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Lake Susan Use Attainability Assessment (UAA) Update

Prepared for:

RILEY PURGATORY BLUFF CREEK WATERSHED DISTRICT

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1.0 Introduction

1.1 PURPOSE

Lake Susan was listed in 2010 as an impaired water body for nutrients by the Minnesota Pollution Control Agency (MPCA). As a result, the Riley Purgatory Bluff Creek Watershed District (RPBCWD) requested Wenck Associates, Inc. to:

1. Establish an appropriate water quality goal for the lake if different than the state standard
2. Provide components similar to a TMDL study (e.g., allocations to achieve water quality goals).
3. Articulate implementation elements to achieve recommended phosphorus reductions that facilitate “delisting” the lake as an impaired water body.

As part of the study, the District wanted to incorporate the recommendations and management activities recently completed on the lake to develop a current management strategy.

1.2 PAST STUDIES AND ACTIVITIES

Several studies and management activities have been completed on Lake Susan over the past 15 years. A list and description of the study or activity is provided below.

1.2.1 Susan and Rice Marsh Lake Use Attainability Analysis

In 1999 a Use Attainability Analysis (UAA) was completed for Lake Susan and Rice Lake Marsh (Barr, 1999). The study looked at establishing a water quality goal for the lake, along with identifying Best Management Practices (BMPs) to help meet the goal.

Watershed loading was analyzed using P8 and an internal load was calculated based on an empirical formula developed by Dillon and Rigler (1974). The watershed model evaluated existing and future conditions to determine ultimate loading conditions for the lake and evaluate the effectiveness of identified watershed BMPs. The analysis resulted in the following recommendations:

- Lake Susan should achieve a “Level II” water quality standard having a phosphorus concentration between 45 to 75 g/l range.
- Improve or add eight ponds to account for future urbanization.
- Upgrade one pond to address an under treated watershed.
- Add eight ponds in watersheds not currently treated.
- Treat Lake Susan with alum.

1.2.2 City of Chanhassen Non-Degradation Plan

In 2008 the City of Chanhassen completed a Non-Degradation Assessment (Wenck, 2008) as part of their National Pollutant Discharge Elimination System (NPDES) Phase II permit. The plan assessed changes in stormwater runoff volume, total phosphorus (TP) and total suspended sediment (TSS) loading in the City of Chanhassen since 1988 to predict how land use changes would impact loading in 2020. The assessment determined that based on current BMP practices, there isa net reduction in TP and TSS loading rates compared to 1988. There was an increase in stormwater runoff volume, however, so the City prescribed the following BMPs:

- New development or redevelopment abstraction requirement
- Implementation of a reforestation program
- Retrofitting volume management BMPs where opportunities arise
- Implementation of stream restoration, erosion control, and shoreline restoration projects to mitigate volume impacts.

1.2.3 University of Minnesota Carp Management and Native Submerged Aquatic Vegetation Establishment Study

The University of Minnesota (U of M) since 2007 has been conducting a study on carp management in Lake Susan (Sorenson, 2013 – Appendix A). The study is focused on identifying carp recruitment and management activities to bring carp biomass levels in line with lakes similar to Lake Susan. The goal of carp management was to limit nutrient reentrainment and improve water clarity associated with excessive carp populations. Activities completed as part of the study include:

- Tagging and tracking of carp
- Collecting water quality samples
- Removing carp in the winter of 2008-2009 Installing aeration in Rice Lake Marsh to limit winterkill of panfish

As a result of these activities, the carp population continues to be managed, lake water clarity has improved, and macrophyte density has increased. Curly-leaf pondweed and Eurasian watermilfoil, both invasive species, are present in the lake and there is a desire to preempt further establishment of the species in the lake (Knopik 2012 – Appendix B).

The U of M is currently evaluating transplanting native species to the lake to help their propagation and preempt further spreading of invasives. As of this report, they are continuing to implement and monitor the results of the transplanted native vegetation.

1.2.4 Carver County Soil and Water Conservation District Susan, Ann, Lucy Subwatershed: Stormwater Retrofit Assessment (SALSA)

In 2011 the Carver County Soil and Water Conservation District (SWCD) conducted a retrofit analysis for the Lake Susan (2011) watershed. The study focused on identifying cost-effective retrofit BMPs to reduce TP loads to the lake. A WINSLAMM model was developed to complete the watershed loading analysis and asses the effectiveness of the proposed BMPs.

The analysis identified installing iron enhanced sand filtration (Minnesota Filter) and increasing targeted pond volume as the two primary BMPs for implementation. In the study it identified 24 different sites where these could be implemented to supplement existing stormwater treatment systems. The cost effectiveness of these systems ranged from $71- $192/lb-TP/yr.

1.2.5 RPBCWD Water Quality Monitoring

The District has monitored the Lake Susan watershed for 15 years. During that time, they collected monitoring data in Lake Susan, Riley Creek, stormwater ponds, and wetlands. The data provided insight into which stormwater ponds were performing as designed and whether wetlands were serving as a source of TP to Lake Susan. These data were also used for calibrating watershed and lake loading models.

2.0 Water Quality Standards and Numeric Phosphorus Target

2.1 WATER QUALITY STANDARDS FOR LAKE SUSAN

Over the past 15 years, water quality goals established for Lake Susan have changed. A timeline and summary table of goals (Table 2-1) is provided below.

- The original UAA established that Lake Susan should achieve a “Level II” water quality standard, having a phosphorus concentration between 45 to 75 g/l range
- The District’s Overall Watershed Management plan (2008) designated Lake Susan as a deep lake and recommended the lake meet MPCA North Central Hardwood Forest (NCHF) ecoregion lake standards. Numeric TP, chlorophyll-*a*, and Secchi depth standards for lakes in the NCHF ecoregion are ≤40 µg/L, ≤14 µg/L, and ≥ 1.4 meter, respectively.
- In 2010 Lake Susan was impaired for nutrients by the MPCA based on NCHF ecoregion shallow lake standards. Numeric TP, chlorophyll-a, and Secchi depth standards for shallow lakes in the NCHF ecoregion are ≤60 µg/L, ≤20 µg/L, and ≥ 1.0 meter, respectively.

Table 2-1. Lake Susan Water Goals Summary.

	Average June-September Values		
	Total Phosphorus (µg/L)	**Chlorophyll-*a* (µg/L)**	**Secchi Depth (m)**
Lake Susan (UAA)	≤75	≤37[1]	≥0.7[1]
Overall Management Plan	≤40	≤14	≥1.4
MPCA NCHF Class 2B Shallow Lakes Standard	≤60	≤20	≥1.0

[1] Corresponding levels based on implied TP goal

To date, Lake Susan is designated as a shallow Class 2B water in the NCHF ecoregion by the MPCA. The MPCA defines a shallow lake as having either a maximum depth less than 15 feet or 80% or more of its surface area shallow enough to support submerged aquatic vegetation. Specific water quality standards for lakes are based on ecoregion and lake type (shallow or deep).

After review of the lake bathymetry (>85% less than 15ft) and the current goal established by the MPCA, it is recommended that Lake Susan be managed to Class 2B NCHF ecoregion shallow lake standards.

3.0 Watershed and Lake Characterization

3.1 OVERVIEW

Lake Susan (DNR # 1000-13) is located within the municipal boundary of Chanhassen in Carver County, Minnesota (Figure 3-1). Lake Susan has an area of 88 acres and a maximum depth of 17 feet. The lake is part of the Riley Creek watershed and is one of the many flow-through lakes along the creek’s path to the Minnesota River. Lake Susan is a recreational lake used for fishing, boating and canoeing. It is readily accessible to the public through two parks featuring a public landing, fishing piers, observation decks, and walking/hiking trails.

Figure 3-1. Lake Susan in Carver County.

3.2 HISTORY OF THE LAKES AND THEIR WATERSHEDS

The predevelopment watershed of Lake Susan is believed to be similar to the current watershed area but dominated by open grassland and oak savannah canopy (Figure 3-2). In the late 1970s and early 1980s, commerical and residential developments increased in the watershed. Along with the development, the City's storm sewer system was installed, changing the efficiency of the runoff to the lake. Lake Susan now receives stormwater from over 2,553 acres, including Lake Ann and Lake Lucy watersheds. Implementation of stormwater management activities since the late 1980s has steadily improved the quality of stormwater runoff .At the same time, dense populations of carp and curly-leaf pondweed caused heavy algae blooms and poor water clarity. Monitoring data suggest conditions may have improved slightly in the early 1980s due to implementation of stormwater management activities and management of carp populations.

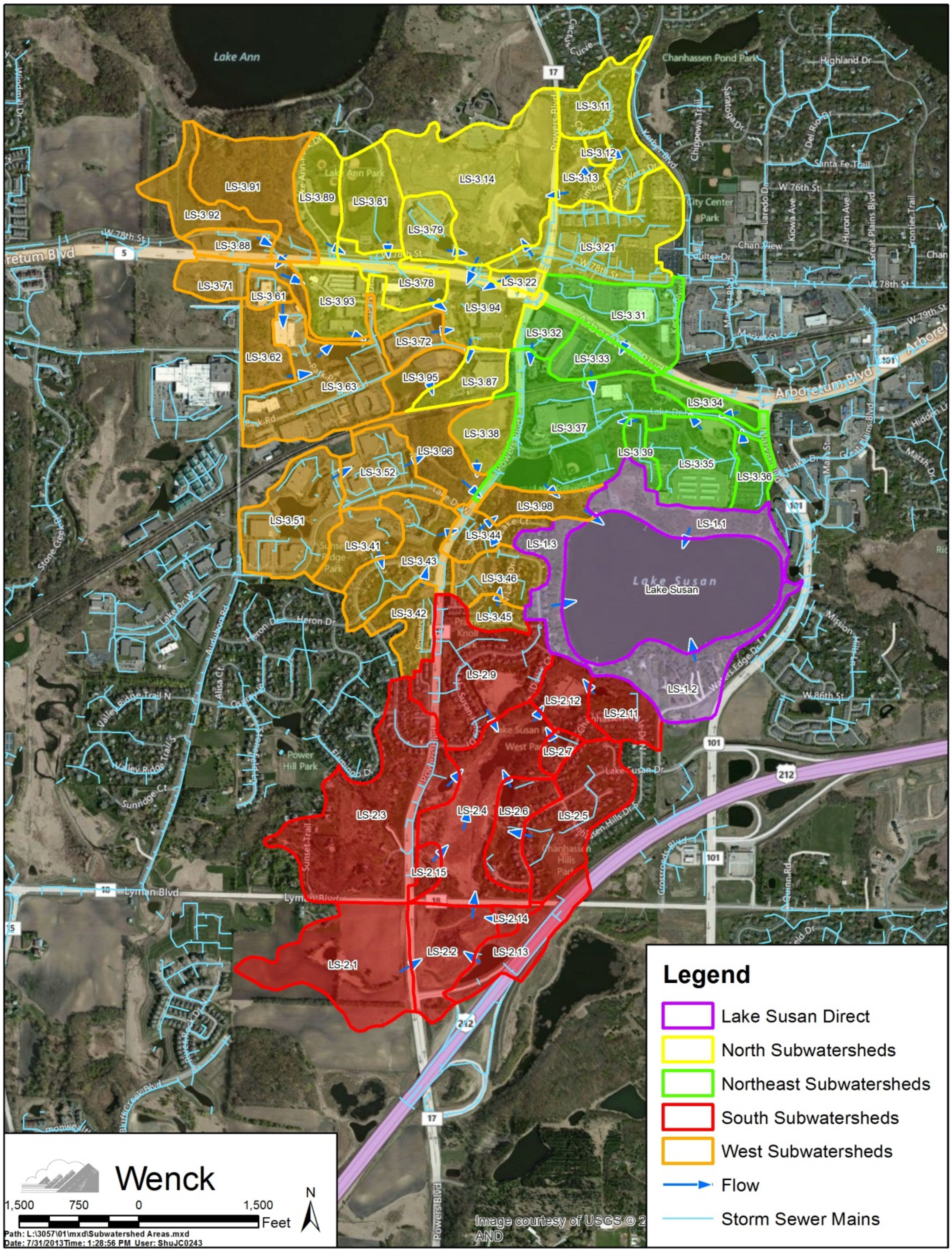

Figure 3-2. Lake Susan Watershed.

3.3 LAND USE

The Lake Susan watershed is characterized primarily by low-density residential, undeveloped, and industrial with stormwater basins throughout the watershed (Tables 3-1 and 3-2 and Figures 3-3 and 3-4).

Table 3-1. 2010 Land Use for the Lake Susan Watershed.

Land use [1]	Percent	Area (Acres)
Agricultural	5%	61
Farmstead	0%	2
Industrial and Utility	14%	178
Institutional	1%	18
Major Highway	6%	73
Mixed Use Commercial	0%	3
Mixed Use Industrial	0%	3
Multifamily	1%	14
Office	2%	22
Open Water	7%	95
Park, Recreational, or Preserve	16%	211
Retail and Other Commercial	4%	51
Single Family Attached	4%	47
Single Family Detached	20%	261
Undeveloped	19%	243
Total	100%	1281

[1] Source Metropolitan Council 2010.

Table 3-2. 2020 Land Use for the Lake Susan Watershed.

Land use [1]	Percent	Area (Acres)
Low Density Residential	21%	273
Medium Density Residential	8%	100.2
High Density Residential	6%	77.5
Industrial	24%	311.1
Institutional	8%	100.5
Commercial	4%	50.3
Mixed Use	0%	4.1
Railway	1%	11.8
Water	7%	86.2
Parks	18%	229.6
Right-of-Way	3%	36.6
Total	100%	1281

[1] Source Metropolitan Council 2020.

Categories used in the land used classification do not allow for a direct comparison between 2010 and 2020. However, a general evaluation of the categories and types of land uses demonstrate the remaining agricultural and undeveloped areas are planned to be converted to residential and commercial land uses. The change in land uses will further increase runoff volumes and TP loads going to Lake Susan.

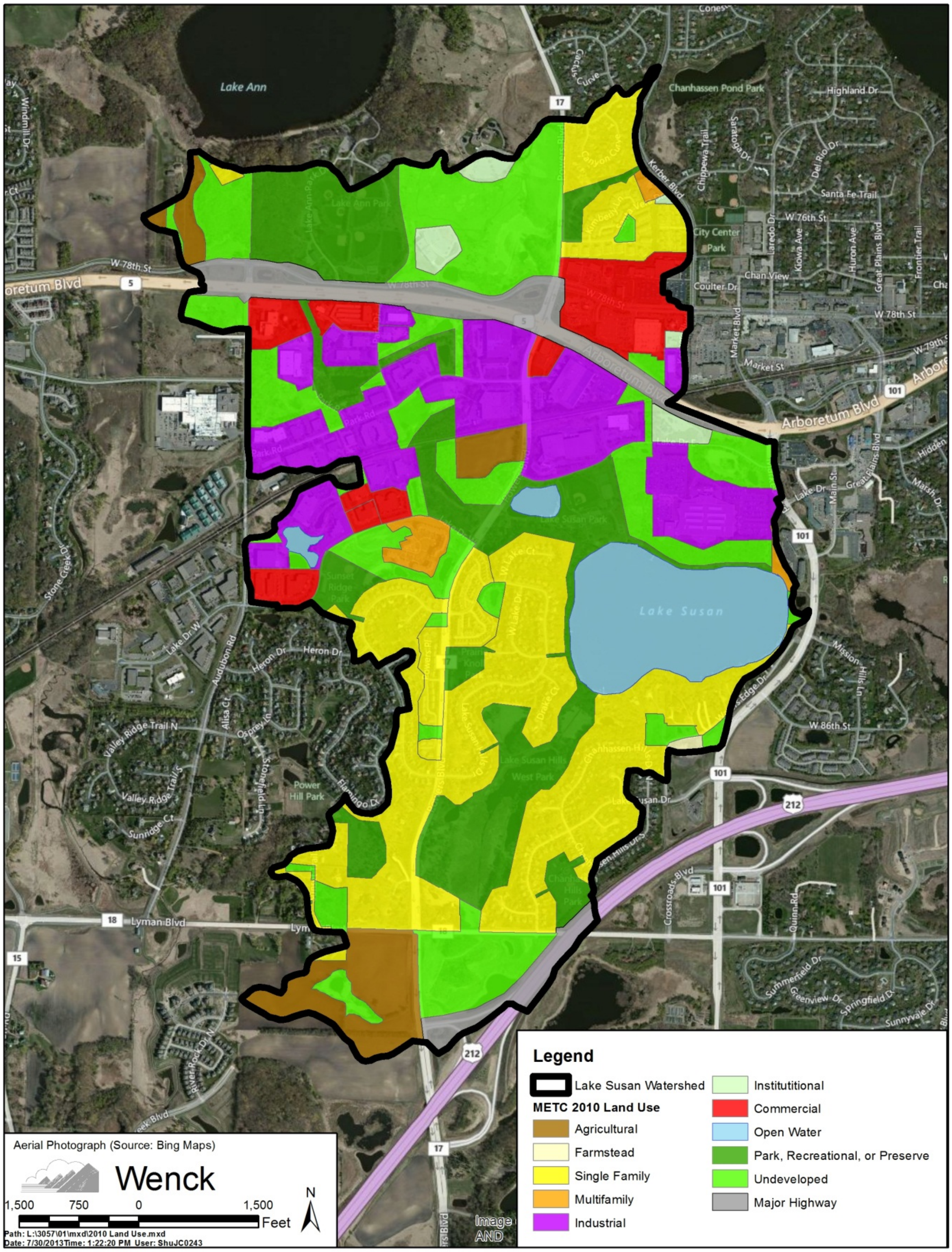

Figure 3-3. Lake Susan Watershed 2010 Land Use (Source: Metropolitan Council 2010).

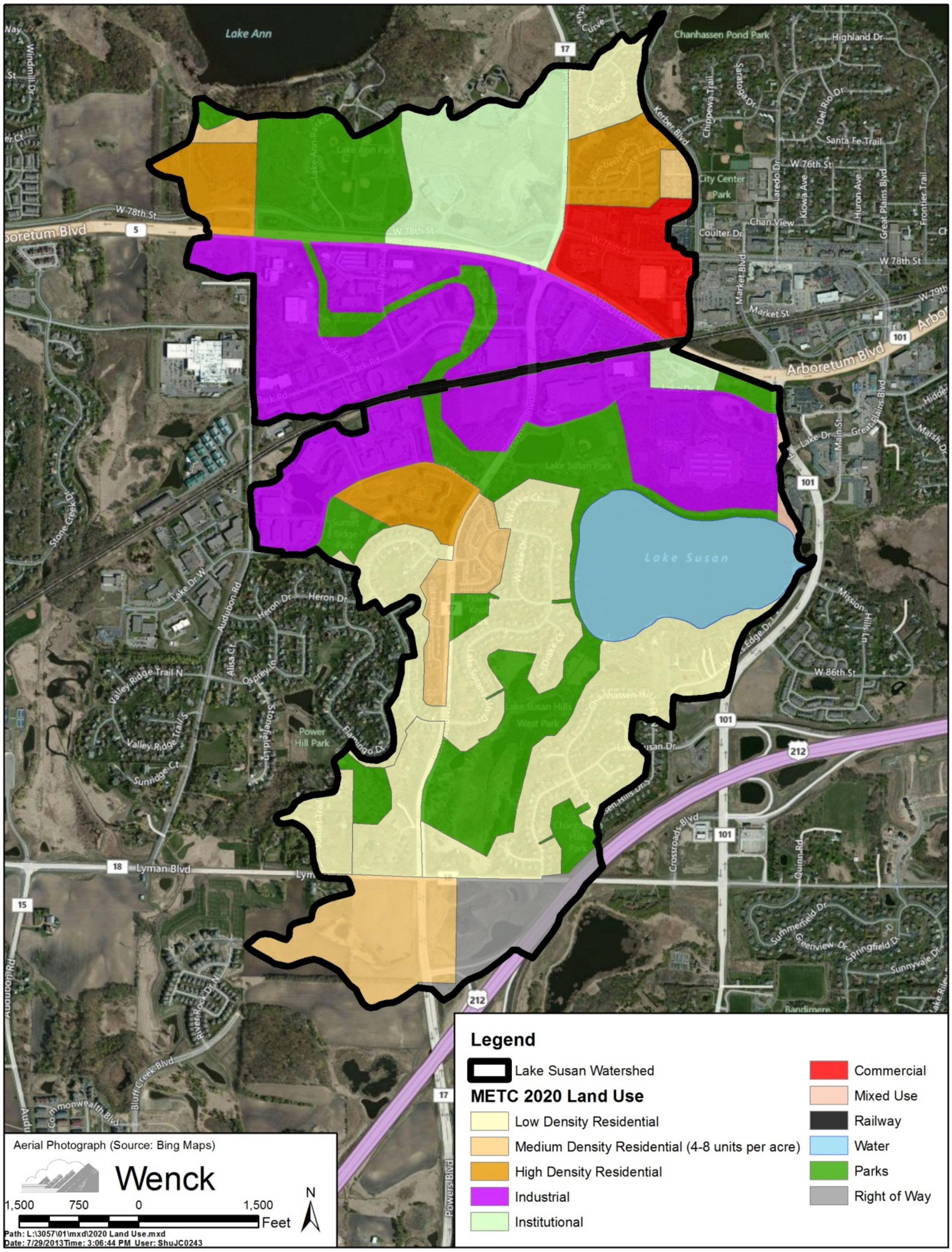

Figure 3-4. Lake Susan Watershed 2020 Land Use (Source: Metropolitan Council 2020).

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3.4 SOILS AND GEOLOGY

Topography in the Lake Susan watershed is dominated by rolling hills with depressions filled with ponds and wetlands. These features are composed of glacial till and outwash from the advance and retreat of glacial lobes during the most recent ice age.

The Lester-Kilkenny series (Figure 3-5) are the most common soil types in the lake watersheds. The series is characterized by a thin layer of loam above a thick layer of clay loam. The thick layer of clay loam limits the ability to implement infiltration practices in the watershed.

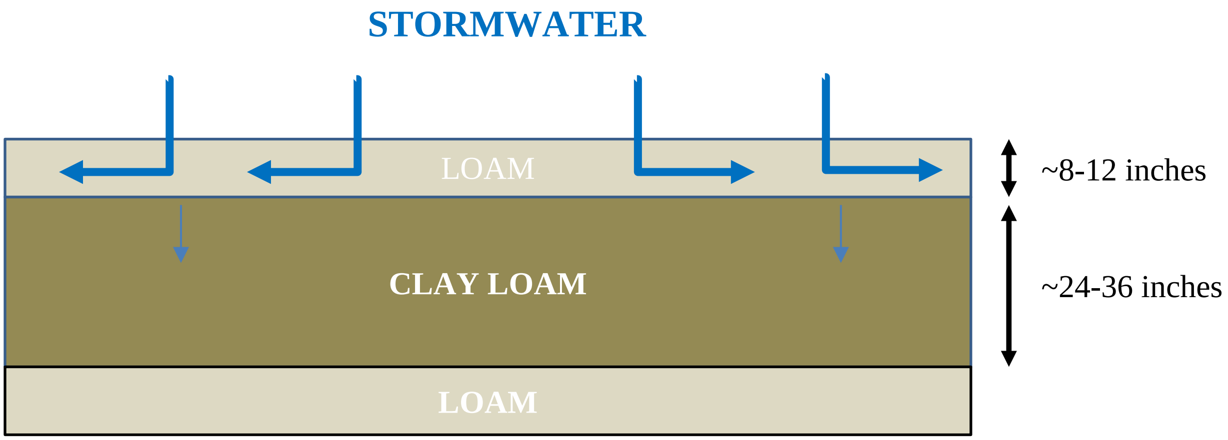

Figure 3-5. Typical Lester-Kilkenny Soil Profile in Lake Susan Watershed.

3.5 CLIMATOLOGICAL SUMMARY

Annual precipitation in the Twin Cities metro area has averaged about 30.3 inches from 1990 to 2012 (Figure 3-6). Average annual snowfall is approximately 50 inches, with the most severe melt runoff conditions usually occurring in March and early April. Lakes in the Minneapolis-St. Paul metropolitan area average approximately 132 days of ice cover per year, with average freeze and thaw dates occurring the last week of November and the first week of April, respectively. The average date of the last below-freezing temperature in the spring is April 27, and the average date of the first below-freezing temperature in the fall is October 2, yielding an average growing season of 157 days.

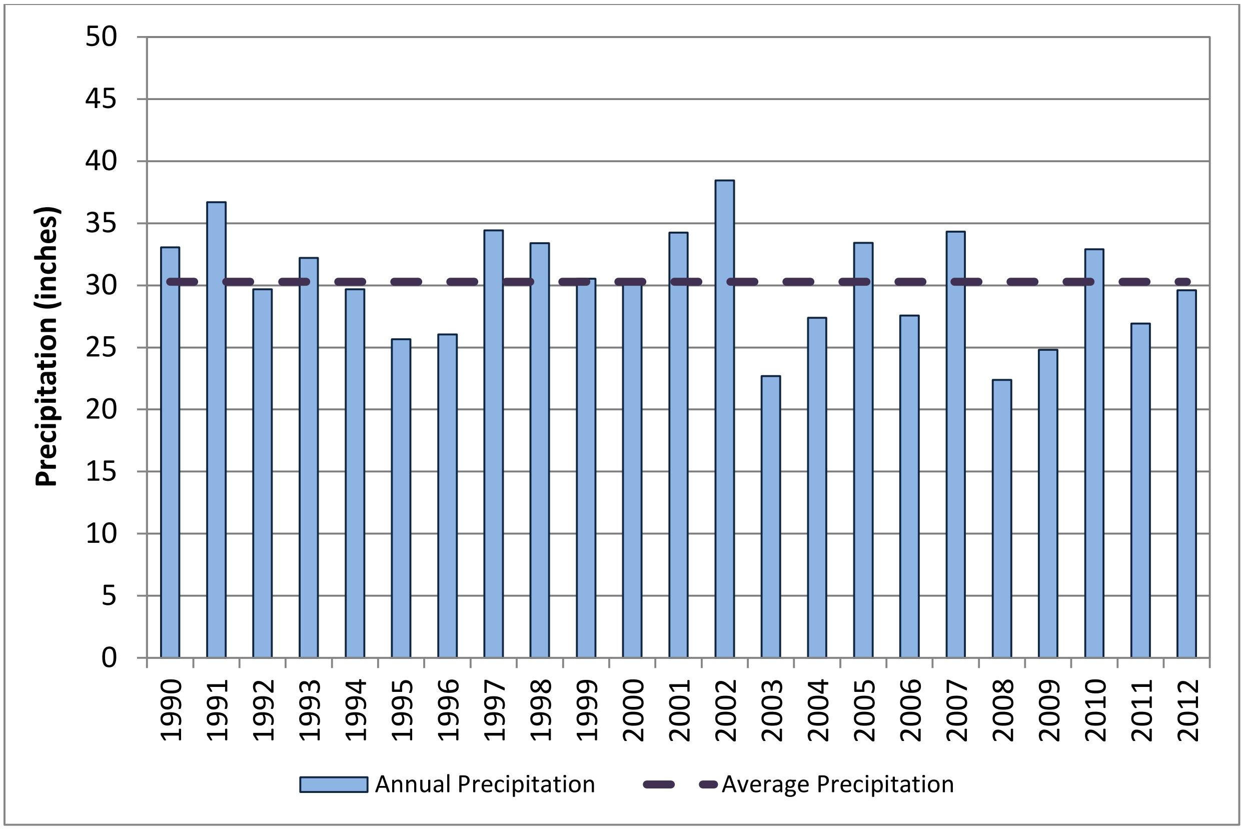

Figure 3-6. Annual and Average Precipitation Recorded at the Minneapolis/St. Paul International Airport.

It should be noted that although the data for the Minneapolis-St. Paul International Airport demonstrates a fairly consistent total average precipitation in a year, the intensity of the larger precipitation events has been changing over the last 20 years.

National Weather Service Hydrometeorological Design Studies Center recently released NOAA Atlas 14, Volume 8 (Atlas 14) which provides new precipitation frequency data for the Upper Midwest (NOAA Atlas 14, Volume 8, 2013). Atlas 14 was adopted and replaced the old Technical Paper-40 (TP-40) data. Atlas 14 is based on a longer period of record, an increased number and wider spatial distribution of rain gauges, and enhanced statistical techniques that greatly increases its accuracy. The report highlights that less frequent storm events have greater rainfall depths than what was previously estimated, resulting in greater strain on existing infrastructure that was designed to handle a lower rainfall depth.

3.6 LAKE MORPHOMETRY

The MPCA defines shallow lakes as enclosed basins with maximum depths less than 15 feet or systems where 80% or more of the surface area may support emerged or submerged aquatic vegetation (littoral zone). Lake Susan meets one of the two criteria for shallow lakes with a maximum depth of 17 ft. (slightly deeper than the shallow lake criteria) and a littoral area of 94% (Table 3-2 and Figure 3-7).

Lake Susan is characterized by very short residence times caused by a large direct watershed along with the upstream watersheds of lakes Ann and Lucy, for a total watershed area of 2,553 acres.

Table 3-2. Lake Susan Physical Parameters and Morphometry.

