Little Green Lake

Green Lake County, Wisconsin

Comprehensive Management Plan

December 2018

Sponsored by:

Little Green Lake Protection and Rehabilitation District

WDNR Grant Program

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Onterra LLC
Lake Management Planning

Little Green Lake

Green Lake County, Wisconsin

Comprehensive Management Plan

December 2018

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This management planning effort was truly a team-based project and could not have been completed without the input of the following individuals:

Little Green Lake Planning Committee

Harlan Barkley
Tom Bartz
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1.0 INTRODUCTION

Little Green Lake, Green Lake County, is a 466-acre seepage lake with a maximum depth of 27 feet and a mean depth of 11 feet (Map 1). This eutrophic lake has a relatively small watershed when compared to the size of the lake. Little Green Lake contains 15 native plant species, of which coontail is the most common plant. Four exotic plant species are known to exist in Little Green Lake.

Field Survey Notes

The sandstone cliffs provide an interesting habitat for terrestrial life, especially ferns, along the lakeshore. Little Green Lake is very productive supporting much plant biomass in the form of algae and macrophytes.

Photograph 1.0-1 Little Green Lake, Green Lake County

Lake at a Glance - Little Green Lake

Morphology	
Acreage	466
Maximum Depth (ft)	27
Mean Depth (ft)	11
Shoreline Complexity	2.1
Vegetation	
Curly-leaf Survey Date	May 26, 2016
Comprehensive Survey Date	July 12, 2016
Number of Native Species	15
Threatened/Special Concern Species	-
Exotic Plant Species	Hybrid watermilfoil, curly-leaf pondweed, narrow-leaved cattail, and reed canary grass
Simpson's Diversity	0.81
Average Conservatism	4.7
Water Quality	
Trophic State	Eutrophic
Limiting Nutrient	Transitional
Water Acidity (pH)	8.88
Sensitivity to Acid Rain	Low
Watershed to Lake Area Ratio	4:1

Past management planning efforts on the lake include a lake management plan created in 1997 (Ramaker & Associates, Inc. 1997), a watershed assessment completed in 2004 (Green Lake County LCD 2004), and an aquatic plant management plan created in 2011 (Natural Resource Group, LLC 2011). In the 1990s, the U.S. Geological survey completed a water quality study on Little Green Lake and the Green Lake County LCD completed a watershed inventory of Green Lake County that included Little Green Lake's drainage basin. The county also facilitated a land use and lake management survey in 1996 that included providing surveys to 12 property owners on Little Green Lake, of which 9 were returned.

Little Green Lake holds high aquatic macrophyte biomass, frequent low dissolved oxygen levels, and elevated nutrient and chlorophyll-a concentrations. The lake is included on the WDNR's 2014 303(d) impaired waterbodies listing for a number of impairments including low dissolved oxygen, eutrophication, water quality use restrictions, degraded habitat and elevated pH. Despite the largely developed watershed, a previous study by Ramaker (1997) estimated that 69% of the lake's phosphorus load was from internal nutrient loading. A destratification system was installed in 2003 in order to de-stratify the lake's summer thermal gradients and reduce internal phosphorus release. A 2013-2014 study completed by WDNR indicated that despite this effort to reduce hypolimnetic anoxia, pulses of phosphorus were still being released to the lake (WDNR 2014).

Eurasian watermilfoil was first found within Little Green Lake in 1993. At a later date, the invasive was confirmed to be a hybrid between Eurasian and northern watermilfoil. Curly-leaf pondweed was first found in the system in 2005.

Despite the installation of best management practices (BMPs) in the watershed, including a barnyard system, grassed waterways, and contour strip cropping; the creation of three sedimentation basins, and the removal of a seawall with subsequent shoreland protection and habitat enhancements; plus, the installation of the destratification system, high nutrient loads continue to spur dense aquatic plant and algae growth. Additionally, the annual decay of this algal and macrophyte biomass has led to fish kills within the lake, most recently in 2012.

2.0 PROPERTY OWNER PARTICIPATION

Property owner participation is an important part of any management planning exercise. During this project, property owners were not only informed about the project and its results, but also introduced to important concepts in lake ecology. The objective of this component in the planning process is to accommodate communication between the planners and the stakeholders. The communication is educational in nature, both in terms of the planners educating the property owners and vice-versa. The planners educate the property owners about the planning process, the functions of their lake ecosystem, their impact on the lake, and what can realistically be expected regarding the management of the aquatic system. The property owners educate the planners by describing how they would like the lake to be, how they use the lake, and how they would like to be involved in managing it. All of this information is communicated through multiple meetings that involve the lake group as a whole or a focus group called a Planning Committee, and the completion of a property owner survey.

The highlights of this component are described below. Materials used during the planning process, including project update presentations made by Harlan Barkley, District Chair, at the 2017 and 2018 annual meetings, can be found in Appendix A.

General Public Meetings

The general public meetings were used to raise project awareness, gather comments, create the management goals and actions, and deliver the study results. These meetings were open to anyone interested and were generally held during the summer, on a Saturday, to achieve maximum participation.

Kick-off Meeting

On May 21, 2016, a project kick-off meeting was held at the Soldiers and Sailors Park in Markesan, WI to introduce the project to the general public. The meeting was announced through a mailing and personal contact by Little Green Lake Protection & Rehabilitation District (LGLPRD) board members. Prior to the district's annual meeting, the Little Green Lake Planning Committee observed a presentation given by Mr. Tim Hoyman, an aquatic ecologist with Onterra. Mr. Hoyman's presentation discussed the planning process, the committee's role in that process, and some of the tasks the committee members would be asked to complete. Following the Planning Committee meeting, Tim attended the district's annual meeting, gave a brief oral presentation regarding the planning project, and answered questions from district members.

Project Wrap-up Meeting

On May 19, 2018, the LGLPRD held its annual meeting. At the meeting, District Chair, Harlan Barkley presented a summary of the project results and conclusions along with a complete list of the goals and actions included within the draft Little Green Lake Management Plan. Following Mr. Barkley's presentation, the LGLPRD voted for a *Vote of Confidence* indicating their acceptance of the draft plan, and thus, the final plan without major changes from the draft.

Committee Level Meetings

Five meetings between Onterra ecologists and the LGLPRD Planning Committee were held to discuss the results and conclusions of the studies completed by Onterra and to create the framework for management goals and actions included in the Implementation Plan (presentations are included in Appendix A). The first meeting was held on February 20, 2017 and focused upon aquatic plants and the development of the 2017 control strategy. The second planning committee meeting was held on April 24, 2017 with the primary topic of water quality. The Little Green Lake watershed, internal nutrient loading, and reasons why the existing destratification system is not functioning as intended were discussed in detail. Aquatic plants were also the primary focus of the third meeting held on May 9, 2017, but the discussion centered primarily on more long-term aquatic invasive plant and nuisance native control. Planning meeting four, held on June 16, 2017, included a presentation on the results of the 2017 Early-Season Aquatic Invasive Species (AIS) Survey and the use and cost of alum and iron to inactivate phosphorus within the sediments of Little Green Lake. Management plan discussion centered on mechanical harvesting and pier treatment goals. The final planning meeting was held on October 17, 2017 and included an in-depth presentation of the 2017 AIS treatment results. The second half of the meeting was used discuss the elements that would be included in the Little Green Lake Implementation Plan.

Property Owner Survey

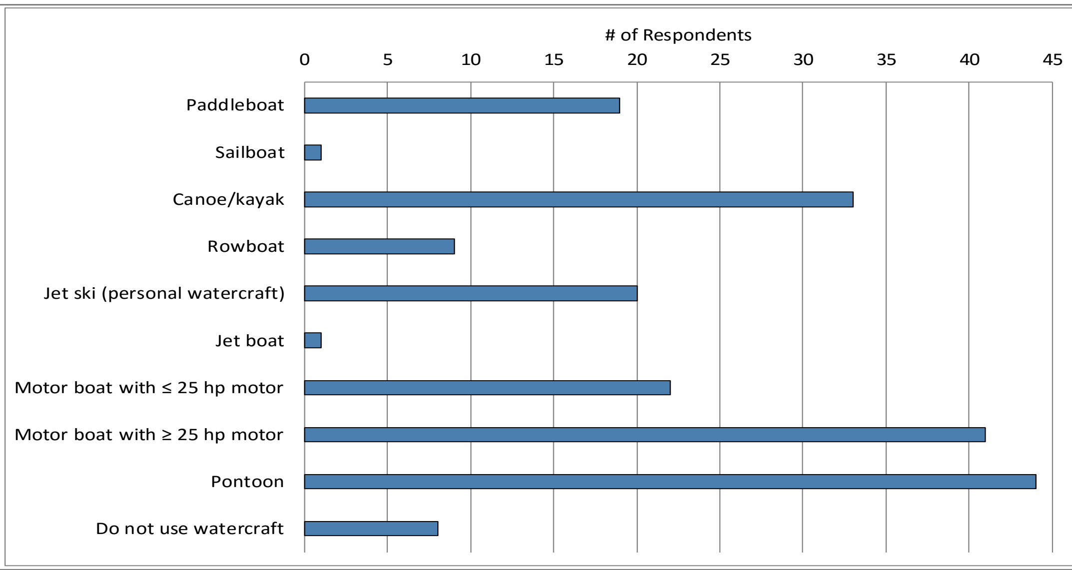
During August 2016, a seven-page, 29-question survey was mailed to 289 riparian property owners in the Little Green Lake area. Thirty-two percent of the surveys were returned and those results were entered into an online survey on SurveyMonkey. The data were summarized and analyzed by Onterra for use at the planning meetings and within the management plan. The full survey and results can be found in Appendix B, while discussion of those results is integrated within the appropriate sections of the management plan and a general summary is discussed below.

Based upon the results of the Property Owner Survey, much was learned about the people that use and care for Little Green Lake. The largest group of respondents (34%) are year-round residents, while 32% visit on weekends through the year and 25% live on the lake during the summer months only. 47% of respondents have owned their property for over 15 years, and 29% have owned their property for over 25 years.

The following sections (Water Quality, Watershed, Aquatic Plants and Fisheries Data Integration) discuss the property owner survey data with respect to these particular topics. Figures 2.0-1 and 2.0-2 highlight several other questions found within this survey. The majority of survey respondents indicate that they use either a pontoon boat, larger motor boat, canoe/kayak, or a combination of these three vessels on Little Green Lake (Question 11). Jet skis were also a popular option. On a lake such as Little Green Lake, the importance of responsible boating activities is increased. The need for responsible boating increases during weekends, holidays, and during times of nice weather or good fishing conditions as well, due to increased traffic on the lake. As seen on Question 14, several of the top recreational activities on the lake involve boat use. Boat traffic was tied for second as a factor potentially impacting Little Green Lake in a negative manner (Question 20), it was ranked 9th on a list of respondent's top concerns regarding the lake (Question 21).

A concern of respondents noted throughout the property owner survey (see Question 21 and survey comments – Appendix B) was algae blooms and water quality degradation within Little Green Lake. These topics were heavily discussed during the Planning Committee meetings and are further discussed in the sections below.

Question 11: What types of watercraft do you currently use on the lake?



Question 14: Please rank up to three activities that are important reasons for owning your property on or near the lake.

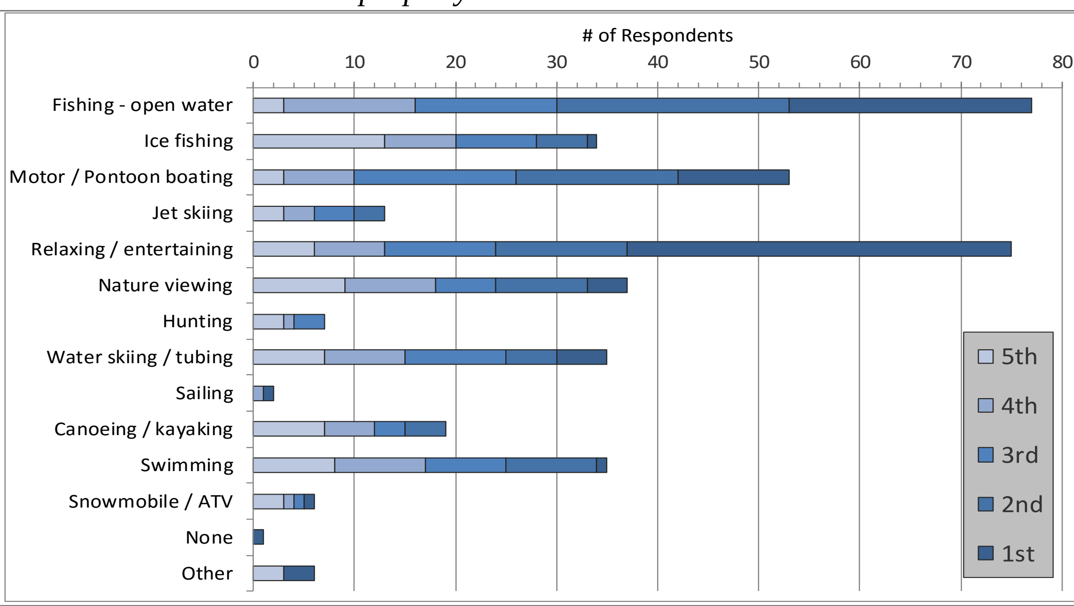
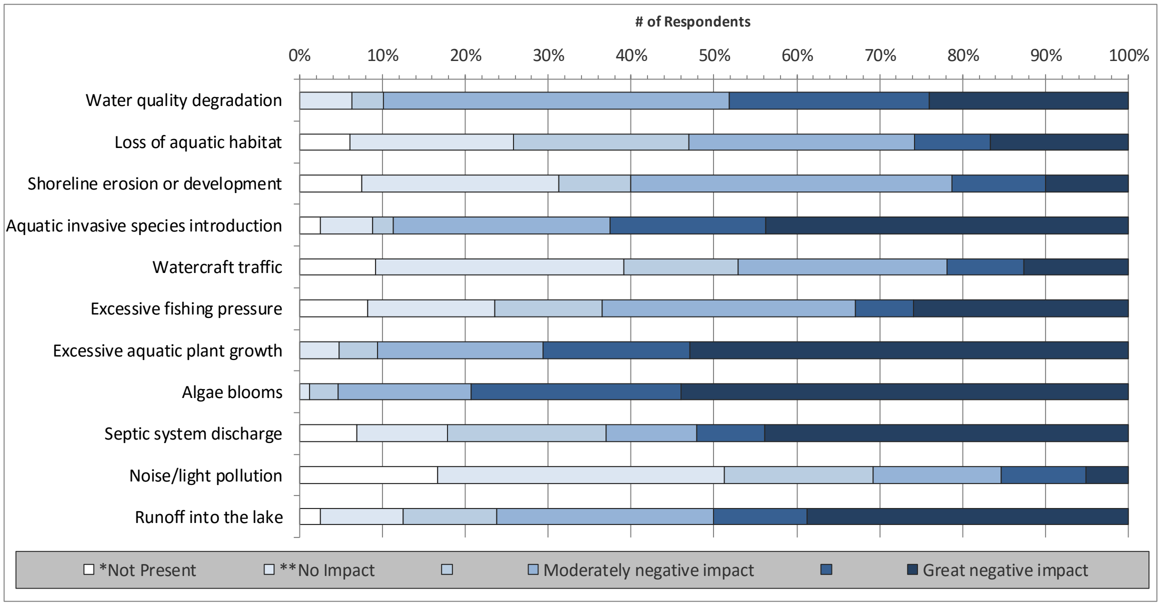


Figure 2.0-1. Select survey responses from the Little Green Lake Property Owner Survey. Additional questions and response charts may be found in Appendix B.

Question 20: To what level do you believe these factors may be negatively impacting Little Green Lake?



Question 21: Please rank your top three concerns regarding Little Green Lake.

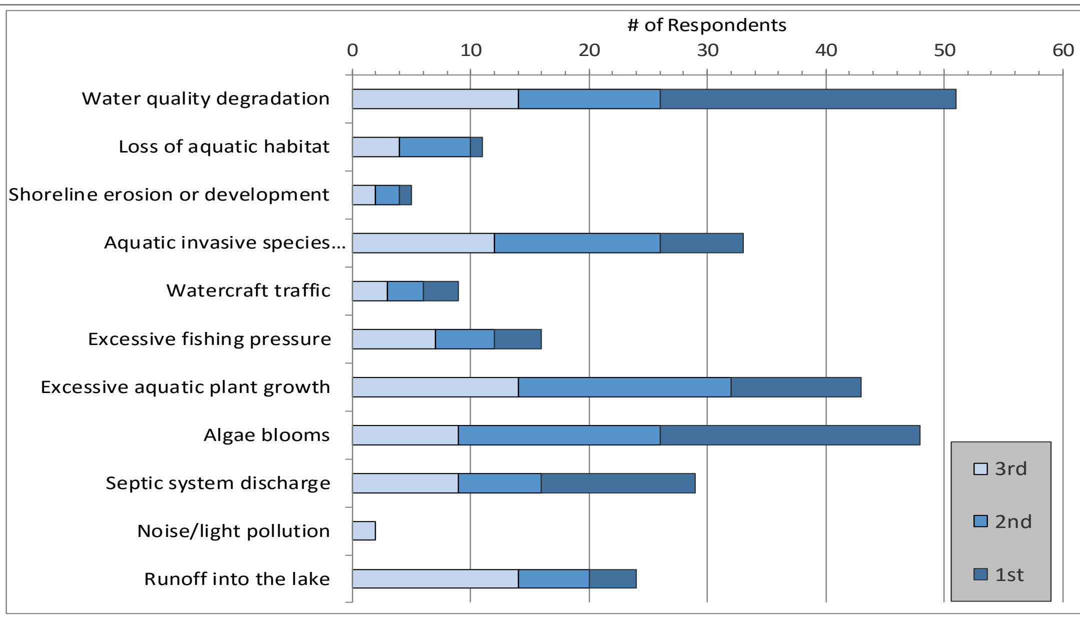


Figure 2.0-2. Select survey responses from the Little Green Lake Property Owner Survey, continued. Additional questions and response charts may be found in Appendix B.

Management Plan Review and Adoption Process

The LGLPRD Planning Committee finalized their review of the plan in October 2018 and agreed to submit it to the LGLPRD Board of Commissioners. The management plan was approved by the LGLPRD Board of Commissioners at the November 7, 2018 monthly meeting.

3.0 RESULTS & DISCUSSION

3.1 Lake Water Quality

Water Quality Data Analysis and Interpretation

Reporting of water quality assessment results can often be a difficult and ambiguous task. Foremost is that the assessment inherently calls for a baseline knowledge of lake chemistry and ecology. Many of the parameters assessed are part of a complicated cycle and each element may occur in many different forms within a lake. Furthermore, water quality values that may be considered poor for one lake may be considered good for another because judging water quality is often subjective. However, focusing on specific aspects or parameters that are important to lake ecology, comparing those values to similar lakes within the same region and historical data from the study lake provides an excellent method to evaluate the quality of a lake's water.

Many types of analyses are available for assessing the condition of a particular lake's water quality. In this document, the water quality analysis focuses upon attributes that are directly related to the productivity of the lake. In other words, the water quality that impacts and controls the fishery, plant production, and even the aesthetics of the lake are related here. Specific forms of water quality analysis are used to indicate not only the health of the lake, but also to provide a general understanding of the lake's ecology and assist in management decisions. Each type of available analysis is elaborated on below.

