MADISON LAKE MANAGEMENT PLAN

Topical Report RSI-2403

prepared for

Madison Lake Watershed and Lake Association
P.O. Box 218
Madison Lake, Minnesota 56063

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RESPEC
CONSULTING & SERVICES

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Topical Report RSI-2403

by

Andrea B. Plevan
Joe M. Pallardy

RESPEC
P.O. Box 725
Rapid City, South Dakota 57709

prepared for

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Madison Lake, Minnesota 56063

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1.0 INTRODUCTION

Madison Lake is one of the more popular lakes in south-central Minnesota and is an important local resource. Covering 1,404 acres and with a maximum depth of 59 feet, Madison Lake is one of the larger and deeper lakes in the region. Recreational opportunities on Madison Lake include fishing, swimming, boating, sailing, and skiing; these opportunities are all important to the local economy. Madison Lake was selected as one of 24 lakes to be included in the Minnesota Department of Natural Resource's (DNR) Sustaining Lakes in a Changing Environment (SLICE) program. Lakes in the SLICE program are the focus of a multiagency approach to improve understanding of how climate change, agriculture, development, and invasive species will affect the ecology of lakes across the state.

Madison Lake is located in Blue Earth County and portions of its watershed extend into LeSueur County and Waseca County. The City of Madison Lake is located along the northwest shoreline, and the remaining shoreline is located in Le Ray Township and Jamestown Township.

Madison Lake and the majority (92 percent) of its watershed are located in the North Central Hardwood Forests (NCHF) Ecoregion. Whereas a small portion (8 percent) of the lake's watershed is in the Western Corn Belt Plains Ecoregion, the lake eutrophication standards for the NCHF Ecoregion apply to the lake[1]. Madison Lake was placed in the Minnesota Pollution Control Agency's (MPCA) inventory of impaired waters in 2010; aquatic recreation on the lake is impaired based on an assessment of nutrient/eutrophication biological indicators. All three water-quality indicators of eutrophication do not meet the state standards (Table 1-1). The MPCA is developing a Total Maximum Daily Load (TMDL) for Madison Lake, which is expected to be completed in 2014.

Table 1-1. Lake Eutrophication Standards and Madison Lake 2008 Water Quality

Parameter	Numeric Criteria (North Central Hardwood Forests Ecoregion)	Madison Lake
Phosphorus (µg/L)	≤ 40	75
Chlorophyll-*a* (µg/L)	≤ 14	27
Secchi depth (m)	≥ 1.4	1.1

µg/L = micrograms per liter
m = meter

[1] Eutrophication standards for lakes in the Western Corn Belt Plains Ecoregion are as follows: ≤ 65 µg/L TP, ≤ 22 µg/L chlorophyll-*a*, ≥ 0.9 m Secchi depth.

The Madison Lake Watershed & Lake Association (MLWLA) is a nonprofit organization with the purpose of organizing and educating all those concerned with Madison Lake, including lakeshore owners, area residents, and visitors, about best practices for maintaining water quality, fish resources, and wildlife resources. The MLWLA would like to develop a lake management plan to guide implementation efforts. The goals of the lake management plan are to achieve the following:

- Improve water quality in the lake and make progress toward delisting the lake from the impaired waters list.
- Enhance and protect the aquatic recreation uses of the lake, including fishing, swimming, boating, sailing, and skiing.

Progress toward these goals will be made through a combination of implementing best management practices (BMPs) in the watershed and along the shoreline; managing invasive aquatic plant species in the lake, specifically curly-leaf pondweed (CLP) and Eurasian water milfoil (EWM); educating stakeholders on the importance of watershed management; and educating lakeshore owners on nearshore BMPs.

This report consists of two components: a diagnostic assessment, and a watershed and lake management plan. The diagnostic component includes a review of the SLICE analysis [Lindon et al., 2010], previous modeling efforts, the TMDL study that is under development, and water-quality data. Based on the results of the diagnostic assessment, a management approach is recommended. Information on the effectiveness of best management practices is included that can be used by the lake association and other stakeholders to support grant and loan applications. The plan is not meant to be prescriptive but rather to provide a menu of options for the lake association and implementation partners. The plan highlights the most appropriate practices for the lake and the watershed. Local knowledge will help the lake association target the practices, and the plan provides information needed to apply for funding for these targeted activities. The management plan focuses on practices to reduce phosphorus loads to the lake because phosphorus loads to Minnesota lakes are a primary driver of water quality. Watershed phosphorus loads must be reduced to levels that the lake can assimilate before management practices with the goal of restoring the lake's ecological interactions should be used. Many of the management practices recommended in the plan for phosphorus reductions will also reduce nitrogen loads to the lake. Lower nitrogen concentrations in the lake can help the native aquatic plant community; native plants are needed to stabilize the sediments, provide habitat, and outcompete invasive species.

2.0. DIAGNOSTIC ASSESSMENT

The purpose of the diagnostic assessment is to review relevant watershed and lake information and summarize the SLICE report [Lindon et al., 2010].

2.1 WATERSHED ASSESSMENT

The Madison Lake watershed covers 11,174 acres (including the area of Madison Lake) with a watershed to lake area ratio of 7.7 to 1, which is relatively small for Minnesota lakes. A small watershed to lake ratio is beneficial for water quality; lakes with smaller watersheds have less land to deliver sediments and nutrients (i.e., phosphorus) to the lake. County Ditch 2 drains approximately 44 percent of the watershed and is the major tributary to Madison Lake (Figure 2-1). County Ditch 2 flows through Indian Lake, Alice Lake, and several smaller wetlands before entering Madison Lake. Runoff from the direct drainage area enters Madison Lake through intermittent ditches and wetlands. The watershed model developed for Madison Lake summarizes information such as land cover and nutrient loads by the two subwatersheds defined in the model: County Ditch 2 and the direct drainage.

2.1.1 Land Cover and Land Use

The Madison Lake Watershed contains land uses that are representative of a transition from the Western Corn Belt Plains Ecoregion (WCB) to the NCHF Ecoregion. Land cover in the watershed is dominated by cropland (Figure 2-1), which represents 56 percent of the total watershed area (Table 2-1). Conventional tillage practices are used on approximately 70 percent of the cropland area. The percentage of cropland within the watershed is greater than the typical range of watersheds in the NCHF, yet it falls within the typical range observed in watersheds in the WCB [Lindon et al., 2010]. The next most dominant land cover in the watershed is wetlands, representing 24 percent of the watershed. The wetlands include several small lakes (Alice, Indian, and Born) and other wetland habitats that are more densely vegetated. The percentage of wetlands observed in the watershed is more typical of a watershed found in the NCHF Ecoregion. Developed land uses represent only 6 percent of the watershed; watersheds in both ecoregions typically have less than 16 percent of their watershed developed.

The shoreline of Madison Lake is heavily developed with lawns maintained up to the water's edge and shorelines altered by rock riprap or sand blankets. The lack of a vegetative buffer around the lake leads to higher phosphorus loading rates from the adjacent land areas, increases the potential for shoreline erosion, and reduces habitat quality. Residential development pressure exists in the undeveloped portions of the shoreline.

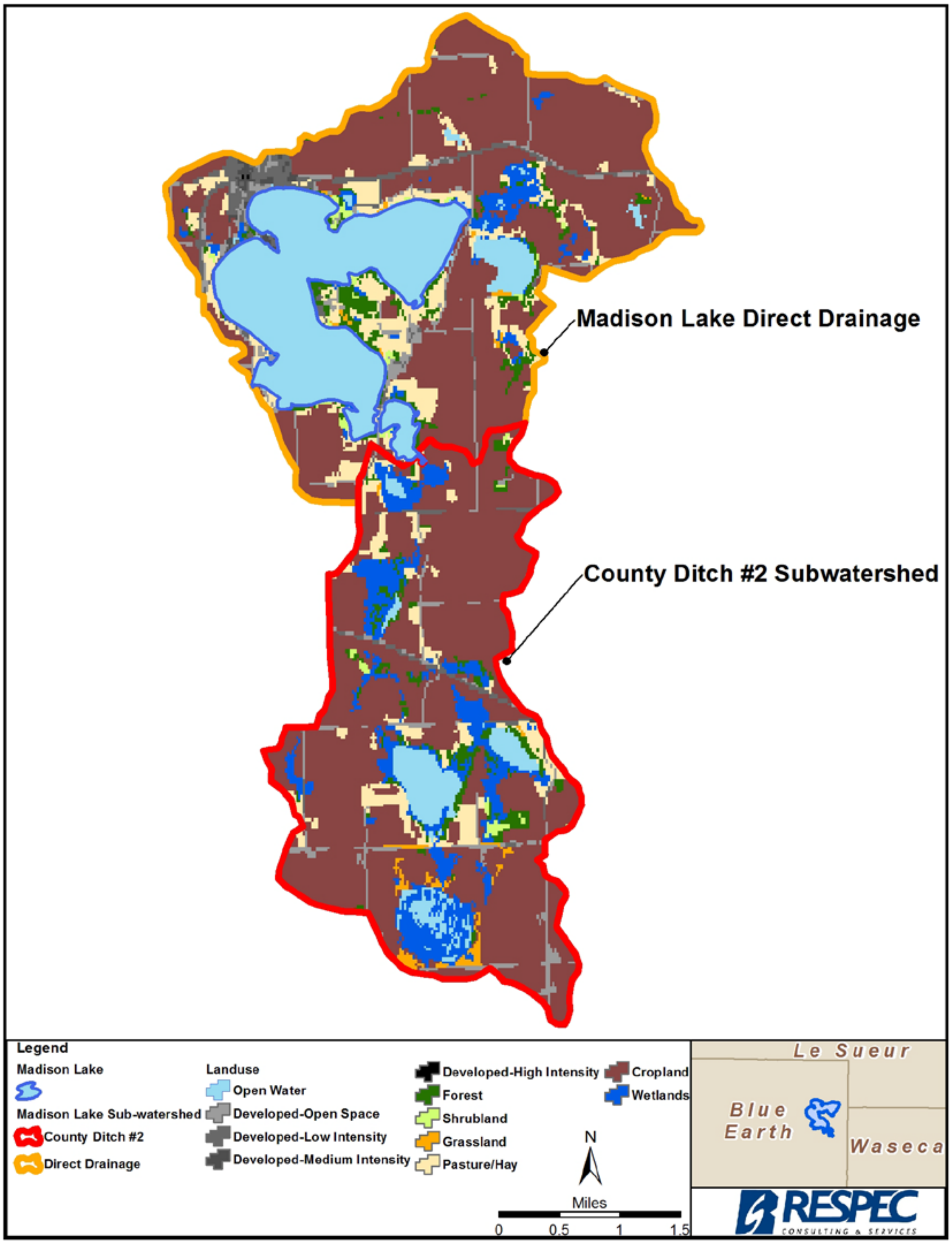

Figure 2-1. Madison Lake Watershed Land Cover.

Table 2-1. Watershed Land Cover

Land Cover	Area (acres)	Area (percent)
Cropland, Conservation Tillage	631	6.5
Cropland, Conventional Tillage	5,658	58
Developed	768	7.9
Feedlot	15	0.15
Forest	430	4.4
Grassland	149	1.5
Pasture	859	8.8
Wetland	1,261	13

Does not include Madison Lake surface area.

2.1.2 Soils

Soil type can affect hydrologic processes such as infiltration, runoff, interflow, and percolation to groundwater. Approximately one-half of the soils in the Madison Lake Watershed are poorly drained (Table 2-2, Figure 2-2), and 70 percent of the cropland is on poorly drained soils. Producers likely strive to maintain ideal soil moisture conditions in cropland by incorporating tile drainage. Installing tile drainage on poorly drained soils alters the length of time that water remains in the soil profile. Soils that are classified as poorly drained in the watershed may behave more like well-drained soils.

A stream power index (SPI) was calculated to identify watershed areas that have a high risk of erosion. Twelve locations with a high erosion potential were identified; these sites have a high SPI (greater than 1.75) and are located on soils with a high runoff potential (Figure 2-3).