Parameter	Lake Susan
Area (acres)	88
Average Depth (feet)	10.3
Maximum Depth (feet)	17
Volume (acre-feet)	885
Residence Time (years)	0.96
Littoral Area (acres)	214
Littoral Area (percent)	94%
Total Watershed Area (acres)	2,553
Direct Drainage Area (acres) (Area below Ann & Lucy)	1,281
Watershed:Lake Area (ratio)	29:1
Lake Outflow (acre-ft/year)	926

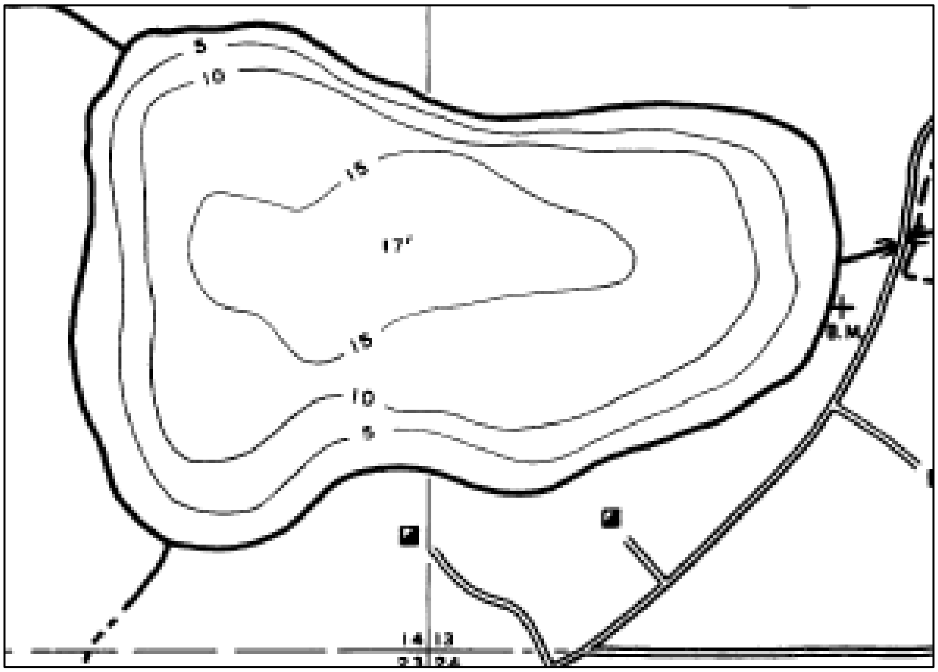

Figure 3-7. Lake Susan (Source: Minnesota DNR).

3.7 WATERSHED HYDROLOGY

The Lake Susan drainage area spans approximately 1,281 acres and is divided into five subwatersheds for this study (Figure 3-8). General flow pattern in the north subwatershed is northeast to southwest, routing stormwater from commercial and residential areas through storm sewer and wetland areas to Riley Creek. The primarily residential and commercial land uses in the west portion of the drainage area route stormwater from west to east through storm sewer and stormwater ponds to Riley Creek. The northeast subwatershed consists primarily of commercial land use that routes water west to the stormwater pond located in Lake Susan Park, which outlets to Riley Creek upstream of Lake Susan. The south watershed collects runoff from residential and agricultural lands and routes water primarily northeast to the large wetland in Lake Susan Hills Park. The area of the Lake Susan direct watershed is approximately 65 acres.

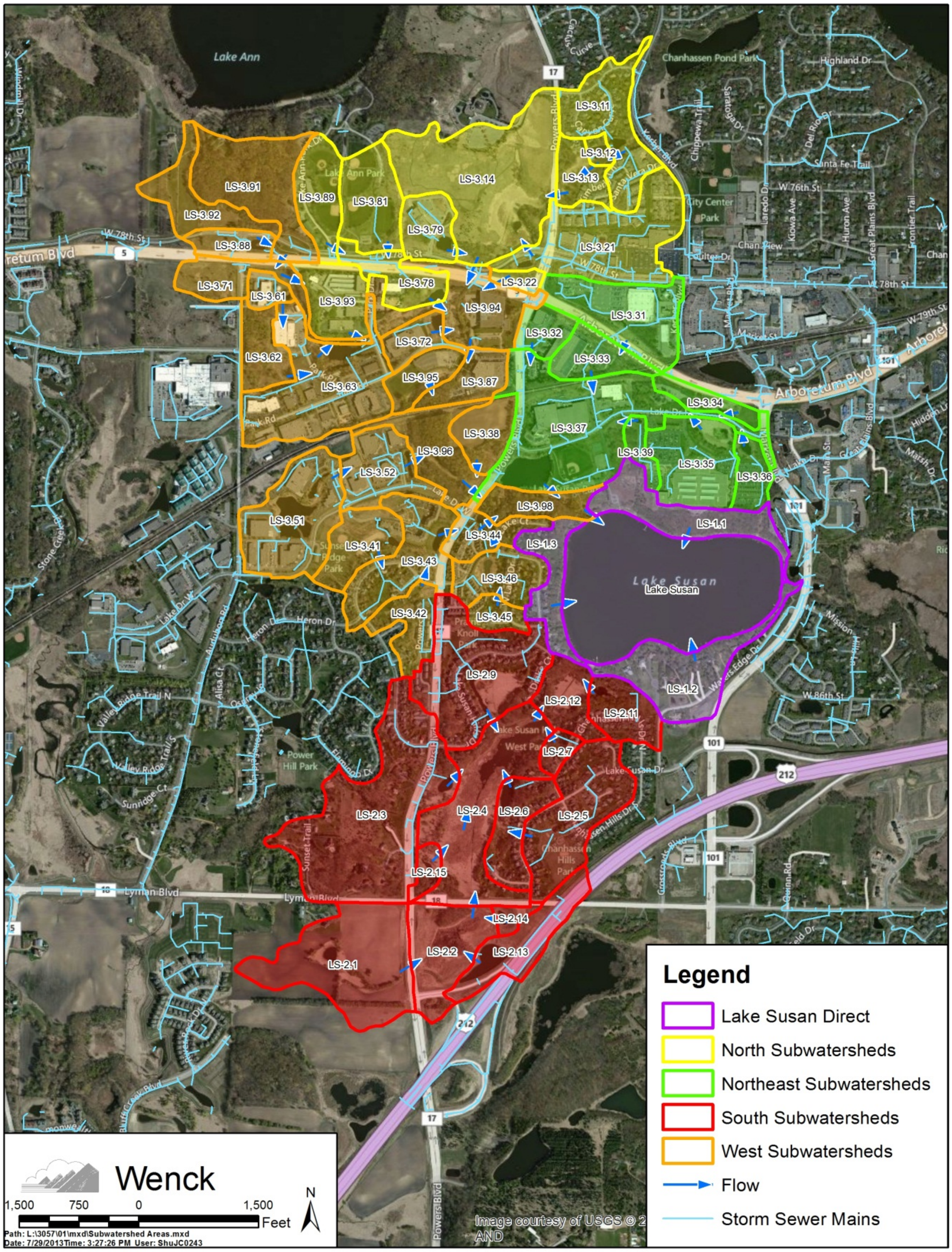

Figure 3-8. Lake Susan Watershed Flow Pattern.

Total water yield to Lake Susan from each of the major watersheds was estimated using a P8 model. A full description and overview of the model is provided in Section 4.1.1. The south subwatershed is the largest, but due to its limited impervious coverage it has the lowest runoff depth. The northeast subwatershed, which is dominated by commercial land use, has the highest runoff yield, whereas the north subwatershed has the second-highest yield along with the greatest runoff contribution to the Lake (Table 3-3 and Figure 3-9).

Table 3-3. Lake Susan Watershed Areas and Average Annual Water Yields.

Watershed	Contributing Area (acres)	Water Yield (acre-ft)	Runoff (inches)
North	317	203	7.7
Northeast	160	119	8.9
West	299	181	7.3
South	350	84	2.9
Direct	66	32	5.8
Total	1192	619	6.2

[1] 2004-2005 & 2008-2012 average annual subwatershed water yield modeled using P8

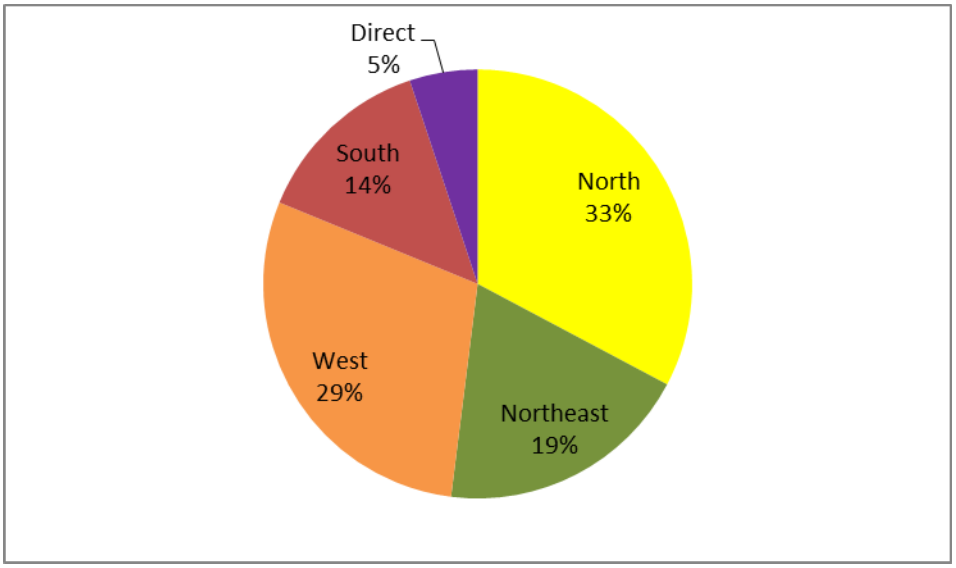

Figure 3-9. Lake Susan Average (2004-2005 & 2008-2012) Water Yield by Watershed.

3.8 WATER QUALITY

Lake water quality is typically measured by assessing the amount of algal growth and water clarity during the summer growing season. Excessive algal growth reduces water clarity and emits noxious odors. These are symptoms of lake eutrophication. When lakes become hypereutrophic, the entire food web is affected by changes in the algal community and water quality, including dissolved oxygen depletion and decreased water clarity. A healthy lake has a balanced growth of algae supporting the base of the food chain without degrading water quality or harming biological organisms. Algal growth (measured as total chlorophyll-*a*) is typically limited by the amount of phosphorus in the water column. Therefore, total phosphorus is considered a good companion measure of water quality along with algal growth and water clarity. Water clarity is affected by the amount of algae and suspended and dissolved particles in the water column.

3.8.1 Total Phosphorus

Lake Susan average summer TP is higher than the shallow lake standard of 60 µg/L in all seven seasons sampled (Figure 3-10). To be considered impaired, lake water quality must exceed the total phosphorus standard for the summer average over the past 10 years, plus exceed one of the response variables. In the seven recorded sampling seasons, there were 32 individual samples higher than the standard (56% of total).

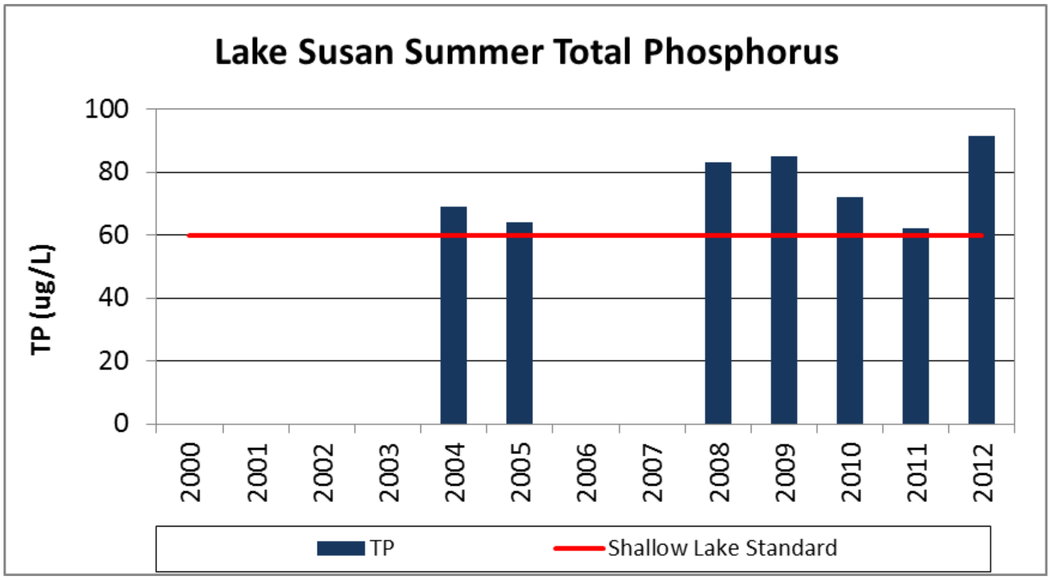

Figure 3-10. Summer (June 1 – September 30) Average Total Phosphorus in Lake Susan.
[1] 2008-2012 data sources are from the University of Minnesota and MPCA Environmental Data Access website
[2] 2004-2005 data was obtained solely from the MPCA Environmental Data Access website

3.8.2 Chlorophyll-*a*

Summer average chlorophyll-*a* was higher than the shallow lake standard of 20 µg/L six of the seven years since 2004 (Figure 3-11). Thirty-four summer chlorophyll-*a* values (June through September) were higher than the state standard (49% of total) since 2004. A majority of exceedances were recorded during the height of the growing season in July and August, when algae blooms are most prevalent.

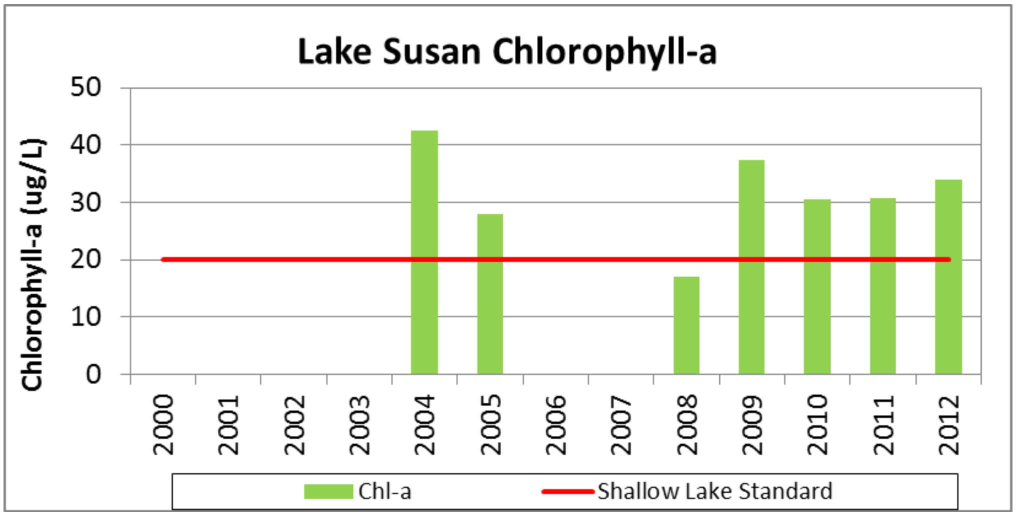

Figure 3-11. Summer (June 1 – September 30) Average Chlorophyll-a in Lake Susan.
[1]2008-2012 data sources are from the University of Minnesota and MPCA Environmental Data Access website
[2]2004-2005 data was obtained solely from the MPCA Environmental Data Access website

3.8.3 Transparency

Average summer Secchi depth is lower than the shallow lake standard in five of the seven sampling seasons since 2004 (Figure 3-12). There were 40 values lower than the state standard (58% of measurements from June to September) since 2004, and most were recorded in July and August during the peak of the growing season. Overall, summer Secchi depth from 2004-2012 has an average of 1.1 meters, suggesting water clarity summer averages are near the shallow lake standard.

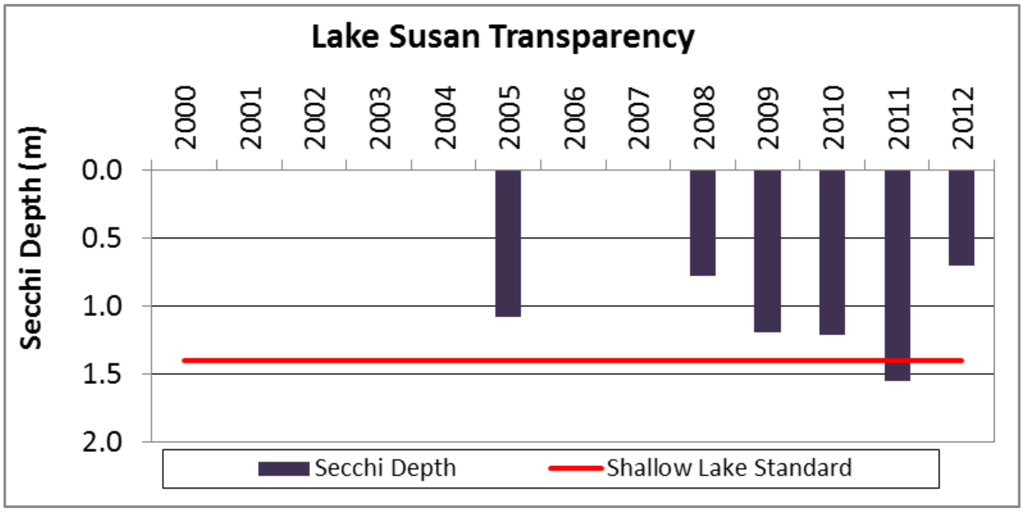

Figure 3-12. Summer (June 1 – September 30) Average Secchi Depth in Lake Susan.
[1]2008-2012 data sources are from the University of Minnesota and MPCA Environmental Data Access website
[2]2004-2005 data was obtained solely from the MPCA Environmental Data Access website

3.9 SHALLOW LAKE ECOLOGY

Shallow lakes are ecologically different from deep lakes. In shallow lakes, there is a greater proportion of sediment area to lake volume, allowing potentially larger sediment contributions to nutrient loads and higher potential sediment resuspension that can decrease water clarity. Biological organisms also play a greater role in maintaining water quality. Rough fish, especially carp, can uproot submerged aquatic vegetation and stir up sediment. Submerged aquatic vegetation stabilizes the sediment, reducing the amount that can be resuspended and cloud water clarity. Submerged aquatic vegetation also provides refuge for zooplankton, a group of small crustaceans that consumes algae.

All of these interactions reflect a lake being in two alternative stable states: a clear water state and a turbid water state. The clear water state is characterized by a robust and diverse submerged aquatic vegetation community, balanced fish community, and large daphnia (zooplankton that are very effective at consuming algae). Alternatively, the turbid water state typically lacks submerged aquatic vegetation, is dominated by rough fish, and is characterized by both sediment resuspension and algal productivity. The state in which the lake persists depends on the biological community as well as the nutrient conditions in the lake. Therefore, lake management must focus on the biological community as well as the water quality of the lake.

The following five-step process for restoring shallow lakes was developed in Europe and is also applicable here in the United States:

- Forward “switch” detection and removal
- External and internal nutrient control
- Biomanipulation (reverse “switch”)
- Plant establishment
- Stabilization and management of the restored system

The first step refers to identifying and eliminating those factors, also known as “switches,” that are driving the lake into a turbid water state. These can include high nutrient loads, invasive species such as carp and curly-leaf pondweed, altered hydrology, and direct physical impacts such as plant removal. Once the switches have been eliminated, an acceptable nutrient load must be established. After the first two steps, the lake is likely to remain in the turbid water state even though conditions have improved, and it must be forced back into the clear lake state by manipulating its biology (also known as biomanipulation). Biomanipulation typically includes whole lake drawdown and fish removal. Once the submerged aquatic vegetation has been established, management will focus on stabilizing the lake in the clear lake state (steps 4 and 5).

3.10 FISHERIES

The U of M is actively managing the rough fish population in lake to improve water clarity and facilitate reestablishment of native macrophyte populations (Sorenson 2013-Appendix A). The U of M is continuing to monitor fish species biomass abundance in the lake to ensure management of carp while also trying to establish a similar specie biomass distribution as seen in Metro lakes similar to Lake Susan.

3.11 AQUATIC VEGETATION

For the past 15 years, aquatic vegetation has been a major issue in Lake Susan. Curly-leaf pondweed and Eurasian watermilfoil are invasive species that present the greatest threat to the lake. In addition to managing carp, the U of M is continuing to establish native species in the lake by transplanting species from lakes Lucy and Ann (Knopik 2012, - Appendix B). As of this report, bushy pondweed, northern watermilfoil, and water star grass have been the most successful in the lake. The U of M intends to continue to evaluate the success of transplanting going forward. Aquatic plant monitoring and management will continue to be an ongoing activity on the lake.

4.0 Phosphorus Source Assessment and Lake Response

4.1 MODELING APPROACH

The following is a general description of the modeling approach and results used to assess water and nutrient loads to Lake Susan as well as the lake response to those loads.

4.1.1 Watershed P8 Model

Watershed nutrient loading was estimated using a P8 model developed for the Lake Susan watershed. P8 is a water quality model based on routing of flow, TP and TSS through networks of water quality treatment devises. TP removal is predicted using an empirical TP retention function. RPBCWD originally developed a P8 model as a part of the original UAA study. The model was updated with most current land use and watershed data and used to predict water yields and TP loading to each lake. The model operates on an hourly time-step and was used to predict watershed yields/loads annually for a seven-year period (2004-05 & 2008-2012).

The watershed model was validated using data from stormwater pond and wetland water quality monitoring data where available. Model runoff coefficients were systematically reduced to provide the best fit possible for runoff volumes. Average modeled runoff volumes over the modeled period agreed with 95% of monitored values and were determined to be reasonable.

4.1.2 Lake Response Model

A BATHTUB lake response model was developed for Lake Susan to assess the impacts of various improvement projects on in-lake water quality. The purpose of the model was to develop a phosphorus budget for the lake, identify the major factors influencing current and future water quality, and provide an understanding of the level and magnitude of project implementation required to meet identified water quality goals. A publicly available model, BATHTUB was developed by William W. Walker for the U.S. Army Corps of Engineers (Walker 1999). BATHTUB has been used successfully in many lake studies in Minnesota and throughout the United States. It is a steady-state annual or seasonal model that predicts a lake’s summer (June – September) mean surface water quality. Its time-scales are appropriate because watershed P loads are determined on an annual or seasonal basis, and the summer season is critical for lake use and ecological health. BATHTUB has built-in statistical calculations that account for data variability and provide a means for estimating confidence in model predictions. It accounts for water and P inputs from tributaries, watershed runoff, the atmosphere, sources internal to the lake, and (if appropriate) groundwater; and accounts for outputs through the lake outlet, groundwater (if appropriate), water loss via evaporation, and P sedimentation and retention in the lake sediments. Through BATHTUB, several different mass-balance P models can be evaluated.

For most lakes in Minnesota, the Canfield-Bachmann lake formulation (Canfield and Bachmann 1981) is typically the appropriate model. BATHTUB's in-lake water quality predictions include two response variables, chlorophyll-*a* concentration and Secchi depth, in addition to TP concentration. Empirical relationships between in-lake TP, chlorophyll-*a*, and Secchi depth form the basis for predicting the two response variables.

4.2 NUTRIENT SOURCE LOADS

The following is a description of the major phosphorus sources to Lake Susan, including a summary of the sources.

4.2.1 Atmospheric Phosphorus Load

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

The atmospheric load (pounds/year) for Lake Susan was calculated by multiplying the lake area (acres) by the atmospheric deposition rate (pounds/acre-year). For example, in an average precipitation year, the atmospheric load to Lake Susan would be 0.239 pounds/acre-year times the lake surface area (88 acres), which is 21.1 pounds/year. The watershed is small enough that it is unlikely that there are significant geographic differences in rainfall intensity and amounts across the watershed.

4.2.2 Watershed Phosphorus Load

Watershed loading to Lake Susan was estimated using the P8 model discussed in Section 4.1.1. A summary table of the P8 output is provided in Appendix C. The following is a description of the model results for each watershed.

4.2.2.1 Lake Susan Watershed

The Lake Susan watershed loading analysis was broken into five subwatersheds (North, Northeast, South, West, and Direct) (Table 4-1). The largest phosphorus load comes from the north subwatershed where there are several developed subwatersheds with no treatment of stormwater prior to discharging into Riley Creek. The south and west subwatersheds are the next highest loading watersheds. The south subwatershed is partially developed, but through monitoring has shown high concentrations of phosphorus in the wetland prior to discharging into Lake Susan, indicating there is a potential it is a source of phosphorus.

Table 4-1. Modeled Stormwater TP Concentration and Load for the Lake Susan Watershed.

Year	North Subwatershed		Northeast Subwatershed		South Subwatershed		West Subwatershed		Direct Subwatershed	
	Outflow TP		Outflow TP		Outflow TP		Outflow TP		Outflow TP	
	(µg/L)	(lbs./yr)	(µg/L)	(lbs./yr)	(µg/L)	(lbs./yr)	(µg/L)	(lbs./yr)	(µg/L)	(lbs./yr)
2004	213	168	141	73	425	165	179	134	245	29
2005	240	154	145	59	528	140	189	114	299	29
2008	265	100	143	28	625	47	198	59	358	21
2009	269	100	150	31	585	59	207	63	354	20
2010	240	149	142	49	485	141	188	101	305	31
2011	215	145	142	55	407	152	172	108	259	29
2012	229	136	136	47	454	115	177	94	287	27
Avg.	**200**	**136**	**142**	**49**	**469**	**117**	**184**	**96**	**291**	**26**

4.2.3 Internal Phosphorus Load

Internal TP loading from lake sediments is an important aspect of phosphorus budgets. Lake sediments release phosphorus when dissolved oxygen levels drop below 2 mg/L. Lake sediments also release phosphorus under oxygenated (oxic) conditions but typically at a much lower rate. However, because shallow lakes have a large sediment-water interaction, oxic release of phosphorus can also be important.

To estimate internal loading in Lake Susan, an anoxic factor (Nürnberg 2004), which summarizes the period where anoxic conditions exist over the sediments, is estimated from the dissolved oxygen profile data. The anoxic factor is expressed in days but is normalized over the area of the lake. The anoxic factor is then used along with a sediment release rate to estimate the TP load from the sediments. Phosphorus release rates were estimated by collecting cores from Lake Susan and incubating them in the lab under oxic and anoxic conditions (ACOE-ERD 2011; Appendix B).

The measured rate of TP release from anoxic sediments in Lake Susan was 9.8 mg/m^2/day (Figure 4-1), which is typical of release rates in eutrophic lakes (productive) The release rates were combined with calculated anoxic factors to estimate the total annual phosphorus mass contributed by sediments (Table 4-2; Nürnburg 2004).

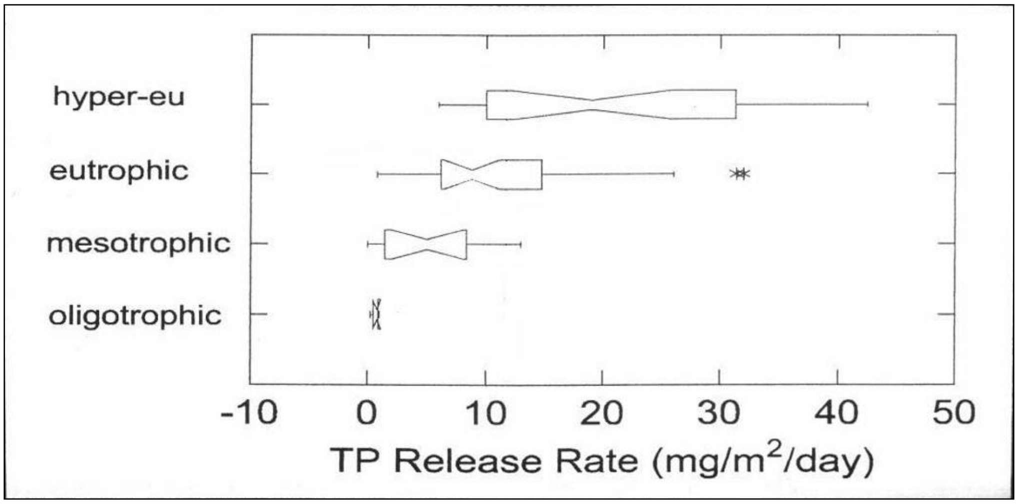

Figure 4-1. Sediment TP Release Rates by Eutrophic Condition. (Nürnberg 1997).

Lake Susan's anoxic factors ranged from 21.2 to 53.1 days (Table 4-2). These constantly long anoxic periods combined with relatively high sediment phosphorus release rates result in substantial internal loading. Calculations show that sediment internal loading can be up to 410 lbs/year, which is similar in magnitude to total watershed loading (Table 4-2).

Table 4-2. Estimated Internal TP Loading Summary for Lake Susan Lake.

Year	Release Rate ($mg/m^2/day$)	Anoxic Factor (days)	Gross Load ($mg/m^2/summer$)	Total Load (kg)	Total Load (pounds)
2004	9.8	21.2	208	74	164
2005	9.8	36.4	357	127	281
2008	9.8	24.5	240	86	189
2009	9.8	46.8	459	163	361
2010	9.8	53.1	520	186	410
2011	9.8	36.4	357	127	281
2012	9.8	36.4	357	127	281
Estimated Modeled Maximum[1]	9.8	36.4	357	127	281

[1] This represents the highest potential internal load based on the maximum measured anoxia. The value is based on a shallow lake equation developed to estimate anoxic factors in polymictic lakes (Nurnberg 2005-6).