As mentioned above, chemistry is a large part of water quality analysis. In most cases, listing the values of specific parameters really does not lead to an understanding of a lake's water quality, especially in the minds of non-professionals. A better way of relating the information is to compare it to lakes with similar physical characteristics and lakes within the same regional area. In this document, a portion of the water quality information collected on Little Green Lake is compared to other lakes in the state with similar characteristics as well as to lakes within the northern region (Appendix C). In addition, the assessment can also be clarified by limiting the primary analysis to parameters that are important in the lake's ecology and trophic state (see below). Three water quality parameters are focused upon in the Little Green Lake's water quality analysis:

> **Phosphorus** is the nutrient that controls the growth of plants in the vast majority of Wisconsin lakes. It is important to remember that in lakes, the term "plants" includes both algae and macrophytes. Monitoring and evaluating concentrations of phosphorus within the lake helps to create a better understanding of the current and potential growth rates of the plants within the lake.
>
> **Chlorophyll-*a*** is the green pigment in plants used during photosynthesis. Chlorophyll-*a* concentrations are directly related to the abundance of free-floating algae in the lake. Chlorophyll-*a* values increase during algal blooms.
>
> **Secchi disk transparency** is a measurement of water clarity. Of all limnological parameters, it is the most used and the easiest for non-professionals to understand. Furthermore, measuring Secchi disk transparency over long periods of time is one of the best methods of monitoring the health of a lake. The measurement is conducted by lowering a weighted, 20-cm diameter disk with alternating black and white quadrates (a Secchi disk) into the water and recording the depth just before it disappears from sight.

The parameters described above are interrelated. Phosphorus controls algal abundance, which is measured by chlorophyll-*a* levels. Water clarity, as measured by Secchi disk transparency, is directly affected by the particulates that are suspended in the water. In the majority of natural Wisconsin lakes, the primary particulate matter is algae; therefore, algal abundance directly affects water clarity. In addition, studies have shown that water clarity is used by most lake users to judge water quality – clear water equals clean water (Canter et al. 1994, Dinius 2007, and Smith et al. 1991).

Trophic State

Trophic states describe the lake's ability to produce plant matter (production) and include three continuous classifications: Oligotrophic lakes are the least productive lakes and are characterized by being deep, having cold water, and few plants. Eutrophic lakes are the most productive and normally have shallow depths, warm water, and high plant biomass. Mesotrophic lakes fall between these two categories.

Total phosphorus, chlorophyll-*a*, and water clarity values are directly related to the trophic state of the lake. As nutrients, primarily phosphorus, accumulate within a lake, its productivity increases and the lake progresses through three trophic states: oligotrophic, mesotrophic, and finally eutrophic. Every lake will naturally progress through these states and under natural conditions (i.e. not influenced by the activities of humans) this progress can take tens of thousands of years. Unfortunately, human influence has accelerated this natural aging process in many Wisconsin lakes. Monitoring the trophic state of a lake gives stakeholders a method by which to gauge the productivity of their lake over time. Yet, classifying a lake into one of three trophic states often does not give clear indication of where a lake really exists in its trophic progression because each trophic state represents a range of productivity. Therefore, two lakes classified in the same trophic state can actually have very different levels of production.

However, through the use of a trophic state index (TSI), an index number can be calculated using phosphorus, chlorophyll-*a*, and clarity values that represent the lake's position within the eutrophication process. This allows for a more clear understanding of the lake's trophic state while facilitating clearer long-term tracking. Carlson (1977) presented a trophic state index that gained great acceptance among lake managers.

Limiting Nutrient

The limiting nutrient is the nutrient which is in shortest supply and controls the growth rate of algae and some macrophytes within the lake. This is analogous to baking a cake that requires four eggs, and four cups each of water, flour, and sugar. If the baker would like to make four cakes, he needs 16 of each ingredient. If he is short two eggs, he will only be able to make three cakes even if he has sufficient amounts of the other ingredients. In this scenario, the eggs are the limiting nutrient (ingredient).

In most Wisconsin lakes, phosphorus is the limiting nutrient controlling the production of plant biomass. As a result, phosphorus is often the target for management actions aimed at controlling plants, especially algae. The limiting nutrient is determined by calculating the nitrogen to phosphorus ratio within the lake. Normally, total nitrogen and total phosphorus values from the surface samples taken during the summer months are used to determine the ratio. Results of this ratio indicate if algal growth within a lake is limited by nitrogen or phosphorus. If the ratio is greater than 15:1, the lake is considered phosphorus limited; if it is less than 10:1, it is considered nitrogen limited. Values between these ratios indicate a transitional limitation between nitrogen and phosphorus.

Temperature and Dissolved Oxygen Profiles

Temperature and dissolved oxygen profiles are created simply by taking readings at different water depths within a lake. Although it is a simple procedure, the completion of several profiles over the course of a year or more provides a great deal of information about the lake. Much of this information relates to whether the lake thermally stratifies or not, which is determined primarily through the temperature profiles. Lakes that show strong stratification during the summer and winter months need to be managed differently than lakes that do not. Normally, deep lakes stratify to some extent, while shallow lakes (less than 17 feet deep) do not.

Lake stratification occurs when temperature gradients are developed with depth in a lake. During stratification, the lake can be broken into three layers: The epilimnion is the top layer of water which is the warmest water in the summer months and the coolest water in the winter months. The hypolimnion is the bottom layer and contains the coolest water in the summer months and the warmest water in the winter months. The metalimnion, often called the thermocline, is the middle layer containing the steepest temperature gradient.

Dissolved oxygen is essential in the metabolism of nearly every organism that exists within a lake. For instance, fish kills are often the result of insufficient amounts of dissolved oxygen. However, dissolved oxygen's role in lake management extends beyond this basic need by living organisms. In fact, its presence or absence impacts many chemical processes that occur within a lake. Internal nutrient loading is an excellent example that is described below.

Internal Nutrient Loading

In lakes that support stratification, whether throughout the summer or periodically between mixing events, the hypolimnion can become devoid of oxygen both in the water column and within the sediment. When this occurs, iron changes from a form that normally binds phosphorus within the sediment to a form that releases it to the overlaying water. This can result in very high concentrations of phosphorus in the hypolimnion. Then, during turnover events, these high concentrations of phosphorus are mixed within the lake and utilized by algae and some macrophytes. In lakes that mix periodically during the summer (polymictic lakes), this cycle can *pump* phosphorus from the sediments into the water column throughout the growing season. In lakes that only mix during the spring and fall (dimictic lakes), this burst of phosphorus can support late-season algae blooms and even last through the winter to support early algal blooms the following spring. Further, anoxic conditions under the winter ice in both polymictic and dimictic lakes can add smaller loads of phosphorus to the water column during spring turnover that may support algae blooms long into the summer. This cycle continues year after year and is termed "internal phosphorus loading"; a phenomenon that can support nuisance algal blooms decades after external sources are controlled.

The first step in the analysis is determining if the lake is a candidate for significant internal phosphorus loading. Water quality data and watershed modeling are used to determine actual and predicted levels of phosphorus for the lake. When the predicted phosphorus level is well below the actual level, it may be an indication that the modeling is not accounting for all of phosphorus sources entering the lake. Internal nutrient loading may be one of the additional contributors that may need to be assessed with further water quality analysis and possibly additional, more intense studies.

Non-Candidate Lakes

- Lakes that do not experience hypolimnetic anoxia.
- Lakes that do not stratify for significant periods (i.e. days or weeks at a time).
- Lakes with hypolimnetic total phosphorus values less than 200 μg/L.

Candidate Lakes

- Lakes with hypolimnetic total phosphorus concentrations exceeding 200 μg/L.
- Lakes with epilimnetic phosphorus concentrations that cannot be accounted for in watershed phosphorus load modeling.

Specific to the final bullet-point, during the watershed modeling assessment, the results of the modeled phosphorus loads are used to estimate in-lake phosphorus concentrations. If these estimates are much lower than those actually found in the lake, another source of phosphorus must be responsible for elevating the in-lake concentrations. Normally, two possibilities exist: 1) shoreland septic systems, and 2) internal phosphorus cycling. If the lake is considered a candidate for internal loading, modeling procedures are used to estimate that load.

Comparisons with Other Datasets

The WDNR document *Wisconsin 2018 Consolidated Assessment and Listing Methodology* (WDNR 2017) is an excellent source of data for comparing water quality from a given lake to lakes with similar features and lakes within specific regions of Wisconsin. Water quality among lakes, even among lakes that are located in close proximity to one another, can vary due to natural factors such as depth, surface area, the size of its watershed and the composition of the watershed's land cover. For this reason, the water quality of Little Green Lake will be compared to lakes in the state with similar physical characteristics. The WDNR groups Wisconsin's lakes into ten natural communities (Figure 3.1-1).

First, the lakes are classified into three main groups: (1) lakes and reservoirs less than 10 acres, (2) lakes and reservoirs greater than or equal to 10 acres, and (3) a classification that addresses special waterbody circumstances. The last two categories have several sub-categories that provide attention to lakes that may be shallow, deep, play host to cold water fish species or have unique hydrologic patterns. Overall, the divisions categorize lakes based upon their size, stratification characteristics, hydrology. An equation developed by Lathrop and Lillie (1980), which incorporates the maximum depth of the lake and the lake's surface area, is used to predict whether the lake is considered a shallow (mixed) lake or a deep (stratified) lake. The lakes are further divided into classifications based on their hydrology and watershed size:

> **Seepage Lakes** have no surface water inflow or outflow in the form of rivers and/or streams.
>
> **Drainage Lakes** have surface water inflow and/or outflow in the form of rivers and/or streams.

Headwater drainage lakes have a watershed of less than 4 square miles.
Lowland drainage lakes have a watershed of greater than 4 square miles.

Because of its depth, small watershed and hydrology, Little Green Lake is classified as a shallow, headwater drainage lake (category 2 on Figure 3.1-1).

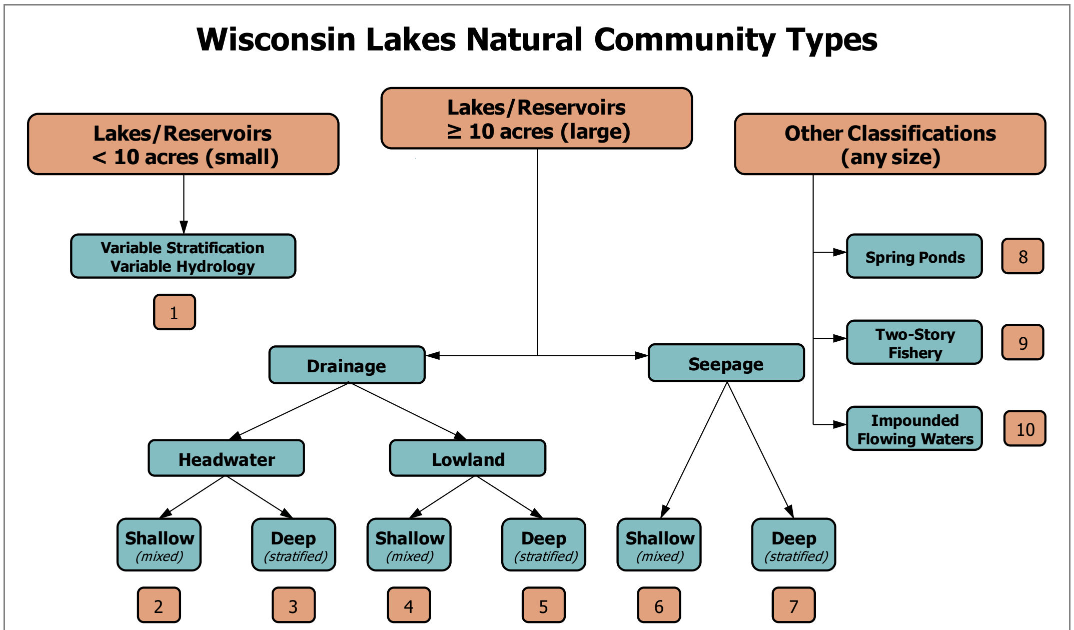


Figure 3.1-1. Wisconsin Lake Natural Communities. Adapted from WDNR 2013A.

Garrison, et. al (2008) developed state-wide median values for total phosphorus, chlorophyll-*a*, and Secchi disk transparency for six of the lake classifications. Though they did not sample sufficient lakes to create median values for each classification within each of the state's ecoregions, they were able to create median values based on all of the lakes sampled within each ecoregion (Figure 3.1-2). Ecoregions are areas related by similar climate, physiography, hydrology, vegetation and wildlife potential. Comparing ecosystems in the same ecoregion is sounder than comparing systems within manmade boundaries such as counties, towns, or states. Little Green Lake is within the Southeastern Wisconsin Till Plains ecoregion.

The Wisconsin 2014 Consolidated Assessment and Listing Methodology document also helps stakeholders understand the health of their lake compared to other lakes within the state. Looking at pre-settlement diatom population compositions from sediment cores collected from numerous lakes around the state, they were able to infer a reference condition for each lake's water quality prior to human development within their watersheds. Using these reference conditions and current water quality data, the assessors were able to rank phosphorus, chlorophyll-*a*, and Secchi disk transparency values for each lake class into categories ranging from excellent to poor.

These data along with data corresponding to statewide natural lake means, historic, current, and average data from Little Green Lake is displayed in Figures 3.1-2 - 3.1-5. Please note that the data in these graphs represent concentrations and depths taken only during the growing season

(April-October) or summer months (June-August). Furthermore, the phosphorus and chlorophyll-*a* data represent only surface samples. Surface samples are used because they represent the depths at which algae grow and depths at which phosphorus levels are not greatly influenced by phosphorus being released from bottom sediments.

Little Green Lake Water Quality Analysis

Little Green Lake Long-term Trends

The water quality of Little Green Lake, Green Lake County, has been sporadically monitored beginning in 1986. Prior to 1990, only Secchi disc transparency data was collected. Beginning in 1990 phosphorus concentrations were monitored and beginning in 1993 chlorophyll-*a* levels were monitored. Monitoring has continued to the present, although in some years, only one or two samples were collected. Only in 2002 were no samples collected. More intensive studies were conducted by WDNR during the period 2003-2005 to determine the efficacy of a newly installed destratification system to reduce internal phosphorus loading. A second study was conducted by WDNR in 2013 and 2014 to again determine if the destratification system was reducing internal loading.

Data is available most years from 1990-2016. Growing season and summer mean concentrations are highly variable. The growing season means range from 56 to 284 µg/L and the summer means range from 62 to 260 µg/L (Figure 3.1-2). The year with the highest concentration was 1999, while the year with the lowest concentration was 2016. From 1990 to 2007, the mean concentrations were in the poor category except for 2001. Since 2011, the concentrations have been in the fair category.

Weighted averages of summer total phosphorus concentration data are used to compare Little Green Lake's total phosphorus concentrations to median values for other shallow, headwater drainage lakes throughout the state and to median values of all lake types within the SWTP ecoregion. The average summer total phosphorus concentrations for the whole lake from all years that data are available 146 µg/L (Figure 3.1-2). This value falls into the *poor* category for shallow, headwater drainage lakes in Wisconsin. While phosphorus concentrations have declined since 2007, summer concentrations are still much higher than the median concentration for shallow, headwater drainage lakes in Wisconsin as well as median value for all lakes within the SWTP ecoregion (Figure 3.1-2).

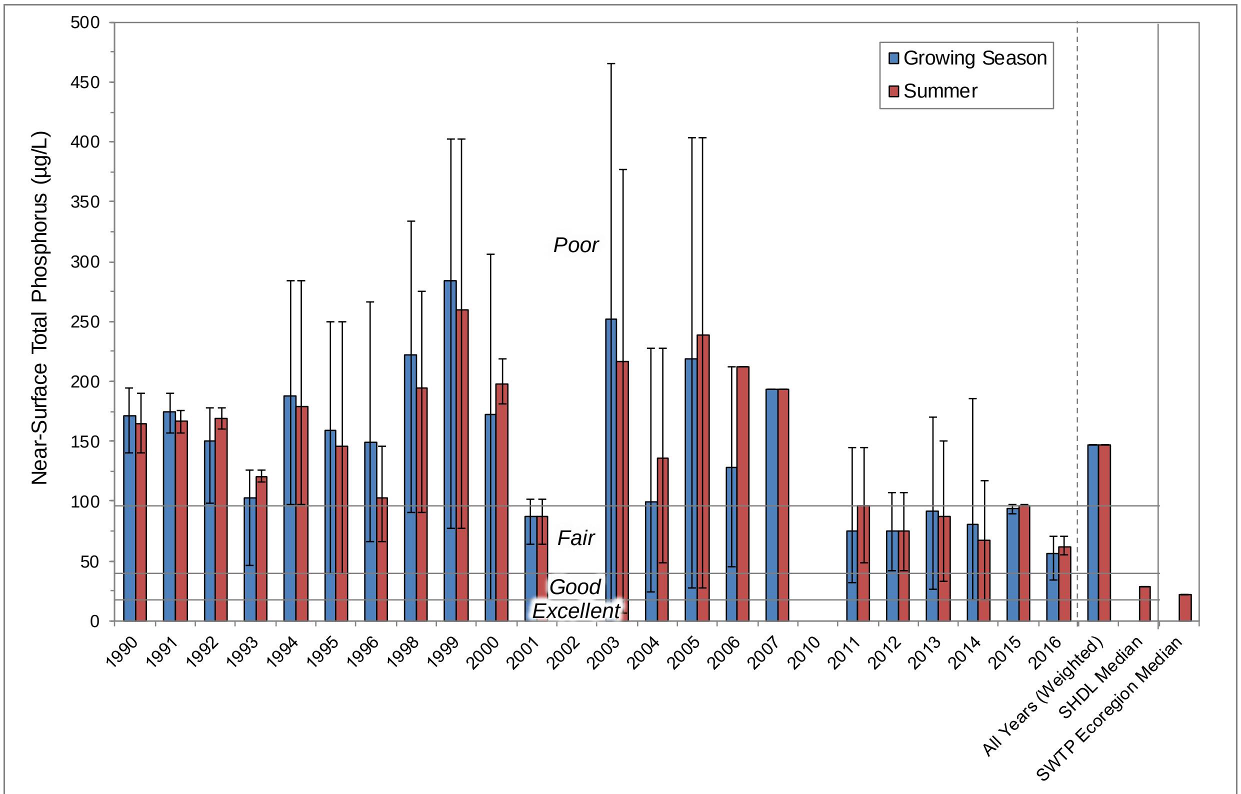


Figure 3.1-2. Growing season and summer weighted average annual total phosphorus concentrations in Little Green Lake. Also displayed are the median total phosphorus concentrations for state-wide shallow, headwater drainage lakes (SHDL) and Southeastern Wisconsin Till Plain (SWTP) ecoregion lakes. Until 2011, values were nearly always in the poor category. For the last 6 years, concentrations have been lower and were in the fair category.