Table 2-2. Soil Drainage Class

Drainage Class	Area (acres)	Area (percent)
Open Water	1,850	17
Very Poorly Drained	2,391	21
Poorly Drained	2,667	24
Somewhat Poorly Drained	225	2.0
Moderately Well-Drained	1,625	15
Well-Drained	2,417	22

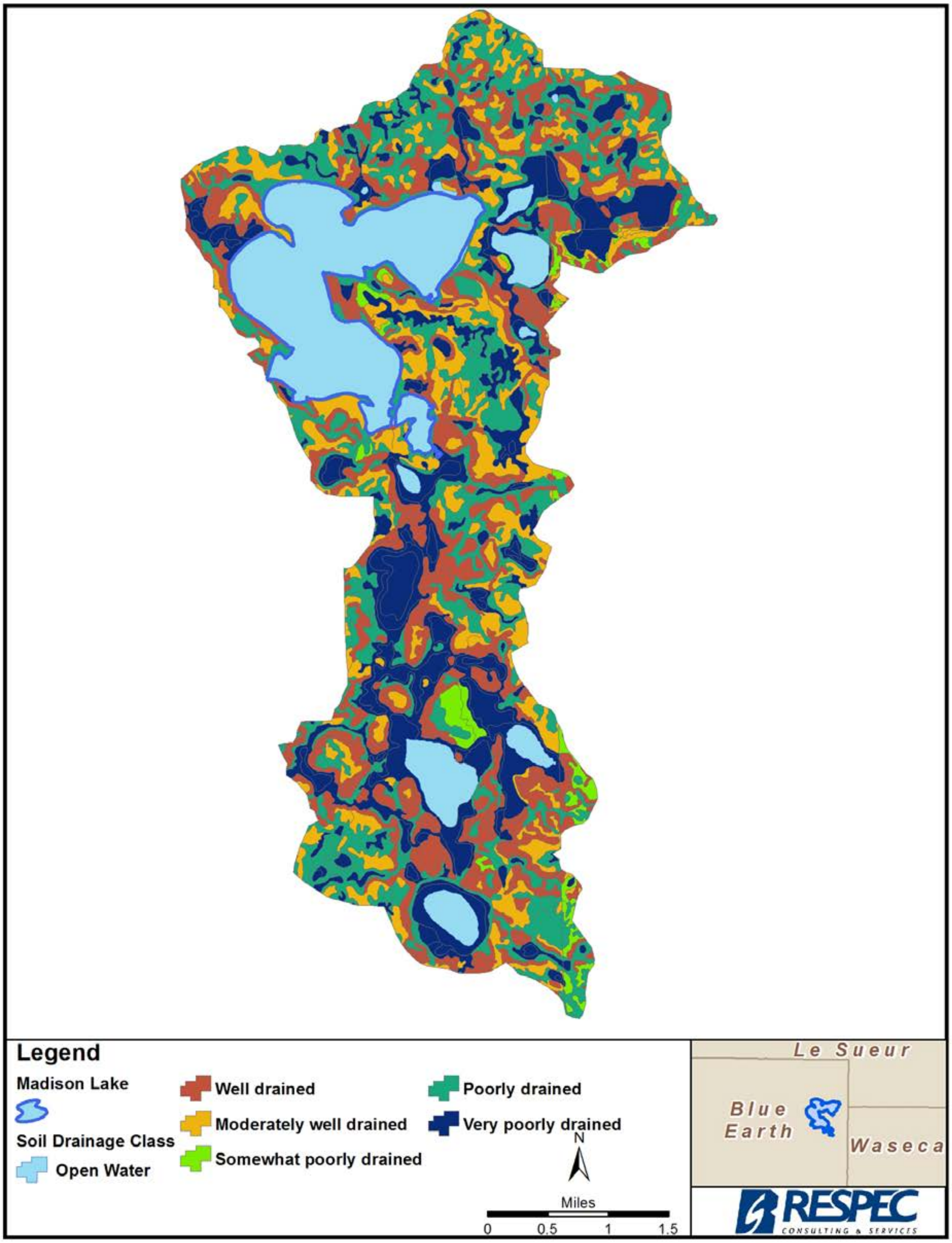

Figure 2-2. Madison Lake Watershed Soil Drainage Class.

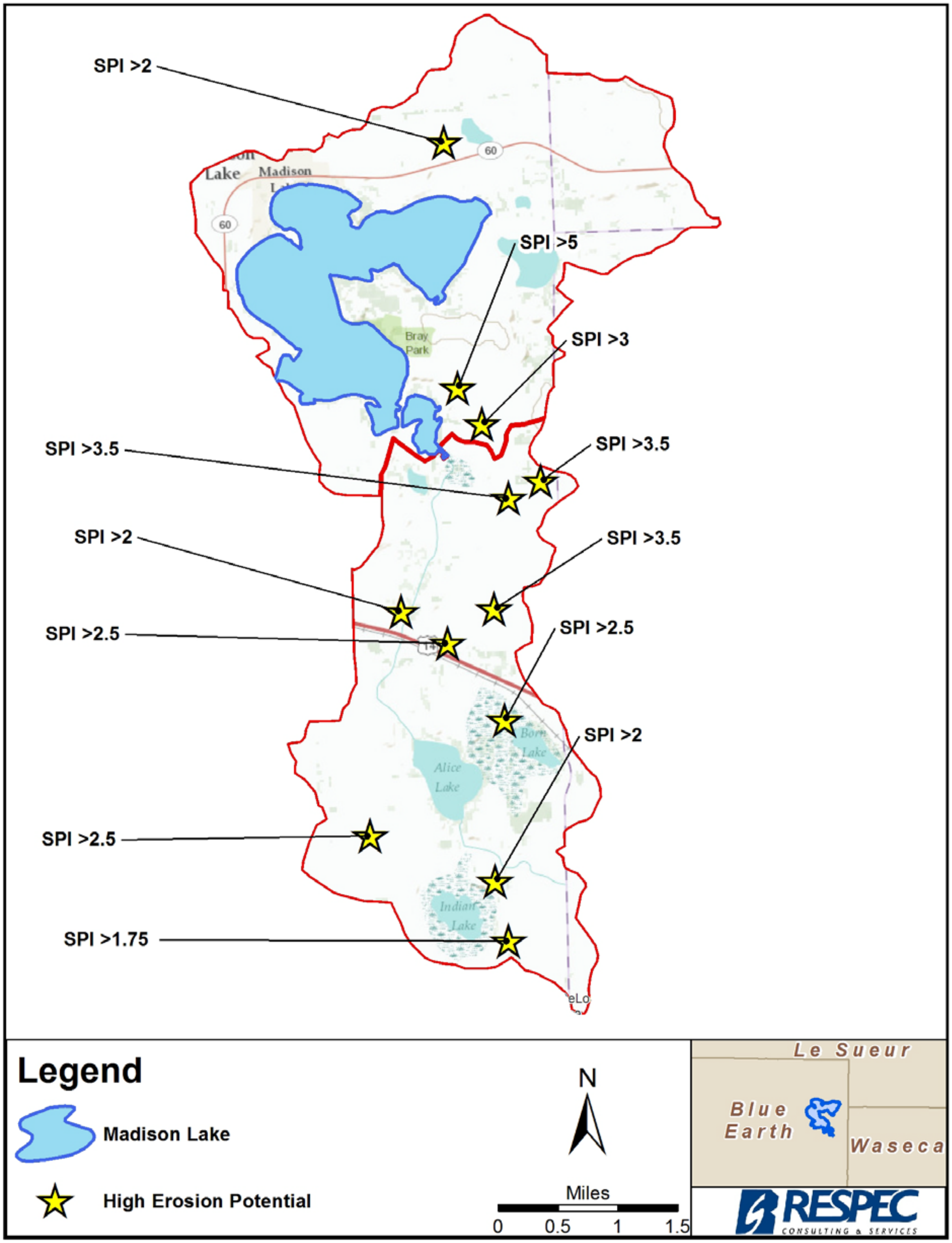

Figure 2-3. Madison Lake Watershed Sites With a High Erosion Potential.

2.1.3 Phosphorus Loading

Phosphorus loads to Minnesota lakes are a primary driver of water quality. In many freshwater lakes, the addition of phosphorus leads to more algae and plant growth. Higher concentrations of algae in a lake decrease the water clarity and can impair the ecological structure and function of a lake and recreational activities on the lake. Nitrogen is another primary nutrient that plants and algae use, and nitrogen concentrations are often elevated in watershed runoff from agricultural areas. An overabundance of nitrogen in a lake can decrease the plant species richness in shallow lakes [James et al., 2005]. However, because algal growth in most Minnesota lakes is primarily driven by phosphorus concentrations, watershed phosphorus loads are the main focus of this diagnostic assessment and management plan. Many of the management practices recommended in the plan for phosphorus reductions will also reduce nitrogen loads to the lake.

Results from a watershed modeling effort completed in conjunction with the MPCA were used to evaluate the watershed phosphorus loads to Madison Lake. The modeling program Hydrological Simulation Program—FORTRAN (HSPF) was used to simulate watershed runoff volumes and phosphorus loads. HSPF contains components to address runoff and constituent loading from pervious land surfaces, runoff and constituent loading from impervious land surfaces, flow of water in stream reaches, and transport/transformation of chemical constituents in stream reaches. Model inputs include meteorological time-series data, watershed characteristics, and point sources. Watershed runoff and water-quality loads are simulated from a number of land covers, including agriculture, urban, forest, and pasture. The results of the model include time series of the runoff, flow rate, and sediment and nutrient concentrations and loads coming into and leaving a given lake or stream (i.e., Madison Lake).

The model simulations were compared with water-quality data collected by volunteers through the Citizen Stream Monitoring Program (CSMP) in 2012 and 2013. The model application simulates phosphorus concentrations from 1996 through 2009. Even though this period does not overlap with the time during which the CSMP data were collected, the monitoring data can be compared to the simulated data with the expectation that the range of monitored concentrations will fit within the range of simulated concentrations.

In 2012 and 2013, data were collected from April through midsummer, after which little or no flow was observed at the sampling locations. Site 5 from the CSMP corresponds to Reach 675 in the HSPF model application, which is where County Ditch 2 discharges into Madison Lake. The phosphorus concentrations at Site 5 fall within the range of those simulated by the model (Figure 2-4), indicating that the model application simulates a reasonable range of phosphorus concentrations.

The simulated flows and phosphorus loads to Madison Lake from County Ditch 2, which is the lake's main tributary, are highest in June. Phosphorus concentrations are also highest in June, and average approximately 250 µg/L. This average concentration is substantially higher than the MPCA's draft total phosphorus criteria for streams in the NCHF Ecoregion (100 µg/L) and the draft criteria for streams in the Western Corn Belt Plains Ecoregion (150 µg/L).

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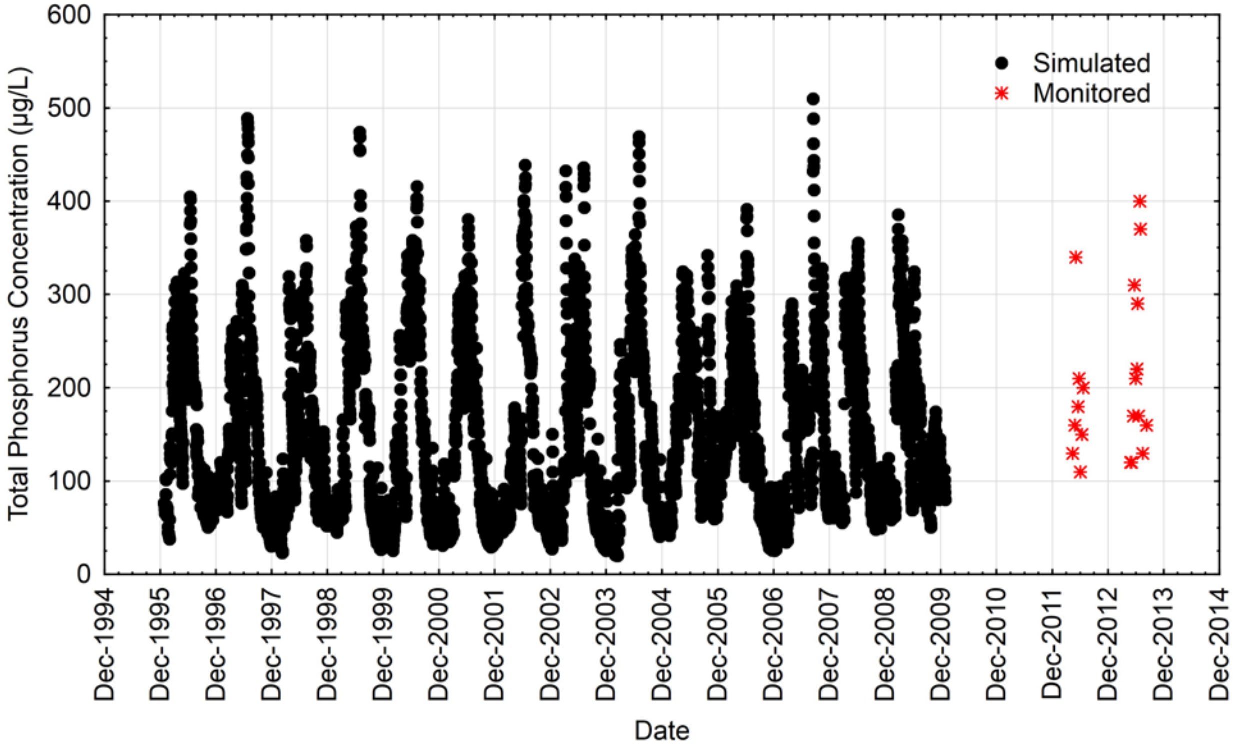

Figure 2-4. Comparison of Simulated Data With Data Collected at Site 5 Through the Citizen Stream Monitoring Program at County Ditch 2.