4.3 SOURCE SUMMARY AND CURRENT PHOSPHORUS BUDGET

Once all of the TP sources have been estimated, the loads from each source are included in a lake response model to evaluate the link between TP loading and lake water quality. The following is a summary of the BATHUB lake response model and the nutrient budgets developed for Lake Susan.

4.3.1 BATHTUB Model Fit

To develop the average TP budget for Lake Susan, a model period of 2004 through 2012 (excluding 2006 and 2007 due to limited data) was selected based on data availability. This recent period had the most complete data set including lake water quality data, hydrologic monitoring in the watershed, and pond water quality data. The average of this seven-year period was used as the baseline for the TP budget development. The Canfield-Bachmann natural lakes model was used for this lake. Appendix C contains a complete summary of the inputs, outputs, and assumptions used in the BATHTUB model for Lake Susan.

The Lake Susan model performed reasonably well with the exception of 2008 and 2012 (Figure 4-2). A possible explanation for low modeled TP concentrations could be due to a relatively low TP load.

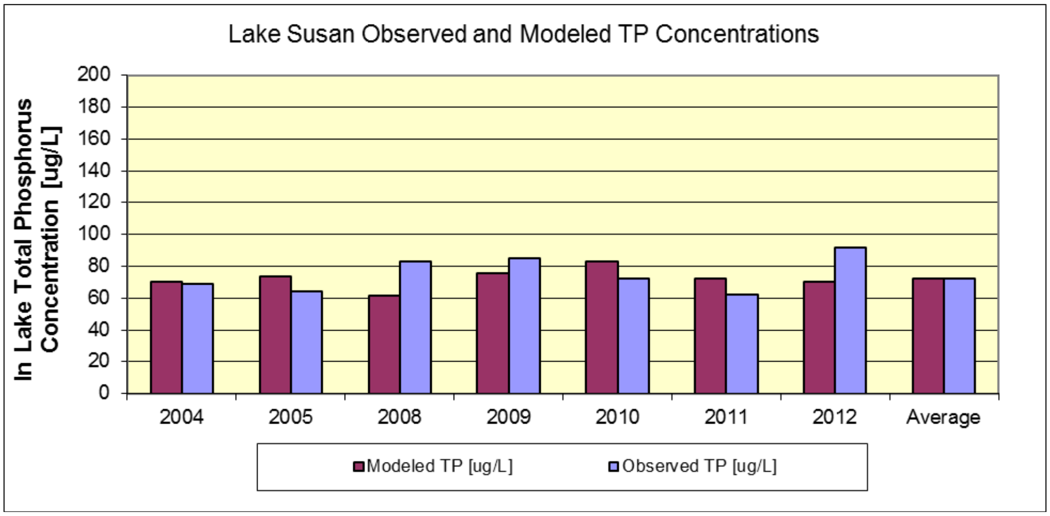

Figure 4-2. Modeled and Observed Summer TP in Lake Susan

4.3.2 Lake Phosphorus Budgets

An average TP budget was developed for Lake Susan (Figure 4-3). Lake Susan water quality is impacted by both stormwater TP loading (57%) and internal loading (38%) of the TP budget for Lake Susan. Developing BMPs which target these two sources will be key to long-term management of TP to Lake Susan.

The upstream watershed (Lake Ann and Lucy) only contribute 2% of the load to the lake indicating preservation of these lakes will also be a key factor in the long-term success of Lake Susan.

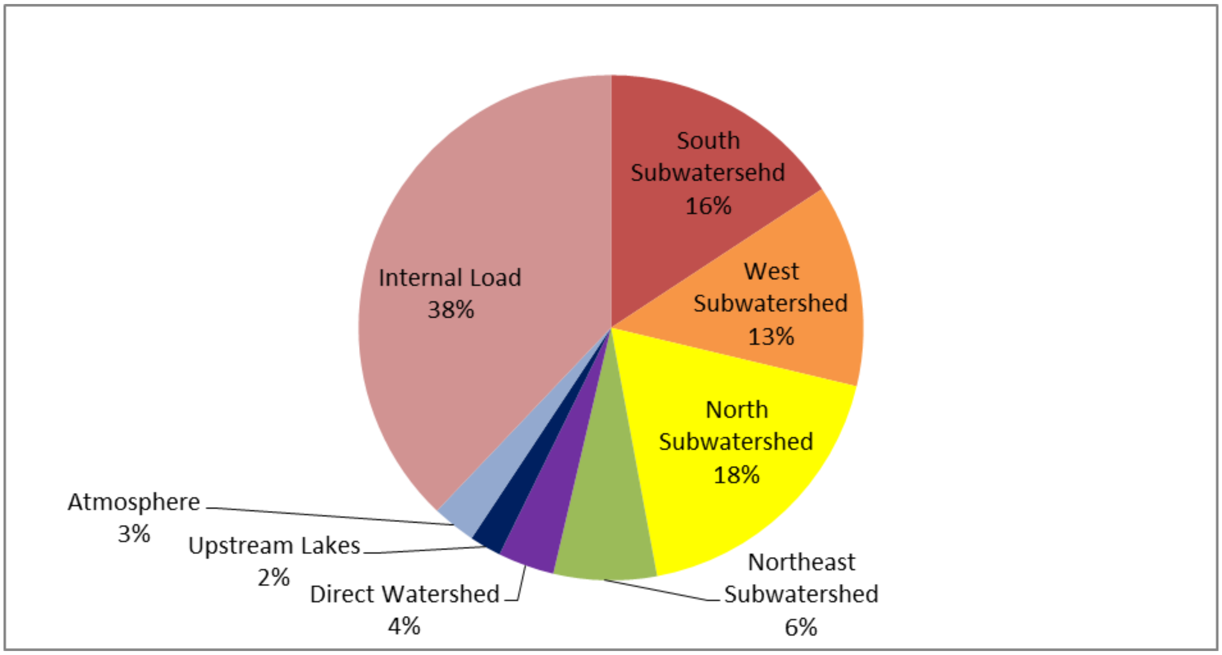

Figure 4-3. Average TP Loading by Source for Lake Susan.

4.4 PHOSPHORUS LOAD ALLOCATIONS

The numerical load reduction calculated for Lake Susan was derived to solve for a numeric target of 60 μg/L of TP as a summer average.

4.4.1 Total Loading Capacity

The first step in developing a nutrient budget for lakes is to estimate the total nutrient loading capacity. For this estimate, the current nutrient budgets and the lake response modeling (average of 2004-2005 and 2008-2012) presented in Section 4.3 were used as the starting point. The nutrient inputs were systematically reduced until the model predicted at what amounts Lake Susan met the current TP standard of 60 μg/L. The model-predicted nutrient loads for this model scenario represent the total loading capacity for each lake. Total loading capacity for Lake Susan is 557 pounds per year. Further details of how this was applied are included in the following sections.

4.4.2 Load Allocations

The Load Allocation includes watershed runoff, upstream lakes contribution, atmospheric deposition, and internal loading. No changes are prescribed for atmospheric deposition because this source is impossible to control. Internal loading in Lake Susan is about 38% of the phosphorus budget and presents a significant opportunity for load reduction. The remainder of the reduction was targeted in the watershed as there are multiple opportunities to implement water quality projects in the upstream watershed. Upstream lakes were held at current conditions assuming they will be protected under stormwater nondegradation rules.

4.4.3 Load Reduction

Table 4-3 presents the results of the load reduction calculation for Lake Susan. Lake Susan requires a 25% reduction in TP loading to meet the shallow lake goal. A 25% reduction equates to an annual TP load reduction of 185 pounds. To achieve this reduction, the internal load needs to be lowered 127 pounds, with the remaining 58 pounds coming from watershed reductions.

Table 4-3. Load Allocation Summary for Lake Susan.

Source	Existing TP Load [1]	Target TP Loading	Recommended Load Reduction	
	(lbs/year)	(lbs/year)	(lbs/year)	%
Watershed	424	366	58	14%
Upstream Lakes	16	16	0	0%
Atmosphere	21	21	0	0%
Internal Load	281	154	127	45%
TOTAL	**742**	**557**	**185**	**25%**

[1] Existing load is the average for the years 2004-2005 and 2008-2012.

5.0 Implementation Plan

5.1 MANAGEMENT ACTIVITY SELECTION

The purpose of this plan is to identify water quality goals for the management of Lake Susan and to identify projects necessary to reach those goals. Potential projects to reduce nutrient loading were selected using the P-8 model, BATHTUB Lake model, and sediment cores collected on the lake. General feasibility of the projects was evaluated to determine if appropriate improvements are possible at the selected sites. Projects deemed feasible were carried forward to effectiveness evaluations and planning-level cost estimates.

5.2 ADAPTIVE MANAGEMENT

Implementation will be conducted using adaptive management principles (Figure 5-1). Adaptive management is essentially a phased approach where a strategy is identified and implemented in the first cycle. After implementation of that phase has been completed, progress toward meeting the goals is assessed. A new strategy is then formed to continue making progress toward meeting the goals. These steps are continually repeated until established goals are met. This process allows for future technological advances that may alter the course of actions. Continued monitoring and "course corrections" responding to monitoring results are the most appropriate strategies for attaining the water quality goals of this management plan.

Adaptive management will be applied using the five-year planning cycle used by MS4s. The first five years will be used to implement projects that are ready to go, develop feasibility studies and designs for other projects, and continue monitoring and outreach activities. The second five years will be used to continue implementing projects on the ground as well as monitoring to assess effectiveness of the selected practices.

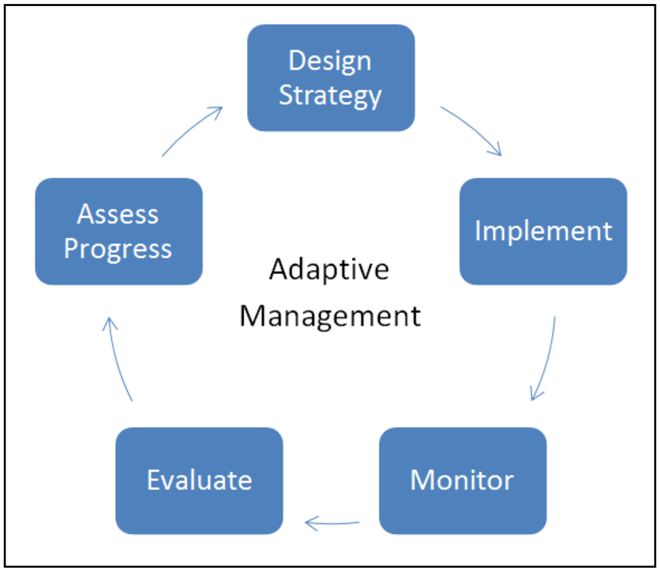

Figure 5-1. Adaptive Management.

5.3 LAKE SUSAN WATERSHED NUTRIENT MANAGEMENT

Prioritization of projects/activities was broken down into three categories:

- **Near-term Projects –** Projects that can leverage existing public properties to facilitate quicker implementation
- **Collaboration Projects –** Projects that require collaboration with multiple partners or are tied to redevelopment/retrofitting a site
- **Management Strategies –** Strategies/Policies to be implemented to assist with maintaining load reductions achieved.

Within each category, several projects were identified to reduce stormwater nutrient loading to Lake Susan. Brief descriptions of projects or activities are provided in this section.

In addition to project descriptions, conceptual cost estimates were developed for all of the near-term projects. Cost estimates assumed a 30-year life expectancy. Cost estimates include design, construction, operation, and maintenance costs associated with effective implementation of the project. This method also was consistent with the approach taken by the SALSA report.

5.3.1 Near-Term Projects

Near-Term projects were identified based on their cost effectiveness and ease of implementation by working with one or two land owners (Table 5-1, Figure 5-2). A conceptual cost estimate and potential effectiveness were completed for each of the near-term projects.

Table 5-1.Near-Term Projects.

Project	Name	Description
1	Alum Treatment - Lake Susan	• Complete Alum treatment on Lake Susan in areas >10ft
2	Lake Susan Park Pond Enhancement	• Increase the pond dead pool storage by 1ft • Install a Minnesota Filter to treat TP
3	Lake Susan Hills West Park – Wetland Restoration	• Install a Minnesota Filter in a modified weir system at the outlet of the wetland to treat TP
4	Lake Drive West Pond Enhancement	• Increase the pond dead pool storage by 1ft • Install a Minnesota Filter to treat TP
5	Target Pond Upgrade	• Expand the footprint of the existing pond to create greater live storage • Increase dead pool storage by 1ft • Install a Minnesota Filter to treat TP

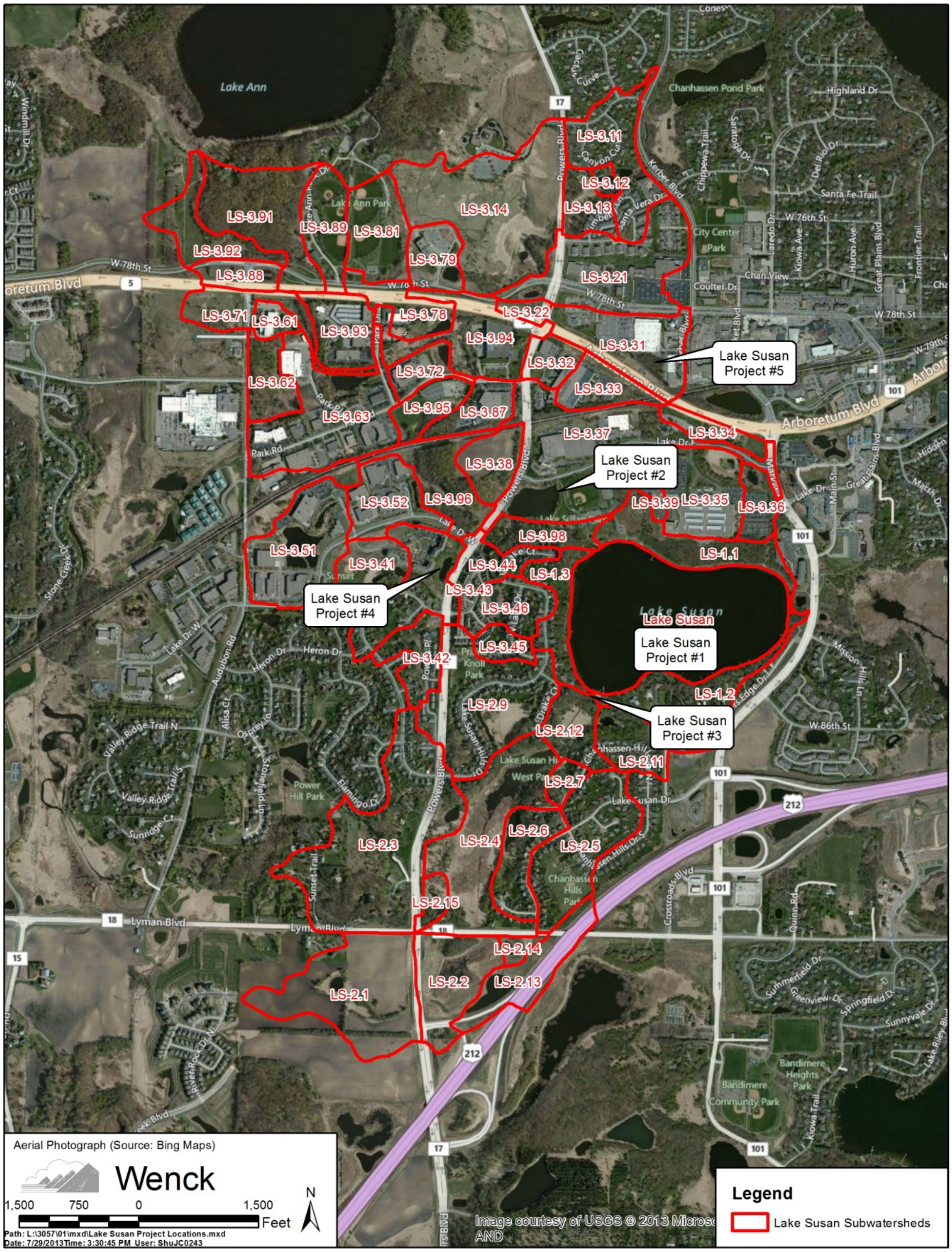

Figure 5-2. Near-Term Projects for Lake Susan.

5.3.2 Project #1 - Alum Treatment – Lake Susan

Internal loading in Lake Susan is 38% of the TP budget. Sediment release rates are relatively high and represent a good opportunity to reduce loading to Lake Susan. Reducing internal phosphorus loading in Lake Susan to similar rates observed in typical metro lakes (1.5 mg/m^2/day) translates to 250 pounds less TP annually.

Sediment phosphorus inactivation is one of the more effective tools to control internal loading in the sediment. Alum is the most common chemical used to permanently bind TP. The aluminum-phosphorus bond is very stable under typical environmental conditions and provides a long-term “depository” for phosphorus in the lake. Coupled with identified near-term watershed improvements, alum treatment could occur now and maintain a long life span, possibly 20 to 30 years (Figure 5-3).

The estimated project life cycle cost for an alum treatment of Lake Susan is $280,071 including the dose calculations, application, and materials (Table 5-2). The estimate efficiency of the project is $37/lb of TP/yr.

Table 5-2. Cost Estimate for Project #1 - Lake Susan Alum Dosing.

Item	Description	Qty	Unit	Unit Price	Item Total
1	Mobilization and Demobilization [1]	1	L.S.	$ 12,500.00	$ 12,500.00
2	Alum Dosing - 100 mg Al/m^2 [1]	52	AC	$ 2,750.00	$ 143,000.00
3	Alum Dosing - 175 mg Al/m^2	15	AC	$ 4,800.00	$ 71,040.00
4	Monitoring of Dosing [1]	1	L.S.	$ 5,000.00	$ 5,000.00
5	Dosing Documentation [1]	1	L.S.	$ 6,000.00	$ 6,000.00
6	Plans/Specs/Bidding Assistance [1]	1	L.S.	$ 6,000.00	$ 6,000.00
				Treatment Total =	$ 243,540.00
				15% Contingency =	$ 36,531.00
				Total Implementation Cost =	$ 280,071.00
				30 yrs Operation and Maintenance ($0/yr) =	$ -
				Project Life Cycle Total Cost =	**$ 280,071.00**
				Project TP Removal (lb TP/Yr) =	**250**
				Project Efficiency ($/lb TP removed) =	**$ 37.34**

[1] Includes follow-up spot treatment in 15 years of 14 acres

Figure 5-3. Project #1 – Alum Treatment Location – Lake Susan.

5.3.3 Project #2 - Lake Susan Park Pond Enhancement

The stormwater pond located in the eastern portion of Lake Susan Park receives stormwater from a mainly industrial and commercial area north and east of the park. It currently provides some TP removal prior to discharging to Riley Creek just upstream of Lake Susan. Improvement of the TP removal could be achieved by increasing the storage of the basin and installing a Minnesota Filter around the perimeter of the basin (Figures 5-4, 5-5, 5-6).

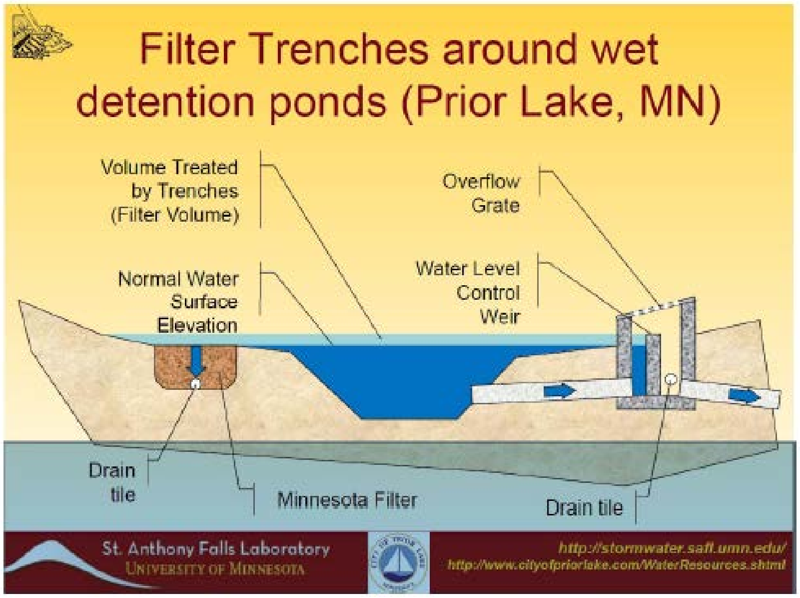

Figure 5-4. Profile overview of Minnesota Filter Installation (Erickson. A and Gulliver J., 2010).

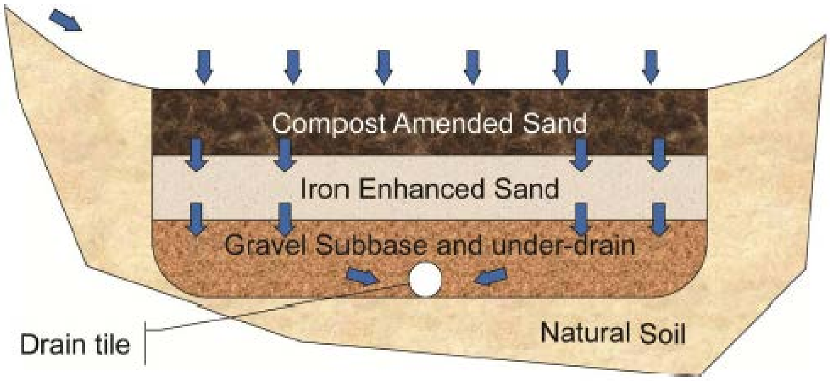

Figure 5-5. Profile view of Minnesota Filter Installation (Erickson. A and Gulliver J., 2010).

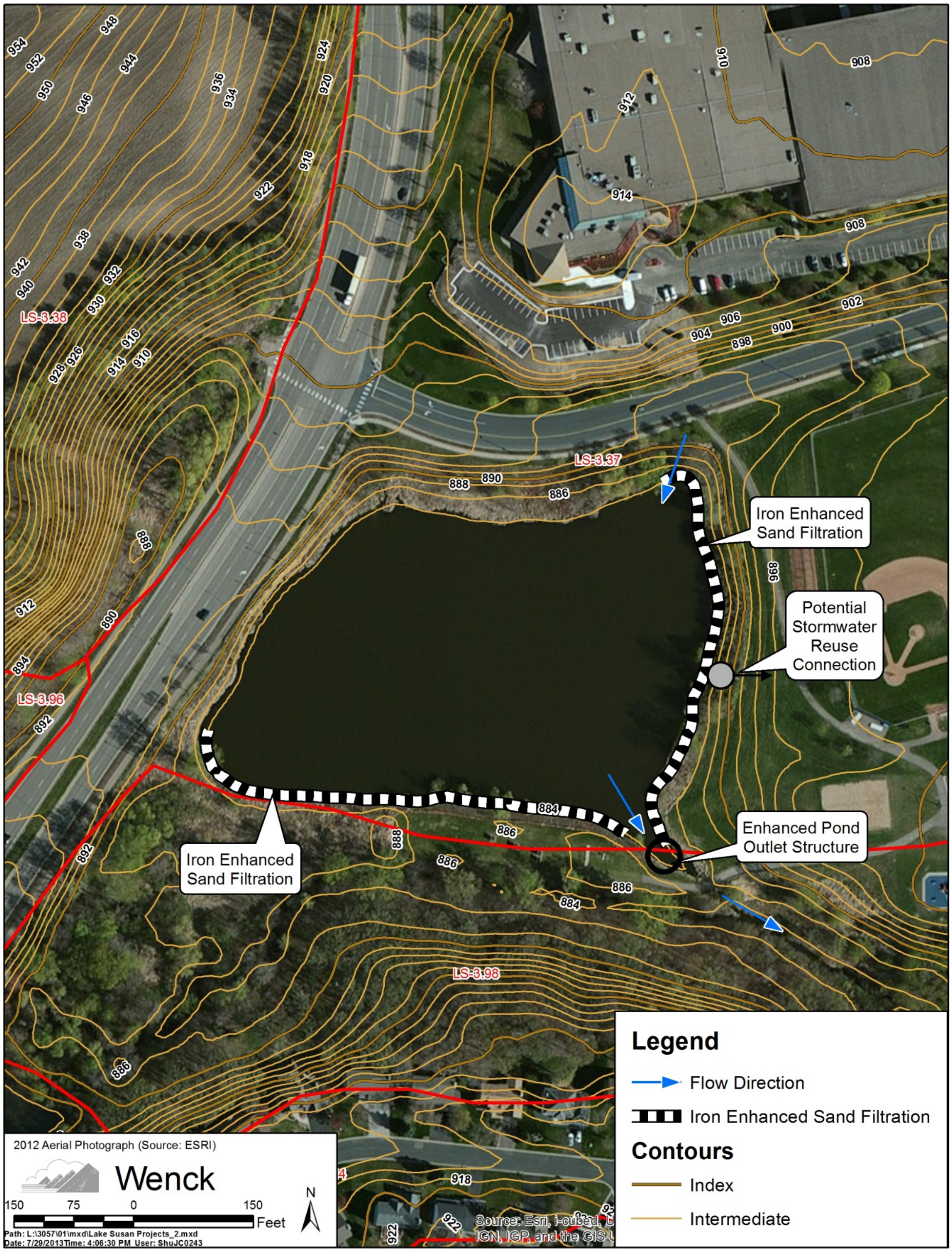

Figure 5-6. Project #2 – Lake Susan Park Pond Enhancement.

Based on an initial review, an additional 6 acre-feet of dead storage could be added to the pond by increasing the outlet elevation by 1.5 feet. The increase in dead storage along with the installation of the Minnesota Filter would result in an additional 31 pounds of TP removal. The project life cycle cost is approximately $89,500, not accounting for any easement or land acquisition costs (Table 5-3). The estimate efficiency of the project is $98/lb of TP/yr.

Table 5-3. Cost Estimate for Project #2 - Lake Susan Park Stormwater Pond Enhancement.

Item	Description	Qty	Unit	Unit Price	Item Total
1	Iron Enhanced Sand Filtration [1, 2]	2,600	S.F.	$ 21.57	$ 56,082.00
2	Outlet Structure	1	L.S.	$ 7,000.00	$ 7,000.00
				Construction Total =	$ 63,082.00
				15% Legal/Design and Administration =	$ 9,462.30
				15% Contingency =	$ 9,462.30
				Total Construction Cost =	$ 82,006.60
				30 yrs Operation and Maintenance ($250/yr) [3] =	$ 7,500.00
				Project Life Cycle Total Cost =	**$ 89,506.60**
				Project TP Removal (lb TP/Yr) =	**30.6**
				Project Efficiency ($/lb TP removed) =	**$ 97.50**

[1] Unit Price from Carver County SWCD Salsa Report - Structural Sand Filter (including peat, compost, iron amendments,

[2] Unit Price from Carver County SWCD Salsa Report - Assumes filter to be 15 feet in width

[3] Carver County SWCD Salsa Report

In addition to the water quality improvements proposed for the pond, stormwater in the pond could be used to irrigate the adjacent parkland. Installing the irrigation system could remove additional phosphorus while saving money by limiting irrigation of parkland.

5.3.4 Project #3 - Lake Susan Hills West Park – Wetland Restoration

The wetland discharging into the southwest portion of the Lake Susan receives runoff from a combination of residential, highway and agricultural land uses (Figure 5-7). As a result of monitoring conducted by the District, this wetland (subwatershed 2.4 and 2.12) has been shown to be a significant source of phosphorus for Lake Susan. Treatment of the wetland is proposed through the installation of a weir that forces water through an iron sand filtration system before entering Lake Susan. This location for treatment was chosen after District monitoring in the wetland showed that phosphorus concentrations increased with distance downstream in the wetland, indicating treatment prior to discharge to the lake as the optimal location for treatment.

The proposed project would install two rows of sheet pile with a layer of iron sand filings located between the two rows of sheet piles. The layout is similar to that used for the Minnesota Filter except that the outflow through the weir would occur through underdrains installed through the weir. The project would aim to establish a permanent pool elevation of 882.5ft in the wetland basin prior to discharging to Lake Susan. This would be an increase in the permanent pool and would provide additional settling prior to discharging to Lake Susan. The increase in elevation would also assure the layer of iron enhanced sand would be above the OHW of Lake Susan, limiting the potential for the iron layer to become anoxic and potentially release phosphorus. A high flow bypass would be installed to allow overflow during high precipitation events.