Chlorophyll-*a* concentrations in the deep hole were available for the period 1993-2016 (Figure 3.1-3). Growing season concentrations ranged from 28 to 115 µg/L (Figure 3.1-3). For the summer, the concentrations ranged from 22 to 115 µg/L. The year with the highest amount of algae was 1995, which was also the year with the highest total phosphorus. The lowest year was 2007. Unlike phosphorus concentrations, chlorophyll-*a* levels are similar the last 6 years as they have been since 1993. In other words, there has not been a reduction in chlorophyll-*a* concentrations as there has been with phosphorus.

Weighted averages of summer chlorophyll-*a* concentration data are used to compare Little Green Lake's chlorophyll-*a* concentrations to median values for other shallow, headwater drainage lakes throughout the state and to median values of all lake types within the SWTP ecoregion. The weighted average growing season and summer chlorophyll-*a* concentrations from all years that data are available for the lake is 55 µg/L (Figure 3.1-3). This value is at the top of the *fair* category for shallow, headwater drainage lakes in Wisconsin. This value is considerably higher than the median concentration for shallow, lowland headwater lakes in Wisconsin and much higher than the median value for all lakes within the SWTP ecoregion (Figure 3.1-3). Perceptible algal blooms occur in lakes when chlorophyll-*a* concentrations reach approximately 30 µg/L, and Little Green Lake's average concentration is nearly twice this threshold.

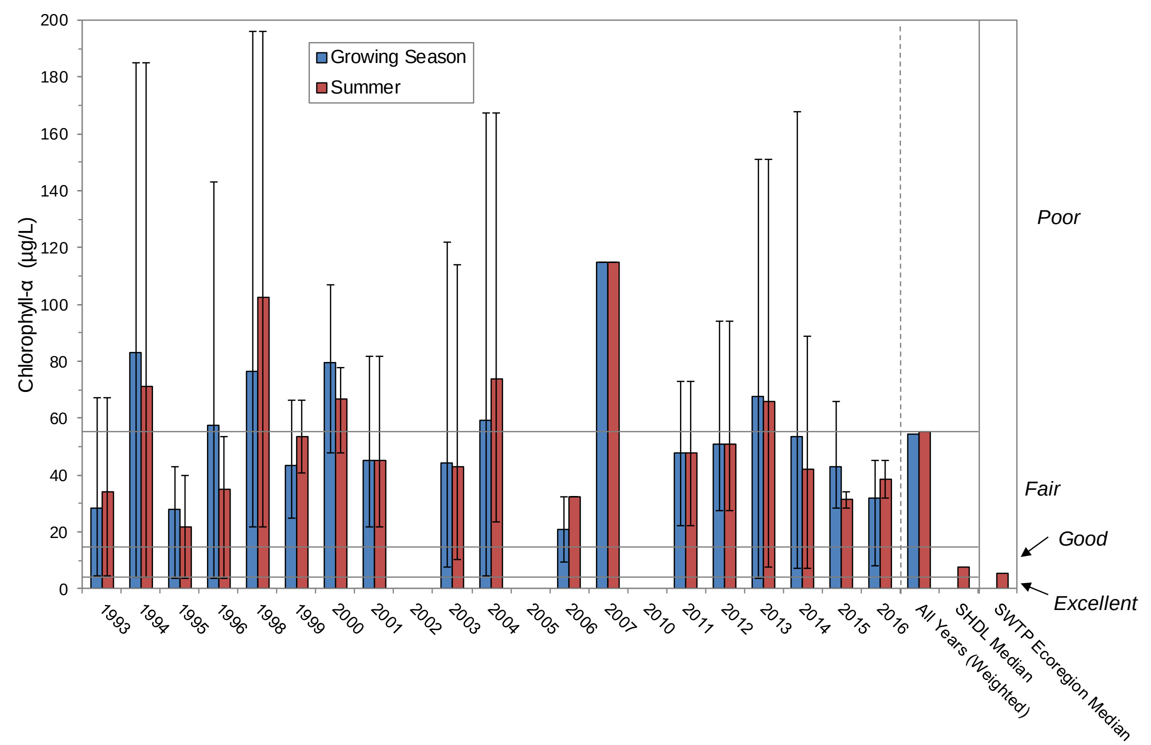


Figure 3.1-3. Growing season and summer weighted average annual chlorophyll-*a* concentrations in Little Green Lake. Also displayed are the median chlorophyll-α concentrations for state-wide shallow, headwater drainage lakes (SHDL) and Southeastern Wisconsin Till Plain (SWTP) ecoregion lakes. Unlike phosphorus, values have not declined in the last 6 years.

Secchi disk transparency is a measure of water clarity. In Little Green Lake, the record for Secchi disc data begins in 1986, which is longer than the other two trophic parameters. The worst recorded Secchi disk transparencies were in 2000 (Figure 3.1-4). Growing season and summer values were the best in 1995, which is when the lowest chlorophyll-*a* concentrations were observed. Secchi depths have ranged from 1.8 to 7.7 feet for summer means while the growing season means ranged from 1.5 to 7.4 feet. The long-term average was 4.2 feet for the growing season and 3.9 feet for the summer.

Summer Secchi disk transparency data are used to compare Little Green Lake's Secchi disk transparency values to median values for other shallow, headwater drainage lakes throughout the state and to median values of all lake types within the SWTP ecoregion. The weighted average summer Secchi disk transparency from all years that data are available is 3.9 feet (Figure 3.1-4). This value falls at the top of the *fair* category for shallow lowland drainage lakes in Wisconsin. These values are almost two times lower than the median concentration for shallow, headwater drainage lakes in Wisconsin and the median value for all lakes within the SWTP ecoregion (Figure 3.1-4).

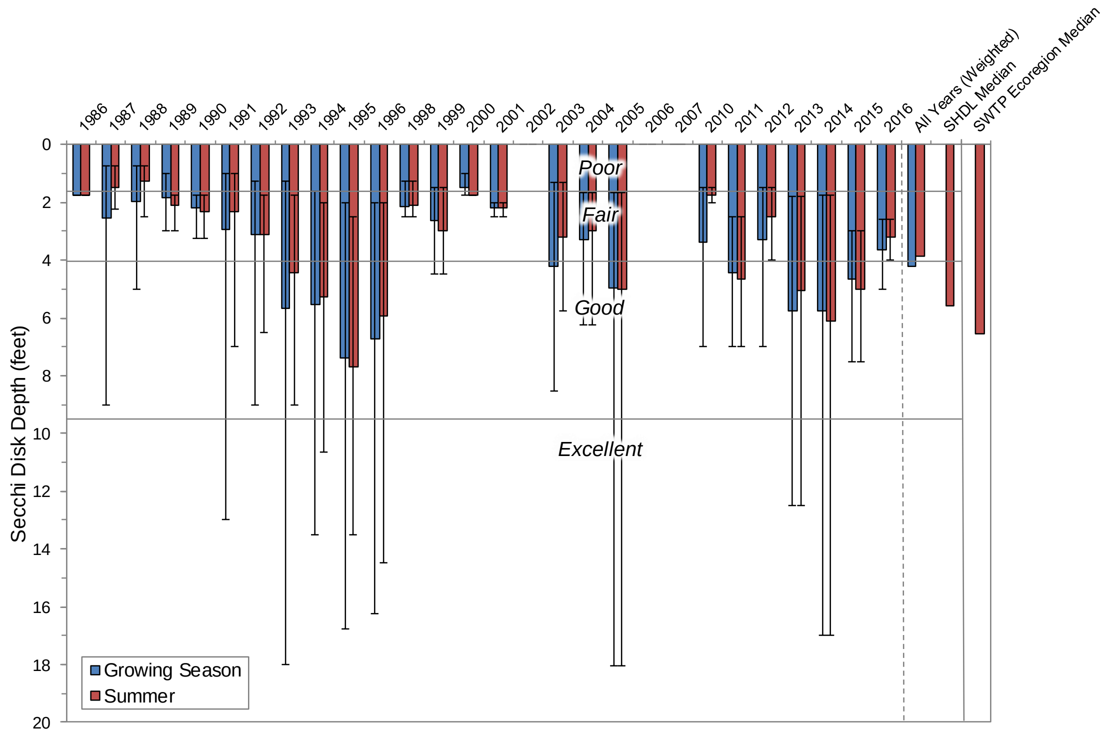


Figure 3.1-4. Growing season and summer weighted average annual Secchi disk transparency values in Little Green Lake. Also displayed are the median Secchi disc transparencies for state-wide shallow, headwater drainage lakes (SHDL) and Southeastern Wisconsin Till Plain (SWTP) ecoregion lakes. Unlike phosphorus, values have not improved in the last 6 years.

Little Green Lake Trophic State

Figure 3.1-5 contains the weighted average Trophic State Index (TSI) values in Little Green Lake for which total phosphorus, chlorophyll-*a*, or Secchi disk transparency data are available. The TSI values are calculated with annual average summer month Secchi disk transparency, chlorophyll-*a*, and total phosphorus values. In general, the best values to use in judging a lake's trophic state are chlorophyll-*a* and total phosphorus, as water clarity can be influenced by other factors such as dissolved organic compounds and abiotic suspended materials. The weighted average TSI values for chlorophyll-*a* and total phosphorus indicate Little Green Lake is in the lower *hypereutrophic* classification (Figure 3.1-5). Hypereutrophic lakes are characterized by having excessive levels of nutrients and algae with poor water clarity. Lakes which have total phosphorus concentrations of greater than 100 µg/L fall into the hypereutrophic category. During 2011-16, most of the parameters have been at the top of the eutrophic range. Prior to 2007, the TSI values for most years for phosphorus have been higher than they were for chlorophyll-*a*. Since 2011 phosphorus and chlorophyll-*a* TSI values have been similar. While it is not clear exactly why phosphorus and chlorophyll TSI values differed prior to 2007, it is likely that this is an indication that phosphorus was not limiting the growth of the algal community. Since 2011 the phosphorus concentrations have been lower in the lake and the similarity of phosphorus and chlorophyll-*a* TSI values indicates that phosphorus is now limiting algal growth. Often, if phosphorus is not limiting algal growth then nitrogen is. Unfortunately, there are no summer nitrogen data available for any years other than 2016.

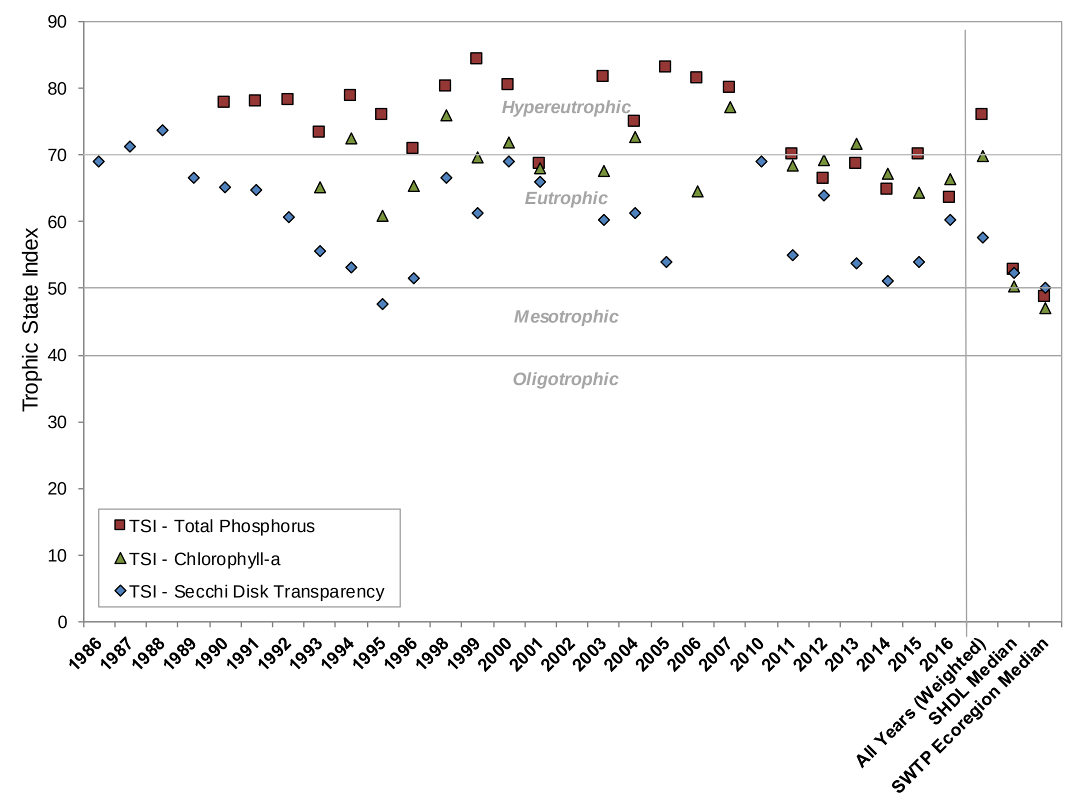


Figure 3.1-5. Trophic State Index (TSI) values for Little Green Lake from 1986 through 2016. Also displayed are the median TSI values for state-wide shallow, headwater drainage lakes (SHDL) and Southeastern Wisconsin Till Plain (SWTP) ecoregion lakes. Prior to 2007, chlorophyll-*a* levels were generally better than would be expected from the phosphorus concentrations. This likely means that algal growth during this time was not phosphorus limited for much of the summer.

The Secchi TSI values have nearly always been better than for either phosphorus or chlorophyll-*a*. It is not clear why this is; apparently, the typical relationship between chlorophyll-*a* and water clarity is not developing in Little Green Lake. Even though the relationship between algal levels and water clarity do not apply in this lake, algal levels are important in determining water clarity. Years with the lowest chlorophyll-*a* levels are also the years with the best water clarity. Conversely years with the worst water clarity have the highest chlorophyll-*a* concentrations.

Internal Phosphorus Loading in Little Green Lake

The sources of phosphorus to a lake can be broken down into external loading, i.e. entering the lake from its watershed and the atmosphere (discussed in Section 3.2), and internal loading, which is phosphorus recycling within the lake itself. Of course, most of this internal phosphorus originally entered the lake from its watershed. In Little Green Lake, there are likely three primary sources of internal loading:

1. Decaying plant material. Every lake with aquatic plants experiences some level of internal nutrient loading at the end of each growing season as the lake's plants die back and decompose. However, in lakes like Little Green Lake that annually support a very high level of curly-leaf pondweed (CLP), this specific plant's die-off in mid-summer can elevate nutrient levels in the lake and drive algae blooms. Figure 3.1-6 displays Little

Green Lake phosphorus data based upon the total mass of phosphorus in the water column. During many of the years, there is a mid-summer spike of phosphorus input that is likely the result of decaying CLP. This is discussed more in the Aquatic Plant Section (3.4).

2. Diurnal release from dense plant beds. Studies in other eutrophic Wisconsin lakes have shown that large amounts of phosphorus can be released from sediments in plant beds. Because of high photosynthetic activity in these beds, the pH is elevated to levels above 9.0, which can result in the release of phosphorus from the sediments. Also, in dense plant beds where water movement is restricted, the water immediately above the sediments can become anoxic resulting in the release of phosphorus. If the architecture of the beds changes as they mature, this phosphorus may be mobilized into the deeper waters of the lake. While Little Green Lake supports a large plant mass, this is likely the smallest of the three contributors to internal nutrient loading.
3. Phosphorus release from anoxic sediments. When oxygen is absent in the deep waters, phosphorus that is bound with iron in the sediments is released into the overlying waters. As the lake periodically mixes throughout the growing season, this phosphorus enters the surface waters where it fuels algal growth. This is likely the greatest source of internal nutrient loading in Little Green Lake.

Measurements in the early 2000s determined that the lake periodically stratified and when a wind event occurred, the lake mixed. While the lake was stratified, the bottom waters became devoid of oxygen, and as discussed above, high levels of phosphorus were released from the bottom sediments. In 2003, a destratification system was installed in the lake with the purpose of keeping the lake mixed throughout the growing season and reducing the internal phosphorus load from the bottom sediments. With the exception of 2014, this system has been operating each summer through 2016. The WDNR conducted a study from 2003 through 2005 that included estimating the amount of internal phosphorus loading that occurs from the bottom sediments. Temperature, dissolved oxygen, and phosphorus profiles were collected twice a week from early June to early September. The WDNR repeated this study in 2013-14 to determine how much internal loading was being reduced by operating the destratification system. The detailed sampling allowed for the estimation of internal loading by measuring the increase in the lake's phosphorus mass from early summer until fall. Internal loads are available for the years 2000, 2003-05, 2013-14 (Figure 3.1-7).

For the period 2000-05 the average internal phosphorus load was 3765 pounds and it was not decreased by the operation of the destratification system. During 2013 and 2014 the internal load was lower by 50% to 1880 pounds. It is not clear why the load is lower in recent years. It does not seem to be the result of the destratification system as loads were not any different in the years when this system did not operate (2000, 2014).

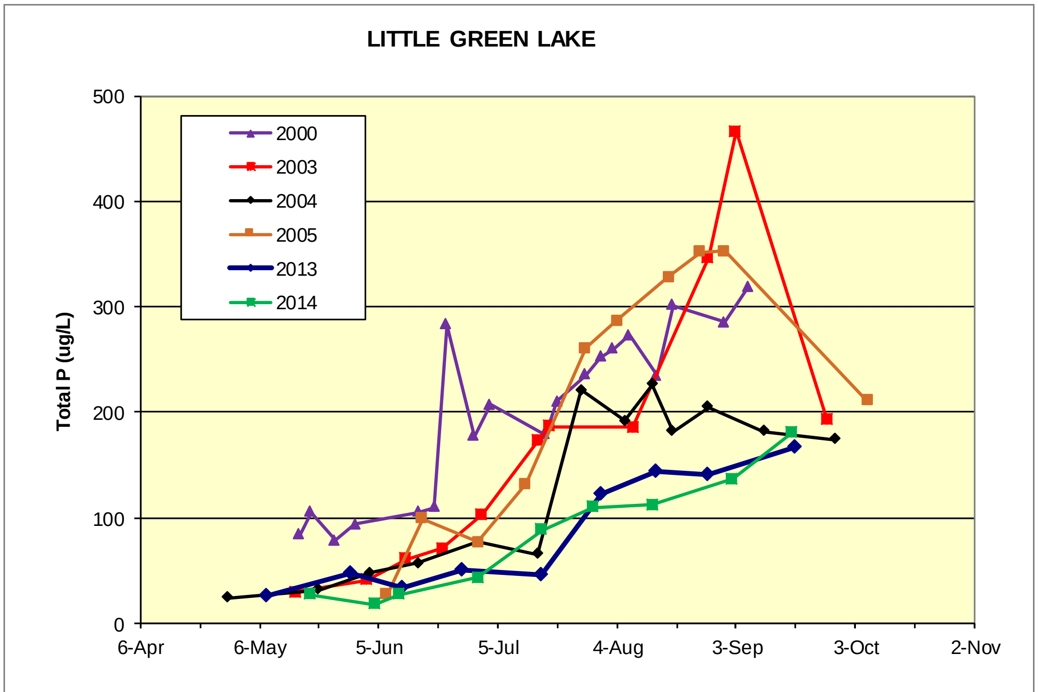


Figure 3.1-6. Weighted total phosphorus concentrations during the summer. In most years there is an increase in mid-summer which likely is the result of phosphorus release from the decaying macrophyte, curly leaf pondweed.