The majority (87 percent) of the watershed phosphorus load is from cropland, and the majority of the cropland is under conventional tillage practices (Table 2-3). The next highest load comes from developed areas, followed by septics, pasture, and other sources that represent less than 1 percent of the watershed load to the lake.

2.2 LAKE ASSESSMENT

The lake assessment is a summary of the data and discussion from the SLICE report [Lindon et al., 2010]. Additional water-quality monitoring data and aquatic vegetation survey data that were collected after the SLICE data collection effort ended in 2009 are also included where applicable.

2.2.1 Morphometry

Madison Lake's surface area covers approximately 1,450 acres. Madison Lake has three distinct bays, each with unique morphometric characteristics (Figure 2-5). Bay 3 (to the northeast) is the most shallow of the three bays, with a maximum depth of 5 to 10 feet. Shallow areas such as these (typically less than 15 feet deep) are referred to as the littoral zone and they represent the areas where rooted submergent and emergent vegetation can live.

Table 2-3. Watershed Phosphorus Loads by Source

Source	Average Annual P load, 1996–2009 (kg/yr)			Total P Load (percent)
	County Ditch 2	Direct Drainage	Total	
Forest	1.09	0.902	1.99	0.13
Cropland, Conservation Tillage	122	0	122	8.0
Cropland, Conventional Tillage	626	576	1,202	79
Grassland	3.76	1.69	5.45	0.4
Pasture	16.0	19.2	35.2	2.3
Wetland	3.15	0.670	3.82	0.25
Feedlot	7.39	1.12	8.51	0.56
Developed	26.3	74.2	101	6.6
Septic	19.1	20.3	39.4	2.6
Internal reach processes	10.0	0	10.0	0.65
Total	**835**	**694**	**1,529**	**100**

The largest and deepest bay is Bay 1 (to the southwest), which reaches a maximum depth of 58 feet. Bay 2 is a small but deep bay in between Bays 1 and 3. Bays 1 and 2 are separated by a narrow shallow area, while Bays 2 and 3 together form a more connected segment of the lake. These differences in depth and connection with other bays influence the aquatic plant community, fisheries, and water quality in each bay.

2.2.2 Lake Level

Lake-level measurements on Madison Lake date back to 1939 when lake levels began to increase following the severe droughts of the 1930s (Figure 2-6). Lake levels have generally remained slightly below the ordinary high water mark of 1,017.0 feet above sea level since the 1940s with the exception of drought periods in 1976 and 1988.

2.2.3 Vegetation

The vegetation in Madison Lake is dominated by the invasive species CLP and EWM. CLP has been commonly observed in Madison Lake since it was first observed in 1970. The growth cycle of CLP follows a pattern of high growth in early spring followed by large die-offs in summer that release phosphorus into the water column. This pattern is typical of many lakes in

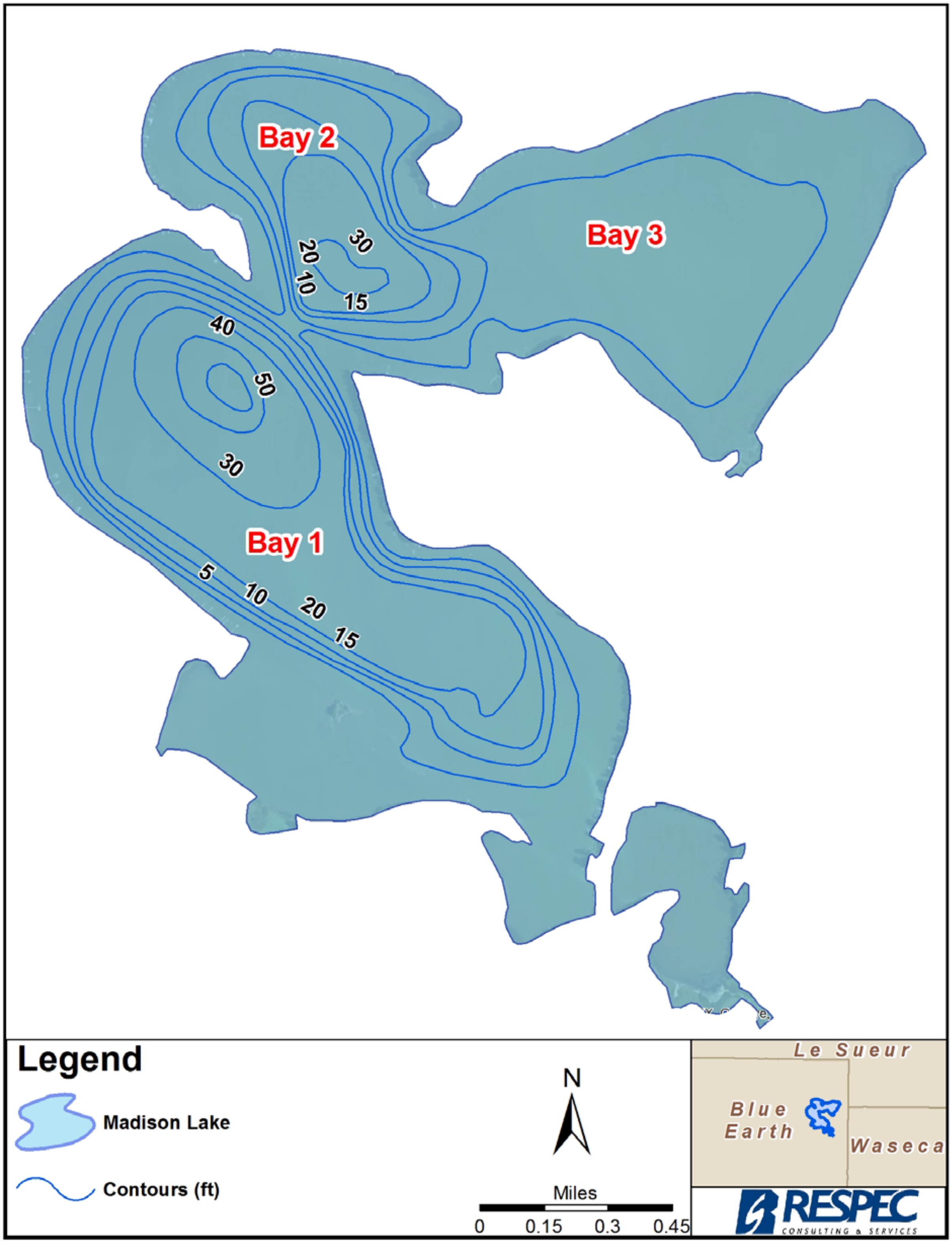

Figure 2-5. Lake Water Depth.

southern Minnesota where CLP forms large monocultures. In the absence of native plants, the CLP die-off is often followed by algae blooms; the higher amount of available phosphorus and the higher light availability fuels these blooms.

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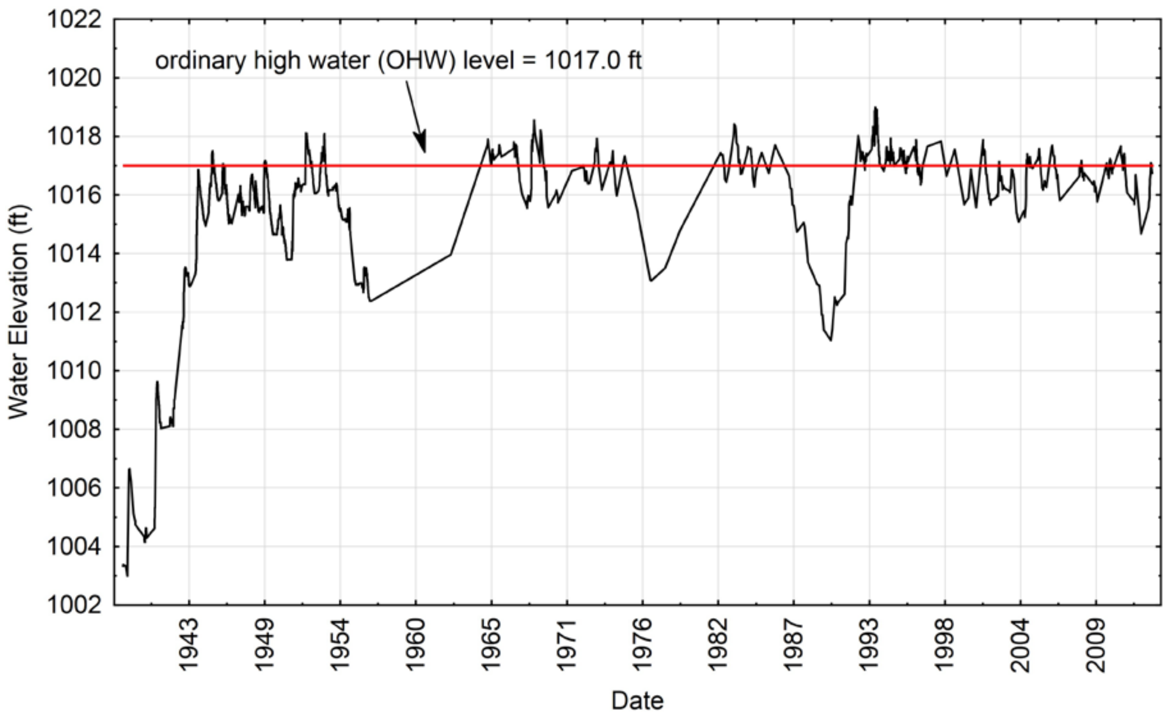

Figure 2-6. Lake Water Elevation.

EWM was first observed in Madison Lake in 2010 [Gamble, 2013]. EWM can form thick stands of underwater vegetation that interfere with aquatic recreation. Higher densities of EWM are more often observed in lakes with few native plants. The plant does not negatively impact water quality.

Aquatic plant surveys were completed in August 2008, June 2009, and August 2013. The surveys show aquatic vegetation typical of a eutrophic lake that has high densities of nonnative invasive species and low densities and diversity of native species (Figure 2-7). CLP coverage and density were high in the June 2009 survey (see Figure 14 in the SLICE report [Lindon et al., 2010] for CLP distribution from the June 2009 survey). The plant community contained some native species that are tolerant to intermediate levels of disturbance. The surveys from 2008 and 2013 were performed in August, after die-off of CLP. In August 2008, the majority of the littoral zone was devoid of aquatic vegetation. The 2013 survey was completed after targeted regions of the lake were treated with an herbicide to reduce EWM abundance. The majority of the littoral zone was devoid of aquatic vegetation in this survey as well. In 2012 and 2013, the MLWLA applied chemical herbicides to help control the spread of EWM; 40.9 acres were permitted for treatment in 2012 and 23.2 acres were permitted for treatment in 2013.