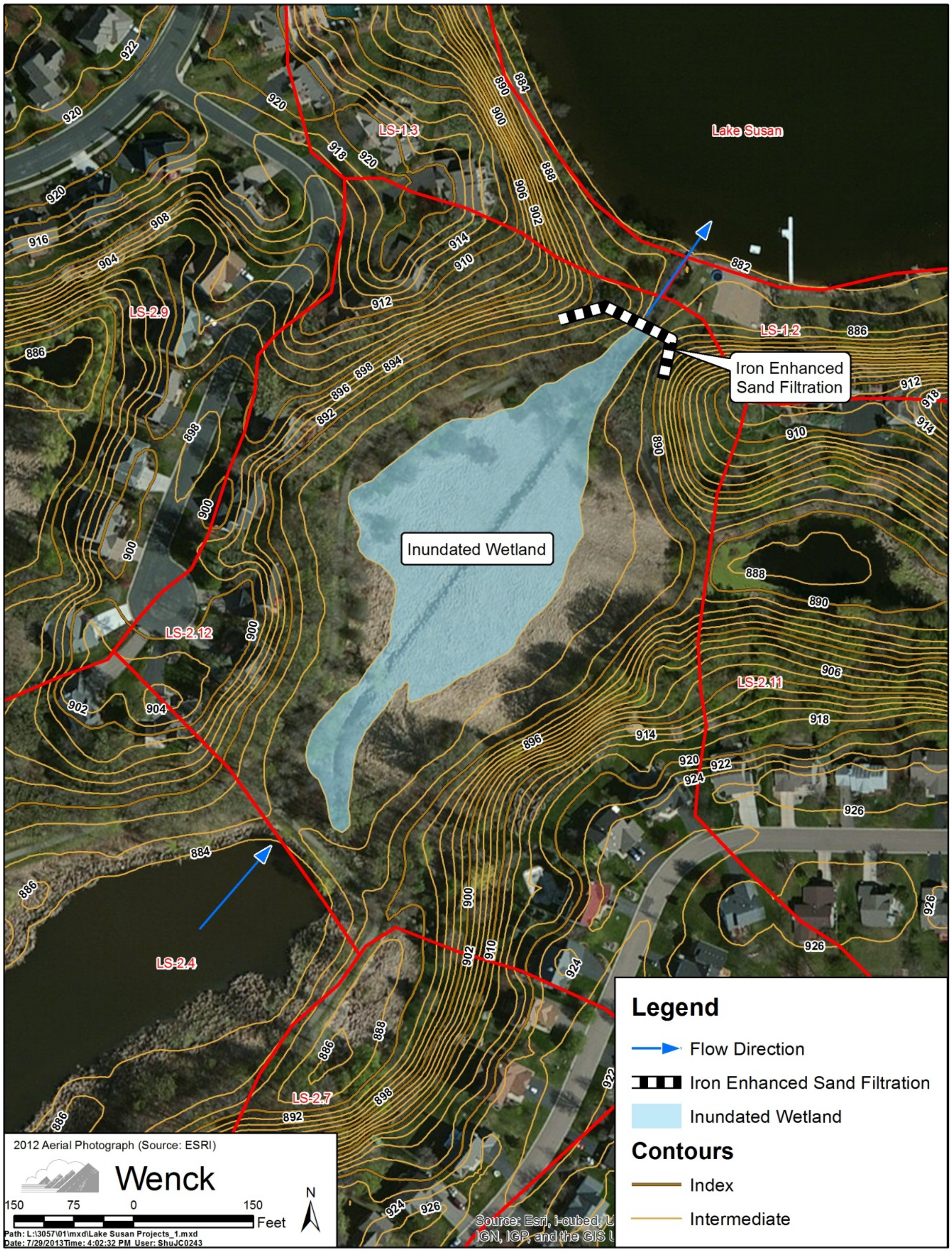

Figure 5-7. Project #3 – Lake Susan Hills Park – Wetland Enhancement.

Additional agency coordination would need to be completed as the project moves closer to a 100% design to ensure any agency concerns are addressed prior to permitting. Based on an initial review, an additional 2.0 acre-feet of dead storage could be added to the pond. The increase in dead storage along with the installation of the Minnesota Filter would result in an additional 67 pounds of TP removal.

The project life cycle cost is approximately $251,500, not accounting for any easement or land acquisition costs (Table 5-4). The estimated efficiency of the project is $126/lb of TP/yr.

Table 5-4. Cost Estimate for Project #3 - Lake Susan Hills Park Wetland Enhancement.

Item	Description	Qty	Unit	Unit Price	Item Total
1	Mobilization and Demobilization	1	L.S.	$ 10,000.00	$ 10,000.00
2	Dewatering	1	L.S.	$ 10,000.00	$ 10,000.00
2	Site Clearing	1	L.S.	$ 5,000.00	$ 5,000.00
3	Iron Enhanced Sand Filtration [1, 2]	2,500	S.F.	$ 21.57	$ 53,925.00
4	Sheetpile	1,750	S.F.	$ 50.00	$ 87,500.00
5	Site Restoration	1	L.S.	$ 4,000.00	$ 4,000.00
				Construction Total =	$ 170,425.00
				15% Legal/Design and Administration =	$ 25,563.75
				15% Contingency =	$ 25,563.75
				Total Construction Cost =	$ 221,552.50
				30 yrs Operation and Maintenance ($1,000/yr) =	$ 30,000.00
				Project Life Cycle Total Cost =	**$ 251,552.50**
				Project TP Removal (lb TP/Yr) =	**66.6**
				Project Efficiency ($/lb TP removed) =	**$ 125.90**

[1] Unit Price from Carver County SWCD Salsa Report - Structural Sand Filter (including peat, compost, iron amendments,

[2] Unit Price from Carver County SWCD Salsa Report - Assumes filter to be 15 feet in width

5.3.5 Project #4 - Lake Drive West Pond Enhancement

The stormwater pond located in the southwest quadrant of Lake Drive West and Powers Boulevard could have its removal efficiency improved by installing a Minnesota Filter (Figure 5-8). It currently treats runoff from a primarily residential area. The City is also evaluating improving this pond based on regular maintenance of existing stormwater ponds in the City. Based on an initial review, an additional 0.75 acre-feet of dead storage could be added to the pond. The increase in dead storage along with installing the Minnesota Filter would result in an additional 5 pounds of TP removal.

The project life cycle cost is approximately $25,400, not accounting for any easement or land acquisition costs (Table 5-5). The estimated efficiency of the project is $177/lb of TP/yr.

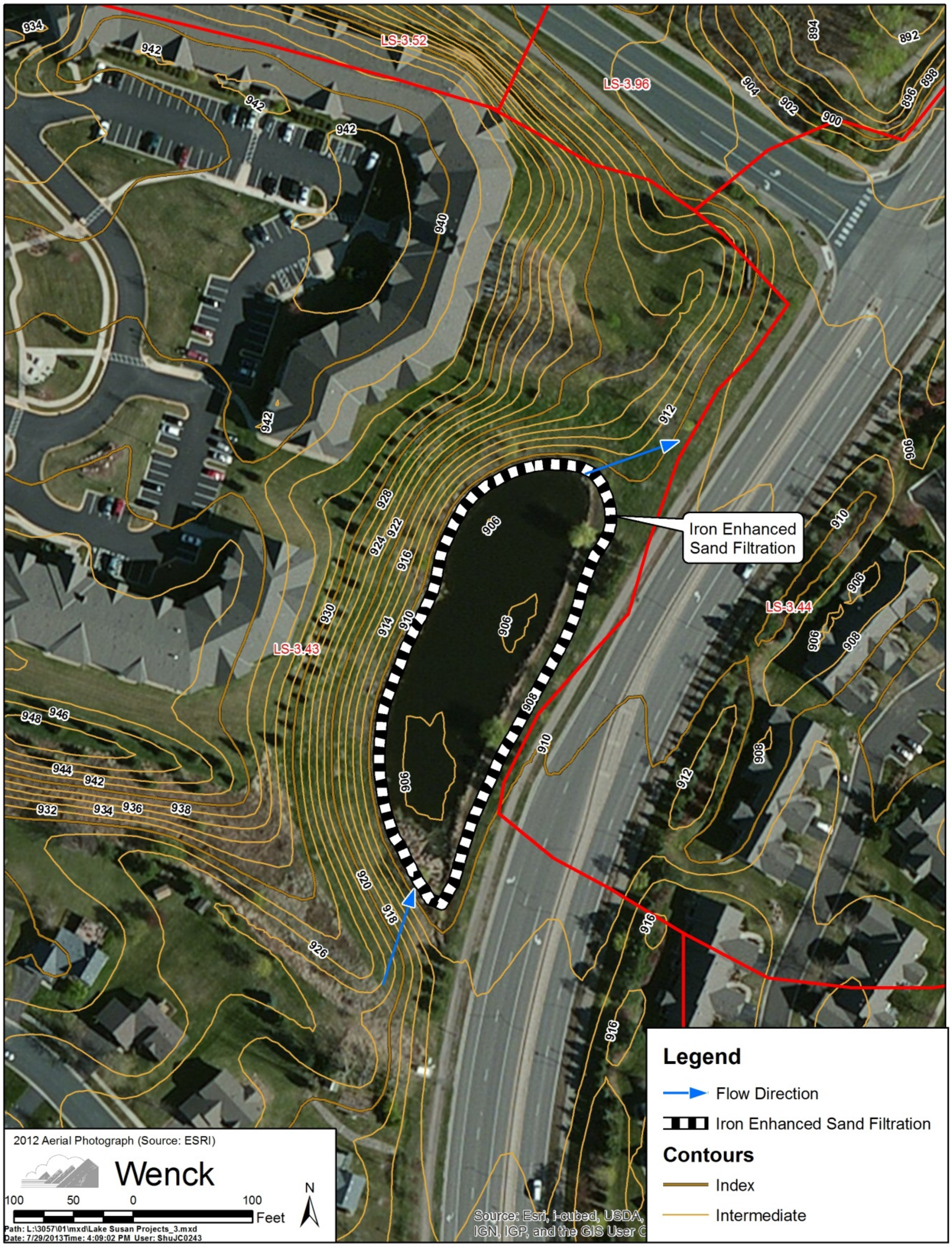

Figure 5-8. Project #4 – Lake Drive West Pond Enhancement.

Table 5-5. Cost Estimate for Project #4 - Lake Drive West Pond Enhancement.

Item	Description	Qty	Unit	Unit Price	Item Total
1	Iron Enhanced Sand Filtration [1, 2]	500	S.F.	$ 21.57	$ 10,785.00
2	Outlet Structure	1	L.S.	$ 3,000.00	$ 3,000.00
				Construction Total =	$ 13,785.00
				15% Legal/Design and Administration =	$ 2,067.75
				15% Contingency =	$ 2,067.75
				Total Construction Cost =	$ 17,920.50
				30 yrs Operation and Maintenance ($250/yr) [3] =	$ 7,500.00
				Project Life Cycle Total Cost =	**$ 25,420.50**
				Project TP Removal (lb TP/Yr) =	**4.8**
				Project Efficiency ($/lb TP removed) =	**$ 176.53**

[1] Unit Price from Carver County SWCD Salsa Report - Structural Sand Filter (including peat, compost, iron amendments,

[2] Unit Price from Carver County SWCD Salsa Report - Assumes filter to be 15 feet in width

[3] Carver County SWCD Salsa Report

5.3.6 Project #5 - Target Pond Upgrade

The Target Pond adjacent to TH 5 includes drainage from primarily commercial development (Figure 5-9). The pond is undersized for its drainage area, leading to frequent overtopping and inadequate water quality treatment. Possible expansion was assessed by evaluating current site constraints, current easements, and load reduction potential. In addition to expansion, installation of a Minnesota Filter Bench was evaluated for reduction of TP to Lake Susan. Based on an initial review, an additional 1.2 acre-feet of dead storage could be added to the pond. The increase in dead storage along with the installation of the Minnesota Filter would result in an additional 19 pounds of TP removal.

The project life cycle cost is approximately $81,200, not accounting for any easement or land acquisition costs (Table 5-6). The estimated efficiency of the project is $142/lb of TP/yr.

Table 5-6. Cost Estimate for Project #5 - Target Pond Upgrade.

Item	Description	Qty	Unit	Unit Price	Item Total
1	Iron Enhanced Sand Filtration [1, 2]	750	S.F.	$ 21.57	$ 16,177.50
2	Outlet Structure	1	L.S.	$ 5,000.00	$ 5,000.00
3	Pond Excavation	2,500	C.Y.	$ 13.00	$ 32,500.00
4	Site Restoration	1	L.S.	$ 3,000.00	$ 3,000.00
				Construction Total =	$ 56,677.50
				15% Legal/Design and Administration =	$ 8,501.63
				15% Contingency =	$ 8,501.63
				Total Construction Cost =	$ 73,680.75
				30 yrs Operation and Maintenance ($250/yr) [3] =	$ 7,500.00
				Project Life Cycle Total Cost =	**$ 81,180.75**
				Project TP Removal (lb TP/Yr) =	**19.0**
				Project Efficiency ($/lb TP removed) =	**$ 142.42**

[1] Unit Price from Carver County SWCD Salsa Report - Structural Sand Filter (including peat, compost, iron amendments, or similar)

[2] Unit Price from Carver County SWCD Salsa Report - Assumes filter to be 15 feet in width

[3] Carver County SWCD Salsa Report

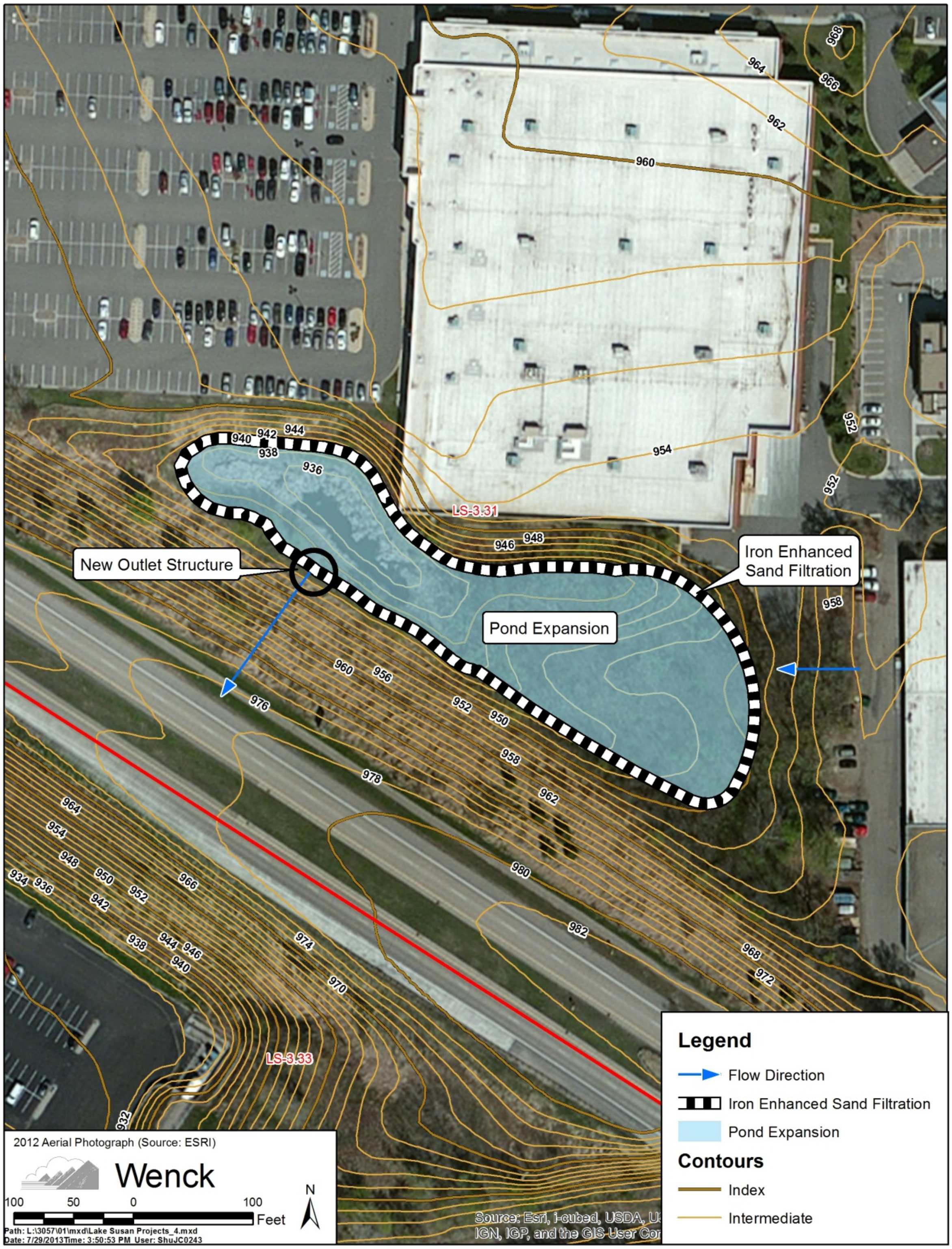

Figure 5-9. Project #5 – Target Pond Upgrade.

5.3.7 Summary

Projects identified for the near-term consist of both in-lake and watershed projects. Targeting of both of these large sources of TP to Lake Susan is critical for the long-term management of the lake. Projects were numbered based on an understanding of ease of implementation and efficiency of the projects. Table 5-7 presents a summary of the costs, TP reduction, and efficiency of each of the five near-term projects.

Table 5-7. Lake Susan Near-Term Project Summary.

Project	Name	Project Life Cycle Cost ($)	TP Reduction (lb/yr)	Efficiency ($/lb TP)
1	Alum Treatment - Lake Susan	$280,071	250	$37
2	Lake Susan Park Pond Enhancement	$89,507	31	$98
3	Lake Susan Hills West Park – Wetland Restoration	$251,553	67	$126
4	Lake Drive West Pond Enhancement	$25,421	5	$177
5	Target Pond Upgrade	$81,181	19	$142
TOTAL		**$727,733**	**372**	**$65**

5.4 COLLABORATION PROJECTS

Collaboration projects (Figure 5-10) were identified based on three criteria:

1. Existing Infrastructure Enhancements – which would provide additional benefit but do not have as high cost/benefit ratio
2. Site Retrofit – sites which require retrofitting on fully developed sites and would require private landowner coordination if/when the site would redevelop
3. Wetland Enhancement – potential locations which require further monitoring to confirm potential load reduction

Collaboration projects could progress faster if sites redevelop, funds become available to target certain areas in the watershed, or land use changes.

Figure 5-10. Collaborative Projects for Lake Susan.

5.4.1 Existing Infrastructure Enhancements

Several pond locations were identified as part of this study that were also identified as part of the SALSA Report (Table 5-8). These ponds were identified to have Minnesota Filters installed to improve their TP removal efficiency. A list of the ponds and proposed removal and costs are provided in the table below:

Table 5-8. Lake Susan – Collaboration Projects – Existing Infrastructure Enhancements.

Project	Pond	Location
E-1	3.63	NE of Park Place Rd - Adjacent to Riley Creek
E-2	3.72	N of Park Road Rd - Adjacent to Riley Creek
E-3	3.78	SE of Park Dr. and TH 5 – adjacent to Riley Creek
E-4	3.79	NE of 78th and Private drive
E-5	3.21	NW of Co. Rd 17 and TH 5
E-6	3.12	N of Kimberly Lane
E-7	2.9	W of Lake Susan Hills Dr.
E-8	2.3	SE of Lake Susan Hills Dr. and Powers Blvd.
E-9	3.44	N of Essex Rd.

5.4.2 Site Retrofits

Three subwatersheds were identified that are adjacent to Riley Creek which through retrofitting could limit potential delivery of TP to Lake Susan. Specific BMPs are not prescribed as it will be at the discretion of the landowner to decide on their preferred alternative. Table 5-9) of the potential stormwater BMP improvements that could be implemented are provided in the table below:

Table 5-9. Lake Susan – Collaboration Projects – Site Retrofits.

Project	Sub.	Description	Site BMPs	Typical Installation Cost[1]
S-1	3.93	Commercial Development adjacent to Park Ct.	Bioretention	$13.87/sq ft.
			Permeable Asphalt	$14.00/sq ft.
			Impervious Conversion	$20.04/sq ft.
			Wet Pond	$5.09/sq ft.
S-2	3.94	Teleplan Site – SE quadrant of Powers Blvd. and TH 5	Wet Pond	$5.09/sq ft.
			Permeable Asphalt	$14.00/sq ft.
			Impervious Conversion	$20.04/sq ft.
			Bioretention	$13.87/sq ft.
S-3	3.87 & 3.95	IWCO Site – SW quadrant of Park Rd and Powers Blvd.	Bioretention	$13.87/sq ft.
			Wet Pond	$5.09/sq ft.
			Permeable Asphalt	$14.00/sq ft.

[1] Carver County Soil and Water Conservation District Susan, Ann, Lucy Subwatershed: Stormwater Retrofit Assessment (SALSA), 2010

5.4.3 Wetland Restoration

Additional investigation should be done on the wetland located in subwatershed 3.14. The wetland appears to have been ditched and may be a source of phosphorus as was determined in Lake Susan Hills Park (Subwatershed 2.4 & 2.12). Monitoring in the future should be done to determine if this is a source of TP. If found as a source, implementation activities should be done to either treat water discharging from the wetland or look to have stormwater routed around the wetland.

5.5 MANAGEMENT STRATEGIES

5.5.1 Management Strategy #1 - Rules Implementation

The RPBCWD is currently undergoing the reinstatement of their rules. As part of the rule development the District should implement water quality goals that at a minimum have post project TP levels that meeting pre-project. Implementation of this strategy will ensure gains captured through other activities/projects in the watershed are maintained.

5.5.2 Management Strategy #2 - Stabilize Stream Corridors

Urban stream corridors experience degradation due to increased volumes and velocities associated with development. Limiting erosion/degradation of stream corridors reduces potential transport of TP to Lake Susan. Improvement of these corridors will also improve biotic integrity and further improves biological uptake of TP.

5.5.3 Management Strategy #3 - Shoreline Restoration

An evaluation of shoreline conditions will identify impacts from trail runoff, invasive vegetation, and other impacts that may reduce habitat quality. Impacted areas may be restored using bioengineering and native vegetation. Lake Susan has minimally developed and impacted shorelines, with only a few areas that appear to be impacted. While shoreline restoration provides minimal TP load reductions, it provides habitat, aesthetic, and shoreline stabilization benefits. A full shoreline restoration with native plantings can cost $30-50 per linear foot, depending on the width of the buffer.

5.5.4 Management Strategy #4 - Coordination with Public Entities

RPBCWD coordination with partner public agencies (City of Chanhassen, Carver County SWCD, Minnesota Department of Natural Resources, etc.) on ongoing activities within the watershed will allow for easier project implementation by leveraging partner resources along with ensure goals are aligned between the different agencies to protect Lake Susan.

An example is coordinating between the District and the City of Chanhassen on BMP implementation associated with road reconstruction projects. Coordination between the entities will help identify opportunities to identify BMPs along create opportunities for cost-sharing

5.5.5 Management Strategy #5 - Education and Outreach

Public information and education is a top priority of RPBCWD. It plays an essential role in protecting aquatic habitat and recreational values by increasing awareness about reducing pollutants at their sources through changes in behavior. Through the District's education and outreach program it can inform stakeholders of how they can make a difference improving the water quality of Lake Susan along with make cost share dollars available to implement projects.

An example project could be community rain gardens. Rain gardens help reduce stormwater phosphorus loading especially in undertreated neighborhoods. The cost of individual, residential rain gardens can range from $4,000 to $7,000, depending on size and whether labor is by the property owner or contractor. Based on soils, it was assumed each rain garden would need an under drain and that 10% of the residential runoff could be treated.

5.5.6 Management Strategy #6 - Aquatic Vegetation Management

The District has actively managed submerged aquatic vegetation in Lake Susan since the late 1980s. Active management has included contracted harvesting and chemical treatment both to prevent the overgrowth of aquatic weeds and to control curly-leaf pondweed control. Active management of submerged aquatic vegetation improves habitat and lake aesthetics.

Currently the District is working with the U of M to monitor the success of establishing native species in the lake (Knopik 2012, Appendix B). The continued effort to establish natives will create a healthier ecosystem for the lake.

Vegetation surveys could be included with aquatic vegetation management activities to track the long term effects of the management activities on the plant community. These data will also help identify key management species to refine management practices. A simple point intercept method every five years provides a long term record for vegetation diversity and abundance.

5.5.7 Management Strategy #7 - Fisheries Management

The University of Minnesota has been actively involved in management of the fisheries on Lake Susan (Sorenson 2013-Appendix A). Through the removal of carp and aeration of Rice Lake Marsh panfish populations have begun to rebound effectively manage carp populations on the lake. However if the District desires it may partner with the Minnesota DNR to develop stocking plans to improve the balance in the fisheries.

5.5.8 Management Strategy #8 – Monitoring

5.5.8.1 Water Quality Monitoring

RPBCWD monitors Lake Susan for water quality, including TP, chlorophyll-*a* and Secchi depth, as well as field parameters such as dissolved oxygen and temperature. This monitoring will continue in the future.

5.5.8.2 Aquatic Vegetation Monitoring

RPBCWD should continue to coordinate with the U of M and DNR to address aquatic vegetation species diversity and abundance to ensure efforts to establish native species is successful.

5.5.8.3 Fish Monitoring

Regular monitoring of the fish community by the University of Minnesota and/or Minnesota DNR will continue to provide information to evaluate any changes that may need to be addressed. Changes that need to be monitored include fishery balance, rough fish, especially common carp, and maintaining their low biomass numbers.

5.6 IMPLEMENTATION PLAN SUMMARY AND COSTS

5.6.1 Implementation Projects

A number of capital projects were identified to reduce TP loading to Lake Susan (Table 5-10). Projects also were assessed by estimating costs per pound TP removal over a 30-year period. These cost estimates provide comparisons among projects; however, there are other factors that may make a project attractive beyond just TP removal.

If all of the projects for Lake Susan were implemented, the total life cycle cost would be about $727,700, with a potential TP load reduction of 372 pounds annually. In total, these projects would exceed the identified reduction goal of 185 pounds annually. The most cost effective projects for Lake Susan are identified as “Near-Term” projects and include the expansion and installation of a Minnesota Filter on the Lake Susan Park Pond, Lake Drive West Pond, and Target Pond. Additionally alum treatments of Lake Susan along with an enhancement of the Lake Susan Hills Park wetland were identified as the most cost effective solutions.

Table 5-10. Lake Susan Near-Term Project Summary.

Project	Name	Project Life Cycle Cost ($)	TP Reduction (lb/yr)	Efficiency ($/lb TP)
1	Alum Treatment - Lake Susan	$280,071	250	$37
2	Lake Susan Park Pond Enhancement	$89,507	31	$98
3	Lake Susan Hills West Park – Wetland Restoration	$251,553	67	$126
4	Lake Drive West Pond Enhancement	$25,421	5	$177
5	Target Pond Upgrade	$81,181	19	$142
TOTAL		**$727,733**	**372**	**$65**

Further, sites identified as “Collaboration Projects” could potentially be designed for additional removals. The projects were identified as pond enhancements, site retrofits and wetland enhancements (Table 5-11).

Table 5-11. Collaboration Projects for Lake Susan.

Existing Infrastructure Enhancements		
Project	**Pond**	**Location**
E-1	3.63	NE of Park Place Rd - Adjacent to Riley Creek
E-2	3.72	N of Park Road Rd - Adjacent to Riley Creek
E-3	3.78	SE of Park Dr. and TH 5 – adjacent to Riley Creek
E-4	3.79	NE of 78th and Private drive
E-5	3.21	NW of Co. Rd 17 and TH 5
E-6	3.12	N of Kimberly Lane
E-7	2.9	W of Lake Susan Hills Dr.
E-8	2.3	SE of Lake Susan Hills Dr. and Powers Blvd.
E-9	3.44	N of Essex Rd.
Site Retrofits		
Project	**Sub.**	**Description**
S-1	3.93	Commercial Development adjacent to Park Ct.
S-2	3.94	Teleplan Site – SE quadrant of Powers Blvd. and TH 5
S-3	3.87 & 3.95	IWCO Site – SW quadrant of Park Rd and Powers Blvd.
Wetland Enhancements		
Project	**Sub.**	**Description**
W-1	3.14	Wetland located in NW quadrant of TH 5 and Powers Blvd.

5.6.2 Management Strategies

Management strategies identified should also be implemented to preserve gains achieved with the implementation of the identified projects.

1. Rules Implementation
2. Stabilize Stream Corridors
3. Shoreline Restoration
4. Coordination with Public Entities
5. Education and Outreach
6. Aquatic Vegetation Management
7. Fisheries Management
8. Monitoring
   a. Water Quality
   b. Aquatic Vegetation
   c. Fisheries

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7.0 Glossary

Aeration Any active or passive process by which intimate contact between air and liquid is assured, generally by spraying liquid in the air, bubbling air through water, or mechanical agitation of the liquid to promote surface absorption of air.

Algae Microscopic organisms/aquatic plants that use sunlight as an energy source (e.g., diatoms, kelp, seaweed). One-celled (phytoplankton) or multicellular plants either suspended in water (plankton) or attached to rocks and other substrates (periphyton). Their abundance, as measured by the amount of chlorophyll-*a* (green pigment) in an open water sample, is commonly used to classify the trophic status of a lake.

Algal Bloom Population explosion of algae in surface waters due to an increase in plant nutrients such as nitrates and phosphates.

Alum Common name for commercial-grade Aluminum Sulfate. Its chemical formula is generally denoted by $Al_2(SO^4)_3$ X $12H_2O$. Most often used in lakes as a way to precipitate a floc that settles through the water column, removing fine particles to the sediment and building up a barrier layer to contain soluble phosphorus in the bottom sediments.

Anoxic Without oxygen.

Aquatic Organisms that live in or frequent water.

Aquifer A saturated permeable geologic unit that can transmit significant quantities of water.

Biomass The total quantity of plants and animals in a lake. Measured as organisms or dry matter per cubic meter, biomass indicates the degree of a lake system's eutrophication or productivity.

Chlorophyll-*a* Green pigment present in all plant life and necessary for photosynthesis. The amount present in lake water depends on the amount of algae and is therefore used as a common indicator of water quality.