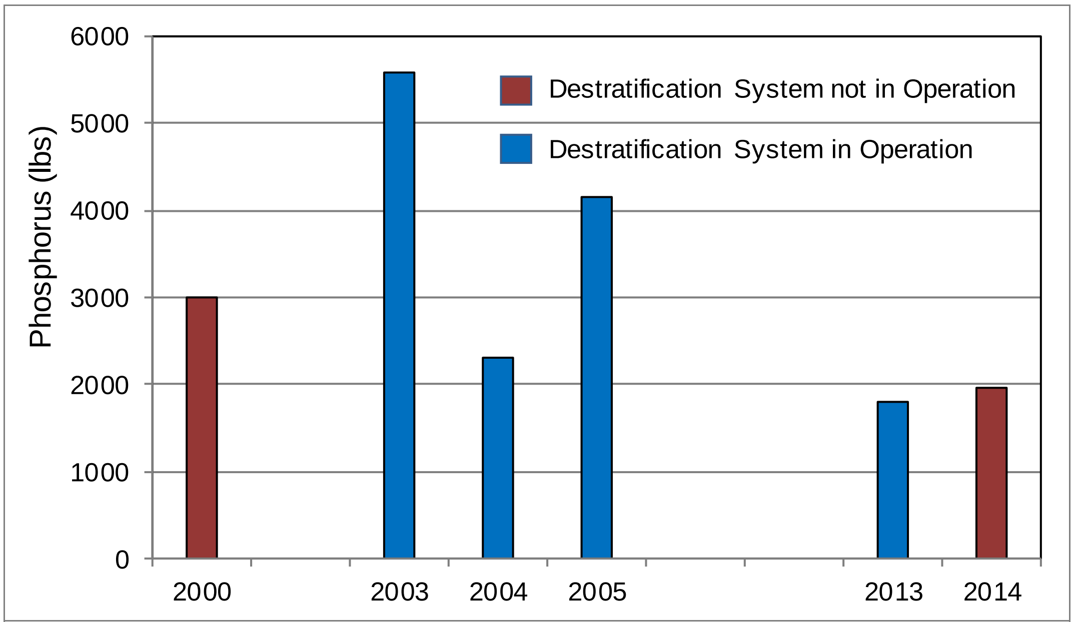


Figure 3.1-7. Internal load measured in Little Green Lake by calculating the increase in phosphorus mass in the lake during the summer. A destratification system was in operation 2003-2013 but internal loading was similar to years when the system was not operational.

External Loading

Following personal communication with Derek Kavanaugh, Green Lake County Conservation Department, it was determined that over the years, three sedimentation basins have been installed in the lake's watershed (Map 2). The oldest one, which was installed in 1992, is no longer in service. The second basin was completed in 2000 and the third one in 2009. The purpose of these basins is to reduce the amount of nutrients and sediment entering the lake. It is unclear how efficient these basins are in reducing phosphorus, but the 2009 basin was designed to remove at least 74% of the phosphorus that would otherwise enter the lake from this part of the watershed.

As noted above, phosphorus concentrations in the lake decreased between 2007 and 2011. Perhaps the reduction in the phosphorus concentration is due in part to the installation of the sedimentation basin in 2009. The reduction in mean growing season and summer phosphorus concentrations since 2011 is also reflected in the spring phosphorus concentrations when the data was available. Prior to 2011, the spring concentrations were usually about 45 µg/L but for the last few years it is lower at around 30 µg/L (Figure 3.1-8). This likely reflects less phosphorus entering from the watershed and not a reduction in internal load. For more information regarding external phosphorus loads please refer to the Watershed section (3.2).

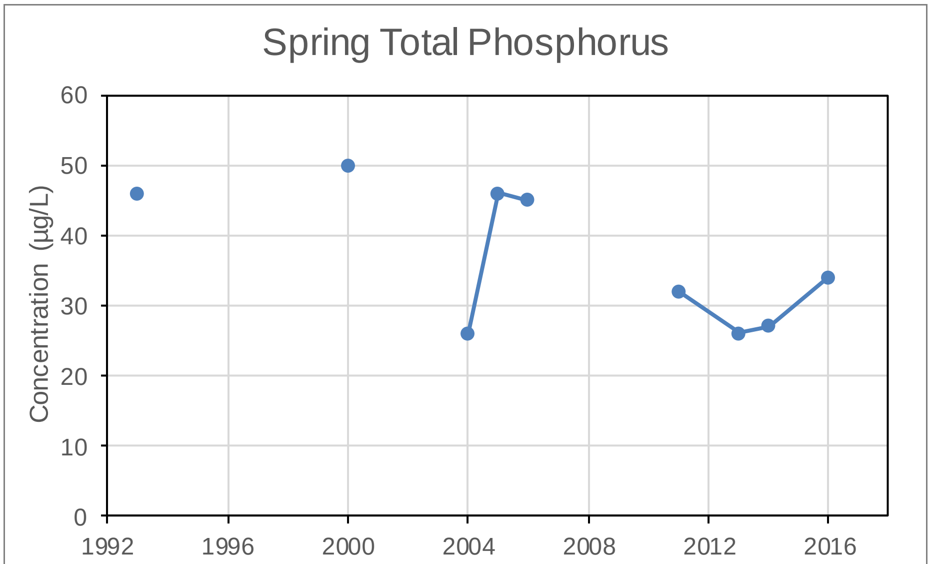


Figure 3.1-8. Spring phosphorus concentrations in Little Green Lake. The reduction in concentration since 2011 may be due to the installation of the sedimentation basin in 2009.

Little Green Lake Destratification System

Studies completed by the WDNR in 2000 documented that much of Little Green Lake's total phosphorus load was originating from within the lake through a process called internal nutrient loading. The internal nutrient loading process is discussed in more detail above. Based upon the results of the 2000 study, the LGLPRD installed a destratification system in 2003 that was to be operated during the open water months aiming to destratify the lake. By destratifying the lake, the water would be mixed and exposed to the atmosphere, which in turn would add oxygen to the water and prevent anoxia. The key objective of the system is to prevent anoxia. By preventing anoxia, phosphorus would remain bound with iron in the sediment and not make its way into the water column where it can spur algal blooms.

During 2013-14 WDNR staff conducted a study to determine whether the destratification system was effective in reducing internal loading from the deep-water sediments. The study was completed by measuring phosphorus, nitrogen, and iron in the bottom waters when the dissolved oxygen was less than 2 mg/L. Samples 1 m below the lake surface were also collected for the above parameters. In addition, chlorophyll-*a* and Secchi depth were determined. A similar study was conducted by WDNR researchers in 2000, 2003-05. The destratification system was not operating during 2000 or 2014, but it was operational the other study years.

In all of the study years, significant internal loading was experienced and was very likely the major source of phosphorus to the lake. The highest amount of internal loading occurred during the years 2000, 2003-05. Internal loading was lower in 2013 and 2014, but still considerably high. In fact, even if internal loading was the only source of phosphorus during 2013 and 2014, Little Green Lake would be eutrophic. Still, the lower level of internal loading is reflected in the summer mean phosphorus concentrations also being lower in 2013 and 2014 compared to earlier years. However, a portion of these lower summer means are likely also the result of the watershed work discussed above, as well. There was not an appreciable difference in internal loading in 2013 when the system was operational and 2014 when it was not. In fact, estimated internal load in 2013 was slightly lower than 2014 (system not operational), but the difference is within the variability measured in earlier years.

It appears that the mechanism of internal loading in Little Green Lake is similar to Kentuck Lake, Vilas County, which has been heavily studied by Onterra over the past four years. Kentuck Lake, like Little Green, is relatively shallow, experiences a great deal of internal loading, and at times, is plagued with blue-green algal blooms. Sediment cores have been collected from both lakes. Laboratory measurements of phosphorus release rates from each lake's respective bottom sediments, under anoxic conditions, greatly underestimate the internal load in the lake as a whole. This is likely the case because as anoxia occurs, phosphorus is released from the sediments and because these lakes are shallow, turbulence created by wind action causes increased flow shear along the anoxic boundary of the hypolimnion and the oxic boundary of the metalimnion, which enhances diffusion into the upper waters where the phosphorus is taken up by algae.

As discussed above and shown in the following section, the primary objective of the destratification system, which is to prevent anoxic conditions in the deep area of the lake, is consistently not being met. Members of the district heavily involved in the set up and maintenance of the system believe that modifications to that system, including upgrading and/or adding diffusers, would allow the system to prevent stratification and anoxia in the deep hole. However, as discussed with the Planning Committee during the April 2017 meeting, even if changes could be made to the current destratification system to meet the primary objective, recent studies from a lake in Wisconsin indicate that the system would likely not reduce internal loading of phosphorus in Little Green Lake significantly. In other words, even if the lake was destratified and thoroughly oxygenated, another factor may limit its impact on internal phosphorus loading. That factor being insufficient concentrations of iron in Little Green Lake.

Research completed at Cedar Lake, Polk County by UW-Stout and the WDNR discovered that an iron:phosphorus ratio of greater than 3.6 is necessary for there to be sufficient iron to bind all of the available phosphorus, even during oxic conditions (James et. al 2015). The iron:phosphorus ratio in Little Green Lake in 2013-14 was less than 2.5 and sometimes less than 1.0. They also observed in Cedar Lake that the amount of phosphorus released is greater than nitrogen, so that in the mid to late summer the algal community is nitrogen limited which favors the growth of cyanobacteria. This likely also the case in Little Green Lake.

In August 2017, the LGLPRD completed some improvements to the existing destratification system. The improvements included upgrading the five existing destratification tube lines with 1000 feet of new ½-inch tubing with micro-sized holes 1 inch apart.

Dissolved Oxygen and Temperature in Little Green Lake

Dissolved oxygen and temperature were measured during water quality sampling visits to Little Green Lake by Onterra staff. Profiles depicting these data are displayed in Figure 3.1-9. Despite the continuous operation of the destratification system, the lake weakly stratified and experienced anoxia in depths of 14-feet and deeper during July. Water samples collected from the anoxic water during the same sampling event were found to have a total phosphorus concentration of 262 µg/L indicating high levels of nutrient release from the sediments. During all four sampling events, much or all of the water column maintained sufficient dissolved oxygen levels to support the Little Green Lake fishery.

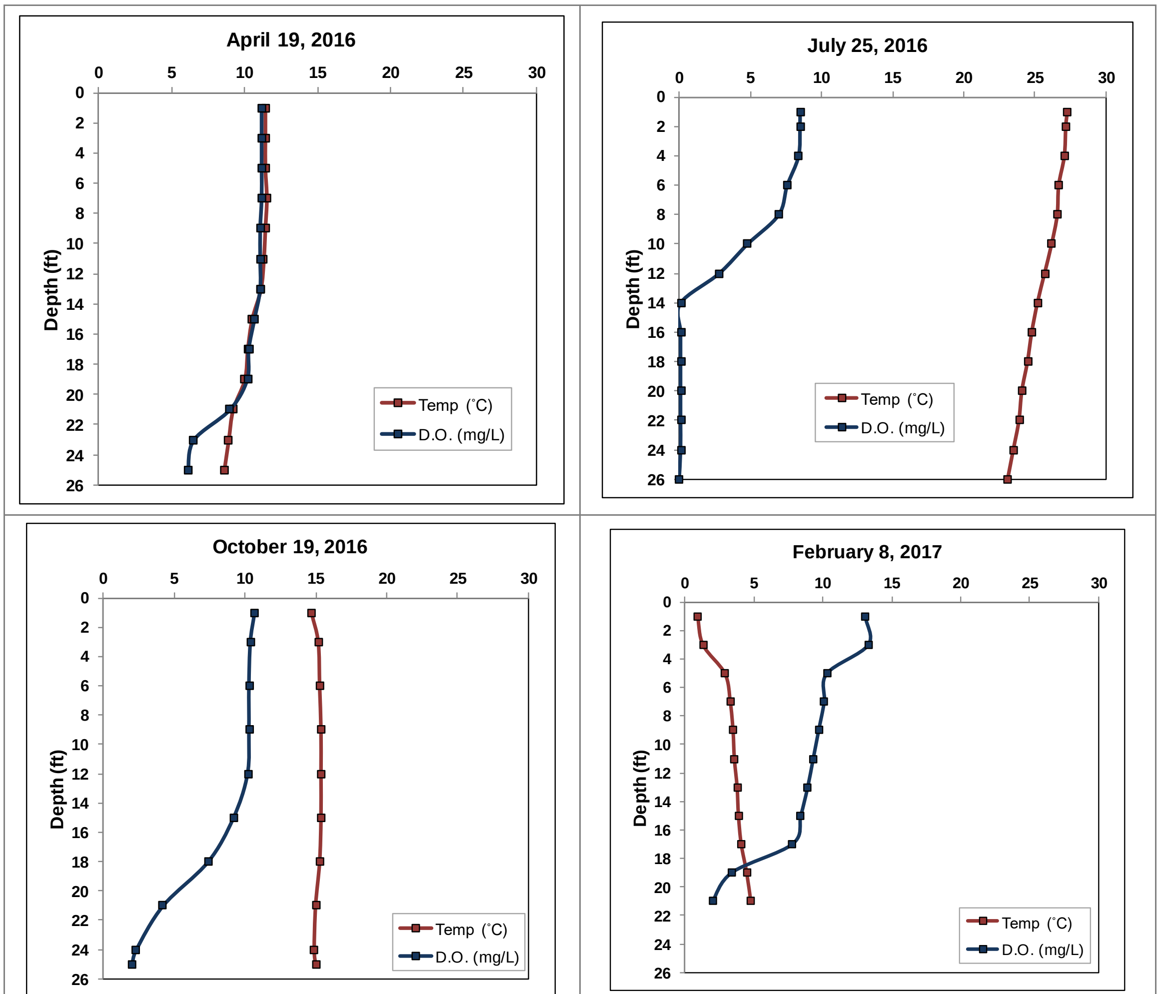


Figure 3.1-9. Little Green Lake dissolved oxygen and temperature profiles.

Additional Water Quality Data Collected at Little Green Lake

The water quality section is centered on lake eutrophication. However, parameters other than water clarity, nutrients, and chlorophyll-*a* were collected as part of the project. These other parameters were collected to increase the understanding of Little Green Lake's water quality and are recommended as a part of the WDNR long-term lake trends monitoring protocol. These parameters include pH, alkalinity, and calcium.

The pH scale ranges from 0 to 14 and indicates the concentration of hydrogen ions (H^+) within the lake's water and is an index of the lake's acidity. Water with a pH value of 7 has equal amounts of hydrogen ions and hydroxide ions (OH^-) and is considered to be neutral. Water with a pH of less than 7 has higher concentrations of hydrogen ions and is considered to be acidic, while values greater than 7 have lower hydrogen ion concentrations and are considered basic or alkaline. The pH scale is logarithmic; meaning that for every 1.0 pH unit the hydrogen ion concentration changes tenfold. The normal range for lake water pH in Wisconsin is about 5.2 to 8.4, though values lower than 5.2 can be observed in some acid bog lakes and higher than 8.4 in some marl lakes. In lakes with a pH of 6.5 and lower, the spawning of certain fish species such as walleye becomes inhibited (Shaw and Nimphius 1985). The pH of the water in Little Green Lake was found to be slightly basic with a value of 8.9 and falls just above the normal range for Wisconsin Lakes and is likely brought on by the high rate of photosynthesis in the lake.

Alkalinity is a lake's capacity to resist fluctuations in pH by neutralizing or buffering against inputs such as acid rain. The main compounds that contribute to a lake's alkalinity in Wisconsin are bicarbonate (HCO_3^-) and carbonate (CO_3^-), which neutralize hydrogen ions from acidic inputs. These compounds are present in a lake if the groundwater entering it comes into contact with minerals such as calcite ($CaCO_3$) and/or dolomite ($CaMgCO_3$). A lake's pH is primarily determined by the amount of alkalinity. Rainwater in northern Wisconsin is slightly acidic naturally due to dissolved carbon dioxide from the atmosphere with a pH of around 5.0. Consequently, lakes with low alkalinity have lower pH due to their inability to buffer against acid inputs. The alkalinity in Little Green Lake was measured at 134 (mg/L as $CaCO_3$), indicating that the lake has a substantial capacity to resist fluctuations in pH and has a low sensitivity to acid rain.

Like associated pH and alkalinity, the concentration of calcium within a lake's water depends on the geology of the lake's watershed. Recently, the combination of calcium concentration and pH has been used to determine what lakes can support zebra mussel populations if they are introduced. The commonly accepted pH range for zebra mussels is 7.0 to 9.0, so Little Green Lake's pH of 8.9 falls slightly inside of this range. Lakes with calcium concentrations of less than 12 mg/L are considered to have very low susceptibility to zebra mussel establishment. The calcium concentration of Little Green Lake was found to be 29.4 mg/L, falling well within the optimal range for zebra mussels.

Zebra mussels (*Dreissena polymorpha*) are small bottom dwelling mussels, native to Europe and Asia, that found their way to the Great Lakes region in the mid-1980s. They are thought to have come into the region through ballast water of ocean-going ships entering the Great Lakes and they have the capacity to spread rapidly. Zebra mussels can attach themselves to boats, boat lifts, and docks, and can live for up to five days after being taken out of the water. These mussels can be identified by their small size, D-shaped shell and yellow-brown striped coloring.

Once zebra mussels have entered and established in a waterway, they are nearly impossible to eradicate. Best practice methods for cleaning boats that have been in zebra mussel infested waters is inspecting and removing any attached mussels, spraying your boat down with diluted bleach, power-washing, and letting the watercraft dry for at least five days.

Researchers at the University of Wisconsin - Madison have developed an AIS suitability model called smart prevention (Vander Zanden and Olden 2008). In regards to zebra mussels, this model relies on measured or estimated dissolved calcium concentration to indicate whether a given lake in Wisconsin is suitable, borderline suitable, or unsuitable for sustaining zebra mussels. Within this model, suitability was estimated for approximately 13,000 Wisconsin waterbodies and is displayed as an interactive mapping tool (www.aissmartprevention.wisc.edu). Based upon this analysis, Little Green Lake was considered very suitable for mussel establishment.

Property Owner Survey Responses to Little Green Lake Water Quality

As discussed in section 2.0, the property owner survey sent to Little Green Lake property owners asked many questions pertaining to perception of the lake and how it may have changed over the years. Of the 289 surveys distributed, 93 surveys (32%) were returned. Without a response rate of 60% or higher, the responses to the following questions regarding water quality cannot be interpreted as being statistically representative of the population sampled. At best, the results may indicate possible trends and opinions about the property owner perceptions of water quality in Little Green Lake but cannot be stated with statistical confidence.

Figure 3.1-10 displays property owner survey responses to questions regarding respondents' perceptions of Little Green Lake's water quality. When asked how they would describe the current water quality of Little Green Lake, 43% indicated *fair*, 28% indicated *poor*, 21% indicated *good*, 7% indicated *very poor*, and 1% indicated *unsure*. As discussed in the previous section, the water quality parameters used to assess Little Green Lake's current water quality all fall within the eutrophic to hypereutrophic for Wisconsin lakes.