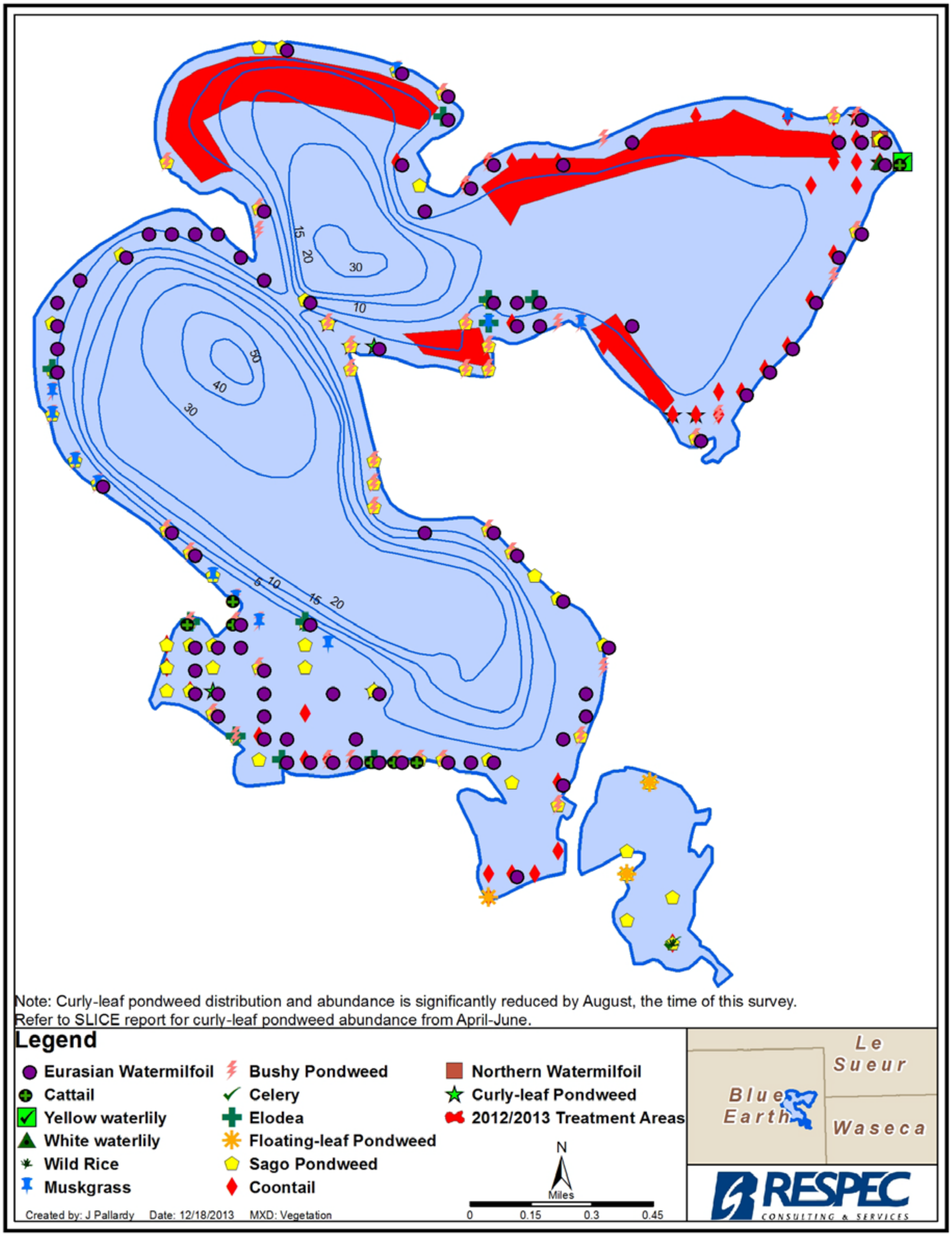

Figure 2-7. August 2013 Madison Lake Aquatic Plant Survey.

CLP outcompetes native plant species in the spring and early summer. After CLP dies-off in June, the nutrients fuel algae blooms. Whereas some native species are present in the lake, CLP and EWM are dominant. A more detailed aquatic plant assessment can be found in Appendix A.

2.2.4 Fish

The fish community in Madison Lake is similar to other productive southern Minnesota lakes. The presence of benthivorous fish such as carp and black bullhead likely leads to internal phosphorus loading from sediments. These fish forage in bottom sediments, which stirs up the sediments and releases phosphorus from the sediments to the water column. Common carp abundance in Madison Lake has been high enough to support a commercial fishery since the 1980s, with an average of 14,000 kilograms (kg) per harvest. Madison Lake has a diverse community of nongame river fish, because of the lake's connection to the Le Sueur River. Madison Lake is the only Minnesota lake that has a self-sustaining population of gizzard shad. Gizzard shad is a planktivorous fish that likely entered the lake from the Le Sueur River during flooding in 1965. They can have negative effects on water quality through impacts to the food web such as overgrazing of zooplankton. Madison Lake has been stocked with walleye and northern pike, and game fish production in the lake is high, supported by river forage species and cover from CLP.

2.2.5 Water Quality

Madison Lake is a eutrophic to hypereutrophic lake, and the average conditions do not meet the state standards for total phosphorus, chlorophyll-*a*, or Secchi transparency (Table 2-4, Figure 2-8). Water-quality data presented here are from Site 202, which is the deep spot in Bay 2. Transparency has remained relatively steady since the SLICE data collection ended in 2008. Phosphorus concentrations increase toward the end of June, accompanied by an increase in chlorophyll-*a* and a decrease in transparency, and water quality remains poor throughout the season. This pattern is typical of eutrophic lakes with CLP; the increase in phosphorus in June results from the CLP die-off.

Table 2-4. Madison Lake Water-Quality Data Summary, Site 202

Parameter	2002–2011 Average[(a)]	Standard
Total Phosphorus	47 µg/l	≤ 40 µg/l
Chlorophyll-*a*	81 µg/l	≤ 14 µg/l
Secchi Depth	1.0 m	≥ 1.4 m

(a) Average of annual growing season mean (June–September) where sample size > 2.

Thermal and dissolved oxygen stratification is evident during the summer in the deep areas of Bays 1 and 2. The pattern and duration of stratification shifts from year to year and is influenced by weather; however, both bays typically remain stratified through July and August with periods of stratification in June and September. The stratification results in low dissolved oxygen concentrations in the deep waters, which leads to the release of phosphorus from the sediments. When the water column mixes in the fall, this phosphorus then becomes available for algal growth in the surface waters.

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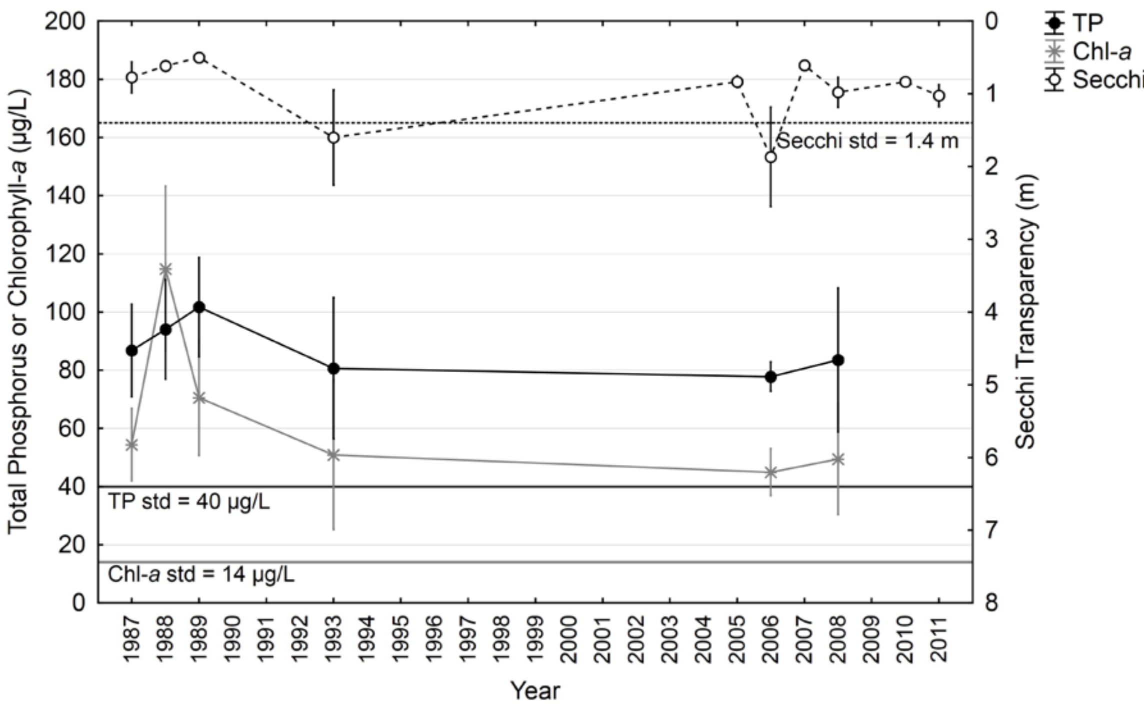

Figure 2-8. Total Phosphorus, Chlorophyll-*a*, and Secchi Transparency Surface Water Growing Season Means ± Standard Error (N > 2), Site 202.

2.2.6 Plankton

Plankton are organisms that live in the open water of a lake and do not have the ability to swim against a current. Algae and zooplankton are the two primary components of a lake's planktonic community. In 2006 and 2008, diatoms dominated the algal community in the spring, and were followed by cyanobacteria (also known as blue-green algae), which remained dominant throughout the summer. Cyanobacteria often produce algal blooms, and the types of cyanobacteria found in Madison Lake have the potential to produce toxins. The concentrations of the algal toxin microcystin was measured several times during 2006. Three of the samples from nearshore algal blooms had microcystin concentrations that were above the World Health Association's high-risk category for recreational waters.

Zooplankton are small animals that are part of a lake's planktonic community, and are typically composed of microscopic crustaceans. Zooplankton were studied in the lake in 2008. Zooplankton biomass was high in the spring and early summer and declined to low levels in August and September. The declines may be caused by a combination of the loss of habitat from the die-off of CLP and overgrazing by planktivorous fish. Low levels of zooplankton are often associated with high algal concentrations because of the lower rates of algal grazing by the zooplankton.

2.2.7 Internal Loading

The following observations suggest that internal loading affects the water quality in Madison Lake:

- CLP represents a substantial amount of the vegetation in the littoral zone in the early summer. When CLP dies off towards the end of June, the release of phosphorus fuels algal growth.
- Common carp abundance is high. These benthivorous fish forage in bottom sediments, which stirs up the sediments and releases phosphorus to the water column.
- Low dissolved oxygen in the bottom waters leads to phosphorus release from the bottom sediments and high hypolimnetic phosphorus concentrations. This phosphorus becomes available for algal growth when it mixes with surface water at fall overturn.

As part of the TMDL under development for Madison Lake, the MPCA estimated that the average internal load in Madison Lake is 985 kg/yr.

2.3 WATER-QUALITY GOALS

Approximately one-half of the phosphorus load to Madison Lake is from the watershed, and approximately one-third is from internal loading sources; the remainder is from precipitation (Table 2-5). As part of the TMDL study that is under development, the MPCA estimated that a phosphorus load reduction of approximately 62 percent, or 1,660 kg/yr, will be needed for the lake to meet water-quality standards. These reductions will need to come from a mix of watershed and internal sources.

In addition to the phosphorus and lake water-quality goals, the other component of the aquatic recreation goals of this management plan is to manage the aquatic vegetation in the lake to enhance and protect the aquatic recreation uses.

2.4 SUMMARY OF ISSUES

The following issues were identified in the diagnostic assessment of Madison Lake:

- The watershed is dominated by agricultural land uses, and the phosphorus loads from the agricultural areas represent approximately 87 percent of the watershed load to the lake. Areas of high erosion potential exist in the watershed.