Clarity The transparency of a water column. Measured with a Secchi disc.

Concentration Expresses the amount of a chemical dissolved in water. The most common units are milligrams per liter (mg/L) and micrograms per liter (µg/L). One milligram per liter is equal to one part per million (ppm). To convert micrograms per liter (µg/1) to milligrams per liter (mg/1), divide by 1000 (e.g. 30 µg/l = 0.03 mg/1). To convert milligrams per liter (mg/1) to micrograms per liter (µg/1), multiply by 1000 (e.g. 0.5 mg/l = 500 µg/1).

Daphnia Small crustacean (zooplankton) found in lakes. Prey for many fish species.

Dissolved Oxygen (DO) The amount of free oxygen absorbed by the water and available to aquatic organisms for respiration; amount of oxygen dissolved in a certain amount of water at a particular temperature and pressure, often expressed as a concentration in parts of oxygen per million parts of water.

Ecosystem A system formed by the interaction of a community of organisms with each other and with the chemical and physical factors making up their environment.

Erosion The wearing away and removal of materials of the earth's crust by natural means.

Eutrophic Pertaining to a lake or other body of water characterized by large nutrient concentrations such as nitrogen and phosphorous and resulting high productivity. Such waters are often shallow, with algal blooms and periods of oxygen deficiency. Lakes can be classified as *oligotrophic* (nutrient poor), *mesotrophic* (moderately productive), *eutrophic* (very productive and fertile), or *hypereutrophic* (extremely productive and fertile).

Eutrophication The process by which lakes and streams are enriched by nutrients, and the resulting increase in plant and algae growth. This process includes physical, chemical, and biological changes that take place after a lake receives inputs for plant nutrients – mostly nitrates and phosphates – from natural erosion and runoff from the surrounding land basin. *Cultural eutrophication* is the accelerated eutrophication that occurs as a result of human activities in the watershed that increase nutrient loads in runoff water that drains into lakes

Filamentous Algae Algae that forms filaments or mats attached to sediment, weeds, piers, etc.

Food Chain The transfer of food energy from plants through herbivores to carnivores. An example: insect-fish-bear or the sequence of algae being eaten by small aquatic animals (zooplankton) which in turn are eaten by small fish which are then eaten by larger fish and eventually by people or predators.

Groundwater Water contained in or flowing through the ground. Amounts and flows of groundwater depend on the permeability, size, and hydraulic gradient of the aquifer.

Habitat The place where an organism lives that provides an organism's needs for water, food, and shelter. It includes all living and non-living components with which the organism interacts.

Hydrologic Referring to or involving the distribution, uses, or conservation of water on the Earth’s surface and in the atmosphere. The hydrologic cycle is the process by which the Earth's water is recycled. Atmospheric water vapor condenses into the liquid or solid form and falls as precipitation to the ground surface. This water moves along or into the ground surface and finally returns to the atmosphere through transpiration and evaporation.

Hydrology The study of water, especially its natural occurrence, characteristics, control and conservation.

Impervious A term denoting the resistance to penetration by water or plant roots; incapable of being penetrated by water; non-porous.

Invertebrates Animals without an internal skeletal structure such as insects, mollusks, and crayfish.

Limiting Nutrient or Factor The nutrient or condition in shortest supply relative to plant growth requirements. Plants will grow until stopped by this limitation; for example, phosphorus in summer, temperature or light in fall or winter.

Littoral The near-shore shallow water zone of a lake, where aquatic plants grow.

Nitrate (NO3-) An inorganic form of nitrogen important for plant growth. Nitrogen is in this stable form when oxygen is present. Nitrate often contaminates groundwater when water originates from manure pits, fertilized fields, lawns or septic systems.

Non-native A species of plant or animal that has been introduced.

Nutrients Elements or substances such as nitrogen and phosphorus that are necessary for plant growth. Large amounts of these substances can become a nuisance by promoting excessive aquatic plant growth.

Organic Matter Elements or material containing carbon, a basic component of all living matter.

Permeability The ability of a substance, such as rock or soil, to allow a liquid to pass or soak through it.

Phosphorus Key nutrient influencing plant growth in freshwater lakes. Soluble reactive phosphorus is the amount of phosphorus in solution that is available to plants. Total phosphorus includes the amount of phosphorus in solution (reactive) and in particulate form.

Photosynthesis The process by which green plants convert carbon dioxide (CO2) dissolved in water to sugar and oxygen using sunlight for energy. Photosynthesis is essential in producing a lake's food base, and is an important source of oxygen for many lakes.

Phytoplankton Microscopic floating plants, mainly algae, that live suspended in bodies of water and that drift about because they cannot move by themselves or because they are too small or too weak to swim effectively against a current.

Plankton Small plant organisms (phytoplankton and nanoplankton) and animal organisms (zooplankton) that float or swim weakly though the water.

Precipitation Rain, snow, hail, or sleet falling to the ground.

Predator An animal that hunts and kills other animals for food.

Prey An animal that is hunted or killed by another for food.

Runoff Water that flows over the surface of the land because the ground surface is impermeable or unable to absorb the water.

Secchi Disc An 8-inch diameter plate with alternating quadrants painted black and white that is used to measure water clarity (light penetration). The disc is lowered into water until it disappears from view. It is then raised until just visible. An average of the two depths, taken from the shaded side of the boat, is recorded as the Secchi disc reading.

Sedimentation The removal, transport, and deposition of detached soil particles by flowing water or wind. Accumulated organic and inorganic matter on the lake bottom. Sediment includes decaying algae and weeds, marl, and soil and organic matter eroded from the lake's watershed. The sedimentation rate of lakes or impoundments can be estimated by measuring the amount of suspended solids (particulate matter) of inflowing streams.

Shorelines With banks, those areas along streams, lakes, ponds, rivers, wetlands, and estuaries where water meets land. The topography of shorelines and banks can range from very steep to very gradual.

Soluble Capable of being dissolved.

Species A group of animals or plants that share similar characteristics such as can reproduce.

Stormwater Runoff Water falling as rain during a storm and entering a surface water body like a stream by flowing over the land. Stormwater runoff picks up heat and pollutants from developed surfaces such as parking lots.

Submerged Aquatic Vegetation (SAV) Aquatic plants larger than algae with all photosynthetic parts below the surface of the water. Many are rooted, but some are free-floating.

Subwatershed A smaller geographic section of a larger watershed unit with a drainage area of between 2 and 15 square miles and whose boundaries include all the land area draining to a point where two second order streams combine to form a third order stream.

Water Table The top or “surface” of groundwater. The water table level changes in response to amounts of groundwater recharge flowing in, and amounts of water leaving the ground through seeps, springs, and wells.

Watershed The geographic region within which water drains into a particular river, stream, or body of water.

Wetland Transitional between terrestrial and aquatic ecosystems, wetlands are places where the water table is at or near the surface and where hydric soils and hydrophytic (water-loving) vegetation predominate.

Zooplankton Microscopic or barely visible animals that eat algae. These suspended plankton are an important component of the lake food chain and ecosystem. For many fish, they are the primary source of food.

Appendix A

2012 Annual Report: Developing and implementing a sustainable program to control common carp in the Riley Purgatory Bluff Creek Watershed District.

Peter Sorensen and Przemek Bajer May 23, 2013
University of Minnesota

2012 Annual Report: Developing and implementing a sustainable program to control common carp in the Riley Purgatory Bluff Creek Watershed District

A. Synopsis

The number of common carp remains low and under control throughout the entire Riley Creek Watershed where aeration is allowing game-fish to control carp recruitment and most adults were removed in 2008. Water clarity is still improved since carp control was established, but with the recent warm winter, some declines were noted in Lake Susan. Research and management efforts focused on plant management and a study has provided new direction on the role of unbalanced (excessive numbers of bluegills) fish communities on water clarity. Alum treatment is recommended in lakes Susan and Riley now that carp are under control. New data on the relationship between carp and total phosphorous (TP) suggests that in thermally stratified lakes with heavy internal loading (such Lake Susan), carp do not have a direct effect on total phosphorus but rather exert most all of their effects on water quality by destroying submersed plants. Progress has been slower in The Purgatory Creek Watershed where winter removal of carp aggregations using radio-tagged Judas fish was frustrated by a warm winter with poor ice conditions. Nevertheless, radio-tagged Judas fish provided insight into the spring-time movement of carp between Lake Staring and the wetland upstream (Purgatory Creek Park Area or 'PCPA') which functions as a carp nursery. Fish capture data also suggest that most carp wait until their second year of life to leave this nursery area, meaning that draw-downs to create winterkill could in theory control them. Carp movement into and out of PCPA is extensive and occurs every few weeks with fluctuating water levels suggesting that spring-time trapping for removal may be reasonable in the creek. A plan to draw-down the PCPA was put into effect as a first step in carp control; the idea is to kill all surviving juvenile carp in the nursery each year in a cost-effective and ecologically safe manner. Water and plant sampling continued in this system so that when carp are eventually removed from it, the effects of carp in shallow lakes can be ascertained.

B. Specific progress on the five contract objectives.

1) Developing reasonable methods to remove adult common carp from lakes.

The Judas fish technique in which radio-tagged fish are used to locate aggregations of adult carp for removal by under-ice seining was tested in 2012 in lakes Lotus and Staring in the Purgatory Chain. This technique previously enabled us to reduce carp densities in lakes Riley, Susan and Lucy (Bajer *et al*. 2011). This year we focused our efforts on Lake Staring because our mark-recapture estimates showed that this lake had an extremely high biomass of carp that warrants removal (489 kg/ha). However, because of the warm and unpredictable winter, ice conditions were a significant challenge. One haul was attempted on February 8, 2012 and while initially promising (4 of 12 radio-tagged fish were initially in the net), the seine net became entangled in what later turned out to be a sunken boat. As a result, all radio-tagged carp escaped from the net and only 892 carp were captured and removed from the lake. The lake was later closed to vehicles by the county due to poor ice conditions which prevented additional seining. A concentrated effort to remove carp using winter seining in the winter of 2012-2013 is planned along with the construction of a carp screen between Lake Staring and PCPA to remove the carp from the creek during their springtime spawning migration. One winter seine was also conducted in Lotus Lake on February 17, 2012 when four of its ten radio-tagged carp were found in a shallow bay in the northeast corner of the lake. Three of these radio-tagged carp were captured along with a total of 450 carp. This relatively low number of captured carp suggested that Lake Lotus is inhabited by only ~ 1,500 carp, which was later confirmed by mark-and-recapture analyses. The biomass of carp in this lake is about 50 kg/ha and probably not especially damaging (ecologically). No evidence of recruitment has been described in this system.

2) Developing removal targets for adult common carp that will increase water quality in lakes

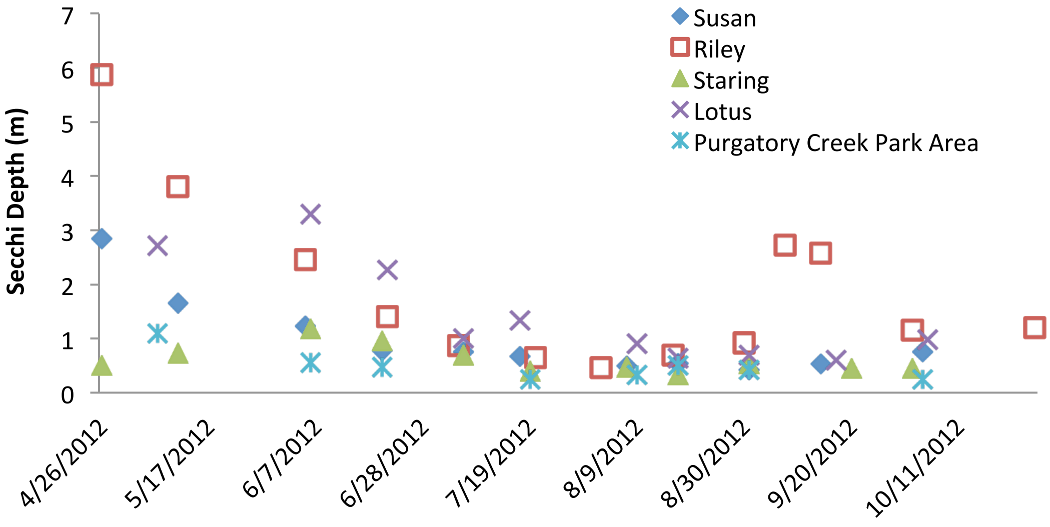
To determine targets for carp removal, we analyzed data on water clarity, total phosphorus and aquatic vegetation in lakes Susan, Riley and Lucy before and after carp removal (years 2008-2011). This is the first analysis of its kind in thermally stratified lakes and it has been submitted for publication in a peer-reviewed journal (Bajer and Sorensen; in review). This research continues along with new data collections on water quality and carp abundance in lakes Susan and Riley. Data is also being collected in PCPA and Staring so that when carp numbers are eventually reduced, the effects of carp biomass on water quality in these systems can also be systematically ascertained (Table 1).

Table 1 Common carp abundance (N), removal history, and biomass.

Lake	Year	Carp Removal	N Mean (95% CI)	Biomass (kg/ha)
Susan	2008	Before	4,181 (3,292 – 5,069)	307.1
	2009	After	756	64.5
	2010	After	374	43.0
	2011	After	281	40.8
Riley	2008	Before	6,419 (6,132 – 6,706)	176.1
	2009	After	3,025	90.0
	2010	After	376	10.5
	2011	After	320	10.5
Staring	2012	Before/Ongoing	26,228 (20,938 – 31, 472)	489.3
PCPA	2012	Before/Ongoing	NA	NA
Lotus	2012	Before[a]	1,663 (462-2864)	58.5

[a] Removal of carp from Lotus lake appears to be unnecessary due to low biomass

To help develop carp removal relationships and targets, we have also continued to measure water clarity (Secchi), total phosphorus (TP), chlorophyll A (ChlA), and total suspended solids (TSS) during May – October. Our results showed that lakes Staring and PCPA had the poorest water clarity, and highest phosphorus concentration (Fig. 1). These two systems also have the highest carp biomass. Lakes Riley and Lotus had the best water quality (Fig. 1).



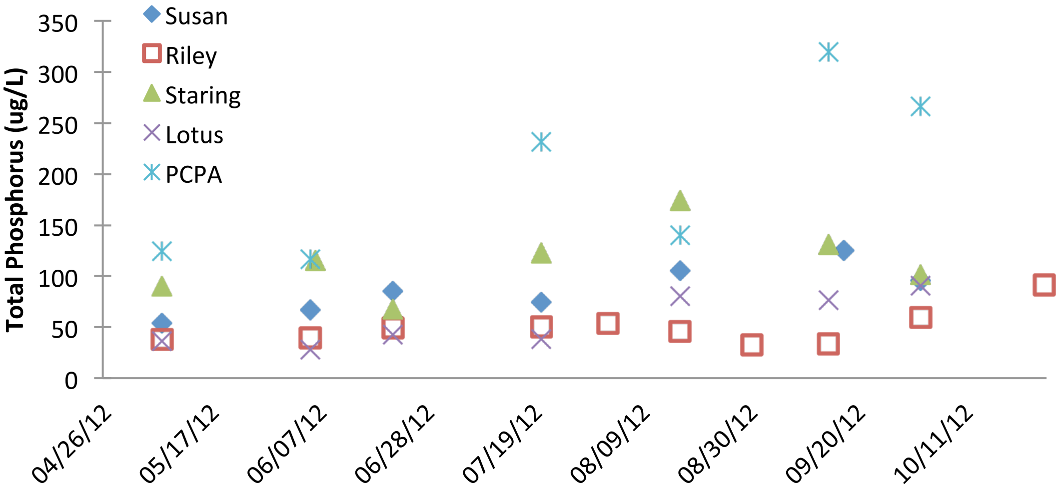
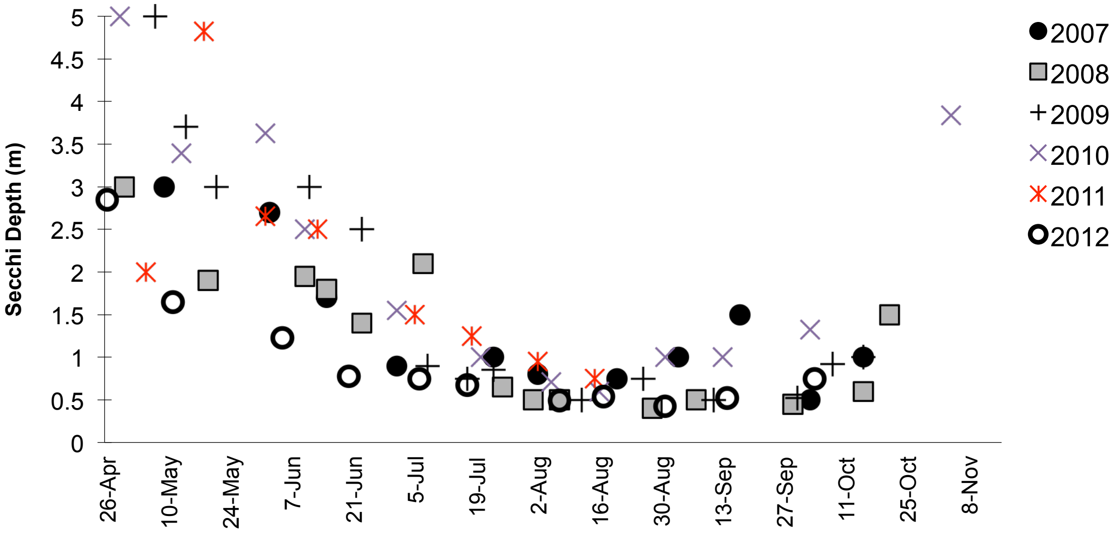


Figure 1. Secchi depth and total phosphorus in RPBCWD lakes in 2012.

Analysis of the water quality data from both of the lakes from which we removed carp in 2009 (lakes Susan and Riley) showed that Lake Susan had excellent spring-time water clarity during 2009-2011 (following carp removal) but that water clarity declined in 2012 (Fig. 2). This decline was likely caused by an uncharacteristically/ relatively high phosphorus concentration in May and June 2012 (Fig. 2). In Lake Riley, water clarity was similar to previous years; it was good in the spring, relatively poor in the first part of the summer, and improved in September (Fig. 3). As in previous years, we observed a rapid increase in TP in Lake Riley in the fall, which was likely driven by internal loading and lake mixing (Fig. 3). We recommended alum treatments for these lakes because internal loading appears to be driving water quality and with the carp removed and under control, effects of alum are now expected to be longer-lived.



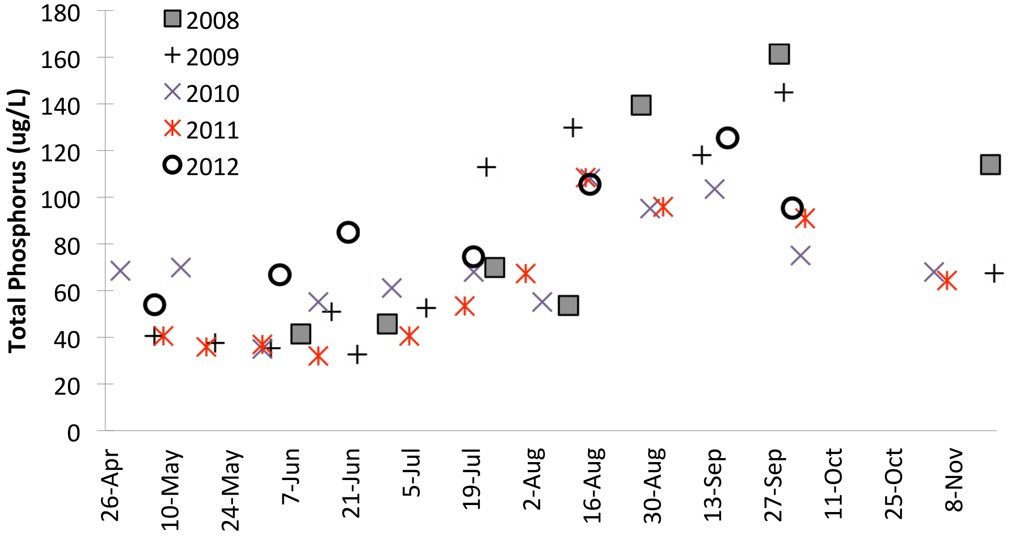


Figure 2. Secchi depth (top) and total phosphorus (bottom) in Lake Susan during 2007-2012 (no phosphorus data were collected in 2007). The carp were removed in January 2009.

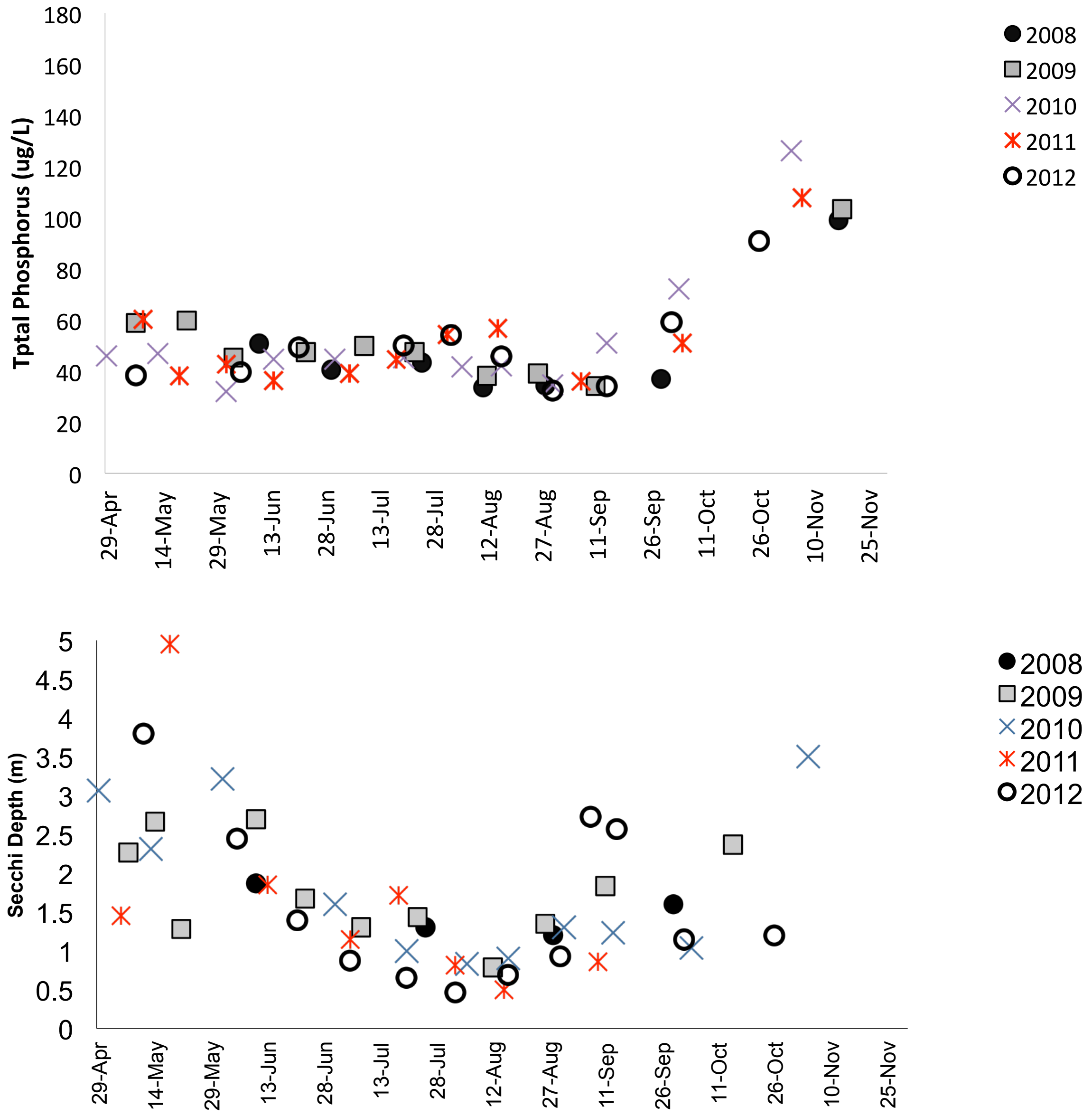


Figure 3. Total phosphorus (top) and Secchi depth (bottom) in Lake Riley during 2008-2012. The carp were removed in January 2009 and March 2010.

Overall in 2012, water clarity was strongly influenced by phosphorus concentrations in RPBCWD lakes but there was a substantial range in water clarity at any given TP concentration suggesting that other processes also played an important role (Fig. 4). Lake Riley had particularly poor water clarity for its phosphorus concentration in late spring and early summer (Fig. 4). We hypothesize that a dense population of bluegill sunfish, which we estimated to be 140 kg/ha in 2011, facilitated algal blooms in Lake Riley, despite its relatively modest phosphorus concentrations, by consuming excessive numbers of large filtering zooplankton (*Daphnia sp*.). To test this hypothesis, we constructed exclosures to exclude fish in Lake Riley in early July of 2012 and monitored water clarity (Chlorophyll A) total phosphorus and zooplankton within the exclosures and in selected sites in the lake until late fall. Our data showed that total phosphorus concentrations inside the exclosures remained similar to those in the lake, but water clarity was dramatically higher in the exclosures as shown by chlorophyll A concentrations (Figs. 5 and 6). The exclosures also had higher densities of large zooplankton (Daphnia and Ceriodaphnia; Fig. 7). This supports our hypothesis and suggests fisheries management is needed in this lake to reduce bluegill biomass while improving their size structure and thus reducing their predation on zooplankton. Improved submersed plant communities would greatly aid in this effort and we worked with Dr. Newman, the DNR, both lake associations and the RPBCWD to develop plant management plans. We plan to continue this work in 2013.

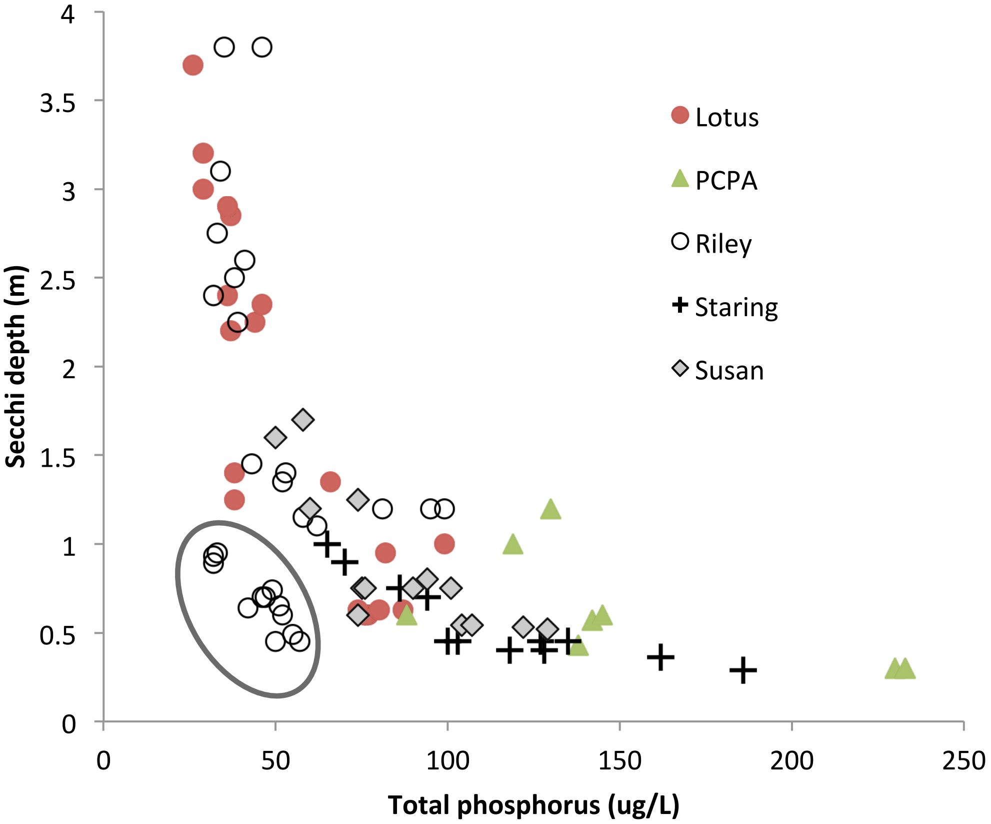


Figure 4. The relationship between total phosphorus and Secchi depth in our study lakes. The oval includes data from late spring/early summer in Lake Riley. Clearly, a different set of mechanisms is in place in Lake Riley. We believe it to be related to an unbalanced biological community but exasperated by internal loading.

Figure 5. One of the two experimental fish exclosures in Lake Riley. Note the difference in water clarity inside vs. outside the fish exclosure. Photo David Florenzano.