When asked how they believe the current water quality has changed since they first visited the lake, 26% indicated it has *somewhat improved* while another 24% indicated that it has *somewhat degraded*, 20% indicated that the water quality has *remained the same*, 13% indicated *greatly improved*, 11% indicated *severely degraded*, and 6% indicated *unsure* (Figure 3.1-11). As discussed in the previous section, data indicates that while total phosphorus concentrations have decreased slightly in recent years, chlorophyll-*a* concentrations and water clarity have not changed. The variance in answers for Question 16 can most likely be attributed to how much individuals understand about water quality versus water clarity versus excessive plant growth. As will be discussed in the Aquatic Plants section, Little Green Lake has a large amount of curly-leaf pondweed that dies back in late June. This loss generally creates an algae bloom which can decrease water clarity. The perception of surface-matted plants and free-floating plants can also impact how individuals view water quality.

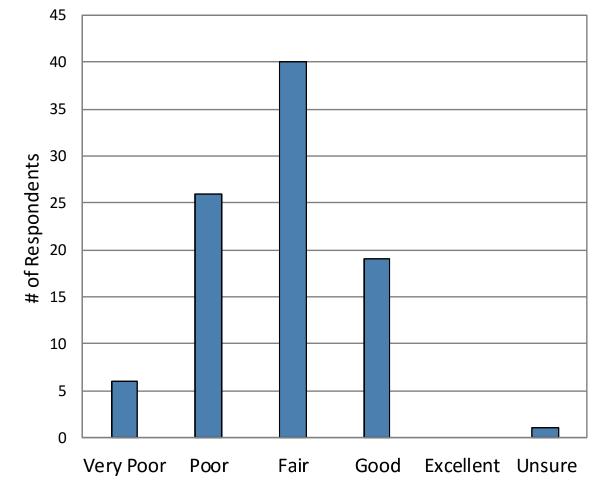


Figure 3.1-10. Property owner survey response Question #15. How would you describe the current water quality of Little Green Lake?

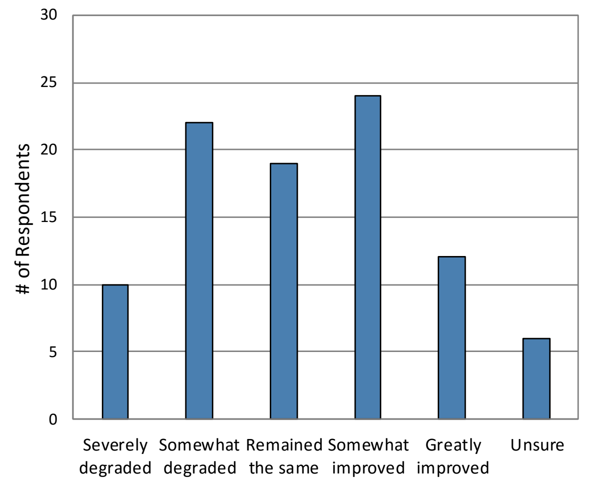


Figure 3.1-11. Property owner survey response Question #16. How as the water quality changed in Little Green Lake since you first visited the lake?

3.2 Watershed Assessment

Watershed Modeling

A lake's **flushing rate** is simply a determination of the time required for the lake's water volume to be completely exchanged. **Residence time** describes how long a volume of water remains in the lake and is expressed in days, months, or years. The parameters are related and both determined by the volume of the lake and the amount of water entering the lake from its watershed. Greater flushing rates equal shorter residence

Two aspects of a lake's watershed are the key factors in determining the amount of phosphorus the watershed exports to the lake; 1) the size of the watershed, and 2) the land cover (land use) within the watershed. The impact of the watershed size is dependent on how large it is relative to the size of the lake. The watershed to lake area ratio (WS:LA) defines how many acres of watershed drains to each surface-acre of the lake. Larger ratios result in the watershed having a greater role in the lake's annual water budget and phosphorus load.

The type of land cover that exists in the watershed determines the amount of phosphorus (and sediment) that runs off the land and eventually makes its way to the lake. The actual amount of pollutants (nutrients, sediment, toxins, etc.) depends greatly on how the land within the watershed is used. Vegetated areas, such as forests, grasslands, and meadows, allow the water to permeate the ground and do not produce much surface runoff. On the other hand, agricultural areas, particularly row crops, along with residential/urban areas, minimize infiltration and increase surface runoff. The increased surface runoff associated with these land cover types leads to increased phosphorus and pollutant loading; which, in turn, can lead to nuisance algal blooms, increased sedimentation, and/or overabundant macrophyte populations. For these reasons, it is important to maintain as much natural land cover (forests, wetlands, etc.) as possible within a lake's watershed to minimize the amount runoff (nutrients, sediment, etc.) from entering the lake.

In systems with lower WS:LA ratios, land cover type plays a very important role in how much phosphorus is loaded to the lake from the watershed. In these systems, the occurrence of agriculture or urban development in even a small percentage of the watershed (less than 10%) can unnaturally elevate phosphorus inputs to the lake. If these land cover types are converted to a cover that does not export as much phosphorus, such as converting row crop areas to grass or forested areas, the phosphorus load and its impacts to the lake may be decreased. In fact, if the phosphorus load is reduced greatly, changes in lake water quality may be noticeable, (e.g. reduced algal abundance and better water clarity) and may even be enough to cause a shift in the lake's trophic state.

In systems with high WS:LA ratios, like those 10-15:1 or higher, the impact of land cover may be tempered by the sheer amount of land draining to the lake. Situations actually occur where lakes with completely forested watersheds have sufficient phosphorus loads to support high rates of plant production. In other systems with high ratios, the conversion of vast areas of row crops to vegetated areas (grasslands, meadows, forests, etc.) may not reduce phosphorus loads sufficiently to see a change in plant production. Both of these situations occur frequently in impoundments.

Regardless of the size of the watershed or the makeup of its land cover, it must be remembered that every lake is different and other factors, such as flushing rate, lake volume, sediment type, and many others, also influence how the lake will react to what is flowing into it. For instance, a deeper lake with a greater volume can dilute more phosphorus within its waters than a less voluminous lake and as a result, the production of a lake is kept low. However, in that same lake, because of its low flushing rate (a residence time of years), there may be a buildup of phosphorus in the sediments that may reach sufficient levels over time and lead to a problem such as internal nutrient loading. On the contrary, a lake with a higher flushing rate (low residence time, i.e., days or weeks) may be more productive early on, but the constant flushing of its waters may prevent a buildup of phosphorus and internal nutrient loading may never reach significant levels.

A reliable and cost-efficient method of creating a general picture of a watershed's effect on a lake can be obtained through modeling. The WDNR created a useful suite of modeling tools called the Wisconsin Lake Modeling Suite (WiLMS). Certain morphological attributes of a lake and its watershed are entered into WiLMS along with the acreages of different types of land cover within the watershed to produce useful information about the lake ecosystem. This information includes an estimate of annual phosphorus load and the partitioning of those loads between the watershed's different land cover types and atmospheric fallout entering through the lake's water surface. WiLMS also calculates the lake's flushing rate and residence times using county-specific average precipitation/evaporation values or values entered by the user. Predictive models are also included within WiLMS that are valuable in validating modeled phosphorus loads to the lake in question and modeling alternate land cover scenarios within the watershed. Finally, if specific information is available, WiLMS will also estimate the significance of internal nutrient loading within a lake and the impact of shoreland septic systems.

Little Green Lake Watershed Assessment

Little Green Lake's total watershed encompasses approximately 2,419 acres (3.8 square miles) in Green Lake County (Map 2). Little Green Lake has a watershed to lake area ratio of 4:1, in other words, approximately four acres of land drains to every one acre of Little Green Lake. According to WiLMS modeling, the lake's water is completely replaced approximately every 3.35 years (residence time) or 0.3 times per year (flushing rate).

As discussed in the Water Quality section (3.1), Little Green Lake has two functioning sedimentation basins. Using topographic maps, the two basins' subwatersheds were delineated (Map 2). Approximately 294 acres drain to the basin installed in 2009 and approximately 520 acres drain to the basin installed in 2000. WiLMS was utilized to estimate the hydraulic load and total phosphorus load being delivered to each sedimentation basin. It was assumed that 75% of the total phosphorus draining to the basins is being retained, with the remaining phosphorus making its way to the lake. The remaining land in the watershed is likely draining directly to Little Green Lake and makes up the lake's direct watershed.

Approximately 40% of Little Green Lake's direct watershed is composed of row crop agriculture, 30% of Little Green Lake's surface, 12% pasture/grass, 9% forest, 6% wetlands, 3% rural residential areas, and less than 1% medium density urban areas (Figure 3.2-1). Both the 2000 and 2009 sedimentation basin subwatersheds are dominated by row crop agriculture at 86% and 90%, respectively.

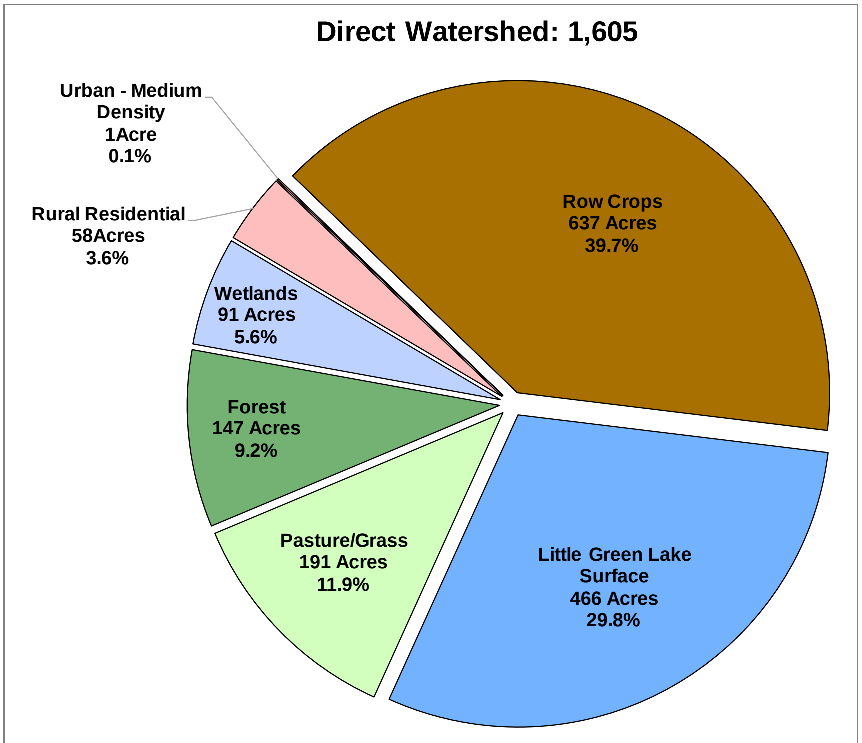


Figure 3.2-1. Little Green Lake watershed land cover types in acres. Based upon National Land Cover Database (NLCD – Fry et. al 2011).

Using the landcover described above, WiLMS was utilized to estimate the annual potential phosphorus load from Little Green Lake's direct watershed, along with the estimated outflow of phosphorus from the sedimentation basin subwatersheds. In total, it was estimated that approximately 3,636 pounds of phosphorus are being delivered annually to Little Green Lake (Figure 3.2-2).

Of the estimated 3,636 pounds of phosphorus being delivered annually to Little Green Lake, the majority, 51%, is estimated to originate from internal nutrient loading, which is discussed further in the Water Quality section, 17% from the sedimentation basin installed in 2000, 16% from row crop agriculture, 10% from the sedimentation basin installed in 2009, 1% from pasture/grass, and 1% from septic systems (Figure 3.2-2). The remaining phosphorus load comes from homes around and near the lake, forest, and wetlands.

Using predictive equations, it was estimated that Little Green Lake should have a growing season mean (GSM) total phosphorus concentration of approximately 95 μg/L, which is similar to the observed 2013 to 2014 GSM total phosphorus concentration of 86 μg/L. The 2013 to 2014 GSM total phosphorus concentration was used for modeling purposes because internal loading data is available for these years. The modelled GSM is likely a bit higher than measured because much of the internal loading occurs in July and August while the GSM encompasses April through October.

As illustrated in the Water Quality section, Little Green Lake is in the lower hypereutrophic classification. While a significant amount of phosphorus is coming from agricultural sources within the lake's watershed, Little Green Lake's biggest phosphorus contributor is definitely internal nutrient loading.

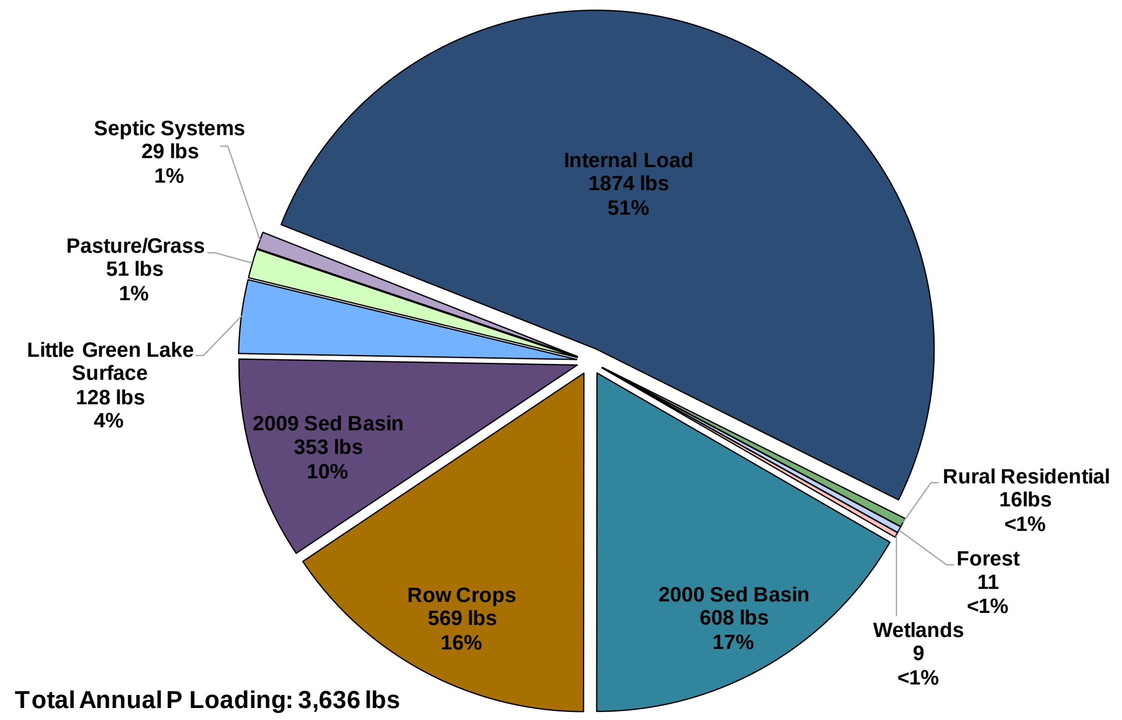


Figure 3.2-2. Little Green Lake watershed phosphorus loading in pounds. Based upon Wisconsin Lake Modeling Suite (WiLMS) estimates.

Evidence does exist showing that the installation of the 2009 sedimentation basin helped to reduce external phosphorus loading to the lake; however, it is difficult to detect. As described in the Water Quality section, the average growing season and average summer phosphorus values, while always high, do tend to fluctuate from year-to-year. In drainage lakes without significant amounts of internal nutrient loading, in-lake phosphorus values are typically highest during the spring runoff. As that pulse of phosphorus is used by algae and those algae die and settle to the bottom, the phosphorus is taken out of the water column and the concentrations decrease over the growing season. In lakes like Little Green Lake, those with significant internal loading issues, the phosphorus levels in the lake increase over the growing season. As internal nutrient loading is occurring, it fuels algal growth in the water column. This is what occurs in Little Green Lake and with the heat of the summer, drives the worst algal blooms to occur late in the season. This elevates the growing season average phosphorus concentrations and masks any evidence of the impacts that watershed improvements, like the sedimentation basin construction projects, have had on the lake's phosphorus budget.

By examining phosphorus data collected during the spring, the impact of internal nutrient loading can be removed from the scenario and focus can be placed upon the impact of watershed run off. Figure 3.2-3 shows available spring phosphorus concentrations (mid-April to mid-May) between 1992 and 2016. These data indicate a noticeable drop in spring concentrations following the installation of the 2009 sedimentation basin.

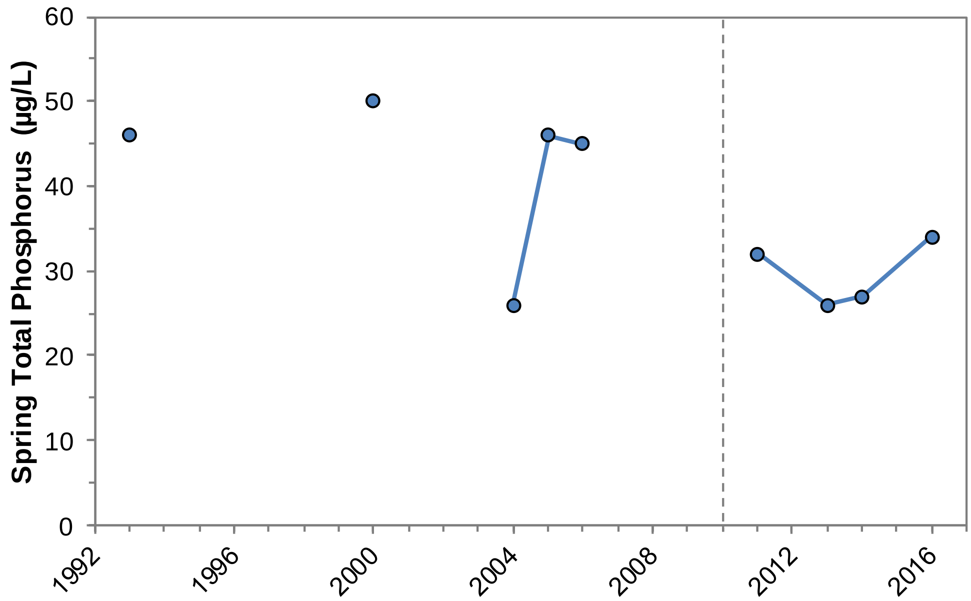


Figure 3.2-3. Little Green Lake spring phosphorus concentrations. These data were collected between mid-April and mid-May for the years indicated. Grey dotted line indicates year 2009 sedimentation basin was installed.

3.3 Shoreland Condition

Lake Shoreland Zone and its Importance

One of the most vulnerable areas of a lake's watershed is the immediate shoreland zone (approximately from the water's edge to at least 35 feet shoreland). When a lake's shoreland is developed, the increased impervious surface, removal of natural vegetation, and other human practices can severely increase pollutant loads to the lake while degrading important habitat. Limiting these anthropogenic (man-made) effects on the lake is important in maintaining the quality of the lake's water and habitat.

The intrinsic value of natural shorelands is found in numerous forms. Vegetated shorelands prevent polluted runoff from entering lakes by filtering this water or allowing it to slow to the point where particulates settle. The roots of shoreland plants stabilize the soil, thereby preventing shoreland erosion. Shorelands also provide habitat for both aquatic and terrestrial animal species. Many species rely on natural shorelands for all or part of their life cycle as a source of food, cover from predators, and as a place to raise their young. Shorelands and the nearby shallow waters serve as spawning grounds for fish and nesting sites for birds. Thus, both the removal of vegetation and the inclusion of development reduces many forms of habitat for wildlife.