- The highly developed shoreline lacks vegetative buffers in many areas, which leads to high phosphorus loading from the watershed, increases the potential for shoreline erosion, and reduces habitat quality. New lakeshore development may exacerbate the problem.
- CLP is a driver of in-lake phosphorus dynamics. The nonnative species outcompetes native plants, provides a midsummer internal loading source of phosphorus, and its midsummer die-off leaves many portions of the lake devoid of vegetation.
- EWM has reached nuisance levels in certain areas of the lake and impedes aquatic recreation.
- Common carp abundance is high. These benthivorous fish forage in bottom sediments, which stirs up the sediments and releases phosphorus to the water column.
- Members of the lake association are concerned about the possibility of zebra mussels reaching Madison Lake.

Table 2-5. Madison Lake Phosphorus Load Summary

Source	Average Annual P load, 1996–2009 (kg/yr)	Contribution to Total Load (%)
Watershed	1,529	57
Forest	1.99	
Cropland, Conservation Tillage	122	
Cropland, Conventional Tillage	1,202	
Grassland	5.45	
Pasture	35.2	
Wetland	3.82	
Feedlot	8.51	
Developed-Pervious	27.5	
Developed-Impervious	73.0	
Septic	39.4	
Internal reach processes	10.0	
Internal load	985	37
Precipitation	170	6
Total	**2,684**	**100**

Watershed and internal phosphorus loads to Madison Lake are both high, and loads from both sources will need to be reduced to restore the lake. In lakes such as Madison Lake, which has a substantial portion of shallow areas, the watershed load must be reduced first. After the watershed load has been reduced to levels that the lake can assimilate, management practices with the goal of restoring the lake's ecological interactions should be used. These practices are typically only successful after the watershed loading rates are under control.

3.0 MANAGEMENT PLAN

The overall strategy for restoring Madison Lake is to first focus on watershed and nearshore phosphorus load reductions. Reductions in watershed phosphorus loading often lead to improvements in the lake's ecological components and interactions. After the watershed reductions are in place, the internal dynamics of the lake should be reevaluated and management practices that address the internal load and ecological interactions should be considered.

This management plan contains options for reducing phosphorus loading to Madison Lake and focuses on the primary sources identified in the diagnostic assessment. The plan is not meant to be prescriptive, but rather to provide a menu of options for the lake association and implementation partners. The plan highlights the most appropriate practices for the lake and the watershed. Local knowledge will help the lake association target the practices, and the plan provides information needed to apply for funding these targeted activities. Phosphorus reduction estimates are included in the plan for each watershed practice, and guidance is provided to allow the lake association and other partners to tailor the phosphorus estimates to the specific projects or programs that they seek to fund. These quantitative load reduction estimates will support and strengthen the grant applications.

3.1 BEST MANAGEMENT PRACTICES

The evaluation of management approaches is organized into watershed, nearshore, and in-lake practices. For each management approach, the following items are provided in the discussion and in the summary tables:

- Description. The management practices are described.
- Opportunity. The extent to which the practice can be applied in the Madison Lake Watershed. For example, the opportunity for tillage management is the area of the watershed where conventional tillage is practiced on well-drained soils. For some practices, it is assumed that it will be feasible to implement the practice for only a portion of the total opportunity. For example, it is assumed that it will be feasible over the long term to implement conservation tillage on 20 percent of the watershed area where conventional tillage is practiced on well-drained soils. The opportunity estimate is not necessarily a goal, but rather was used to quantify the load reductions that are feasible from each type of practice.
- Potential phosphorus load reduction. An estimate of the phosphorus load reduction that can be obtained by implementing the practice, applied to the opportunity estimate. Where applicable, references cited in The *Agricultural BMP Handbook for Minnesota* [Miller et al., 2012] were used.

- Phosphorus removal calculations. Generalized guidance is provided to estimate each practice's phosphorus removal for an individual project. These calculations can be used when applying for funding.

3.1.1 Watershed Management Reduction Options

The majority of the watershed load is from agricultural land uses, followed by developed areas. This section addresses the agricultural loads. Because the developed areas are primarily along the lake's shoreline, management practices for the developed areas are presented with the nearshore management options.

3.1.1.1 Conservation Tillage

Description. Tillage practices that leave crop residue on the soil surface are referred to as conservation tillage, and they are primarily used to control erosion on agricultural fields. Examples of conservation tillage are no-till and strip till, and the feasibility of a conservation tillage practice depends on climate, available equipment, soil type, crop type, and slope of the land. Conservation tillage is typically most effective on well-drained soils and may cause delayed field access on poorly drained soils.

Opportunity. Of the 5,658 acres of conventional tillage cropland in the watershed, approximately 36 percent (2,037 acres) is on well-drained soils. Of that area, implementing conservation tillage on 20 percent (407 acres) of cropland was assumed to be feasible.

Potential Phosphorus Load Reduction. The modeled phosphorus loading rate from conventional tillage is 0.212 pounds per acre per year (lb/ac-yr), or 86 kg/yr across the 407 acres. A 70 percent phosphorus removal is assumed (60 kg/yr) based on Andraski et al. [1985], which found a 70 percent reduction in total phosphorus losses when chisel plowing (with a minimum of 30 percent residue) is used relative to conventional tillage.

Phosphorus Removal Calculations. To estimate the total phosphorus (TP) removal from the conversion of conventional tillage to conservation tillage, follow the steps outlined in Table 3-1.

Table 3-1. Generalized Phosphorus Removal Calculations for Conservation Tillage

Row	Description	Notes	Example Value
A	Area (ac)	Area of conventional tillage being converted to conservation tillage (chisel plow with a minimum of 30 percent residue)	100
B	TP load (kg/yr)	A × 0.212 kg/ac-yr	21
C	TP removal efficiency (%)	70% for chisel plow [Andraski et al., 1985]	70
D	TP removal (kg/yr)	B × C	15

3.1.1.2 Ravine and Gully Stabilization

Description. Ravines and gullies are erosional features in the landscape that form where flow accumulates and has erosive power. They can deliver a substantial portion of sediment and phosphorus loads to surface waterbodies.

Opportunity. A ravine within Bray Park was previously identified and a project is underway to stabilize the slope. Smaller gullies may exist in other portions of the watershed, and areas with a high potential for soil erosion were identified with the stream power index (see Figure 2-3 in Section 2.1.2: Soils). These sites should be evaluated in the field to determine if gullies or other signs of erosion are present.

Potential Phosphorus Load Reduction. The phosphorus load from ravines and gullies can be calculated if the dimensions of the feature and the length of time that it has been eroding are known. The ravine at Bray Park is estimated to be eroding 118 kg/yr of phosphorus. The average gully in the watershed (3 feet × 8 feet × 500 feet, over 5 years) is estimated to be eroding at a rate of 46 kg/yr. Twelve similar features are in the watershed; it is assumed that it is feasible to stabilize half of them. The total potential load reduction from ravine and gully stabilization is 394 kg/yr.

Phosphorus Removal Calculations. To estimate the phosphorus removal from ravine and gully stabilization, follow the steps outlined in Table 3-2.

Table 3-2. Generalized Phosphorus Removal Calculations for Ravines and Gullies

Row	Description	Notes	Example Value
A	Height (ft)	Height of erosion	4
B	Width (ft)	Width of erosion	20
C	Length (ft)	Length of erosion	100
D	Volume (cubic feet)	A × B × C	8,000
E	Total mass lost (tons)	D × soil density (assumes silt soil at 85 lb/ft^3)/2,000	340
F	Time (years)	Estimated time erosion has been occurring	10
G	Soil loss (tons/year)	E ÷ F	34
H	Phosphorus loss (kg/year)	G ÷ 2.2 (assumes 1 lb P per ton of soil)	15

3.1.1.3 Nutrient Management

Description. Nutrient management refers to the practices that producers implement to manage the amount, method, and timing of application of fertilizers, manure, and other soil amendments. Examples of nutrient management practices include switching from surface application of fertilizers to subsurface application, conducting soil tests to determine the correct amount and type of fertilizer to apply, and avoiding manure application on snow covered soils. Nutrient losses can be significantly lower when manure is applied in fall or early winter [Komiskey et al., 2011].

Opportunity. A University of Minnesota extension study of 700 nutrient management plans found that 86 percent of producers could improve their nutrient management techniques [cited in Miller et al., 2012]. Conventional tillage practices are used on 5,658 of the 6,289 acres of cropland in the watershed while conservation tillage practices are used on the remaining 631 acres of cropland. Assuming nutrient management practices can be improved on 86 percent of all cropland suggests that nutrient management techniques can be improved on 4,867 acres of conventional tillage and 543 acres of conservation tillage. Of this area, it is estimated that it will be feasible to implement improved nutrient management practices on 20 percent of the remaining cropland area, which is equivalent to 973 acres of conventional tillage and 109 acres of conservation tillage.

Potential Phosphorus Load Reduction. Switching from broadcasting fertilizer on the soil surface to injecting the fertilizer into the soil can result in a 45 percent reduction on conventional tillage cropland and a 55 percent reduction in conservation tillage cropland [Rehm et al., 1997]. In the Madison Lake Watershed, this is equivalent to a reduction of 93 kg/year on conventional tillage cropland and 12 kg/year on conservation tillage cropland.

Phosphorus Removal Calculations. To estimate the phosphorus removal from nutrient management, follow the steps outlined in Table 3-3.

Table 3-3. Generalized Phosphorus Removal Calculations for Nutrient Management

Row	Description	Notes	Example Value
A	Area (ac)	Area of cropland for which a nutrient management plan will be developed and followed	100
B	TP load (kg/yr)	A × 0.212 kg/ac-yr for conventional tillage A × 0.194 kg/ac-yr for conservation tillage	21
C	TP removal efficiency (%)	45% reduction on conventional tillage, 55% reduction on conservation tillage	45
D	TP removal (kg/yr)	B × C	9

3.1.1.4 Filter Strips

Description. Filter strips are bands of permanent vegetation planted between the field edge and surface water. They are designed to filter runoff and capture sediments, organics, nutrients, pesticides, and other contaminants.

A 50-foot-wide buffer strip of permanent vegetation is required by county ordinance and state rule along agricultural lands that are adjacent to lakes, rivers, and streams. Blue Earth County and Blue Earth Soil and Water Conservation District (SWCD) are working to inventory shoreland areas within the county to determine compliance with this standard. A 16.5-foot-wide buffer strip on land adjacent to new public ditches or public ditches that undergo ditch improvements is required by state statute. NRCS practice standards provide guidance to appropriately size a filter strip for the drainage area.

Opportunity. The major inlet to Madison Lake is well buffered. Four smaller intermittent streams totaling 2.4 miles are somewhat buffered, but improvements could be made.

Potential Phosphorus Load Reduction. Total phosphorus removal is a function of buffer width ($y = 15.84 \ln(x) + 5.9$, where y is the removal efficiency (%) and x is the buffer width in feet) [Nieber et al., 2011]. It was assumed that the current buffer width of the 2.4 miles of intermittent stream is 10 feet (42 percent removal), and that the width can be increased to 16.5 feet (50 percent removal).

The four intermittent streams drain an area of 1,518 acres with a loading rate of 0.210 kg/ac-yr, for a total load of 319 kg/yr. A 10-foot buffer would provide 42 percent removal (134 kg/yr) and a 16.5-foot buffer would provide 50 percent removal (160 kg/yr). The improvement is a reduction of 26 kg/yr.

Phosphorus Removal Calculations. To estimate the phosphorus removal from filter strips, follow the steps outlined in Table 3-4.

Table 3-4. Generalized Phosphorus Removal Calculations for Filter Strips

Row	Description	Notes	Example Value
A	Drainage area (ac)	Watershed area that drains to the proposed buffered segment	500
B	TP load (kg/yr)	A × 0.210 kg/ac-yr	105
C	Existing buffer width (ft)	Assumes both sides of the stream have this buffer width	5
D	Existing TP removal efficiency (%)	15.84 × ln(C) + 5.9	31
E	New buffer width (ft)	Assumes both sides of the stream have this buffer width	16.5
F	New TP removal efficiency (%)	15.84 × ln(C) + 5.9	50
G	TP removal (kg/yr)	(F × B) – (D × B)	20

3.1.1.5 Field Borders

Description. Field borders function similarly to filter strips, but they are planted at the edge of a cropland field.

Opportunity. Field borders exist along many of the fields in the watershed. Of the 6,289 acres of cropland in the watershed, it was estimated that it will be feasible to implement field borders on 10 percent of the area, or 629 acres.