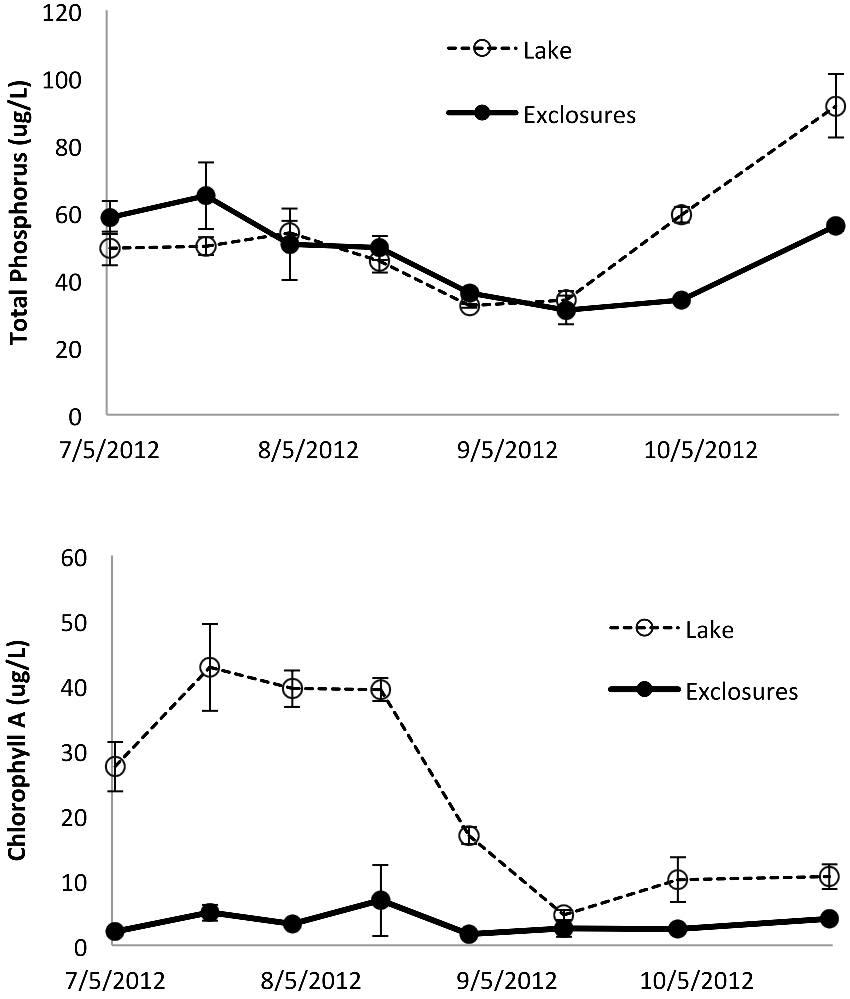


Figure 6. Total phosphorus (top) and chlorophyll A (bottom) in experimental fish exclosures and in Lake Riley. Lines show mean values and error bars show standard deviations.

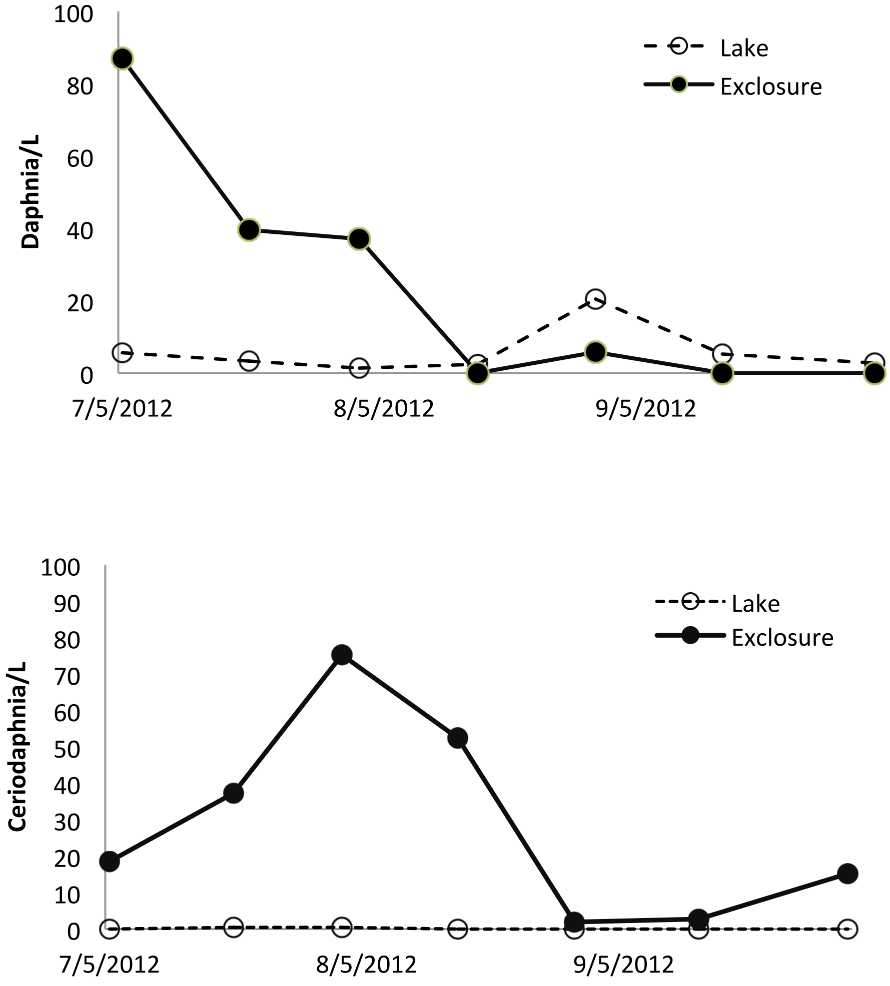


Figure 7. Mean daily densities of Daphnia sp. (top panel) and Ceriodaphnia sp. (bottom panel) in experimental fish exclosures and in Lake Riley.

3) Developing means to block carp movement (re-infestation)

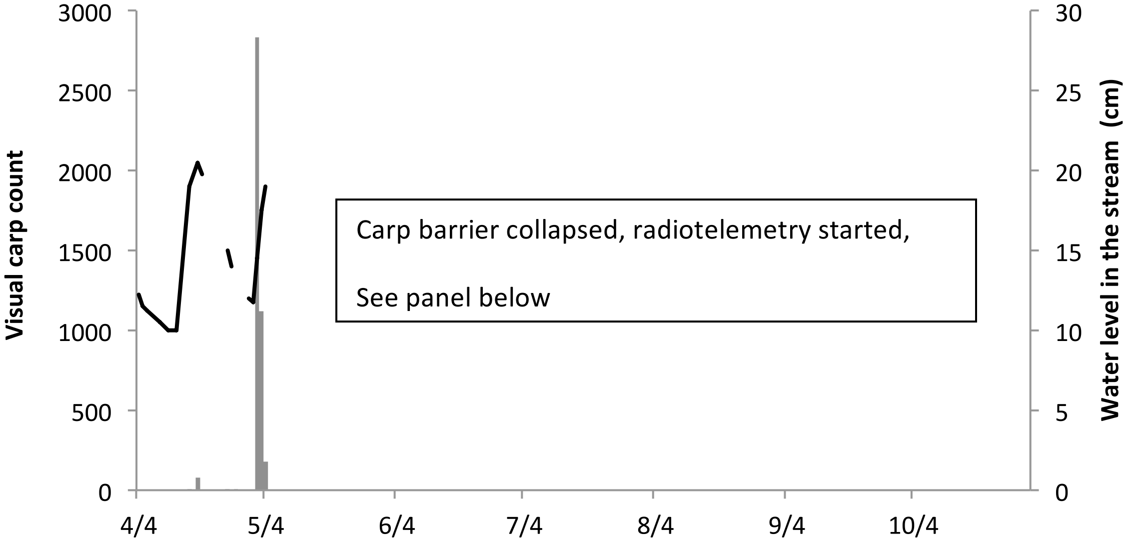
We conducted more tests of our portable carp deterrent fence. This system uses horizontally-mounted PVC pipes. Once again, we successfully used this system to block adult carp moving from lakes Susan and Riley into Rice Marsh Lake. Two movements on May 25 and May 28, 2012 were blocked. The runs were the smallest ever and because winter aeration has stopped winterkills for many years in Rice Marsh Lake (we monitor oxygen concentrations each winter) and its native game-fish community remains robust and capable of controlling carp eggs and larvae, we have elected to not install these fences in 2013 (but keep them in reserve). Our ultimate goal is to achieve carp control without poisons or barriers.

We also tested a portable carp fence between Lake Staring and the PCPA in 2012. Although the barrier was successfully maintained during April 2012, it collapsed in early May due to high water flow. Meanwhile, we met with the city of Eden Prairie, the DNR, Barr Engineering and the watershed district to develop a more permanent barrier that could be used to both block the movement of spawning carp and remove them at the same time.

4) Developing an understanding of carp movement so that it can be addressed appropriately

We collected carp movement data between lakes Susan, Rice Marsh and Riley. As with previous years, carp moved in sporadic but synchronized bursts that followed rain events after temperatures reached about 16^{o}C. More specifically, the carp attempted to move from Lake Susan to Rice Marsh on May 25, after a rapid increase in stream water level, and then again on May 28. No other movement of carp was observed. These data have been analyzed and are being prepared for publication (Chizinski *et al*., in prep.).

We also monitored the movement of common carp between Lake Staring and the Purgatory Creek Park Area in 2012. Two methods were deployed. First, we collecting carp counts in combination with electrofishing 30 m transects downstream of the PVC carp barrier. Later, after the barrier collapsed in early May, we monitored movement by conducting radiotelemetry surveys on 22 tagged carp in Lake Staring and PCPA. There were four discrete movement events (Fig. 7). Two of these events occurred in early and late May and were most likely associated with spawning, while the other two occurred later in the season and were likely associated with feeding. Each of these movement events coincided with rain and an increase in stream water level. The carp tended to move from Lake Staring to PCPA in 1-2 days and then gradually returned back to Staring over the next week or two (Fig. 7). Following each of these movement pulses, up to 80% of all radio-tagged carp were found in the PCPA, while this proportion declined to ~ 30% during intervals between movement pulses. This suggests that most carp leave Lake Staring and move to PCPA for brief periods of time on several occasions each year. These repeated and semi-predictable movements from Lake Staring to PCPA create an opportunity to remove a substantial proportion of carp from that system, which we will attempt in the spring of 2013.



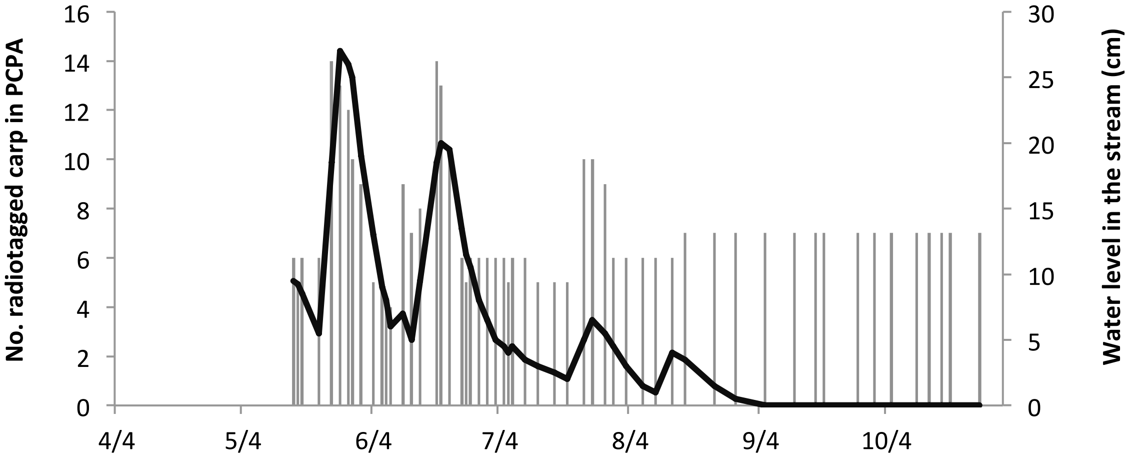


Figure 7. Movement of carp from Lake Staring to PCPA. The top panel shows visual counts of carp moving towards the PCPA (downstream of the carp barrier) and water level in Purgatory Creek. The bottom panel shows the number of radio-tagged carp (number of 14 found in the entire system which contains about 25,000 adults) found in Purgatory Creek Park Area (vertical bars) and water level in Purgatory Creek (lines). Note the relationship between the two.

C. Miscellaneous other issues

i. Summary of activities in the Riley Chain of Lakes and its condition.

Fisheries sampling showed that the abundance of carp remained low and non-damaging through the entire chain. No juvenile carp have been captured in six years. Adult carp barriers have been removed, as winter aeration in Rice Marsh prevented winterkills and a stabilized native fish community that is expected to be able to control carp eggs and larvae. Evidence strongly suggests that internal loading is the cause of relatively poor water clarity in lakes Susan and Riley and alum treatment is recommended because the carp have now been removed and will not be disruptive. Submersed aquatic vegetation increased in lakes Susan and Riley following carp removal. A plant management plan is now in place to promote native plants and control invasives. Removal of carp was associated with faster growth rate and increased size structure of bluegill sunfish in Lake Susan but excessive fishing pressure eliminated these gains. The abundance of bluegill sunfish appears to be excessive in Lake Riley. We recommend a fisheries management plan following the planned invasive plant and alum treatments.

ii) Summary of activities in the Purgatory Chain and its overall condition.

Several years of fish sampling have shown that carp are in very low abundance or nonexistent in lakes Silver, Red Rock, Duck, Round, Mitchell and McCoy. Relatively low numbers of adult carp are also now found in Lake Lotus. Furthermore, the population of carp in Lotus is comprised of large and old individuals suggesting that carp cannot find adequate conditions for their eggs and larvae to survive in this lake. Because this population appears to be low and stable (no young carp), we recommend no additional removal, unless an easy opportunity presents itself (a large aggregation in an area that is easy to seine). Carp numbers remain very high in Lake Staring where water quality is extremely poor. Our data show that carp from Lake Staring use the Purgatory Creek Park Area as a nursery and high numbers of age-0 carp are present in PCPA after winterkills when population of native fish are severely reduced. However, the juvenile carp do not disperse to Staring for two years and might be controlled in PCPA by water draw-downs and winter freeze-outs. We are currently developing a comprehensive strategy to control carp in Staring-PCPA system which will include winter seining, strategically placed carp barriers, carp removal from the stream and winter freeze-outs in PCPA. This strategy will be finalized by the spring of 2014.

D. Peer-reviewed publications that acknowledge RPBCWD (*=cited above)

*Bajer, P.G. and P.W. Sorensen. In prep. The effects of common carp on vegetative cover, total phosphorus and water clarity in thermally stratified Midwestern lakes. Hydrobiologia.

*Bajer, P. G., and P. W. Sorensen. 2012. Estimating the abundance of invasive common carp using boat electrofishing. North American Journal of Fisheries Management 32:817-822.

*Bajer, P.G., C.J. Chizinski, and P.W. Sorensen. 2011. Using the Judas technique to locate and remove wintertime aggregations of invasive common carp. Fisheries Management and Ecology 18: 497-505.

*Bajer, P. G., J. Silbernagel, C. J. Chizinski, and P. W. Sorensen. 2012. Variability in native micro-predator abundance explains the recruitment of an invasive fish in a naturally unstable environment. Biological Invasions 14:1919-1929.

*Chizinski, C, P.G. Bajer, and P.W. Sorensen. In prep. Movement of adult carp and northern pike between overwintering and spawning lakes. Fisheries Management and Ecology

Vander Hook, J., P. Tokekar, E. Branson, P. G. Bajer, P. W. Sorensen, V. Isler. 2012. Local-Search Strategy for Multi-Modal, Multi-Target, Active Localization of Invasive Fish. 13th International Symposium on Experimental Robotics 2012.

Zielinski, D.A., V.R. Voller, J. Svendsen, M. Honzo, P.W. Sorensen. In review. A relatively simple bubble curtain system that inhibits the movement of common carp. Ecological Engineering.

E. Presentations of RPBWD data that acknowledged the Watershed District

Bajer, P.G. and P.W. Sorensen. 2012. The effects of common carp on vegetative cover, total phosphorus and water clarity in thermally stratified Midwestern lakes. National Meeting of the American Fisheries Society, St. Paul, MN. (invited)

Bajer, P. G., J. Silbernagel, C. J. Chizinski, and P. W. Sorensen. 2012. Variability in native micro-predator abundance explains the recruitment of an invasive fish in a naturally unstable environment. Midwest AIS Meeting. LaCrosse WI.

Sorensen, P.W., and P.G. Bajer. 2012 Integrated Pest Management of the Common Carp in the American Midwest. National Meeting of the American Fisheries Society, St. Paul, MN. (invited)

Sorensen, PW and P.G. Bajer. 2012 Integrated control of common carp. Midwest AIS meeting, Lacrosse WI.

Sorensen Lab 2012 Evening with the Watershed May 2012

Sorensen Lab 2012 Controlling AIS. Senate Environment Committee, St. Paul

Sorensen Lab. 2012 Lessard-Sams Outdoor Heritage Committee, St. Paul

Sorensen Lab. 2012 Clean Water Fund hearing, St. Paul

Appendix B

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

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

Table of Contents

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^oC. 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^oC) 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).

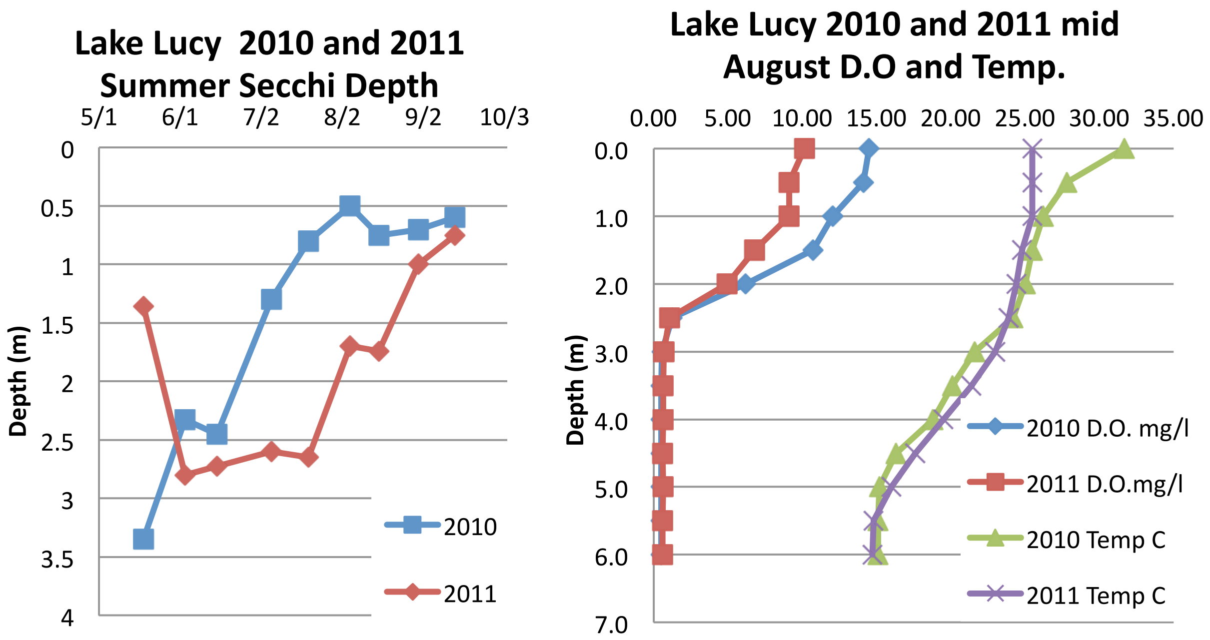


Figure 1. Comparison of 2010 and 2011 Secchi depth (Bajer and Sorenson, unpublished data), temperature, and dissolved oxygen profiles for Lake Lucy 2010 and 2011.

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

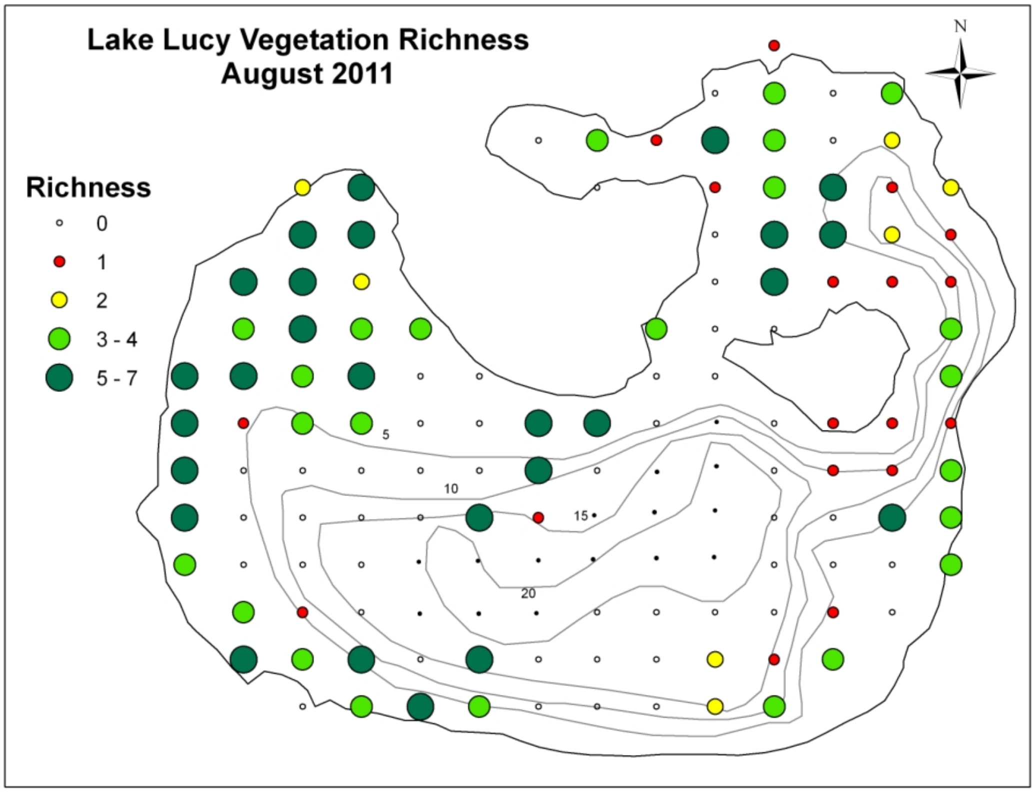


Figure 2. Sampling point locations and the number of species found per site in August 2011.

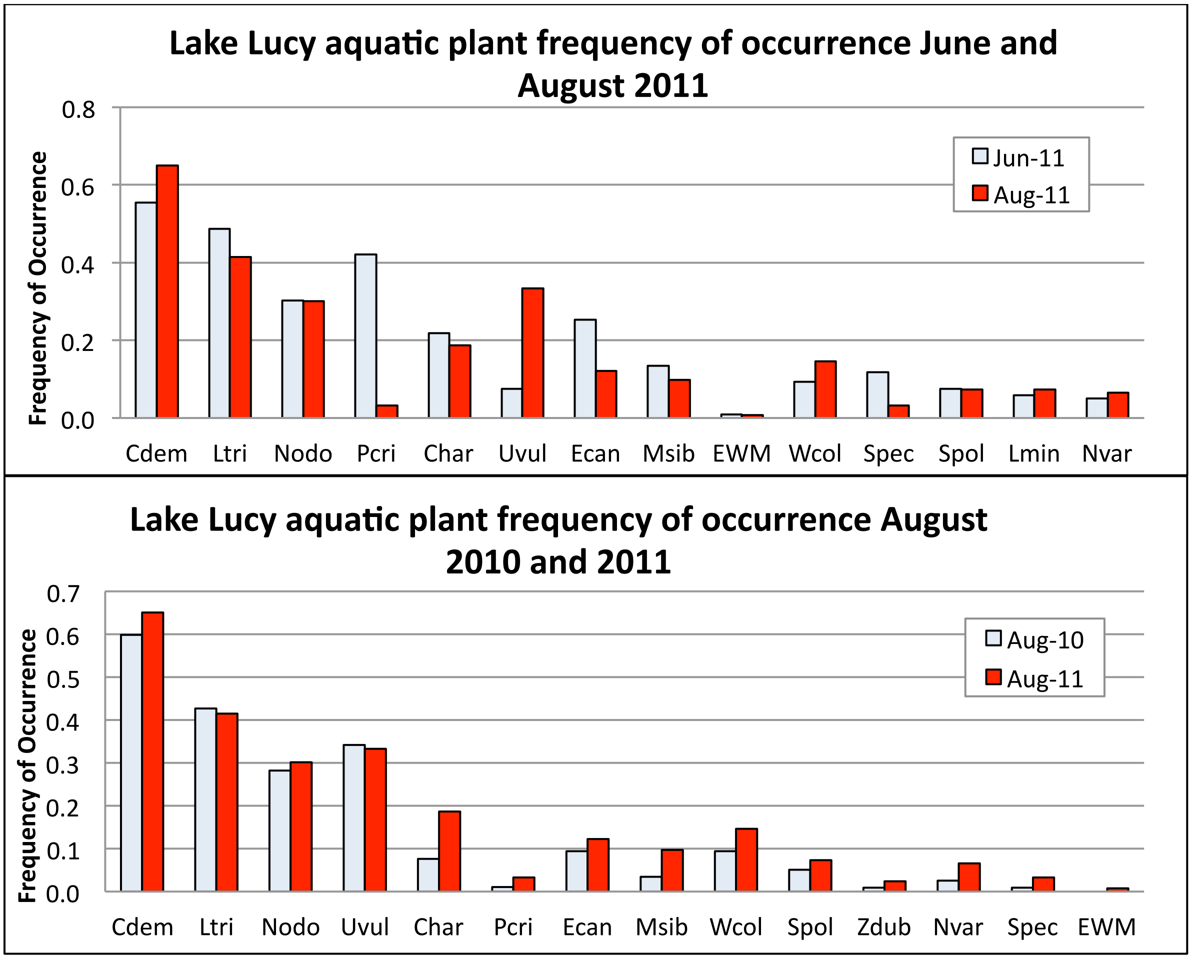


Figure 3. Comparison of frequency of occurrence by species of aquatic plants found in Lake Lucy during surveys done June and August 2011(top), August 2010 and August 2011(bottom). See Table 1 for abbreviation legend.

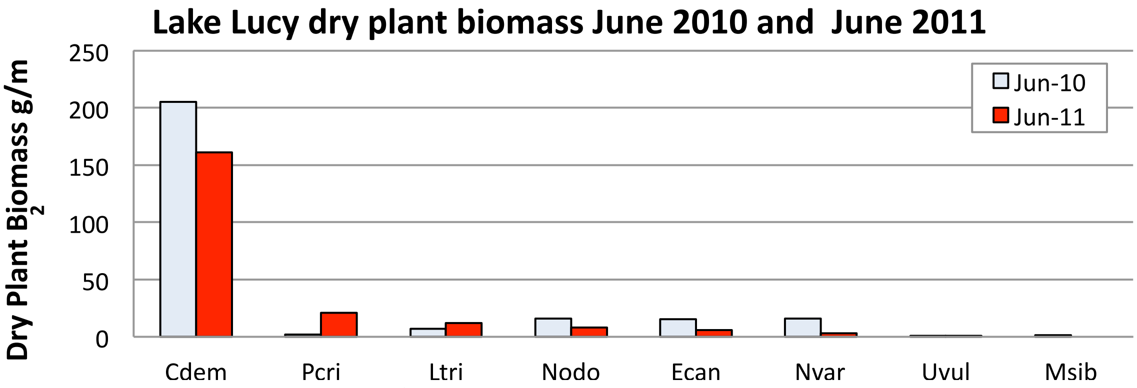


Figure 4. Dry plant biomass (g/m^2) for the most common species found in Lake Lucy in June 2010 and 2011. See Table 1 for abbreviation legend.

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).

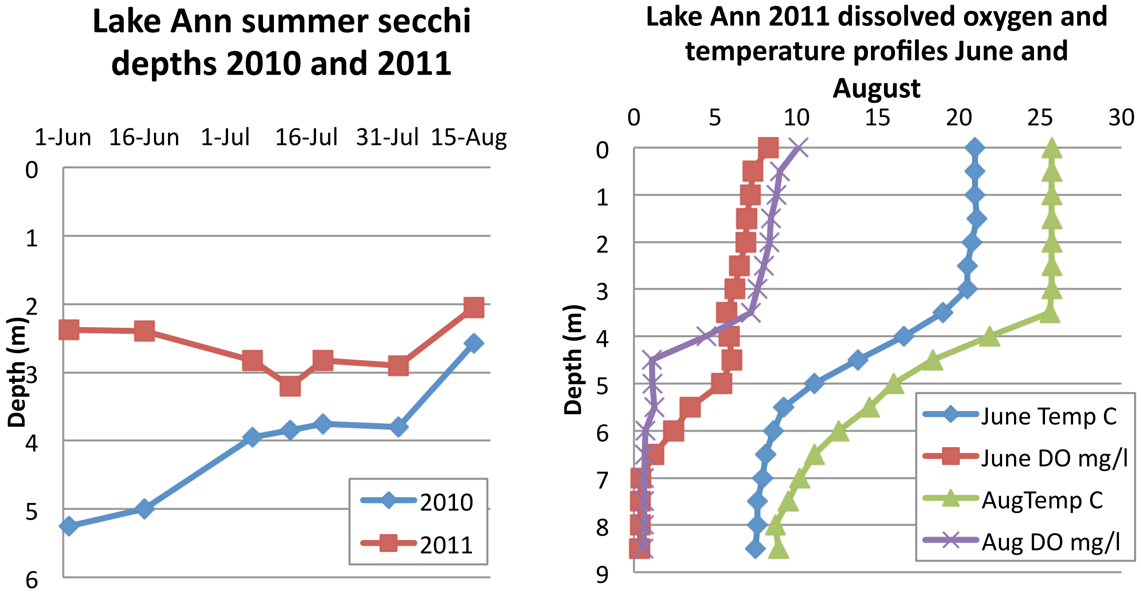


Figure 5. Midsummer Secchi depths for Lake Ann in 2010 and 2011, and temperature (^{o}C) and dissolved oxygen (mg/l) profiles taken on Lake Ann 14 June and 16 August 2011.

