	**Subtotal**	
				$50,100	**Contingency (30%)**	
				$65,130	**Engineering and Design (30%)**	Monitoring and observation during application
				$290,000	**Total**	
				$410,000.00	+40%	
				$240,000.00	-20%	

Description	Unit	Estimated Quantity	Unit Price	Extension	Assumptions
Annual Operation and Maintenance Costs	Lump Sum	1		$0	