Potential Phosphorus Load Reduction. With an average loading rate of 0.210 kg/ac-yr, the 629 acres of cropland has a load of 132 kg/yr. Using the same buffer equation as in the filter strips calculations [Nieber et al., 2011], a 16.5-foot buffer was estimated to provide 50 percent removal, or 66 kg/yr.

Phosphorus Removal Calculations. To estimate the phosphorus removal from field borders, follow the steps outlined in Table 3-5.

Table 3-5. Generalized Phosphorus Removal Calculations for Field Borders

Row	Description	Notes	Example Value
A	Area (ac)	Cropland area where field borders will be added	100
B	TP load (kg/yr)	A × 0.210 kg/ac-yr	21
C	Field border width (ft)		10
D	TP removal efficiency (%)	15.84 × ln(C) + 5.9	42
E	TP removal (kg/yr)	B × D	9

3.1.1.6 Cover Crops

Description. Cover crops are grasses, legumes, or forbs that are planted to provide seasonal soil cover. Because the soil would otherwise be bare, cover crops can reduce nutrient leaching and wind erosion, outcompete weeds, and improve soil fertility.

Opportunity. There are 6,289 acres of cropland in the watershed. Of that area, it was estimated that it will be feasible to implement cover crops on 20 percent (1,258 acres).

Potential Phosphorus Load Reduction. It was assumed that cover crops will reduce loading by 0.15 kg/ac-yr, or 189 kg/yr over the 1,258 acres. This rate is based on calculation procedures in the Southern Minnesota Beet Sugar Cooperative's National Pollutant Discharge Elimination System (NPDES) permit [cited in Fang et al., 2005].

Phosphorus Removal Calculations. To estimate the phosphorus removal from cover crops, follow the steps outlined in Table 3–6.

Table 3-6. Generalized Phosphorus Removal Calculations for Cover Crops

Row	Description	Notes	Example Value
A	Area (ac)	Cropland area that will be planted with cover crops	100
B	Load reduction (kg/yr)	A × 0.15 kg/ac-yr	15

3.1.1.7 Wetland Restoration

Description. The goal of wetland restoration is to return a degraded or former wetland to its original hydrologic regime, including hydrology, vegetation, and soils. Nutrient runoff from the site itself is reduced because of the conversion of the land from cropland to wetland, and nutrient runoff from the land area that drains to the wetland is reduced because the wetland acts as a best management practice that treats the runoff that flows to it. In addition to lowered nutrient export, wetlands provide numerous benefits, including wildlife habitat and flood control.

Opportunity. Using a compound topographic index (CTI) calculation, 698 acres of restorable wetlands were identified in the Madison Lake Watershed; a similar area was identified in the DNR's restorable wetlands spatial data. These former wetlands are primarily being used for agricultural production. Restoration of up to 10 percent of the area (70 acres) was considered feasible.

Potential Phosphorus Load Reduction. The 70 acres of restorable wetlands are on current cropland, which has a loading rate of 0.210 kg/ac-yr, for a total load of 14.7 kg/yr. Converting that land to wetland at a loading rate of 0.0030 kg/ac-yr leads to a reduction of 14.5 kg/yr. The total drainage area to those wetlands is 481 acres. This agricultural drainage area (0.210 kg/ac-yr) has a total load of 101 kg/yr. An average of 43 percent removal of phosphorus was found in restored wetlands on former agricultural land [Woltemade, 2000], which yields a reduction of 43.4 kg/yr in the Madison Lake Watershed. A zero to 50 percent removal of phosphorus was found in restored wetlands southwest of Trimont, Minnesota [Miller et al., 2012].

The total load reduction from the conversion of agricultural land to wetland and the treatment that the wetland provides is 58 kg/yr.

Calculations. To estimate the phosphorus removal from wetland restoration, follow the steps outlined in Table 3–7.

Table 3-7. Generalized Phosphorus Removal Calculations for Wetland Restoration

Row	Description	Notes	Example Value
A	Area (ac)	Area of wetland restoration	15
B	Load reduction from conversion to wetland (kg/yr)	(A × 0.210 kg/ac-yr) – (A × 0.003 kg/ac-yr)	3
C	Drainage area (ac)	Area that drains to wetland being restored	100
D	TP removal efficiency for wetlands (%)	43% from Woltemade [2000]	43
E	Load reduction from wetland treatment (kg/yr)	D × (0.210 kg/ac-yr × C)	9
F	Total TP removal (kg/yr)	B + E	12

3.1.1.8 Livestock Exclusion

Description. Livestock are temporarily or permanently excluded from surface waterbodies. This reduces bank erosion and direct defecation into the water.

Opportunity. Most feedlot operators in the watershed do not allow their livestock direct access to surface waterbodies. Efforts should focus on maintaining the existing livestock exclusion practices and preventing livestock access to surface waterbodies in the future.

3.1.1.9 Feedlot Runoff Control

Description. Feedlot runoff control practices reduce the transport of manure in watershed runoff to surface waters. Livestock manure is collected and stored, and watershed runoff is diverted around the feedlot.

Opportunity. Phosphorus loads from feedlots represent a small portion of the load to Madison Lake (Table 2-3); however, feedlot runoff control practices have the potential to reduce phosphorus loads to the lake and have the additional benefit of reducing fecal contamination of surface waters.

3.1.1.10 Alternative Tile Intakes

Description. Alternative tile intakes, such as gravel inlets, perforated risers, or dense pattern tile, increase the amount of sediment and phosphorus trapped relative to open intakes.

Opportunity. There are 6,288 acres of cropland in the watershed. Of that area, it was estimated that it will be feasible to implement alternative tile intakes on 40 percent (2,516 acres).

Potential Phosphorus Load Reduction. The modeled phosphorus loading rate from cropland is 0.210 lb/ac-yr, or 528 kg/yr across the 2,516 acres. An 85 percent phosphorus removal is assumed, based on Wilson et al. [1999], which found a total phosphorus reduction of 82 to 88 percent for gravel inlets. When the median (85 percent) is applied to the 2,516 acres of cropland, a reduction of 449 kg/yr was estimated.

Phosphorus Removal Calculations. To estimate the phosphorus removal from alternative tile intakes, follow the steps outlined in Table 3–8.

Table 3-8. Generalized Phosphorus Removal Calculations for Alternative Tile Intakes

Row	Description	Notes	Example Value
A	Area (ac)	Cropland area where alternative tile intakes will be added.	100
B	TP load (kg/yr)	A × 0.210 kg/ac-yr	21
C	TP removal efficiency (%)	85% from Wilson et al. [1999]	85
D	TP removal (kg/yr)	B × C	18

3.1.2 Nearshore Management Options

3.1.2.1 Removal of Individual Septic Systems

Individual septic systems on shoreland residences will be connected to the Madison Lake Area Sanitary Sewer District in the next few years. This will lead to a reduction of 20 kg/yr, which is the loading from septic systems in the direct drainage area.

3.1.2.2 Rain Gardens

Description. Rain gardens are shallow depressions that are planted with native perennial, flood-tolerant plants and are designed for stormwater runoff infiltration, filtration, storage, and uptake by vegetation. Rain gardens typically are used to treat small areas (up to approximately 1 acre), such as runoff from the impervious surfaces in residential areas.

Opportunity. The shoreline of Madison Lake is heavily developed and many suitable locations for rain gardens exist. Developed areas cover approximately 159 acres within a 500-foot buffer of the shoreline, and it is assumed that it is feasible to construct rain gardens to treat the runoff from 20 percent of the developed areas (32 acres). A larger-scale rain garden is planned for a site adjacent to the lake.

Potential Phosphorus Load Reduction. The modeled phosphorus loading rate from developed areas is 0.131 kg/ac-yr, or 4.2 kg/yr across the 32 acres. A 65 percent phosphorus removal is assumed for rain gardens in the Minnesota Stormwater Manual [MPCA, 2013], based on Winer

[2000], leading to a reduction of 2.7 kg/yr. The planned larger-scale rain garden is estimated to remove 2.2 kg/yr.

Phosphorus Removal Calculations. To estimate the phosphorus removal from rain gardens, follow the steps outlined in Table 3-9.

Table 3-9. Generalized Phosphorus Removal Calculations for Rain Gardens

Row	Description	Notes	Example Value
A	Area (ac)	Drainage area	1
B	TP load (kg/yr)	A × 0.131 kg/ac-yr	0.131
C	TP removal efficiency (%)	85% from Wilson et al. [1999]	85
D	TP removal (kg/yr)	B × C	0.11

3.1.2.3 Shoreland Buffers

Description. Vegetative buffers consisting of native trees, shrubs, and grasses can filter stormwater runoff and reduce shoreland erosion.

Opportunity. The shoreline of Madison Lake is heavily developed with lawns maintained up to the waters edge and shorelines altered by rock riprap or sand blankets. Suitable locations for shoreland buffers include areas where natural shorelines have been replaced with sod, riprap, or retaining walls. Developed areas cover approximately 159 acres within a 500-foot buffer of the shoreline, and it is assumed that it is feasible to add or improve shoreland buffers that will treat stormwater runoff from 20 percent of the area (32 acres).

Potential Phosphorus Load Reduction. The modeled phosphorus loading rate from developed areas is 0.131 kg/ac-yr, or 4.2 kg/yr across the 32 acres. A 42 percent phosphorus removal is assumed for a 10-foot buffer (see Section 3.1.1.4), which leads to a reduction of 1.8 kg/yr.

Habitat and Food Web Improvements. Shoreland buffers improve habitat in the littoral zones of lakes and provide refuge for organisms such as zooplankton and fish. The vegetation stabilizes the shoreline, which reduces erosion and increases water clarity.

Phosphorus Removal Calculations. To estimate the phosphorus removal from shoreland buffers, follow the steps outlined in Table 3-10.

Table 3-10. Generalized Phosphorus Removal Calculations for Shoreland Buffers

Row	Description	Notes	Example Value
A	Area (ac)	Drainage area	1
B	TP load (kg/yr)	A × 0.131 kg/ac-yr	0.13
C	Buffer width (ft)	Width of proposed shoreland buffer	10
D	TP removal efficiency (%)	15.84 × ln(C) + 5.9	42
E	TP removal (kg/yr)	D × B	0.055

3.1.2.4 Good Housekeeping

The shoreline of Madison Lake is heavily developed, with impervious surfaces such as homes, buildings, driveways, and roadways near the lake. Good housekeeping practices comprise a set of actions that residents and businesses can take to improve water quality. The following items are examples of good housekeeping practices:

- **Disconnection of impervious surfaces.** Stormwater is redirected from impervious surfaces to vegetated areas where it is filtered or infiltrated into the soil. A common application of this practice is redirecting downspouts; instead of discharging directly to a paved surface such as a driveway or parking lot, the downspout is directed to a vegetated area.
- **Rain barrels.** Rooftop runoff is directed through a downspout into a rain barrel where it is stored for use by the homeowner for garden and lawn watering.
- **Landscaping with native plants.** Landscaping with native vegetation increases infiltration of rainwater into the soils and reduces the need for watering, thereby decreasing stormwater runoff from the site.
- **Lawn care.** Certain lawn-care practices can reduce stormwater and nutrient runoff into nearby surface waters. These practices include yard waste management, minimizing the use of fertilizers, and lawn aeration.

3.1.3 In-Lake Management Options

After the watershed and nearshore phosphorus loads have been reduced to a level that the lake can assimilate, the internal dynamics of the lake should be evaluated and management practices that address the internal load and ecological interactions should be considered. The effects on internal phosphorus loading from these practices are highly variable and difficult to quantify. This section describes each approach and its applicability to Madison Lake.

3.1.3.1 Vegetation Management

Eurasian watermilfoil (EWM) and curly-leaf pondweed (CLP) are invasive plant species that are established in Madison Lake. Two approaches to controlling these invasives are herbicides and mechanical harvesting. The lake association has treated portions of the littoral zone with an herbicide with the goal of reducing the EWM plant growth that interferes with recreational activities. Treatment of EWM will not reduce phosphorus loading to the lake. The lake association may continue to treat EWM as needed for recreational purposes. EWM does well in nutrient-rich lakes, and it may not be as successful as the lake water quality improves as a result of watershed management practices. Because the presence of native vegetation in any lake restoration practice is important, every attempt should be made to avoid harming the native vegetation.