Some forms of development may provide habitat for less than desirable species. Disturbed areas are often overtaken by invasive species, which are sometimes termed "pioneer species" for this reason. Some waterfowl, such as geese, prefer to linger upon open lawns near waterbodies because of the lack of cover for potential predators. The presence of geese on a lake resident's beach may not be an issue; however, the feces the geese leave are unsightly and pose a health risk. Geese feces may become a source of fecal coliforms as well as flatworms that can lead to swimmer's itch. Development such as rip rap or masonry, steel or wooden seawalls completely remove natural habitat for most animals but may also create some habitat for snails; this is not desirable for lakes that experience problems with swimmer's itch, as the flatworms that cause this skin reaction utilize snails as a secondary host after waterfowl.

In the end, natural shorelines provide many ecological and other benefits. Between the abundant wildlife, the lush vegetation, and the presence of native flowers, shorelands also provide natural scenic beauty and a sense of tranquility for humans.

Shoreland Zone Regulations

Wisconsin has numerous regulations in place at the state level which aim to enhance and protect shorelands. Additionally, counties, townships and other municipalities have developed their own (often more comprehensive or stronger) policies. At the state level, the following shoreland regulations exist:

Wisconsin-NR 115: Wisconsin's Shoreland Protection Program

Wisconsin's shoreland zoning rule, NR 115, sets the minimum standards for shoreland development. First adopted in 1966, the code set a deadline for county adoption of January 1, 1968. By 1971, all counties in Wisconsin had adopted the code and were administering the shoreland ordinances it specified. Interestingly, in 2007 it was noted that many (27) counties had recognized inadequacies within the 1968 ordinance and had actually adopted more strict shoreland ordinances. Passed in February of 2010, the final NR 115 allowed many standards to remain the same, such as lot sizes, shoreland setbacks and buffer sizes. However, several standards changed as a result of efforts to balance public rights to lake use with private property rights. The regulation sets minimum standards for the shoreland zone and requires all counties in the state to adopt shoreland zoning ordinances. Counties were previously able to set their own, stricter, regulations to NR 115 but as of 2015, all counties have to abide by state regulations. Minimum requirements for each of these categories are described below. Please note that at the time of this writing, changes to NR 115 were last made in October of 2015 (Lutze 2015).

- Vegetation Removal: For the first 35 feet of property (shoreland zone), no vegetation removal is permitted except for: sound forestry practices on larger pieces of land, access and viewing corridors (may not exceed 35 percent of the shoreline frontage), invasive species removal, or damaged, diseased, or dying vegetation. Vegetation removed must be replaced by replanting in the same area (native species only).

- Impervious surface standards: The amount of impervious surface is restricted to 15% of the total lot size, on lots that are within 300 feet of the ordinary high-water mark of the waterbody. If a property owner treats their run off with some type of treatment system, they may be able to apply for an increase in their impervious surface limit.

- Nonconforming structures: Nonconforming structures are structures that were lawfully placed when constructed but do not comply with distance of water setback. Originally, structures within 75 ft of the shoreline had limitations on structural repair and expansion. Language in NR-115 allows construction projects on structures within 75 feet with the following caveats:
    - No expansion or complete reconstruction within 0-35 feet of shoreline
    - Re-construction may occur if the same type of structure is being built in the previous location with the same footprint. All construction needs to follow general zoning or floodplain zoning authority
    - Construction may occur if mitigation measures are included either within the existing footprint or beyond 75 feet.
    - Vertical expansion cannot exceed 35 feet

- Mitigation requirements: Language in NR-115 specifies mitigation techniques that may be incorporated on a property to offset the impacts of impervious surface, replacement of nonconforming structure, or other development projects. Practices such as buffer restorations along the shoreland zone, rain gardens, removal of fire pits, and beaches all may be acceptable mitigation methods.

Wisconsin Act 31

While not directly aimed at regulating shoreland practices, the State of Wisconsin passed Wisconsin Act 31 in 2009 in an effort to minimize watercraft impacts upon shorelines. This act prohibits a person from operating a watercraft (other than personal watercraft) at a speed in excess of slow-no-wake speed within 100 feet of a pier, raft, buoyed area or the shoreline of a lake. Additionally, personal watercraft must abide by slow-no-wake speeds while within 200 feet of these same areas. Act 31 was put into place to reduce wave action upon the sensitive shoreland zone of a lake. The legislation does state that pickup and drop off areas marked with regulatory markers and that are open to personal watercraft operators and motorboats engaged in waterskiing/a similar activity may be exempt from this distance restriction. Additionally, a city, village, town, public inland lake protection and rehabilitation district or town sanitary district may provide an exemption from the 100-foot requirement or may substitute a lesser number of feet.

Shoreland Research

Studies conducted on nutrient runoff from Wisconsin lake shorelands have produced interesting results. For example, a USGS study on several Northwoods Wisconsin lakes was conducted to determine the impact of shoreland development on nutrient (phosphorus and nitrogen) export to these lakes (Graczyk et al. 2003). During the study period, water samples were collected from surface runoff and ground water and analyzed for nutrients. These studies were conducted on several developed (lawn covered) and undeveloped (undisturbed forest) areas on each lake. The study found that nutrient yields were greater from lawns than from forested catchments, but also that runoff water volumes were the most important factor in determining whether lawns or wooded catchments contributed more nutrients to the lake. Ground-water inputs to the lake were found to be significant in terms of water flow and nutrient input. Nitrate plus nitrite nitrogen and total phosphorus yields to the ground-water system from a lawn catchment were three or sometimes four times greater than those from wooded catchments.

A separate USGS study was conducted on the Lauderdale Lakes in southern Wisconsin, looking at nutrient runoff from different types of developed shorelands – regular fertilizer application lawns (fertilizer with phosphorus), non-phosphorus fertilizer application sites, and unfertilized sites (Garn 2002). One of the important findings stemming from this study was that the amount of dissolved phosphorus coming off of regular fertilizer application lawns was twice that of lawns with non-phosphorus or no fertilizer. Dissolved phosphorus is a form in which the phosphorus molecule is not bound to a particle of any kind; in this respect, it is readily available to algae. Therefore, these studies show us that it is a developed shoreland that is continuously maintained in an unnatural manner (receiving phosphorus rich fertilizer) that impacts lakes the greatest. This understanding led former Governor Jim Doyle into passing the Wisconsin Zero-Phosphorus Fertilizer Law (Wis Statue 94.643), which restricts the use, sale and display of lawn and turf fertilizer which contains phosphorus. Certain exceptions apply, but after April 1 2010, use of this type of fertilizer is prohibited on lawns and turf in Wisconsin. The goal of this action is to reduce the impact of developed lawns and is particularly helpful to developed lawns situated near Wisconsin waterbodies.

Shorelands provide much in terms of nutrient retention and mitigation, but also play an important role in wildlife habitat. Woodford and Meyer (2003) found that green frog density was negatively correlated with development density in Wisconsin lakes. As development increased, the habitat for green frogs decreased and thus populations became significantly lower. Common loons, a bird species notorious for its haunting call that echoes across Wisconsin lakes, are often associated more so with undeveloped lakes than developed lakes (Lindsay et al. 2002). And studies on shoreland development and fish nests show that undeveloped shorelands are preferred as well. In a study conducted on three Minnesota lakes, researchers found that only 74 of 852 black crappie nests were found near shorelines that had any type of dwelling on it (Reed, 2001). The remaining nests were all located along undeveloped shoreland.

Photograph 3.3-1. Example of coarse woody habitat in a lake.

Emerging research in Wisconsin has shown that coarse woody habitat (sometimes called "coarse woody debris"), often stemming from natural or undeveloped shorelands, provides many ecosystem benefits in a lake. Coarse woody habitat describes habitat consisting of trees, limbs, branches, roots and wood fragments at least four inches in diameter that enter a lake by natural or human means. Coarse woody habitat provides shoreland erosion control, a carbon source for the lake, prevents suspension of sediments and provides a surface for algal growth which is important for aquatic macroinvertebrates (Sass 2009). While it impacts these aspects considerably, one of the greatest benefits coarse woody habitat provides is habitat for fish species.

Coarse woody habitat has shown to be advantageous for fisheries in terms of providing refuge, foraging area as well as spawning habitat (Hanchin et al 2003). In one study, researchers observed 16 different species occupying coarse woody habitat areas in a Wisconsin lake (Newbrey et al. 2005). Bluegill and bass species in particular are attracted to this habitat type; largemouth bass stalk bluegill in these areas while the bluegill hide amongst the debris and often feed upon many macroinvertebrates found in these areas, who themselves are feeding upon algae and periphyton growing on the wood surface. Newbrey et al. (2005) found that some fish species prefer different complexity of branching on coarse woody habitat, though in general some degree of branching is preferred over coarse woody habitat that has no branching.

With development of a lake's shoreland zone, much of the coarse woody habitat that was once found in Wisconsin lakes has disappeared. Prior to human establishment and development on lakes (mid to late 1800's), the amount of coarse woody habitat in lakes was likely greater than under completely natural conditions due to logging practices. However, with changes in the logging industry and increasing development along lake shorelands, coarse woody habitat has decreased substantially. Shoreland residents are removing woody debris to improve aesthetics or for recreational opportunities (boating, swimming, and, ironically, fishing).

National Lakes Assessment

Unfortunately, along with Wisconsin's lakes, waterbodies within the entire United States have shown to have increasing amounts of developed shorelands. The National Lakes Assessment (NLA) is an Environmental Protection Agency sponsored assessment that has successfully pooled together resource managers from all 50 U.S. states in an effort to assess waterbodies, both natural and man-made, from each state. Through this collaborative effort, over 1,000 lakes were sampled in 2007, pooling together the first statistical analysis of the nation's lakes and reservoirs.

Through the National Lakes Assessment, a number of potential stressors were examined, including nutrient impairment, algal toxins, fish tissue contaminants, physical habitat, and others. The 2007 NLA report states that "*of the stressors examined, poor lakeshore habitat is the biggest* *problem in the nations lakes; over one-third exhibit poor shoreline habitat condition*" (USEPA 2009). Furthermore, the report states that "*poor biological health is three times more likely in lakes with poor lakeshore habitat*".

The results indicate that stronger management of shoreline development is absolutely necessary to preserve, protect and restore lakes. This will become increasingly important as development pressure on lakes continue to steadily grow.

Native Species Enhancement

The development of Wisconsin's shorelands has increased dramatically over the last century and with this increase in development a decrease in water quality and wildlife habitat has occurred. Many people that move to or build in shoreland areas attempt to replicate the suburban landscapes they are accustomed to by converting natural shoreland areas to the "neat and clean" appearance of manicured lawns and flowerbeds. The conversion of these areas immediately leads to destruction of habitat utilized by birds, mammals, reptiles, amphibians, and insects (Jennings et al. 2003). The maintenance of the newly created area helps to decrease water quality by considerably increasing inputs of phosphorus and sediments into the lake. The negative impact of human development does not stop at the shoreland. Removal of native plants and dead, fallen timbers from shallow, near-shore areas for boating and swimming activities destroys habitat used by fish, mammals, birds, insects, and amphibians, while leaving bottom and shoreland sediments vulnerable to wave action caused by boating and wind (Jennings et al. 2003, Radomski and Goeman 2001, and Elias & Meyer 2003). Many homeowners significantly decrease the number of trees and shrubs along the water's edge in an effort to increase their view of the lake. However, this has been shown to locally increase water temperatures, and decrease infiltration rates of potentially harmful nutrients and pollutants. Furthermore, the dumping of sand to create beach areas destroys spawning, cover and feeding areas utilized by aquatic wildlife (Scheuerell and Schindler 2004).

Photograph 3.3-2. Example of a biolog restoration site.

In recent years, many lakefront property owners have realized increased aesthetics, fisheries, property values, and water quality by restoring portions of their shoreland to mimic its unaltered state. An area of shore restored to its natural condition, both in the water and on shore, is commonly called a shoreland buffer zone. The shoreland buffer zone creates or restores the ecological habitat and benefits lost by traditional suburban landscaping. Simply not mowing within the buffer zone does wonders to restore some of the shoreland's natural function.

Enhancement activities also include additions of submergent, emergent, and floating-leaf plants within the lake itself. These additions can provide greater species diversity and may compete against exotic species.

Cost

The cost of native, aquatic, and shoreland plant restorations is highly variable and depends on the size of the restoration area, the depth of buffer zone required to be restored, the existing plant density, the planting density required, the species planted, and the type of planting (e.g. seeds, bare-roots, plugs, live-stakes) being conducted. Other sites may require erosion control stabilization measures, which could be as simple as using erosion control blankets and plants and/or seeds or more extensive techniques such as geotextile bags (vegetated retaining walls), geogrids (vegetated soil lifts), or bio-logs (see above picture). Some of these erosion control techniques may reduce the need for rip-rap or seawalls which are sterile environments that do not allow for plant growth or natural shorelines. Questions about rip-rap or seawalls should be directed to the local Wisconsin DNR Water Resources Management Specialist. Other measures possibly required include protective measures used to guard newly planted area from wildlife predation, wave-action, and erosion, such as fencing, erosion control matting, and animal deterrent sprays. One of the most important aspects of planting is maintaining moisture levels. This is done by watering regularly for the first two years until plants establish themselves, using soil amendments (i.e., peat, compost) while planting, and using mulch to help retain moisture.

Most restoration work can be completed by the landowner themselves. To decrease costs further, bare-root form of trees and shrubs should be purchased in early spring. If additional assistance is needed, the lakefront property owner could contact an experienced landscaper. For properties with erosion issues, owners should contact their local county conservation office to discuss cost-share options.

In general, a restoration project with the characteristics described below would have an estimated materials and supplies cost of approximately $1,400. The more native vegetation a site has, the lower the cost. Owners should contact the county’s regulations/zoning department for all minimum requirements. The single site used for the estimate indicated above has the following characteristics:

- Spring planting timeframe.
- 100’ of shoreline.
- An upland buffer zone depth of 35’.
- An access and viewing corridor 30’ x 35’ free of planting (recreation area).
- Planting area of upland buffer zone 2- 35’ x 35’ areas
- Site is assumed to need little invasive species removal prior to restoration.
- Site has only turf grass (no existing trees or shrubs), a moderate slope, sandy-loam soils, and partial shade.
- Trees and shrubs planted at a density of 1 tree/100 sq. ft and 2 shrubs/100 sq. ft, therefore, 24 native trees and 48 native shrubs would need to be planted.
- Turf grass would be removed by hand.
- A native seed mix is used in bare areas of the upland buffer zone.
- An aquatic zone with shallow-water 2 - 5’ x 35’ areas.
- Plant spacing for the aquatic zone would be 3 feet.

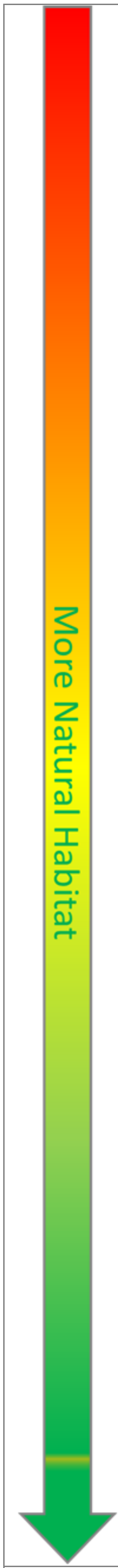
- Each site would need 70’ of erosion control fabric to protect plants and sediment near the shoreland (the remainder of the site would be mulched).
- Soil amendment (peat, compost) would be needed during planting.
- There is no hard-armor (rip-rap or seawall) that would need to be removed.
- The property owner would maintain the site for weed control and watering.

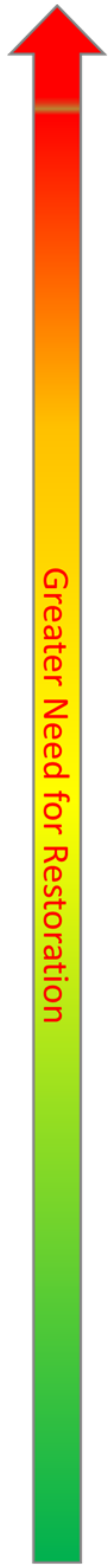
Advantages	***Disadvantages***
• Improves the aquatic ecosystem through species diversification and habitat enhancement. • Assists native plant populations to compete with exotic species. • Increases natural aesthetics sought by many lake users. • Decreases sediment and nutrient loads entering the lake from developed properties. • Reduces bottom sediment re-suspension and shoreland erosion. • Lower cost when compared to rip-rap and seawalls. • Restoration projects can be completed in phases to spread out costs. • Once native plants are established, they require less water, maintenance, no fertilizer; provide wildlife food and habitat, and natural aesthetics compared to ornamental (non-native) varieties. • Many educational and volunteer opportunities are available with each project.	• Property owners need to be educated on the benefits of native plant restoration before they are willing to participate. • Property owners must be willing to wait 3-4 years for restoration areas to mature and fill-in. • Monitoring and maintenance are required to assure that newly planted areas will thrive. • Harsh environmental conditions (e.g., drought, intense storms) may partially or completely destroy project plantings before they become well established.

Little Green Lake Shoreland Zone Condition

Shoreland Development

Little Green Lake’s shoreland zone can be classified in terms of its degree of development. In general, more developed shorelands are more stressful on a lake ecosystem, while definite benefits occur from shorelands that are left in their natural state. Figure 3.3-1 displays a diagram of shoreland categories, from “Urbanized”, meaning the shoreland zone is completely disturbed by human influence, to “Natural/Undeveloped”, meaning the shoreland has been left in its original state.





Urbanized: This type of shoreline has essentially no natural habitat. Areas that are mowed or unnaturally landscaped to the water's edge and areas that are rip-rapped or include a seawall would be placed in this category.

Developed-Unnatural: This category includes shorelines that have been developed, but only have small remnants of natural habitat yet intact. A property with many trees, but no remaining understory or herbaceous layer would be included within this category. Also, a property that has left a small (less than 30 feet), natural buffer in place, but has urbanized the areas behind the buffer would be included in this category.

Developed-Semi-Natural: This is a developed shoreline that is mostly in a natural state. Developed properties that have left much of the natural habitat in state, but have added gathering areas, small beaches, etc. within those natural areas would likely fall into this category. An urbanized shoreline that was restored would likely be included here, also.

Developed-Natural: This category includes shorelines that are developed property, but essentially no modifications to the natural habitat have been made. Developed properties that have maintained the natural habitat and only added a path leading to a single pier would fall into this category.

Natural/Undeveloped: This category includes shorelines in a natural, undisturbed state. No signs of anthropogenic impact can be found on these shorelines. In forested areas, herbaceous, understory, and canopy layers would be intact.

Figure 3.3-1. Shoreland assessment category descriptions.

On Little Green Lake, the development stage of the entire shoreland was surveyed during the fall of 2016, using a GPS unit to map the shoreland. Onterra staff only considered the area of shoreland 35 feet inland from the water's edge and did not assess the shoreland on a property-by-property basis. During the survey, Onterra staff examined the shoreland for signs of development and assigned areas of the shoreland one of the five descriptive categories in Figure 3.3-2.