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

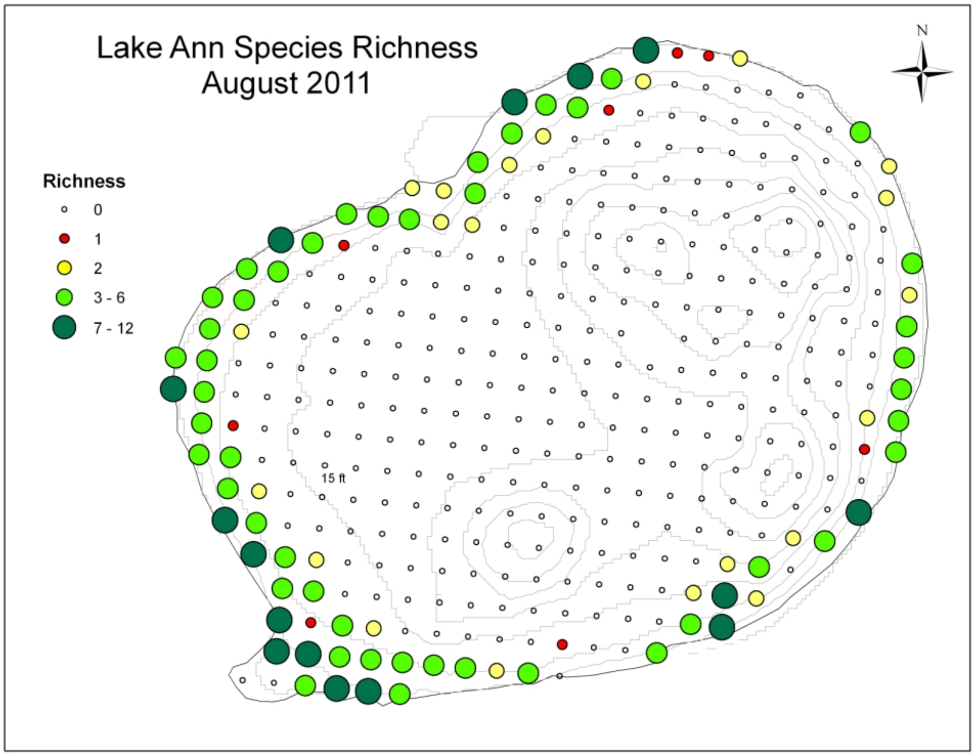


Figure 6. The number of aquatic plant species present at each site in Lake Ann, August 2011.

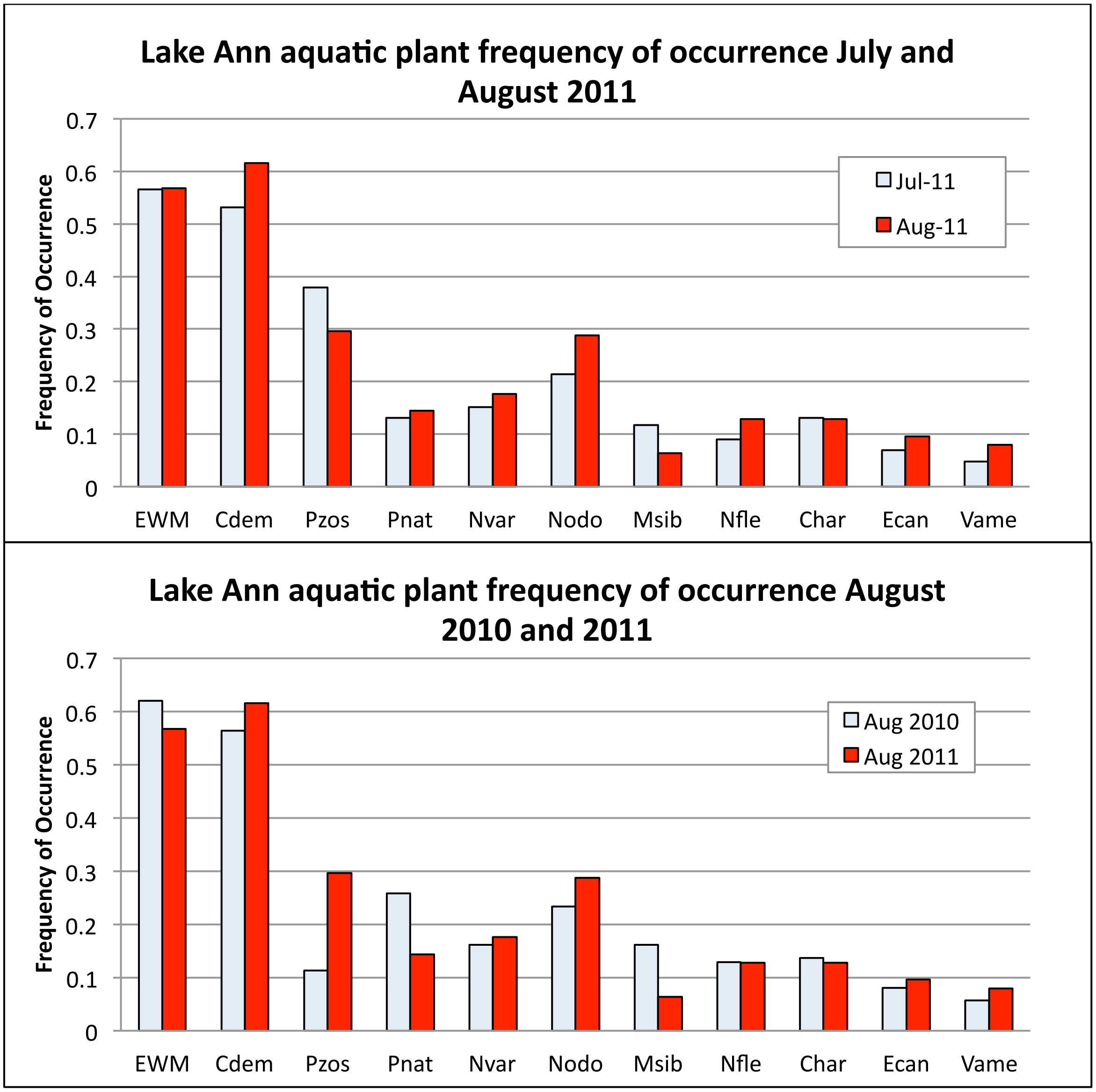


Figure 7. A comparison of the frequency of occurrence of the most common aquatic plants found in Lake Ann during surveys done July 2011 and August 2011 (top), and August 2010 and August 2011 (bottom). See Table 4 for abbreviations.

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

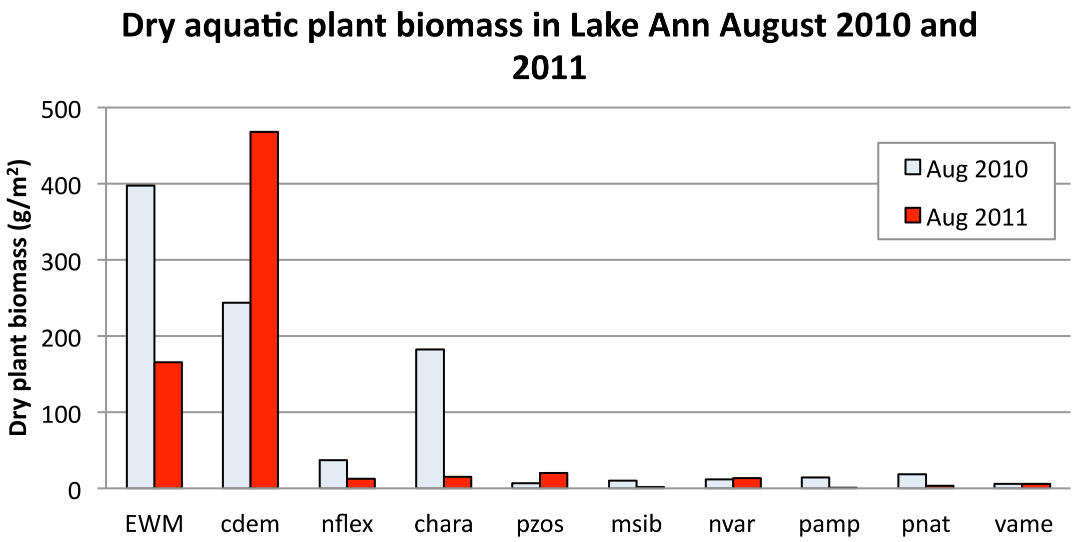


Figure 8. Dry plant biomass (g/m^2) of the most common species found in Lake Ann in August 2010 and August 2011. See Table 4 for abbreviations.

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.

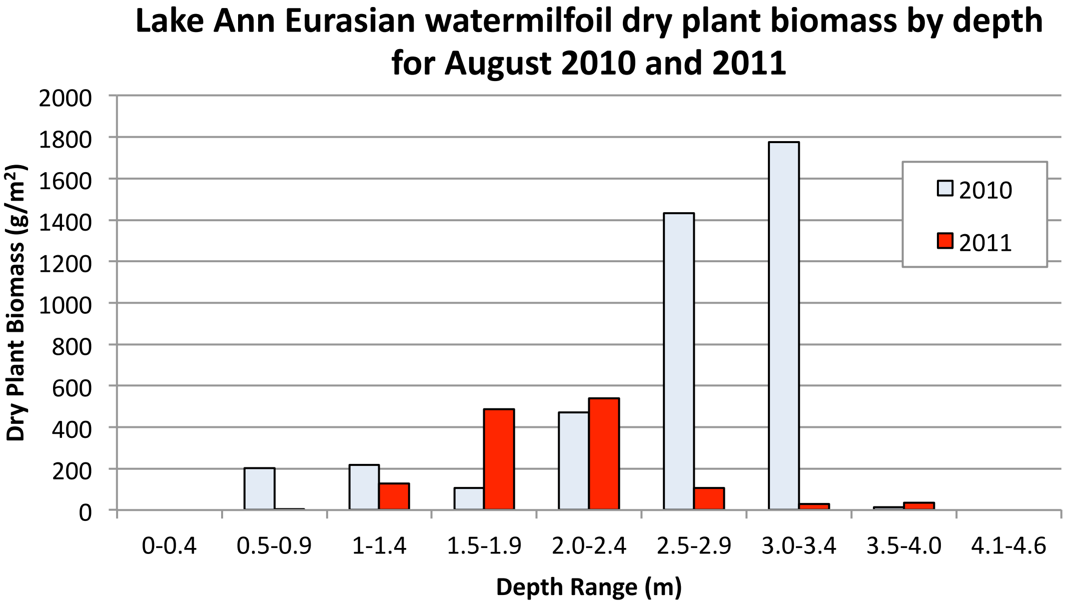


Figure 9. Mean dry plant biomass for Eurasian watermilfoil, categorized by 0.5m depth range, in Lake Ann surveyed August 2010 and 2011.

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

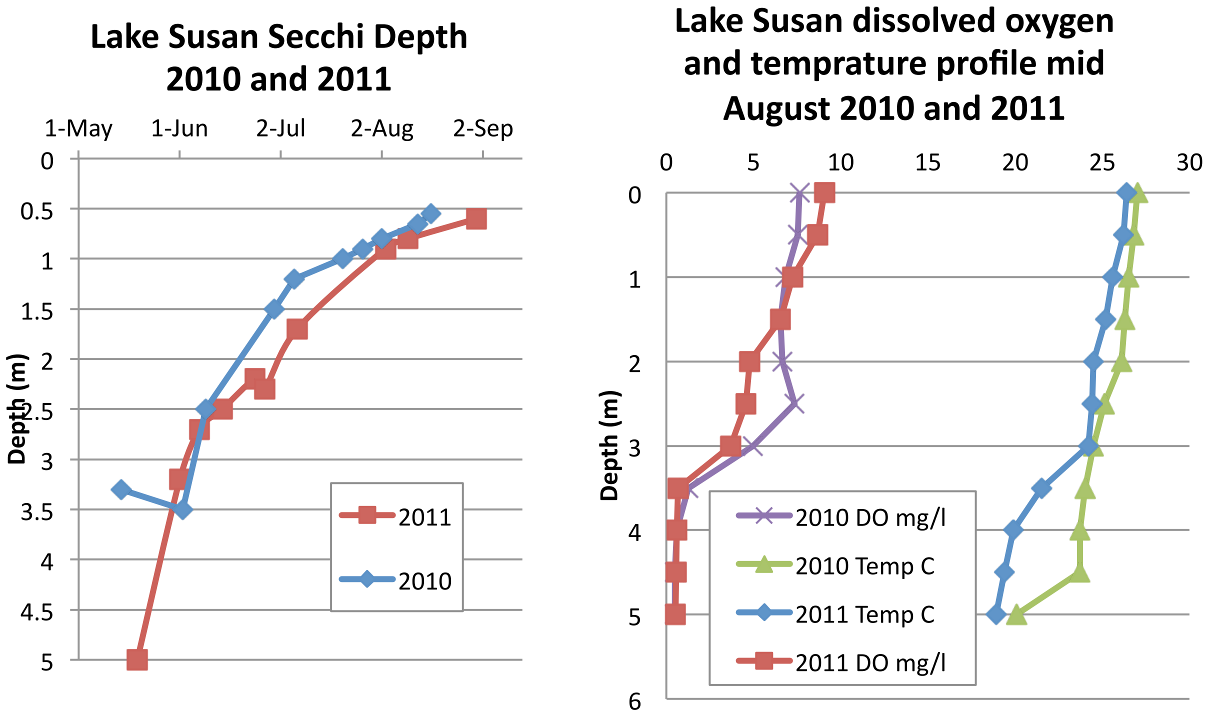


Figure 10. Secchi depth of Lake Susan throughout the summer of 2010 and 2011 and dissolved oxygen and temperature profiles from 10 August 2011.

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

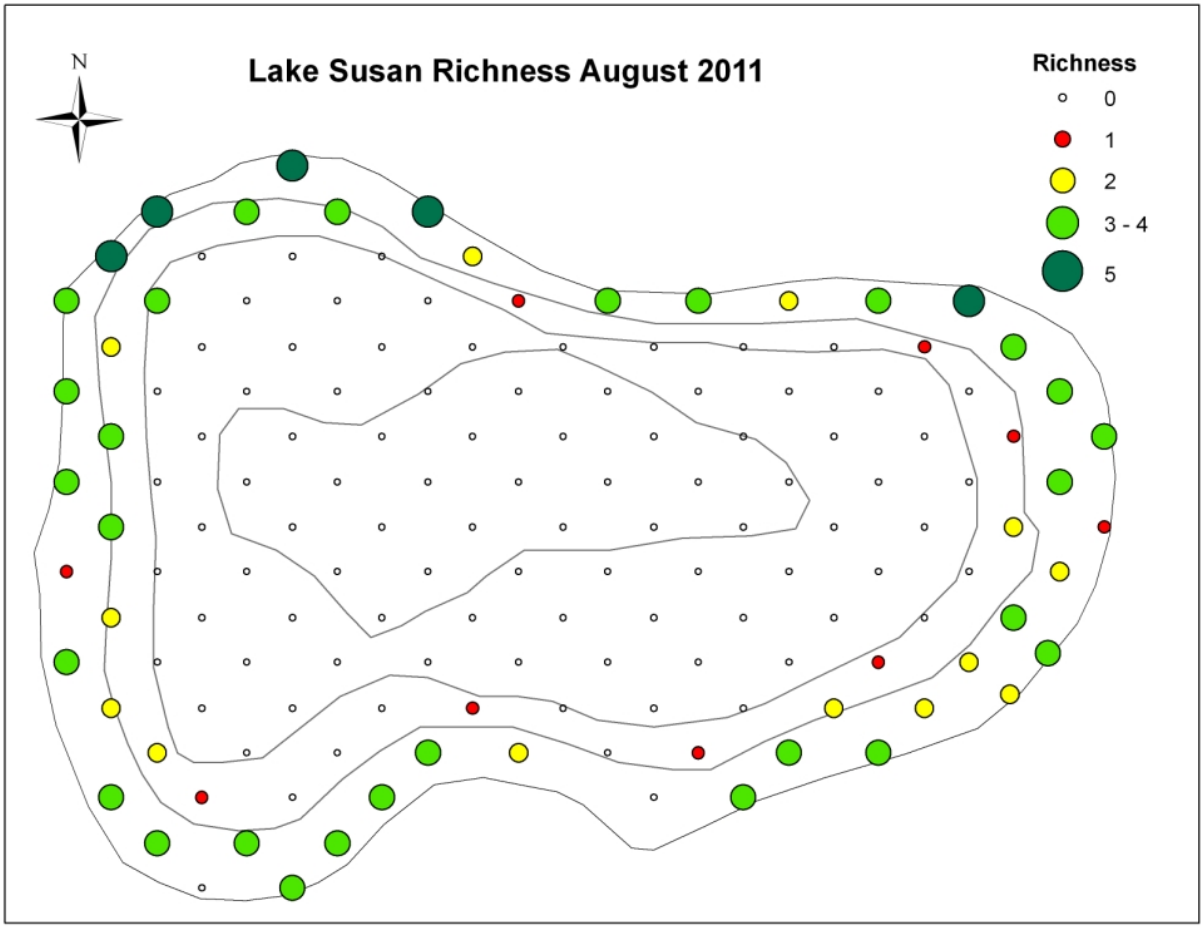


Figure 11. The number of aquatic plant species present at each site in Lake Susan, August 2011.

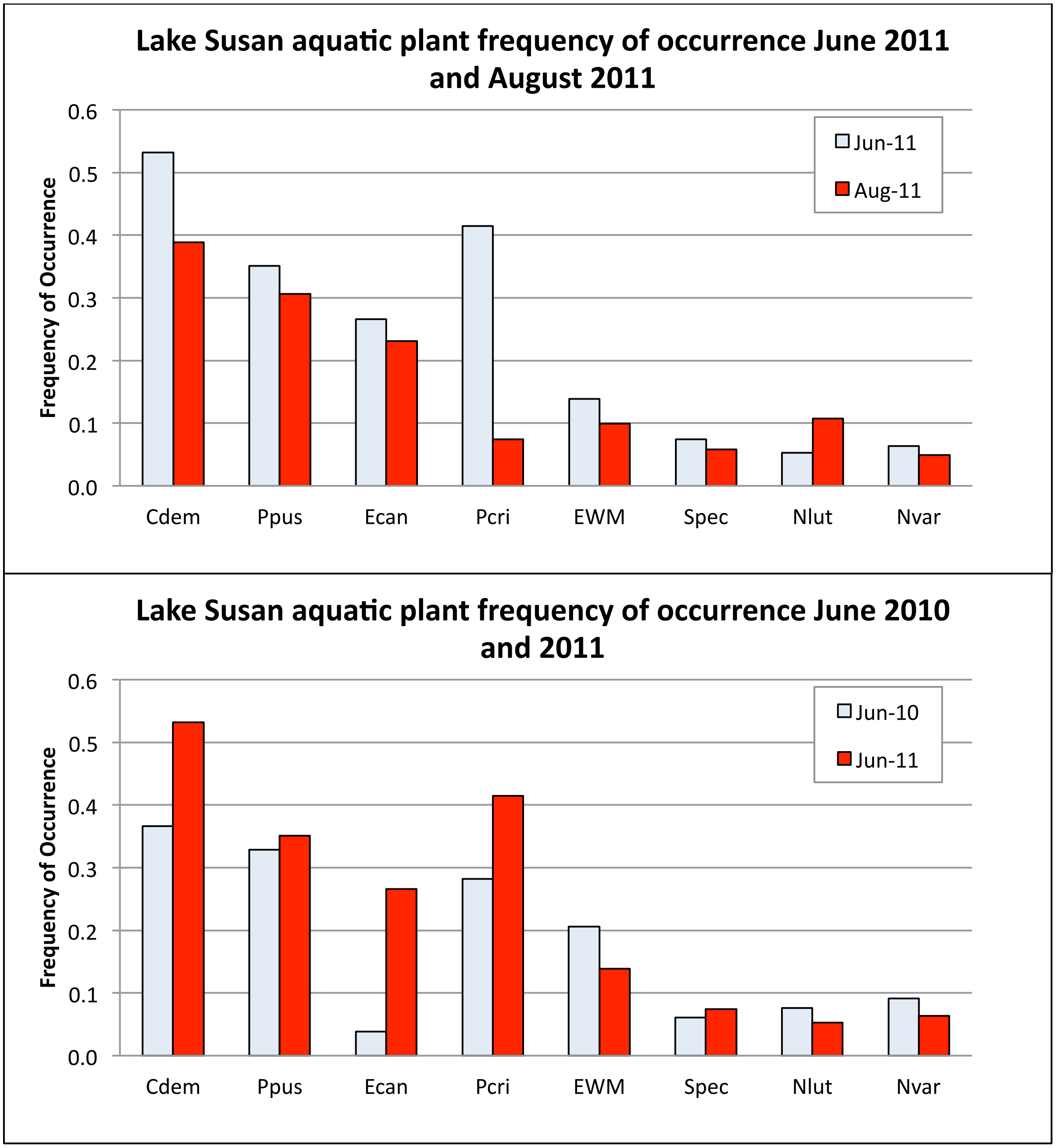


Figure 12. A comparison of the frequency of occurrence by species found in Lake Susan in June 2011 to August 2011 (top), and June 2010 to June 2011 (bottom). See Table 6 for abbreviations.

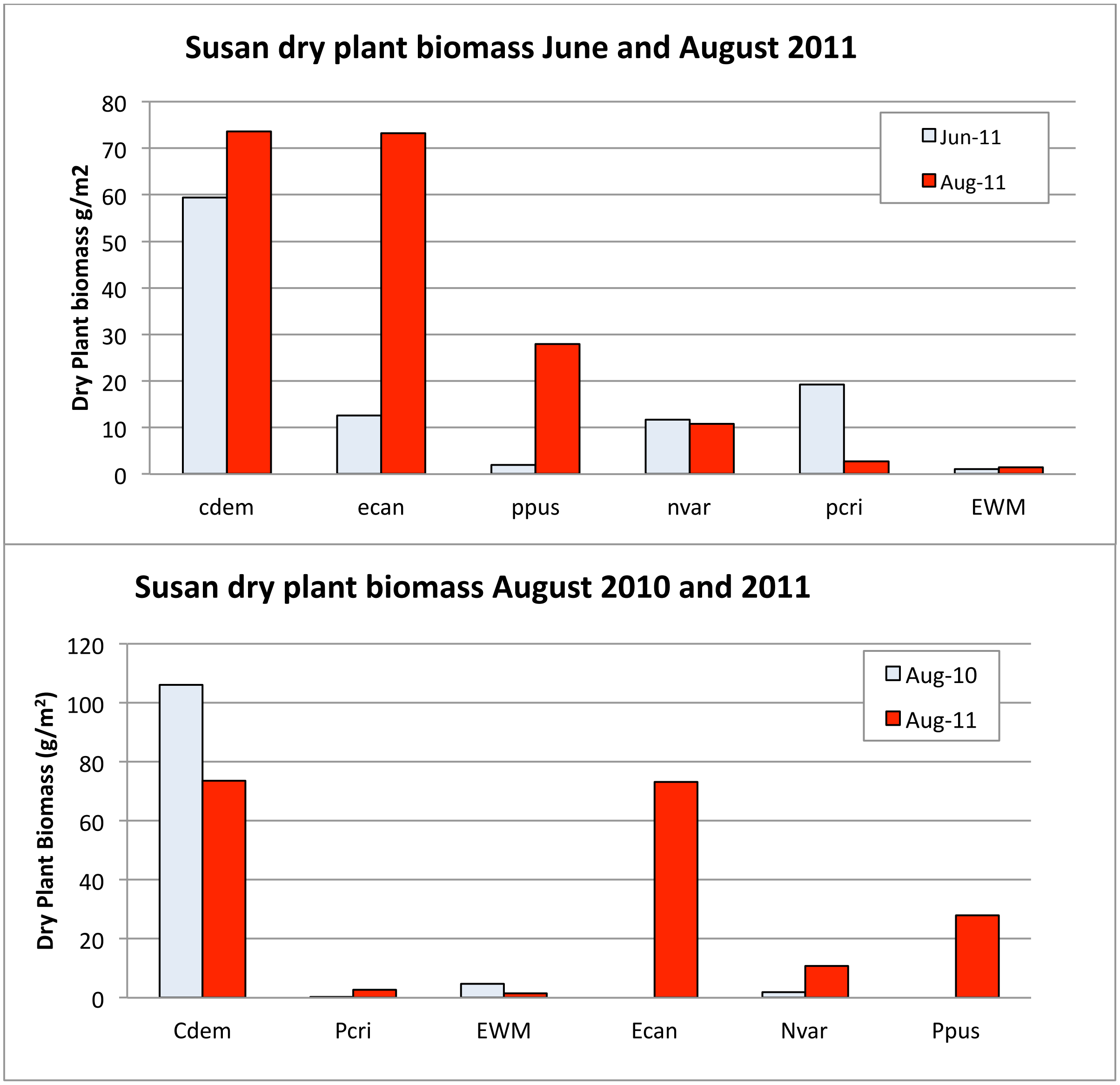


Figure 13. Comparison of dry plant biomass (g/m^2) of the most common species in Lake Susan for June 2011 to August 2011 (top), and August 2010 to August 2011 (bottom). See Table 6 for abbreviations.

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.

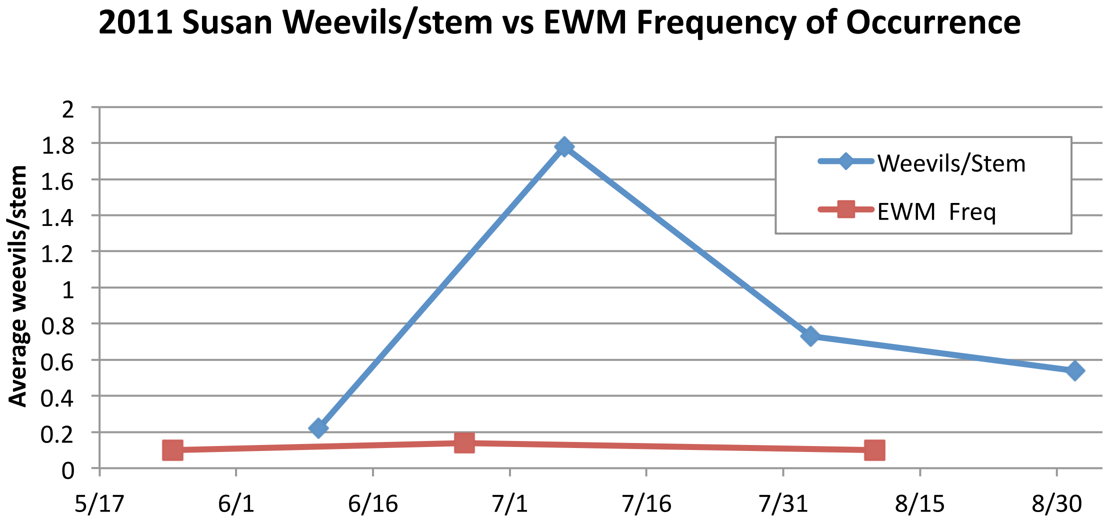


Figure 14. Abundance of weevils of any life stage per stem (blue), and the frequency of occurrence of Eurasian watermilfoil (red) in Lake Susan, 2011.