Chemically treating CLP can reduce internal phosphorus loading in the lake if sufficient native aquatic macrophytes persist in the shallow areas. Native aquatic macrophytes help stabilize the sediments, provide habitat for fish and invertebrates, and prevent high concentrations of algae in these shallow areas. Treating CLP is sometimes combined with other methods to allow the reestablishment or persistence of native plants. Because of the importance of the presence of native vegetation in any lake restoration practice, every attempt should be made to avoid harming the native vegetation.

Mechanically harvesting EWM and CLP can spread the overwintering plant buds, or turions, within the lake. This risk outweighs the benefits of mechanical harvesting for Madison Lake; mechanical harvesting is more applicable to lakes that have a widespread coverage of these invasive species.

3.1.3.2 Fisheries Management

Fisheries management practices alter the food web to reduce the fish species that disturb bottom sediments (benthivores) and to favor grazing on algae by zooplankton through reduction of zooplanktivorous fish. One approach to reduce the density of benthivorous fish such as carp and black bullhead is to install fish barriers on the lake inlet and/or outlet coupled with a fish kill in the lake. Another approach is to remove the benthivores through a water-level drawdown, chemical treatment (such as rotenone), and targeted netting.

Reducing the density of zooplanktivorous fish can improve water clarity through an increase in the densities of zooplankton, which leads to higher grazing rates on algae. Approaches include adding predatory fish, a water-level drawdown, chemical treatment (such as rotenone), and trapping.

3.1.3.3 Phosphorus Cycling Management

Various types of approaches exist that aim to make phosphorus unavailable for algal growth, typically by removing phosphorus from the water column and/or sealing it in the bottom sediments. The following items are options for phosphorus cycling management.

- **Alum:** Aluminum sulfate is injected into the water column, where it binds with phosphorus, settles out of the water column, and remains bound in the lake-bottom sediments.
- **Phoslock:** Lanthanum embedded in bentonite (a type of clay) is added to the water column, where it binds with phosphorus, settles out of the water column, and remains bound in the lake-bottom sediments. This practice is less common than alum application.
- **Iron:** Iron particles are added to bottom sediments to bind the phosphorus in the sediment. This practice is only applicable to lakes with iron-poor sediments in oxygenated zones.
- **Summer aeration:** Hypolimnetic water is oxygenated to prevent the anoxic release of phosphorus from bottom sediments. Installation and maintenance costs are typically high, and the practice is often unsuccessful.

If internal phosphorus cycling practices are considered after the watershed load has been reduced, an alum treatment is likely the most applicable approach for Madison Lake.

3.1.3.4 No-Wake Zones

Motorboat activity can disturb sediments in the shallow areas of a lake and affect aquatic plant growth, shoreline erosion, and wildlife habitat. A no-wake ordinance could be considered to decrease the disturbance to lake water quality from motorboat activity.

3.1.3.5 Watercraft Inspections

Members of the lake association are concerned about the potential for zebra mussels to invade Madison Lake. Watercraft inspections can be used as a preventive measure. The DNR Invasive Species Program[2] offers grants to local government units for assistance with aquatic invasive species prevention programs. The grant is designed to help prevent and slow down the spread of invasive species such as zebra mussels, and provides financial assistance and training for watercraft inspectors. The Blue Earth SWCD is eligible to apply to this program.

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[2] For more information see *http://www.dnr.state.mn.us/grants/aquatic_invasive/watercraft_inspections_lgu.html*

3.2 PLANNING AND ZONING

Residential development around the lake impacts water quality through runoff from impervious surfaces and lawns and alteration of shoreline vegetation. Planning and zoning regulations that minimize the negative impacts to Madison Lake, such as increased setbacks and reduced densities, will help maintain property values and preserve the tax base. Uniform zoning between the City of Madison Lake and Blue Earth County (on behalf of the townships) would help to protect the shoreline and maintain consistency in shoreland development.

3.3 OUTREACH AND EDUCATION

Stakeholder outreach and education is the first step for implementing land-use behavior changes. Unfortunately, providing education to stakeholders is a financial investment that often does not show an immediate return; therefore, education can be offered jointly with other organizations that share the same focus to help offset the costs. In the Madison Lake Watershed, the following groups may be interested in joint education efforts:

- **Madison Lake Association (*www.madisonlake.org*):** Committed to improving the water quality of Madison Lake, this group has already started compiling resources on its website to encourage stakeholders to make positive land use behavior changes.
- **Blue Earth Soil and Water Conservation District (SWCD) (*www.blueearthswcd.org*):** Established in 1959, the Blue Earth SWCD has been offering support to the agricultural community in the forms of technical assistance and cost share (partial payments for the construction of best management practices such as grassed waterways and filter strips).
- **LeSueur River Watershed Network:** Since 2012, a volunteer group of citizens has been meeting to discuss the issues of the polluted LeSueur River and discuss citizen solutions to the problems. Funding to continue this grass roots effort has been extended through 2014 with support from the McKnight Foundation.

Lakeshore education is often the first focus of a lake improvement group. Because lakeshore owners have the most reason to work on being part of the solution, they are usually a captive audience. Although a single lakeshore buffer does not significantly improve water quality, the sum of many buffers can make a difference. Furthermore, not only will water quality improve, but habitat will also. Popular programs that can be used for lakeshore education include the following:

- **Blue Thumb (*www.bluethumb.org/shorelines*):** Contains a virtual tour of shoreline projects, how-to videos, project cost calculator, blue prints for design, grant opportunities, planning packets, and plant selector tools. Blue Thumb Workshops are available as well.

- **Restore Your Shore (*www.dnr.state.mn.us/restoreyourshore/index.html*):** An online program created by the DNR that teaches the importance of and how-to skills to restore your shoreline.
- **Score Your Shore (*www.dnr.state.mn.us/scoreyourshore/index.html*):** Program from the DNR that assesses the current health of shorelines before and after restoration efforts are completed. The program can be used on an individual lakeshore lot or for an entire lake. Often implemented by a lake association, the overall health of the lakeshore can be scored annually to check or watch for improvement.

Lastly, and most importantly, networking with the agricultural community is extremely important because they have the most abundant opportunities to impact water quality through land-use behavior changes. However, these practices are often adopted slowly. Widespread adoption typically will not be reached until the practices are proven to be cost effective with minimal to no decrease in yields. To decrease the risk that early adopters face when implementing new practices, the following techniques are often employed:

- **Pilot projects:** A producer will work with technical professionals to alter the land use on a small portion of their land as a test plot. The results are calculated and shared with the farm community and possibly expanded if favorable results are discovered.
- **Incentive payments:** A producer will be given a cash payment for each acre that is enrolled in a new practice. The contracts can be short (1 year) or long term (10 years), and they will help to offset losses or investments made during implementation.

3.4 RECOMMENDED IMPLEMENTATION APPROACH

Watershed load reductions should be the first focus for restoring Madison Lake; in-lake management practices are typically successful only after watershed loads have been reduced. Management practices that decrease the load from agricultural areas are a priority because the majority of the load comes from these areas and this is where the greatest load reductions can be achieved. Of the applicable management practices, the high priority practices are conservation tillage, nutrient management, cover crops, and alternative tile intakes (Table 3-11). These practices typically provide the most benefit per unit cost, but both benefit and cost can vary depending on local factors. A different combination of the practices proposed here can be used and should be based on local priorities and opportunities. Adaptive management should drive implementation; the opportunities and needs should be considered and potential projects should be informed by past efforts.

If all of the watershed and nearshore management practices included in the plan were implemented at the level of the opportunity estimate, the watershed load would be reduced by approximately 1,382 kg/yr (Table 3-11). This would achieve 83 percent of the 1,660 kg/yr reduction needed to meet water-quality standards. Watershed load reductions can lead to

Table 3-11. Summary of Recommended Management Practices (High Priority Practices Are Highlighted)

Load Reduction Method	Description	Opportunity for Madison Lake	Potential Phosphorus Load Reduction (kg/yr)	Benefit: Cost, Priority
Conservation Tillage	Any tillage practice that leaves additional residue on the soil surface. Changing to a tillage system that leaves 30% residue cover can reduce erosion by 50–60% in comparison to a 0% residue system.	407 acres	60	H
Ravine and Gully Stabilization	Identify erosive ravines or gullies and apply the appropriate grade-control structures diversion, log and rock steps, porous weirs, or drop structures in addition to water and sediment control basins for inlets to the ravine.	Bray Park ravine Gullies	394	M
Nutrient Management	Work with local government units (LGUs) to provide incentives to producers through EQIP that properly manage the amount, method, and timing of applications of fertilizers, manure, and other soil amendments.	1,082 acres	105	H
Filter Strips	Strips or bands of permanent vegetation planted between field edge and surface water that are designed to filter runoff and capture sediments, nutrients, and pesticides.	2.4 miles of intermittent streams	26	M
Field Borders	Field borders function similarly to filter strips, but they are planted at the edge of a cropland field.	629 acres	66	M
Cover Crops	Use of grass, legume, or forbs to provide seasonal soil cover on cropland when the soil would otherwise be bare.	1,258 acres	189	H
Wetland Restoration	Reestablishing the hydrology, hydric vegetation, and hydric soils of a former wetland that has been drained, farmed, or otherwise modified since European settlement.	70 acres	58	M
Livestock Exclusion	Maintain existing livestock exclusion practices.	No new practices	0	H
Feedlot Runoff Control	Reduce the transport of manure in watershed runoff to surface waters.	Low	8.5	L
Alternative Tile Intakes	Work with LGU to provide incentives to producers that convert open tile intakes to alternative tile intakes such as gravel inlets, perforated risers, or dense pattern tile.	2,516 acres	449	H
Removal of Individual Septic Systems	Individual septic systems on shoreland residences will be connected to the Madison Lake Area Sanitary Sewer District in the next few years.	Shoreland residences	20	H
Rain Gardens	Shallow man-made depression filled with native flood tolerant plants, designed to capture and infiltrate rain within a day.	32 acres + planned larger-scale rain garden	4.9	L
Shoreland Buffers	Shoreland buffers consisting of native trees, shrubs, and grasses in a strip as narrow as 10 feet can help to minimize erosion, absorb water and nutrients, and maintain water quality.	32 acres	1.8	M
Good Housekeeping	Good housekeeping practices comprise a set of actions that residents and businesses can take to improve water quality, including disconnection of impervious surfaces, rain barrels, landscaping with native plants, and lawn care.	Shoreland residences	L	L
Vegetation Management	Chemical treatment for CLP to reduce summer pulse of phosphorus to the lake; in conjunction with practices to ensure that native plant species are present in lake to stabilize bottom sediments and provide habitat.	For future consideration	M	NA
	Chemical treatment for EWM to reduce interference with recreational activities.	As needed	0	NA
Fisheries Management	Alter the food web to reduce the fish species that disturb bottom sediments (benthivores) and to favor grazing on algae by zooplankton by reducing zooplanktivorous fish.	For future consideration	M	NA
Phosphorus Cycling Management	Make phosphorus unavailable for algal growth, typically by removing phosphorus from the water column and/or sealing it in the bottom sediments. The most applicable approach is alum, which involves the injection of aluminum sulfate into the water column. The goal is to bind phosphorus so that it is no longer biologically active or available to support algae or macrophyte growth.	For future consideration	M	NA
No-Wake Zones	Motor boat activity can disturb the sediments in the littoral zone of lake. Establishing a no-wake ordinance in portions of the shoreline would help to reduce the level of disturbance.	Depends on extent of motor boat activity in shallow areas	M	M

NA = Not applicable

reductions in internal loading through shifts in ecological interactions. After a substantial amount of watershed reductions have been achieved, the lake response to the reductions should be evaluated.