Little Green Lake has stretches of shoreland that fit all of the five shoreland assessment categories. In all, 1.3 miles of natural/undeveloped and developed-natural shoreland were observed during the survey (Figure 3.3-2). These shoreland types provide the most benefit to the lake and should be left in their natural state if at all possible. During the survey, 2.5 miles of urbanized and developed–unnatural shoreland were observed. If restoration of the Little Green Lake shoreland is to occur, primary focus should be placed on these shoreland areas as they currently provide little benefit to, and actually may harm, the lake ecosystem. Map 3 displays the location of these shoreland lengths around the entire lake.

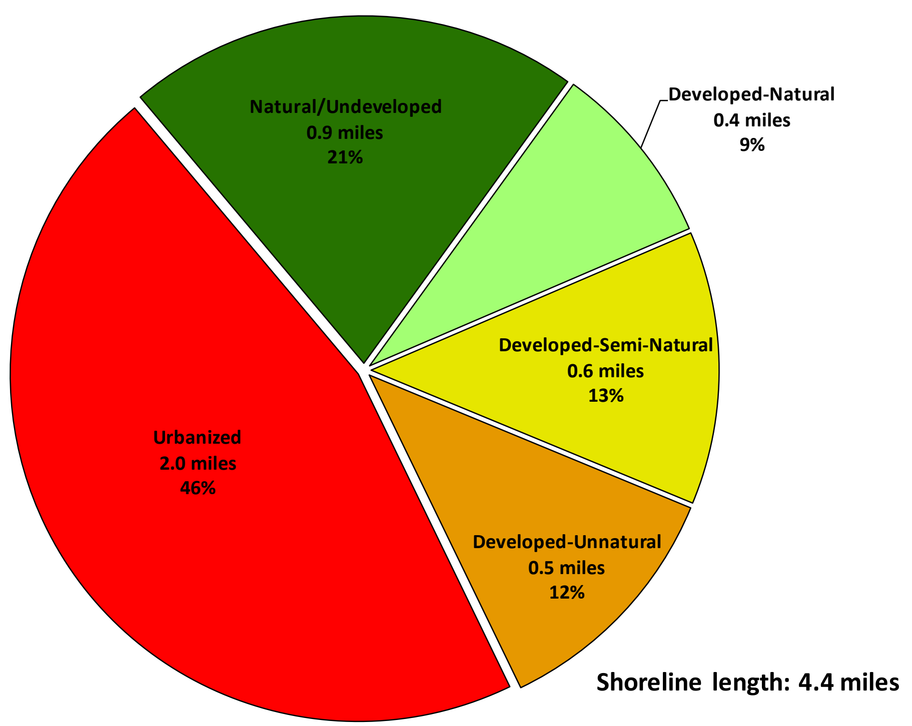


Figure 3.3-2. Little Green Lake shoreland categories and total lengths. Based upon a Fall 2016 survey. Locations of these categorized shorelands can be found on Map 3.

While producing a completely natural shoreland is ideal for a lake ecosystem, it is not always practical from a human's perspective. However, riparian property owners can take small steps in ensuring their property's impact upon the lake is minimal. Choosing an appropriate landscape position for lawns is one option to consider. Placing lawns on flat, unsloped areas or in areas that do not terminate at the lake's edge is one way to reduce the amount of runoff a lake receives from a developed site. And, allowing tree falls and other natural habitat features to remain along a shoreline may result not only in reducing shoreline erosion, but creating wildlife habitat also.

Coarse Woody Habitat

Little Green Lake was surveyed in 2016 to determine the extent of its coarse woody habitat. A survey for coarse woody habitat was conducted in conjunction with the shoreland assessment (development) survey. Coarse woody habitat was identified and classified in two size categories (2-8 inches diameter, >8 inches diameter) as well as four branching categories: no branches, minimal branches, moderate branches, and full canopy. As discussed earlier, research indicates that fish species prefer some branching as opposed to no branching on coarse woody habitat, and increasing complexity is positively correlated with higher fish species richness, diversity and abundance.

During this survey, 96 total pieces of coarse woody habitat were observed along 4.4 miles of shoreline, which gives Little Green Lake a coarse woody habitat to shoreline mile ratio of 22:1. Locations of coarse woody habitat are displayed on Map 4. To put this into perspective, Wisconsin researchers have found that in completely undeveloped lakes, an average of 345 coarse woody habitat structures may be found per mile (Christensen et al. 1996).

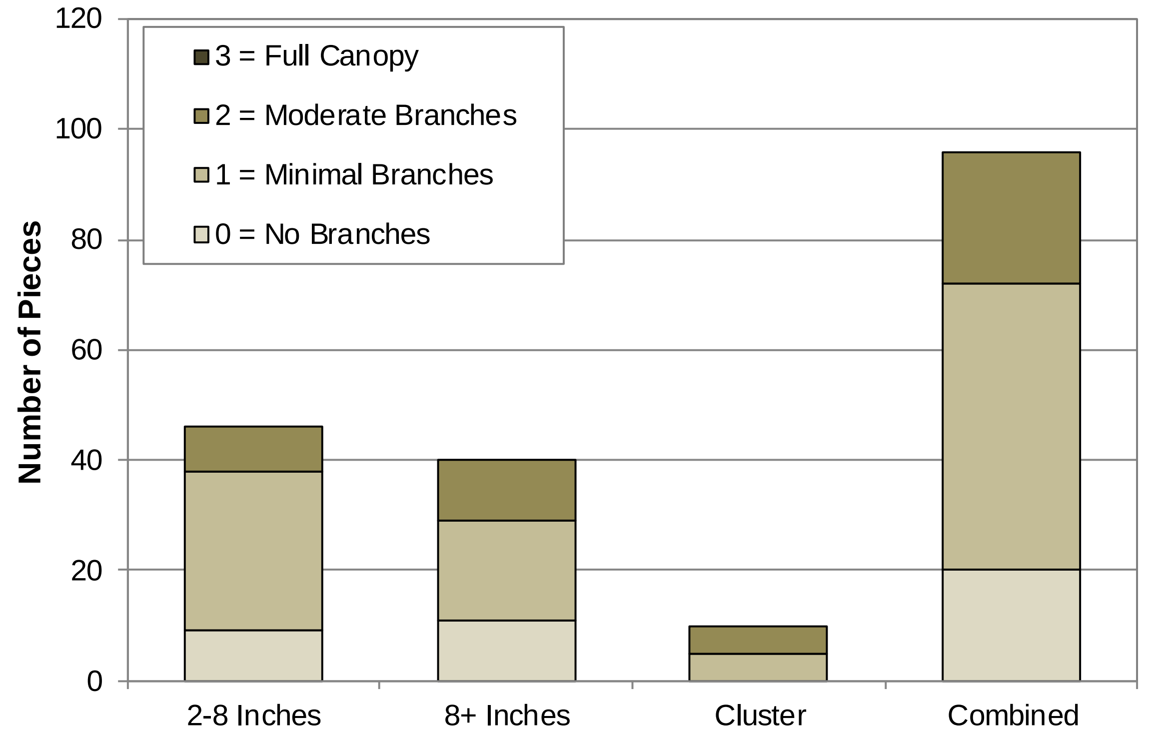


Figure 3.3-3. Little Green Lake coarse woody habitat survey results. Based upon a Fall 2016 survey. Locations of Little Green Lake coarse woody habitat can be found on Map 4.

3.4 Aquatic Plants

Introduction

Although the occasional lake user considers aquatic macrophytes to be "weeds" and a nuisance to the recreational use of the lake, the plants are actually an essential element in a healthy and functioning lake ecosystem. It is very important that lake stakeholders understand the importance of lake plants and the many functions they serve in maintaining and protecting a lake ecosystem. With increased understanding and awareness, most lake users will recognize the importance of the aquatic plant community and their potential negative effects on it.

Photograph 3.4-1. Emergent and floating-leaf aquatic plant community.

Diverse aquatic vegetation provides habitat and food for many kinds of aquatic life, including fish, insects, amphibians, waterfowl, and even terrestrial wildlife. For instance, wild celery (*Vallisneria americana)* and wild rice (*Zizania aquatica* and *Z. palustris*) both serve as excellent food sources for ducks and geese. Emergent stands of vegetation provide necessary spawning habitat for fish such as northern pike (*Esox lucius*) and yellow perch (*Perca flavescens*). In addition, many of the insects that are eaten by young fish rely heavily on aquatic plants and the periphyton attached to them as their primary food source. The plants also provide cover for feeder fish and zooplankton, stabilizing the predator-prey relationships within the system. Furthermore, rooted aquatic plants prevent shoreland erosion and the resuspension of sediments and nutrients by absorbing wave energy and locking sediments within their root masses. In areas where plants do not exist, waves can resuspend bottom sediments decreasing water clarity and increasing plant nutrient levels that may lead to algae blooms. Lake plants also produce oxygen through photosynthesis and use nutrients that may otherwise be used by phytoplankton, which helps to minimize nuisance algal blooms.

Under certain conditions, a few species may become a problem and require control measures. Excessive plant growth can limit recreational use by deterring navigation, swimming, and fishing activities. It can also lead to changes in fish population structure by providing too much cover for feeder fish resulting in reduced predation by predator fish, which could result in a stunted pan-fish population. Exotic plant species, such as Eurasian water-milfoil (*Myriophyllum spicatum*) and curly-leaf pondweed (*Potamogeton crispus*) can also upset the delicate balance of a lake ecosystem by out competing native plants and reducing species diversity. These species will be discussed further in depth in the Aquatic Invasive Species section. These invasive plant species can form dense stands that are a nuisance to humans and provide low-value habitat for fish and other wildlife.

When plant abundance negatively affects the lake ecosystem and limits the use of the resource, plant management and control may be necessary. The management goals should always include the control of invasive species and restoration of native communities through environmentally sensitive and economically feasible methods. No aquatic plant management plan should only contain methods to control plants, they should also contain methods on how to protect and possibly enhance the important plant communities within the lake. Unfortunately, the latter is often neglected and the ecosystem suffers as a result.

Aquatic Plant Management and Protection

Many times, an aquatic plant management plan is aimed at only controlling nuisance plant growth that has limited the recreational use of the lake, usually navigation, fishing, and swimming. It is important to remember the vital benefits that native aquatic plants provide to lake users and the lake ecosystem, as described above. Therefore, all aquatic plant management plans also need to address the enhancement and protection of the aquatic plant community. Below are general descriptions of the many techniques that can be utilized to control and enhance aquatic plants. Each alternative has benefits and limitations that are explained in its description. Please note that only legal and commonly used methods are included. For instance, the herbivorous grass carp (*Ctenopharyngodon idella*) is illegal in Wisconsin and rotovation, a process by which the lake bottom is tilled, is not a commonly accepted practice. Unfortunately, there are no "silver bullets" that can completely cure all aquatic plant problems, which makes planning a crucial step in any aquatic plant management activity. Many of the plant management and protection techniques commonly used in Wisconsin are described below.

Important Note:
Even though most of these techniques are not applicable to Little Green Lake, it is still important for lake users to have a basic understanding of all the techniques so they can better understand why particular methods are or are not applicable in their lake. The techniques applicable to Little Green Lake are discussed in Summary and Conclusions section and the Implementation Plan found near the end of this document.

Permits

The signing of the 2001-2003 State Budget by Gov. McCallum enacted many aquatic plant management regulations. The rules for the regulations have been set forth by the WDNR as NR 107 and 109. A major change includes that all forms of aquatic plant management, even those that did not require a permit in the past, require a permit now, including manual and mechanical removal. Manual cutting and raking are exempt from the permit requirement if the area of plant removal is no more than 30 feet wide and any piers, boatlifts, swim rafts, and other recreational and water use devices are located within that 30 feet. This action can be conducted up to 150 feet from shore. Please note that a permit is needed in all instances if wild rice is to be removed. Furthermore, installation of aquatic plants, even natives, requires approval from the WDNR.

Permits are required for chemical and mechanical manipulation of native and non-native plant communities. Large-scale protocols have been established for chemical treatment projects covering >10 acres or areas greater than 10% of the lake littoral zone and more than 150 feet from shore. Different protocols are to be followed for whole-lake scale treatments (≥160 acres or ≥50% of the lake littoral area). Additionally, it is important to note that local permits and U.S. Army Corps of Engineers regulations may also apply. For more information on permit requirements, please contact the WDNR Regional Water Management Specialist or Aquatic Plant Management and Protection Specialist.

Manual Removal

Photograph 3.4-2. Example of aquatic plants that have been removed manually.

Manual removal methods include hand-pulling, raking, and hand-cutting. Hand-pulling involves the manual removal of whole plants, including roots, from the area of concern and disposing them out of the waterbody. Raking entails the removal of partial and whole plants from the lake by dragging a rake with a rope tied to it through plant beds. Specially designed rakes are available from commercial sources or an asphalt rake can be used. Hand-cutting differs from the other two manual methods because the entire plant is not removed, rather the plants are cut similar to mowing a lawn; however, Wisconsin law states that all plant fragments must be removed. One manual cutting technique involves throwing a specialized "V" shaped cutter into the plant bed and retrieving it with a rope. The raking method entails the use of a two-sided straight blade on a telescoping pole that is swiped back and forth at the base of the undesired plants.

In addition to the hand-cutting methods described above, powered cutters are now available for mounting on boats. Some are mounted in a similar fashion to electric trolling motors and offer a 4-foot cutting width, while larger models require complicated mounting procedures, but offer an 8-foot cutting width. Please note that the use of powered cutters may require a mechanical harvesting permit to be issued by the WDNR.

When using the methods outlined above, it is very important to remove all plant fragments from the lake to prevent re-rooting and drifting onshore followed by decomposition. It is also important to preserve fish spawning habitat by timing the treatment activities after spawning. In Wisconsin, a general rule would be to not start these activities until after June 15th.

Cost

Commercially available hand-cutters and rakes range in cost from $85 to $150. Power-cutters range in cost from $1,200 to $11,000.

Advantages	***Disadvantages***
• Very cost effective for clearing areas around docks, piers, and swimming areas. • Relatively environmentally safe if treatment is conducted after June 15th. • Allows for selective removal of undesirable plant species. • Provides immediate relief in localized area. • Plant biomass is removed from waterbody.	• Labor intensive. • Impractical for larger areas or dense plant beds. • Subsequent treatments may be needed as plants recolonize and/or continue to grow. • Uprooting of plants stirs bottom sediments making it difficult to conduct action. • May disturb benthic organisms and fish-spawning areas. • Risk of spreading invasive species if fragments are not removed.

Bottom Screens

Bottom screens are very much like landscaping fabric used to block weed growth in flowerbeds. The gas-permeable screen is placed over the plant bed and anchored to the lake bottom by staking or weights. Only gas-permeable screen can be used or large pockets of gas will form under the mat as the result of plant decomposition. This could lead to portions of the screen becoming detached from the lake bottom, creating a navigational hazard. Normally the screens are removed and cleaned at the end of the growing season and then placed back in the lake the following spring. If they are not removed, sediments may build up on them and allow for plant colonization on top of the screen. Please note that depending on the size of the screen a Wisconsin Department of Natural Resources permit may be required.

Cost

Material costs range between $.20 and $1.25 per square-foot. Installation cost can vary largely but may roughly cost $750 to have 1,000 square feet of bottom screen installed. Maintenance costs can also vary, but an estimate for a waterfront lot is about $120 each year.

Advantages	***Disadvantages***
• Immediate and sustainable control. • Long-term costs are low. • Excellent for small areas and around obstructions. • Materials are reusable. • Prevents fragmentation and subsequent spread of plants to other areas.	• Installation may be difficult over dense plant beds and in deep water. • Not species specific. • Disrupts benthic fauna. • May be navigational hazard in shallow water. • Initial costs are high. • Labor intensive due to the seasonal removal and reinstallation requirements. • Does not remove plant biomass from lake. • Not practical in large-scale situations.

Water Level Drawdown

The primary manner of plant control through water level drawdown is the exposure of sediments and plant roots/tubers to desiccation and either heating or freezing depending on the timing of the treatment. Winter drawdowns are more common in temperate climates like that of Wisconsin and usually occur in reservoirs because of the ease of water removal through the outlet structure. An important fact to remember when considering the use of this technique is that only certain species are controlled and that some species may even be enhanced. Furthermore, the process will likely need to be repeated every two or three years to keep target species in check.

Cost

The cost of this alternative is highly variable. If an outlet structure exists, the cost of lowering the water level would be minimal; however, if there is not an outlet, the cost of pumping water to the desirable level could be very expensive. If a hydro-electric facility is operating on the system, the costs associated with loss of production during the drawdown also need to be considered, as they are likely cost prohibitive to conducting the management action.

Advantages	***Disadvantages***
• Inexpensive if outlet structure exists. • May control populations of certain species, like Eurasian water-milfoil for a few years. • Allows some loose sediment to consolidate, increasing water depth. • May enhance growth of desirable emergent species. • Other work, like dock and pier repair may be completed more easily and at a lower cost while water levels are down.	• May be cost prohibitive if pumping is required to lower water levels. • Has the potential to upset the lake ecosystem and have significant effects on fish and other aquatic wildlife. • Adjacent wetlands may be altered due to lower water levels. • Disrupts recreational, hydroelectric, irrigation and water supply use. • May enhance the spread of certain undesirable species, like common reed and reed canary grass. • Permitting process may require an environmental assessment that may take months to prepare. • Non-selective.

Mechanical Harvesting


Photograph 3.4-3. Mechanical harvester.

Aquatic plant harvesting is frequently used in Wisconsin and involves the cutting and removal of plants much like mowing and bagging a lawn. Harvesters are produced in many sizes that can cut to depths ranging from 3 to 6 feet with cutting widths of 4 to 10 feet. Plant harvesting speeds vary with the size of the harvester, density and types of plants, and the distance to the off-loading area. Equipment requirements do not end with the harvester. In addition to the harvester, a shore-conveyor would be required to transfer plant material from the harvester to a dump truck for transport to a landfill or compost site. Furthermore, if off-loading sites are limited and/or the lake is large, a transport barge may be needed to move the harvested plants from the harvester to the shore in order to cut back on the time that the harvester spends traveling to the shore conveyor. Some lake organizations contract to have nuisance plants harvested, while others choose to purchase their own equipment. If the latter route is chosen, it is especially important for the lake group to be very organized and realize that there is a great deal of work and expense involved with the purchase, operation, maintenance, and storage of an aquatic plant harvester. In either case, planning is very important to minimize environmental effects and maximize benefits.

Cost

Equipment costs vary with the size and features of the harvester, but in general, standard harvesters range between $45,000 and $100,000. Larger harvesters or stainless-steel models may cost as much as $200,000. Shore conveyors cost approximately $20,000 and trailers range from $7,000 to $20,000. Storage, maintenance, insurance, and operator salaries vary greatly.

Advantages	***Disadvantages***
• Immediate results. • Plant biomass and associated nutrients are removed from the lake. • Select areas can be treated, leaving sensitive areas intact. • Plants are not completely removed and can still provide some habitat benefits. • Opening of cruise lanes can increase predator pressure and reduce stunted fish populations. • Removal of plant biomass can improve the oxygen balance in the littoral zone. • Harvested plant materials produce excellent compost.	• Initial costs and maintenance are high if the lake organization intends to own and operate the equipment. • Multiple treatments are likely required. • Many small fish, amphibians and invertebrates may be harvested along with plants. • There is little or no reduction in plant density with harvesting. • Invasive and exotic species may spread because of plant fragmentation associated with harvester operation. • Bottom sediments may be re-suspended leading to increased turbidity and water column nutrient levels.