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

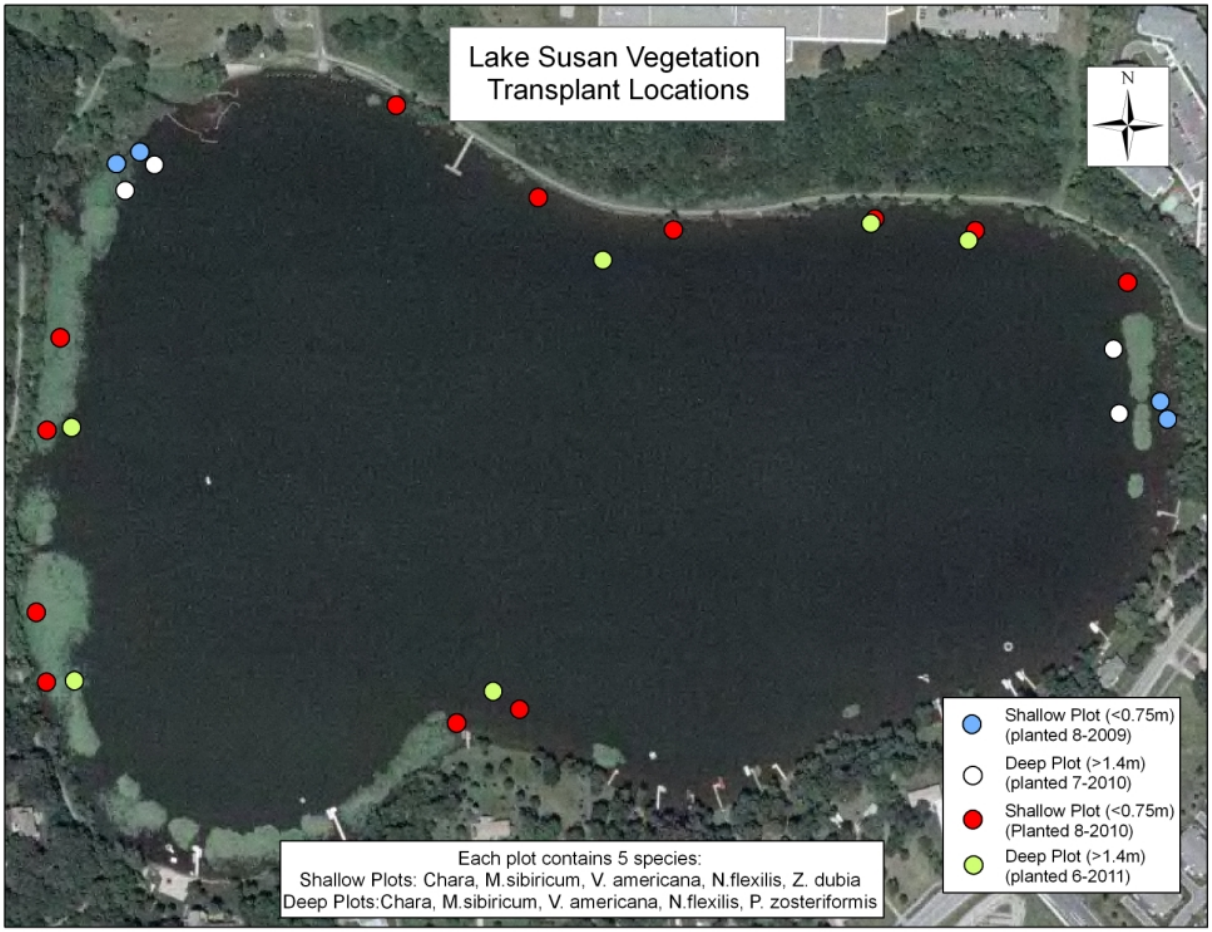


Figure 15. Locations of transplant plots in Lake Susan. Each plot contains five sites with one species planted at each site.

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.

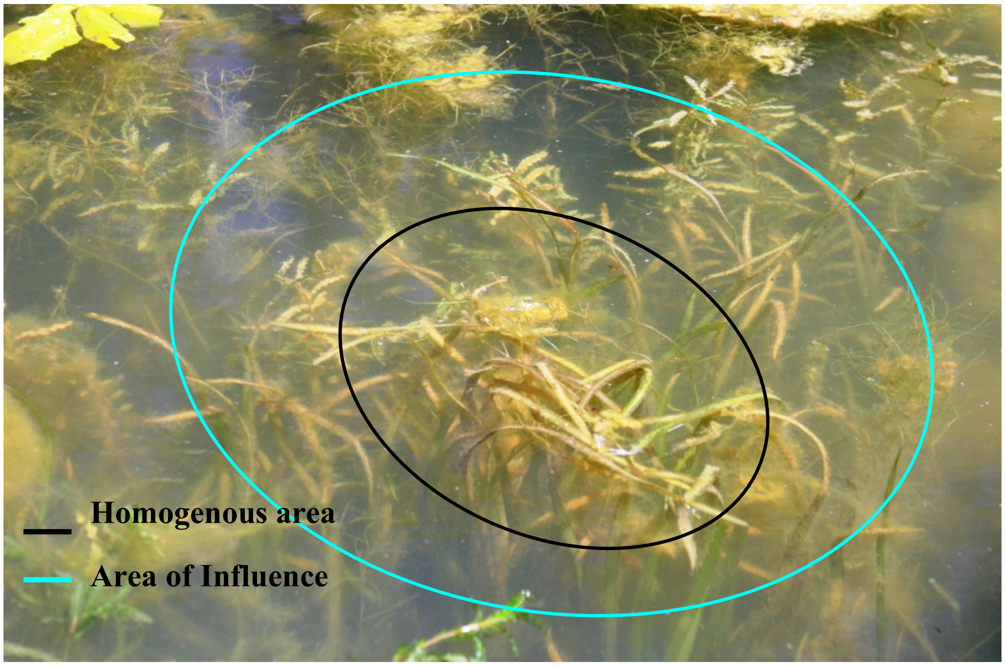


Figure 16. Example of plant growth assessment, wild celery (*Vallisneria americana*) at site 35

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

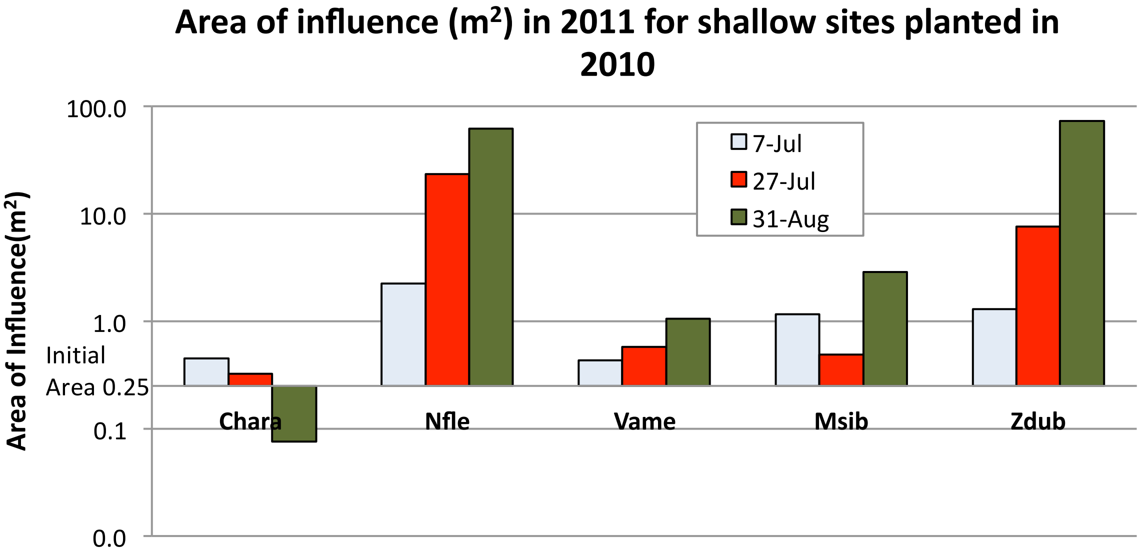


Figure 17. The mean area of influence (maximum expansion in 2011) of species transplanted in shallow water (0.5 to 1.0m) in summer 2010. Means calculated for all sites, including successful and failed sites. Note that each site started as covering $0.25m^2$ and the area scale is logarithmic. See Table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

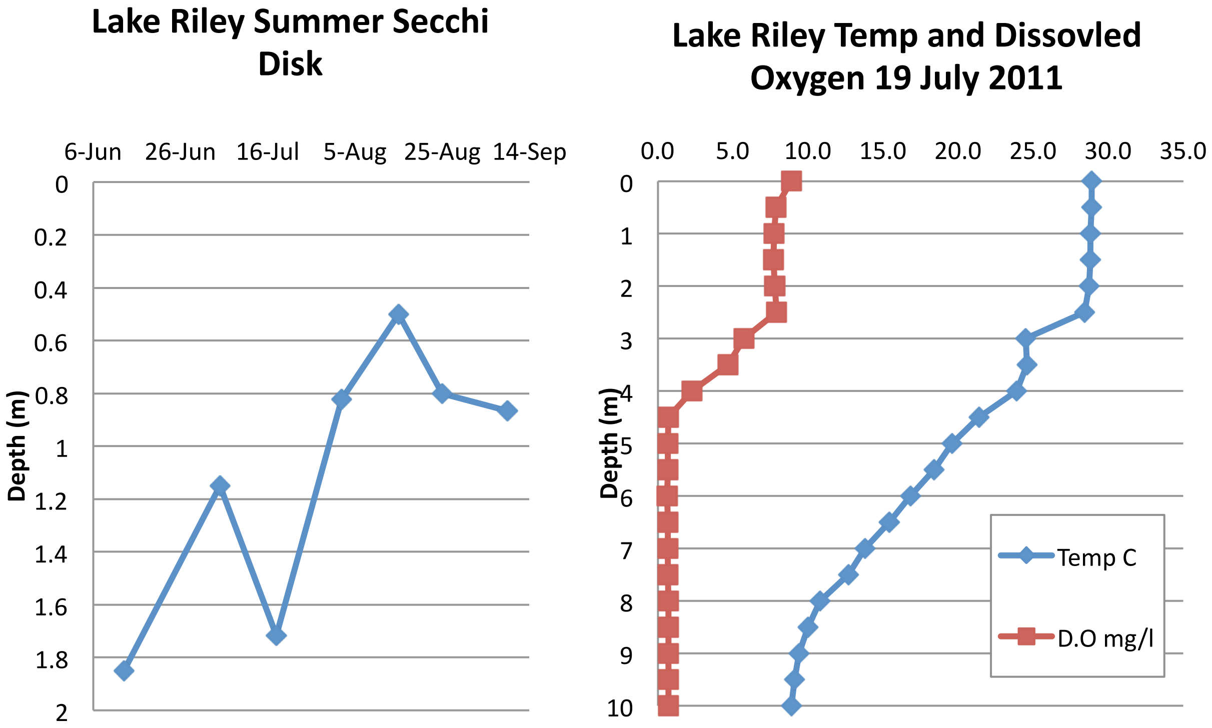


Figure 18. Lake Riley summer Secchi disk and typical summer temperature and dissolved oxygen profile from 2011.

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

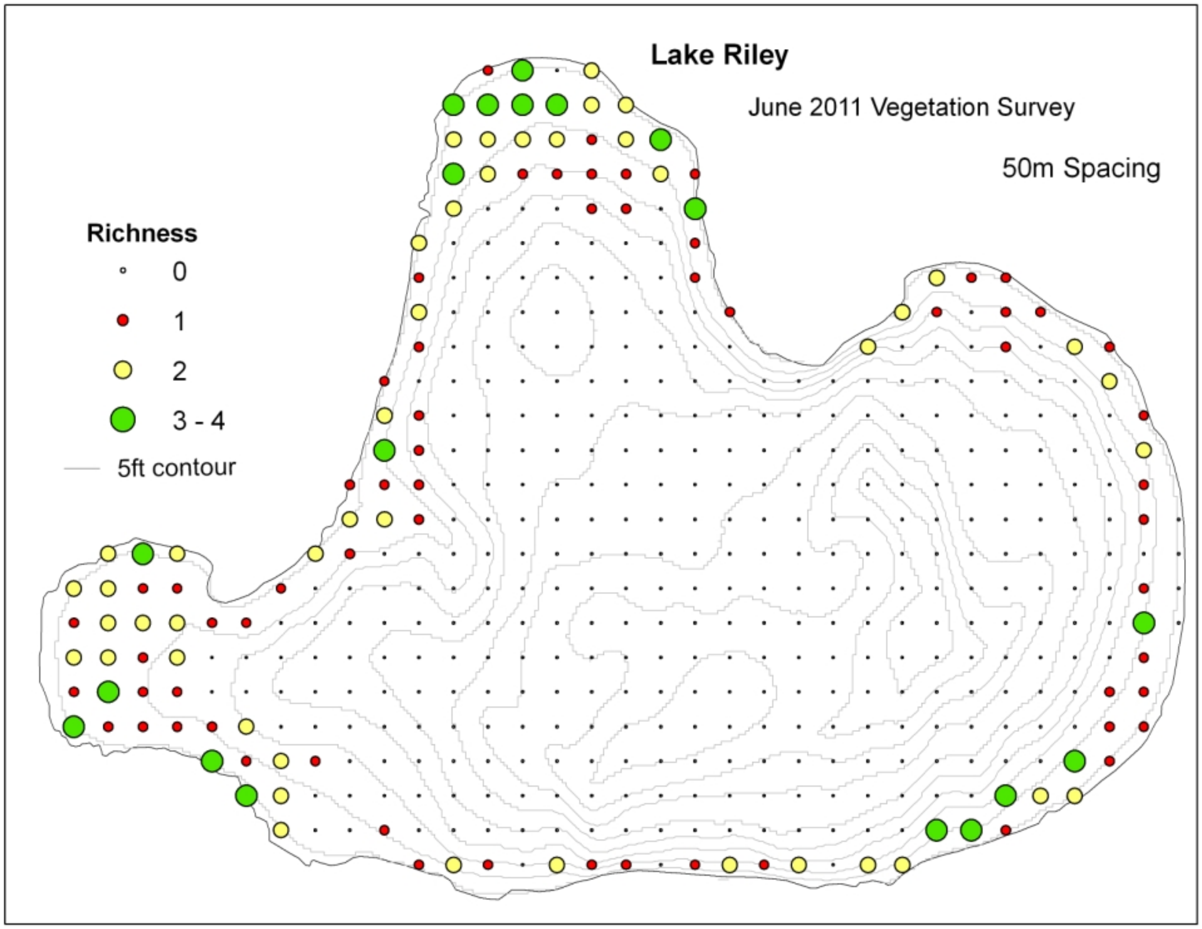


Figure 19. Sampling point locations and the number of species found per site in Lake Riley.

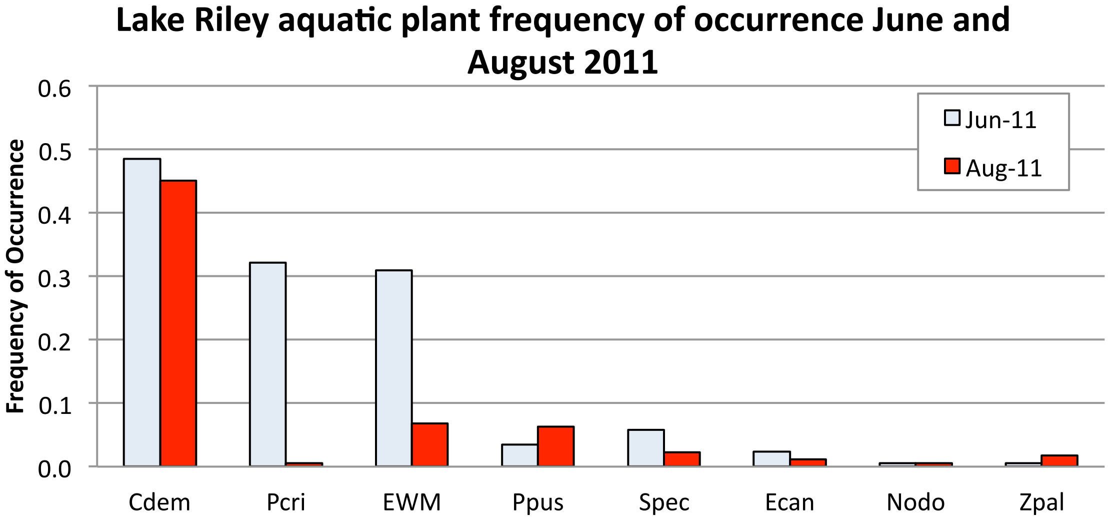


Figure 20. Frequency of occurrence of submerged aquatic plants in Lake Riley June and August 2011. See Table 12 for abbreviations.

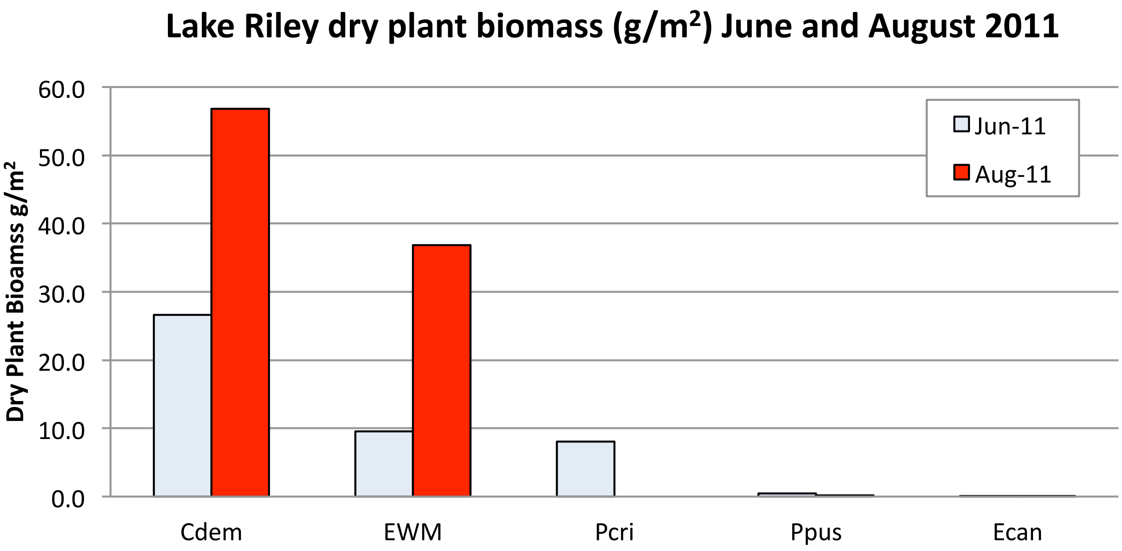


Figure 21. Dry plant biomass (g/m^2) for surveys conducted in Lake Riley June and August 2011. See Table 12 for abbreviations.

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:

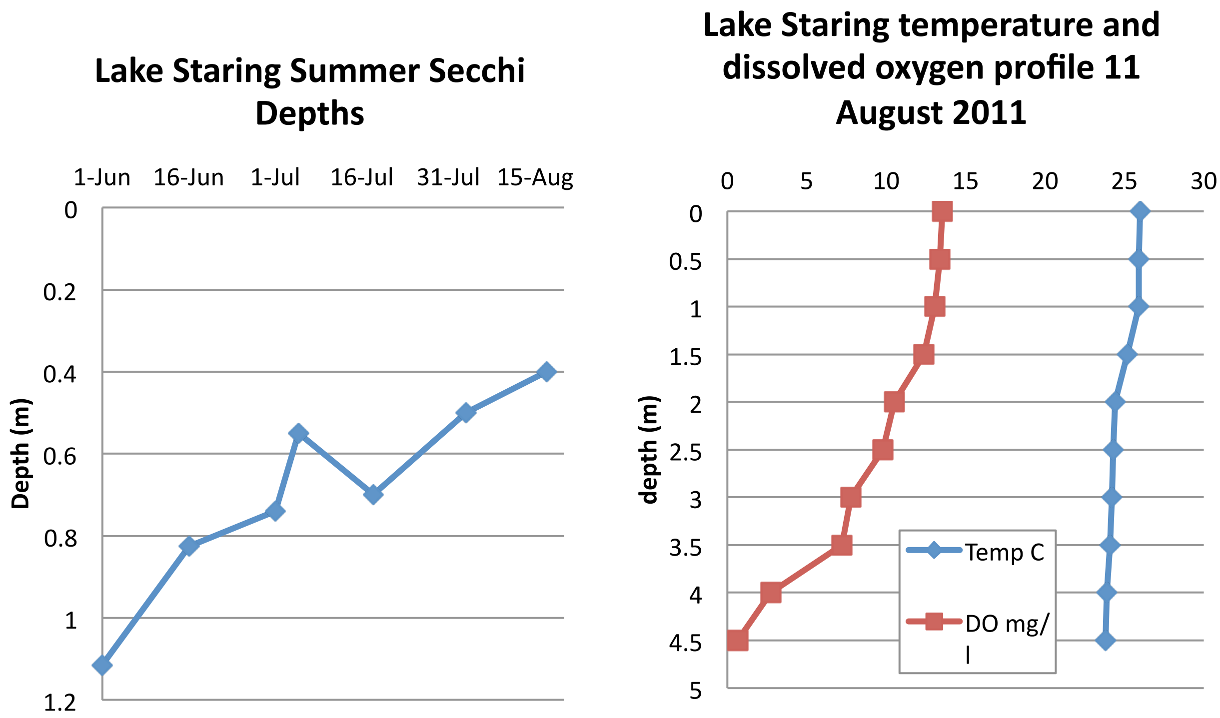
- Work with lake association on vegetation management.
- Conduct one vegetation and one herbivore survey in mid-summer.
- Provide guidance and recommendations on future management based on objectives and preferences of the lake association.

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.


Lake Staring Summer Secchi Depths

Lake Staring temperature and dissolved oxygen profile 11 August 2011

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.

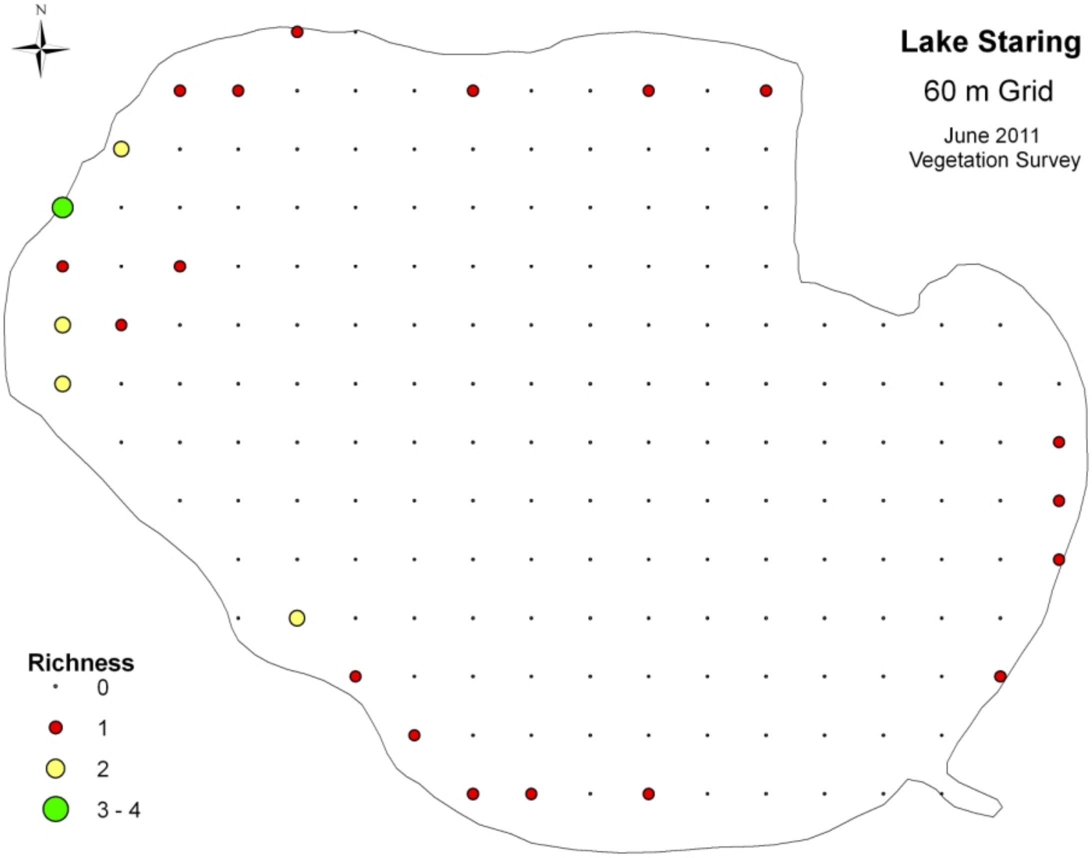


Figure 23. Sampling point locations and the number of species of aquatic plants found in Lake Staring June 2011.

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

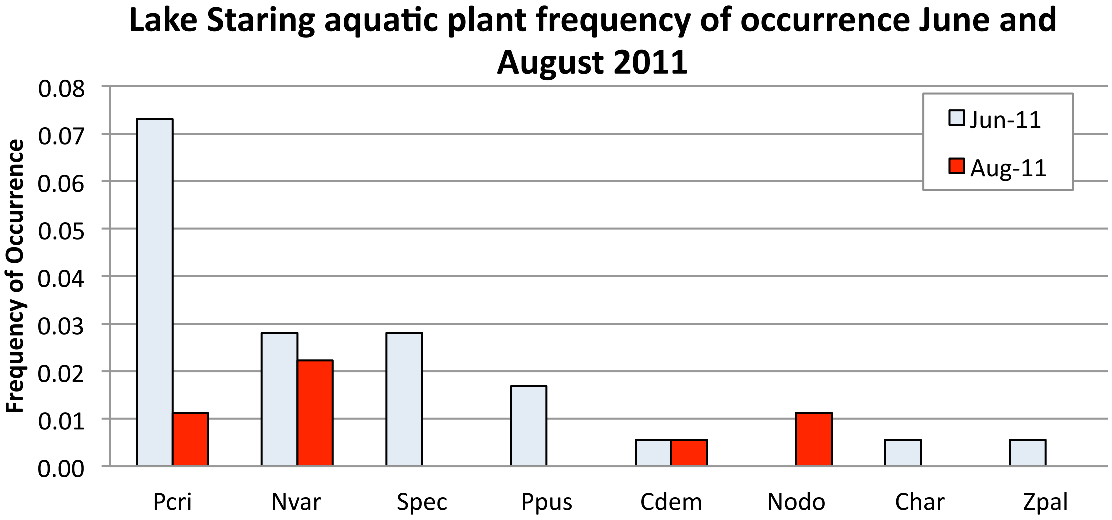


Figure 24. Frequency of occurrence of submerged aquatic plants in Lake Staring June and August 2011. Note the scale is considerably smaller than for other lakes. See Table 15 for abbreviations.

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 Susan Loading Analysis – Existing Conditions

Lake Susan Loading Analysis - Existing Conditions

Watershed	Model Watershed Reference	Device Name	Area (acre)	Surface Outflow TP (lbs/yr)	TP Trapped (Removed) (lbs/yr)	Removal Efficiency (%)
LS-1.1	52	1.1p	23.0	7.92		
LS-1.2	53	1.2p	28.3	10.75		
LS-1.3	50	1.3p	14.6	5.51		
LS-2.1	58	2.1	47.4	0.67	4.44	84.57
LS-2.11	39	2.11	13.9	1.08	5.00	79.84
LS-2.12	49	2.12p	13.4	104.25		
LS-2.13	43	2.13	20.1	5.83	10.27	62.87
LS-2.14	44	2.14	3.2	0.28	0.32	51.40
LS-2.15	47	2.15	4.5	0	2.03	94.86
LS-2.2	45	2.2	24.9	13.96	2.30	14.13
LS-2.3	46	2.3	73.8	20.27	9.13	31.00
LS-2.4	48	2.4	47.6	98.31	70.02	40.87
LS-2.5	40	2.5	34.1	9.48	3.34	25.98
LS-2.6	42	2.6	16.8	3.94	12.19	73.15
LS-2.7	41	2.7	4.3	0.83	0.87	50.88
LS-2.9	38	2.9	46.0	6.62	12.87	65.10
LS-3.11	2	3.11	27.0	6.37	8.11	55.58
LS-3.12	3	3.12	2.4	2.04	5.15	68.63
LS-3.13	4	3.13	10.3	3.95	2.41	37.79
LS-3.14	12	3.14	64.4	38.21	3.21	7.73
LS-3.21	5	3.21	43.4	21.88	20.84	48.62
LS-3.22	9	3.22	3.4	2.2	1.22	35.70
LS-3.31	7	3.31	28.9	25.69	6.50	20.17
LS-3.32	8	3.32p	8.5	8.35		
LS-3.33	6	3.33p	12.5	38.79		
LS-3.34	32	3.34	7.6	0.1	4.60	94.65
LS-3.35	35	3.35	25.8	5.18	21.52	79.03
LS-3.36	31	3.36	8.5	0.01	9.17	96.54
LS-3.37	33	3.37	63.7	43.12	63.08	58.84
LS-3.38	29	3.38p	12.4	2.48		
LS-3.39	34	3.39	4.9	1.3	1.55	54.35
LS-3.41	25	3.41	16.0	1.13	4.19	76.91
LS-3.42	36	3.42p	13.2	6.51		
LS-3.43	26	3.43	27.6	11.32	10.66	48.26
LS-3.44	27	3.44	11.6	12.25	6.94	35.80
LS-3.45	37	3.45	6.2	1.07	1.62	59.61
LS-3.46	28	3.46	15.6	2.63	4.91	64.16
LS-3.51	24	3.51	34.4	3.25	29.01	87.24
LS-3.52	23	3.52	19.5	12.55	9.26	42.40
LS-3.61	18	3.61	4.7	0.87	2.24	70.81
LS-3.62	19	3.62	12.4	1.44	2.42	61.67
LS-3.63	22	3.63	46.5	24.43	27.17	52.36
LS-3.71	17	3.71p	15.3	9.34		
LS-3.72	20	3.72	8.5	1.87	7.32	78.03
LS-3.78	15	3.78	13.3	10.21	12.67	54.90
LS-3.79	11	3.79	12.3	2.29	3.70	61.25
LS-3.81	13	3.81p	20.6	7.17		
LS-3.87	57	3.87p	11.5	11.56		
LS-3.88	55	3.88	8.4	4.26	5.30	55.28
LS-3.89	14	3.89p	16.6	5.52		
LS-3.91	56	3.91p	33.9	10.18		
LS-3.92	54	3.92p	16.7	4.52		
LS-3.93	16	3.93p	16.5	18.81		
LS-3.94	10	3.94p	28.7	68.75		
LS-3.95	21	3.95p	10.3	5.26		
LS-3.96	30	3.96p	20.2	6.68		
LS-3.98	51	3.98p	11.4	3.91		

▨ No BMP Treatment in watershed