Those seeking funding for conservation practices are urged to contact their local SWCD to explore funding options. SWCDs implement several funding programs including, but not limited to, the State Cost Share Program (for structural agricultural practices that reduce erosion), the State Revolving Fund (low-interest loans for conservation tillage equipment and septic system replacement), the Conservation Reserve Enhancement Program (CREP), and the Reinvest in Minnesota (RIM) program. SWCDs can also apply for Clean Water Funds that were made available after passage of the 2008 Clean Water Land and Legacy Amendment. Lastly, SWCDs work closely with their federal conservation partner, the NRCS. Several programs exist at the federal level for funding projects including the Environmental Quality Incentive Program (EQIP), Wildlife Habitat Incentive Program (WHIP), and the Wetland Reserve Program (WRP). Installation of alternative tile intakes may be a good first focus for conservation practices, because of the overall low cost, high efficiency, and general acceptance of alternative tile intakes.

The lake association and local partners should use the phosphorus removal calculation tables provided with each management practice to estimate the load reductions that will be achieved by specific projects. Progress made toward the load reduction goals should be tracked in a table similar to Table 3-12. Practices can be added and goals can be adjusted as progress is made, and the load reductions can be refined if additional knowledge becomes available. The table should be updated annually and presented to the members of the MLWLA. Progress should be reviewed in more detail every 5 years to evaluate the extent of the management efforts aimed at improving water quality in the lake and to prioritize implementation efforts for the following 5 years. The 5-year review should also assess the lake's water quality and whether or not it has improved. If substantial improvement is seen, in-lake management practices may be considered.

The extent of change needed in the watershed and in the lake is large and will require a long term coordinated effort among the lake association, SWCDs, state agencies, the agricultural community, and shoreland owners. The lake association should work with Blue Earth County to have the Madison Lake Management Plan adopted into the county water plan; the Blue Earth SWCD may be able to facilitate this process.

Table 3-12. Phosphorus Load Reduction Tracking Table (Page 1 of 2)

Load Reduction Method	Description	Adoption Goal	Adoption Achieved	Phosphorus Reduction Goal (kg/yr)	Phosphorus Reduction Achieved (kg/yr)
Conservation Tillage	Any tillage practice that leaves additional residue on the soil surface. Changing to a tillage system that leaves 30% residue cover can reduce erosion by 50–60% in comparison to a 0% residue system.	407 acres		60	
Ravine and Gully Stabilization	Identify erosive ravines or gullies and apply the appropriate grade control structures diversion, log and rock steps, porous weirs, or drop structures in addition to water and sediment control basins for inlets to the ravine.	Bray Park ravine 6 gullies		394	
Nutrient Management	Work with LGUs to provide incentives to producers through EQIP that properly manage the amount, method, and timing of applications of fertilizers, manure, and other soil amendments.	1,082 acres		105	
Filter Strips	Strips or bands of permanent vegetation planted between field edge and surface water that are designed to filter runoff and capture sediments, nutrients, and pesticides.	2.4 miles of intermittent streams		26	
Field Borders	Field borders function similarly to filter strips, but they are planted at the edge of a cropland field.	629 acres		66	
Cover Crops	Use of grass, legume, or forbs to provide seasonal soil cover on cropland when the soil would otherwise be bare.	1,258 acres		189	

Table 3-12. Phosphorus Load Reduction Tracking Table (Page 2 of 2)

Load Reduction Method	Description	Adoption Goal	Adoption Achieved	Phosphorus Reduction Goal (kg/yr)	Phosphorus Reduction Achieved (kg/yr)
Wetland Restoration	Reestablishing the hydrology, hydric vegetation, and hydric soils of a former wetland that has been drained, farmed, or otherwise modified since European settlement.	70 acres		58	
Alternative Tile Intakes	Work with LGU to provide incentives to producers that convert open tile intakes to alternative tile intakes such as gravel inlets, perforated risers, or dense pattern tile	2,516 acres		449	
Removal of Individual Septic Systems	Individual septic systems on shoreland residences will be connected to the Madison Lake Area Sanitary Sewer District in the next few years.	Shoreland residences		20	
Rain Gardens	Shallow man-made depression filled with native flood tolerant plants, designed to capture and infiltrate rain within a day.	32 acres + planned larger-scale rain garden		4.9	
Shoreland Buffers	Shoreland buffers consisting of native trees, shrubs, and grasses in a strip as narrow as 10 feet can help or minimize erosion, absorb water and nutrients, and maintain water quality.	32 acres		1.8	
TOTAL				1374	0

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APPENDIX A

AQUATIC PLANT ASSESSMENT

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AQUATIC PLANT ASSESSMENT

A.1 INVASIVE SPECIES

Curly-leaf pondweed (CLP) was first noted in Madison Lake in 1970 and has been a commonly observed species in Madison Lake ever since. Aquatic plant surveys conducted in July and August have documented an absence of CLP. The growth cycle of CLP follows a perpetual pattern of high growth in early spring followed by large die-offs in summer that is often followed by large algae blooms. This pattern is typical of many lakes in southern Minnesota where CLP forms large monocots.

Eurasian watermilfoil (EWM) was first observed in Madison Lake in 2010 at 2.7 percent of points sampled during a survey conducted by the Minnesota Department of Natural Resources (DNR)[1]. The Madison Lake Watershed & Lake Association (MLWLA) was awarded grants in 2012 and 2013 to apply chemical herbicides to help control the spread of EWM. In 2012, 40.9 acres were permitted for treatment, and 23.2 acres were permitted for treatment in 2013. EWM was the most commonly observed plant species during the 2013 survey; it was found at 18.6 percent of point-intercept sampling sites located within the littoral zone.

The factors contributing to the successful or unsuccessful invasion of CLP and/or EWM on a given lake are relatively unknown. In certain lakes, invasive species may completely replace native species while in other lakes, invasive species may have little effect on other species[2]. Analyses of point-intercept survey data collected on Madison Lake in 2008, 2009, and 2013 by the DNR were performed to assess the overall health of the aquatic plant community and the potential impact of the arrival of EWM on the plant community.

A.2 METHODS

The point-intercept method allows researchers to sample a variety of points that include locations nearshore and locations offshore to collect a representative sample of the aquatic plant community present in a given lake at a given time[3].

[1] **Gamble, A., 2013.** Personal communication between J. Pallardy, RESPEC, Roseville, MN, and A. Gamble, Minnesota Department of Natural Resources, Mankato MN, October 14.

[2] **Barko, J. W. and R. M. Smart, 1986.** "Sediment-Related Mechanisms of Growth Limitation in Submersed Macrophytes," *Ecology*, Vol. 67, No. 5, 1328–1340.

[3] **Madsen, J. D., 1999.** *Point-Intercept and Line Intercept Methods for Aquatic Plant Management*, Aquatic Plant Control Technical Note MI-02, prepared for the U.S. Army Engineer Research and Development Center, Vicksburg, MS.

The first analysis of the aquatic plant community was the floristic quality index (FQI). The FQI is used in Minnesota and other states to provide an indication of the biotic health of a given aquatic resource. The FQI looks at all plant species found within a lake. Certain aquatic plant species found in Minnesota lakes are less tolerant to disturbance and pollution than others. Species that are not tolerant of pollution are given a high coefficient of conservatism score (C-score) because they are only found in lakes with minimal pollution and/or disturbance. Other species that are more tolerant of pollution are given a lesser score; all species are scored on a scale from 0–10 (Table A-1). The FQI score is based on the average C-score and the total number of species found in a given lake. Previous research has shown that FQI scores are highly correlated with the trophic status of a given lake[4]. Improvements in FQI scores are also highly correlated with improvements in water quality and provide a useful means of measuring changes in water quality.

The second analysis of the aquatic plant community was the Shannon's evenness index (SEI). Species evenness refers to the distribution and abundance of all species identified within an ecosystem such as Madison Lake. Changes in SEI scores for Madison Lake were used to demonstrate changes in the distribution and abundance of native species following a change in Madison Lake, such as the arrival of EWM in 2010 or the seasonal changes that take place following midsummer CLP senescence.

Table A-1. Description of C-Scores With Examples of Species Found in Madison Lake

C-Score	Description	Example Found in Madison Lake
0	Plants with a wide range of ecological tolerances. These plants are often opportunistic invaders of natural communities or native species typical of disturbed communities.	Curly-leaf pondweed
1–2	Widespread taxa that are not typical of a particular community.	Cattails
3–5	Plants with an intermediate range of ecological tolerances that typify a stable phase of some native communities but persist under some disturbance.	Clasping-leaf pondweed
6–8	Plants with a moderately narrow range of ecological tolerances that typify stable or late successional native plant communities.	Muskgrass
9–10	Plants with a narrow range of ecological tolerances that exhibit very high fidelity to a narrow range of stable habitat requirements.	NA

NA = Not applicable

[4] **Beck, M. W., L. K. Hatch, B. Vondracek, and R. D. Valley, 2010.** "Development of a Macrophyte Based Index of Biotic Integrity for Minnesota Lakes," *Ecological Indicators*, Vol. 10, pp. 968–979.

A.3 RESULTS AND ANALYSES

The DNR conducted a point-intercept survey of 502 sampling locations in August 2013 to document changes to the aquatic plant community following a July application of chemical herbicides to reduce EWM abundance. A total of 17 species of plants were documented, including EWM and CLP (Figure 2-7). EWM density in areas that were chemically treated with herbicide was low. By August, only 32 percent of the points sampled in the littoral zone had aquatic vegetation present.

The mean C-score of the 17 species observed during the August survey was 4.4, which indicates a plant community that contains some native species that are tolerant to intermediate levels of disturbance. The SEI score for the 2013 survey was 2.61, which is indicative of a plant community dominated by a few species. EWM was the most commonly sampled species in 2013; other commonly sampled species sampled include sago pondweed, bushy pondweed, and coontail.

The DNR completed point-intercept surveys in 2008 and 2009 as part of the Madison Lake Sustaining Lakes in a Changing Environment (SLICE) program. The 2009 survey was conducted in June when CLP coverage and density were high. During the 2009 survey, 59 percent of points sampled in the littoral zone had aquatic vegetation present, and CLP was found at 43.7 percent of locations. CLP coverage in June 2009 was estimated at 408 acres. A total of 12 species were observed with a mean C-score of 4.09 and an FQI score of 13.57, which was the lowest FQI score observed among the three point-intercept surveys. The SEI score for the 2009 survey was 2.03; again, this was the lowest observed among the three point-intercept surveys. The low FQI and SEI scores observed during June when CLP is most abundant suggest that CLP has a negative effect on the distribution and abundance of the native plant community. EWM had not been found in Madison Lake as of the 2009 survey. In 2009, the most commonly sampled plant species was CLP followed by sago pondweed, muskgrass, and narrow leaf pondweed.

The 2008 survey was completed in August 2008. Eighteen species were sampled during the 2008 survey; however, only 25 percent of sites sampled in the littoral zone had aquatic vegetation present. The lack of aquatic vegetation within the littoral zone during August 2008 and August 2013 is typical of a lake that has high CLP coverage. Lakes with high CLP coverage often undergo a seasonal switch from a clear-water, aquatic plant-dominated state to a turbid, algae-dominated system following CLP senescence. The algae restrict light penetration in the water column, thus restricting other aquatic plants to nearshore areas with adequate light availability.

In 2008, the average C-score of 4.4 and FQI score of 18.8 were very close to values observed during the August 2013 survey. The FQI scores from the 2008 and 2013 surveys were less than the mean FQI score for lakes in Minnesota of 23.7[5]. The FQI scores less than the mean for Minnesota lakes suggest that there may be fewer natural areas left in Madison Lake in comparison with other Minnesota lakes. The 2008 survey SEI score of 3.56 was the highest among the three surveys. In 2008, the most commonly sampled plant species included sago pondweed, muskgrass, coontail, and northern watermilfoil. A reduction in SEI scores from August 2008 (3.56) to August 2013 (2.61) suggests an increase in dominance by a fewer number of species. Since 2008, EWM has become the most commonly sampled species in Madison; this trend suggests that EWM may be outcompeting other previously dominant native plant species. Calculations of SEI scores from future plant surveys conducted in August will help determine if the trend toward an increased dominance by EWM is continuing. Trends in the abundance and distribution of preferred species, based on FQI and SEI scores, can be used to determine if a certain management practice (e.g., application of herbicides) is having a beneficial effect on the plant community.

[5] **Radomski, P. and D. Perleberg, 2012.** "Application of a Versatile Aquatic Macrophyte Integrity Index for Minnesota Lakes," *Ecological Indicators*, Vol. 20, pp. 252–268.