Herbicide Treatment

The use of herbicides to control aquatic plants and algae is a technique that is widely used by lake managers. Traditionally, herbicides were used to control nuisance levels of aquatic plants and algae that interfere with navigation and recreation. While this practice still takes place in many parts of Wisconsin, the use of herbicides to control aquatic invasive species is becoming more prevalent. Resource managers employ strategic management techniques towards aquatic invasive species, with the objective of reducing the target plant's population over time; and an overarching goal of attaining long-term ecological restoration. For submergent vegetation, this largely consists of implementing control strategies early in the growing season; either as spatially-targeted, small-scale spot treatments or low-dose, large-scale (whole lake) treatments. Treatments occurring roughly each year before June 1 and/or when water temperatures are below 60°F can be less impactful to many native plants, which have not emerged yet at this time of year. Emergent species are targeted with foliar applications at strategic times of the year when the target plant is more likely to absorb the herbicide.

Photograph 3.4-4. Granular herbicide application.

While there are approximately 300 herbicides registered for terrestrial use in the United States, only 13 active ingredients can be applied into or near aquatic systems. All aquatic herbicides must be applied in accordance with the product's US Environmental Protection Agency (EPA) approved label. There are numerous formulations and brands of aquatic herbicides and an extensive list can be found in Appendix F of Gettys et al. (2009).

Applying herbicides in the aquatic environment requires special considerations compared with terrestrial applications. WDNR administrative code states that a permit is required if "you are standing in socks and they get wet." In these situations, the herbicide application needs to be completed by an applicator licensed with the Wisconsin Department of Agriculture, Trade and Consumer Protection. All herbicide applications conducted under the ordinary high-water mark require herbicides specifically labeled by the United States Environmental Protection Agency

Aquatic herbicides can be classified in many ways. Organization of this section follows Netherland (2009) in which mode of action (i.e. how the herbicide works) and application techniques (i.e. foliar or submersed treatment) group the aquatic herbicides. The table below provides a general list of commonly used aquatic herbicides in Wisconsin and is synthesized from Netherland (2009).

The arguably clearest division amongst aquatic herbicides is their general mode of action and fall into two basic categories:

1. Contact herbicides act by causing extensive cellular damage, but usually do not affect the areas that were not in contact with the chemical. This allows them to work much faster, but in some plants, does not result in a sustained effect because the root crowns, roots, or rhizomes are not killed.
2. Systemic herbicides act slower than contact herbicides, being transported throughout the entire plant and disrupting biochemical pathways which often result in complete mortality.

General Mode of Action		Compound	Specific Mode of Action	Most Common Target Species in Wisconsin
Contact		Copper	plant cell toxicant	Algae, including macro-algae (i.e. muskgrasses & stoneworts)
		Endothall	Inhibits respiration & protein synthesis	Submersed species, largely for curly-leaf pondweed; Eurasian water milfoil control when mixed with auxin herbicides
		Diquat	Inhibits photosynthesis & destroys cell membranes	Nusiance natives species including duckweeds, targeted AIS control when exposure times are low
Systemic	Auxin Mimics	2,4-D	auxin mimic, plant growth regulator	Submersed species, largely for Eurasian water milfoil
		Triclopyr	auxin mimic, plant growth regulator	Submersed species, largely for Eurasian water milfoil
	In Water Use Only	Fluridone	Inhibits plant specific enzyme, new growth bleached	Submersed species, largely for Eurasian water milfoil
	Enzyme Specific (ALS)	Penoxsulam	Inhibits plant-specific enzyme (ALS), new growth stunted	New to WI, potential for submergent and floating-leaf species
		Imazamox	Inhibits plant-specific enzyme (ALS), new growth stunted	New to WI, potential for submergent and floating-leaf species
	Enzyme Specific (foliar use only)	Glyphosate	Inhibits plant-specific enzyme (ALS)	Emergent species, including purple loosestrife
		Imazapyr	Inhibits plant-specific enzyme (EPSP)	Hardy emergent species, including common reed

Both types are commonly used throughout Wisconsin with varying degrees of success. The use of herbicides is potentially hazardous to both the applicator and the environment, so all lake organizations should seek consultation and/or services from professional applicators with training and experience in aquatic herbicide use.

Herbicides that target submersed plant species are directly applied to the water, either as a liquid or an encapsulated granular formulation. Factors such as water depth, water flow, treatment area size, and plant density work to reduce herbicide concentration within aquatic systems. Understanding concentration and exposure times are important considerations for aquatic herbicides. Successful control of the target plant is achieved when it is exposed to a lethal concentration of the herbicide for a specific duration of time. Much information has been gathered in recent years, largely as a result of an ongoing cooperative research project between the Wisconsin Department of Natural Resources, US Army Corps of Engineers Research and Development Center, and private consultants (including Onterra). This research couples quantitative aquatic plant monitoring with field-collected herbicide concentration data to evaluate efficacy and selectivity of control strategies implemented on a subset of Wisconsin lakes and flowages. Based on their preliminary findings, lake managers have adopted two main treatment strategies; 1) whole-lake treatments, and 2). spot treatments.

Spot treatments are a type of control strategy where the herbicide is applied to a specific area (treatment site) such that when it dilutes from that area, its concentrations are insufficient to cause significant affects outside of that area. Spot treatments typically rely on a short exposure time (often hours) to cause mortality and therefore are applied at a much higher herbicide concentration than whole-lake treatments. This has been the strategy historically used on most Wisconsin systems.

Whole-lake treatments are those where the herbicide is applied to specific sites, but when the herbicide reaches equilibrium within the entire volume of water (entire lake, lake basin, or within the epilimnion of the lake or lake basin); it is at a concentration that is sufficient to cause mortality to the target plant within that entire lake or basin. The application rate of a whole-lake treatment is dictated by the volume of water in which the herbicide will reach equilibrium. Because exposure time is so much longer, target herbicide levels for whole-lake treatments are significantly less than for spot treatments.

Cost

Herbicide application charges vary greatly between $400 and $1,500 per acre depending on the chemical used, who applies it, permitting procedures, and the size/depth of the treatment area.

Advantages	***Disadvantages***
• Herbicides are easily applied in restricted areas, like around docks and boatlifts. • Herbicides can target large areas all at once. • If certain chemicals are applied at the correct dosages and at the right time of year, they can selectively control certain invasive species, such as Eurasian water-milfoil. • Some herbicides can be used effectively in spot treatments. • Most herbicides are designed to target plant physiology and in general, have low toxicological effects on non-plant organisms (e.g. mammals, insects)	• All herbicide use carries some degree of human health and ecological risk due to toxicity. • Fast-acting herbicides may cause fish kills due to rapid plant decomposition if not applied correctly. • Many people adamantly object to the use of herbicides in the aquatic environment; therefore, all stakeholders should be included in the decision to use them. • Many aquatic herbicides are nonselective. • Some herbicides have a combination of use restrictions that must be followed after their application. • Overuse of same herbicide may lead to plant resistance to that herbicide.

Biological Controls

There are many insects, fish and pathogens within the United States that are used as biological controls for aquatic macrophytes. For instance, the herbivorous grass carp has been used for years in many states to control aquatic plants with some success and some failures. However, it is illegal to possess grass carp within Wisconsin because their use can create problems worse than the plants that they were used to control. Other states have also used insects to battle invasive plants, such as water hyacinth weevils (*Neochetina spp.*) and hydrilla stem weevil (*Bagous spp.*) to control water hyacinth (*Eichhornia crassipes*) and hydrilla (*Hydrilla verticillata),* respectively.

However, Wisconsin, along with many other states, is currently experiencing the expansion of lakes infested with Eurasian water-milfoil and as a result has supported the experimentation and use of the milfoil weevil (*Euhrychiopsis lecontei*) within its lakes. The milfoil weevil is a native weevil that has shown promise in reducing Eurasian water-milfoil stands in Wisconsin, Washington, Vermont, and other states. Research is currently being conducted to discover the best situations for the use of the insect in battling Eurasian watermilfoil. Currently the milfoil weevil is not a WDNR grant-eligible method of controlling Eurasian watermilfoil.

Cost

Stocking with adult weevils costs about $1.20/weevil and they are usually stocked in lots of 1000 or more.

Advantages	*Disadvantages*
• Milfoil weevils occur naturally in Wisconsin. • Likely environmentally safe and little risk of unintended consequences.	• Stocking and monitoring costs are high. • This is an unproven and experimental treatment. • There is a chance that a large amount of money could be spent with little or no change in Eurasian water-milfoil density.

Wisconsin has approved the use of two species of leaf-eating beetles (*Galerucella calmariensis* and *G. pusilla*) to battle purple loosestrife. These beetles were imported from Europe and used as a biological control method for purple loosestrife. Many cooperators, such as county conservation departments or local UW-Extension locations, currently support large beetle rearing operations. Beetles are reared on live purple loosestrife plants growing in kiddy pools surrounded by insect netting. Beetles are collected with aspirators and then released onto the target wild population. For more information on beetle rearing, contact your local UW-Extension location.

In some instances, beetles may be collected from known locations (cella insectaries) or purchased through private sellers. Although no permits are required to purchase or release beetles within Wisconsin, application/authorization and release forms are required by the WDNR for tracking and monitoring purposes.

Cost

The cost of beetle release is very inexpensive, and in many cases, is free.

Advantages	*Disadvantages*
• Extremely inexpensive control method. • Once released, considerably less effort than other control methods is required. • Augmenting populations many lead to long-term control.	• Although considered “safe,” reservations about introducing one non-native species to control another exist. • Long range studies have not been completed on this technique.

Analysis of Current Aquatic Plant Data

Aquatic plants are an important element in every healthy lake. Changes in lake ecosystems are often first seen in the lake's plant community. Whether these changes are positive, such as variable water levels or negative, such as increased shoreland development or the introduction of an exotic species, the plant community will respond. Plant communities respond in a variety of ways. For example, there may be a loss of one or more species. Certain life forms, such as emergents or floating-leaf communities, may disappear from specific areas of the lake. A shift in plant dominance between species may also occur. With periodic monitoring and proper analysis, these changes are relatively easy to detect and provide very useful information for management decisions.

As described in more detail in the methods section, multiple aquatic plant surveys were completed on Little Green Lake; the first looked strictly for the exotic plant, curly-leaf pondweed, while the others that followed assessed both native and non-native species. Combined, these surveys produce a great deal of information about the aquatic vegetation of the lake. These data are analyzed and presented in numerous ways; each is discussed in more detail below.

Primer on Data Analysis & Data Interpretation

Species List

The species list is simply a list of all of the species that were found within the lake, both exotic and native. The list also contains the life-form of each plant found, its scientific name, and its coefficient of conservatism. The latter is discussed in more detail below. Changes in this list over time, whether it is differences in total species present, gains and losses of individual species, or changes in life-forms that are present, can be an early indicator of changes in the health of the lake ecosystem.

Frequency of Occurrence

Frequency of occurrence describes how often a certain species is found within a lake. Obviously, all of the plants cannot be counted in a lake, so samples are collected from pre-determined areas. In the case of Little Green Lake, plant samples were collected from plots laid out on a grid that covered the entire lake. Using the data collected from these plots, an estimate of occurrence of each plant species can be determined. In this section, two types of data are displayed: littoral frequency of occurrence and relative frequency of occurrence. Littoral frequency of occurrence is used to describe how often each species occurred in the plots that are less than the maximum depth of plant growth (littoral zone). Littoral frequency is displayed as a percentage. Relative frequency of occurrence uses the littoral frequency for occurrence for each species compared to the sum of the littoral frequency of occurrence from all species. These values are presented in percentages and if all of the values were added up, they would equal 100%. For example, if water lily had a relative frequency of 0.1 and we described that value as a percentage, it would mean that water lily made up 10% of the population.

In the end, this analysis indicates the species that dominate the plant community within the lake. Shifts in dominant plants over time may indicate disturbances in the ecosystem. For instance, low water levels over several years may increase the occurrence of emergent species while decreasing the occurrence of floating-leaf species. Introductions of invasive exotic species may result in major shifts as they crowd out native plants within the system.

Floristic Quality Assessment

The floristic quality of a lake's aquatic plant community is calculated using its native *species richness* and their *average conservatism*. Species richness is the number of native aquatic plant species that were physically encountered on the rake during the point-intercept survey. Average conservatism is calculated by taking the sum of the coefficients of conservatism (C-values) of the native species located and dividing it by species richness. Every plant in Wisconsin has been assigned a coefficient of conservatism, ranging from 1-10, which describes the likelihood of that species being found in an undisturbed environment. Species which are more specialized and require undisturbed habitat are given higher coefficients, while species which are more tolerant of environmental disturbance have lower coefficients.

For example, algal-leaf pondweed (*Potamogeton confervoides*) is only found in nutrient-poor, acid lakes in northern Wisconsin and is prone to decline if degradation of these lakes occurs. Because of algal-leaf pondweed's special requirements and sensitivity to disturbance, it has a C-value of 10. In contrast, sago pondweed (*Stuckenia pectinata*) with a C-value of 3, is tolerant of disturbance and is often found in greater abundance in degraded lakes that have higher nutrient concentrations and low water clarity. Higher average conservatism values generally indicate a healthier lake as it is able to support a greater number of environmentally-sensitive aquatic plant species. Low average conservatism values indicate a degraded environment, one that is only able to support disturbance-tolerant species.

On their own, the species richness and average conservatism values for a lake are useful in assessing a lake's plant community; however, the best assessment of the lake's plant community health is determined when the two values are used to calculate the lake's floristic quality. The floristic quality is calculated using the species richness and average conservatism value of the aquatic plant species that were solely encountered on the rake during the point-intercept surveys (equation shown below). This assessment allows the aquatic plant community of Little Green Lake to be compared to other lakes within the region and state.

$$\text{FQI} = \text{Average Coefficient of Conservatism} * \sqrt{\text{Number of Native Species}}$$

Species Diversity and Richness

Species diversity is often confused with species richness. As defined previously, species richness is simply the number of species found within a given community. While species diversity utilizes species richness, it also takes into account evenness or the variation in abundance of the individual species within the community. For example, a lake with 10 aquatic plant species that had relatively similar abundances within the community would be more diverse than another lake with 10 aquatic plant species were 50% of the community was comprised of just one or two species.

An aquatic system with high species diversity is more stable than a system with a low diversity. This is analogous to a diverse financial portfolio in that a diverse aquatic plant community can withstand environmental fluctuations much like a diverse portfolio can handle economic fluctuations. A lake with a diverse plant community is also better suited to compete against exotic infestations than a lake with a lower diversity. The diversity of a lake's aquatic plant community is determined using the Simpson's Diversity Index (1-D):

$$D = \sum (n/N)^2$$

where:
n = the total number of instances of a particular species
N = the total number of instances of all species and
D is a value between 0 and 1

If a lake has a diversity index value of 0.90, it means that if two plants were randomly sampled from the lake there is a 90% probability that the two individuals would be of a different species. The Simpson's Diversity Index value from Little Green Lake is compared to data collected by Onterra and the WDNR Science Services on 77 lakes withn the Southeast Wisconsin Till Plain ecoregion and on 392 lakes throughout Wisconsin.

Community Mapping

A key component of any aquatic plant community assessment is the delineation of the emergent and floating-leaf aquatic plant communities within each lake as these plants are often underrepresented during the point-intercept survey. This survey creates a snapshot of these important communities within each lake as they existed during the survey and is valuable in the development of the management plan and in comparisons with future surveys. Examples of emergent plants include cattails, rushes, sedges, grasses, bur-reeds, and arrowheads, while examples of floating-leaf species include the water lilies. The emergent and floating-leaf aquatic plant communities in Little Green Lake were mapped using a Trimble Global Positioning System (GPS) with sub-meter accuracy.

Exotic Plants

Because of their tendency to upset the natural balance of an aquatic ecosystem, exotic species are paid particular attention to during the aquatic plant surveys. Two exotics, Eurasian watermilfoil (*Myriophyllum spicatum*; EWM) and curly-leaf pondweed (*Potamogeton crispus*; CLP) are the primary targets of this extra attention.

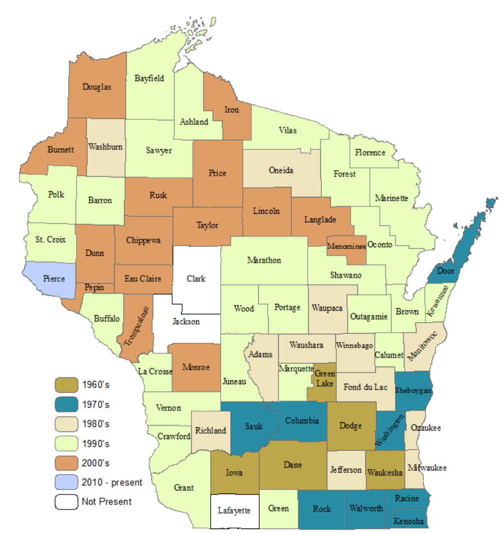


Figure 3.4-1. Spread of Eurasian watermilfoil within WI counties. WDNR Data 2011 mapped by Onterra.

Eurasian watermilfoil is an invasive species, native to Europe, Asia and North Africa, that has spread to most Wisconsin counties (Figure 3.4-1). Eurasian watermilfoil is unique in that its primary mode of propagation is not by seed. It actually spreads by shoot fragmentation, which has supported its transport between lakes via boats and other equipment. In addition to its propagation method, EWM has two other competitive advantages over native aquatic plants, 1) it starts growing very early in the spring when water temperatures are too cold for most native plants to grow, and 2) once its stems reach the water surface, it does not stop growing like most native plants, instead it continues to grow along the surface creating a canopy that blocks light from reaching native plants. Eurasian watermilfoil can create dense stands and dominate submergent communities, reducing important natural habitat for fish and other wildlife, and impeding recreational activities such as swimming, fishing, and boating.

Curly-leaf pondweed is a European exotic first discovered in Wisconsin in the early 1900's that has an unconventional lifecycle giving it a competitive advantage over our native plants. Curly-leaf pondweed begins growing almost immediately after ice-out and by mid-June is at peak biomass. While it is growing, each plant produces many turions (asexual reproductive shoots) along its stem. By mid-July most of the plants have senesced, or died-back, leaving the turions in the sediment. The turions lie dormant until fall when they germinate to produce winter foliage, which thrives under the winter snow and ice. It remains in this state until spring foliage is produced in early May, giving the plant a significant jump on native vegetation. Like EWM, CLP can become so abundant that it hampers recreational activities within the lake. Furthermore, its mid-summer die back can cause algal blooms spurred from the nutrients released during the plant's decomposition.

Because of its odd life-cycle, a special survey is conducted early in the growing season to inventory and map CLP occurrence within the lake. Although EWM starts to grow earlier than our native plants, it is at peak biomass during most of the summer, so it is inventoried during the comprehensive aquatic plant survey completed in mid to late summer.

Aquatic Plant Survey Results

During the aquatic plant surveys completed on Little Green Lake in 2016, a total of 19 species of plants were located, four of which are considered non-native, invasive species: Eurasian watermilfoil hybrid (hybrid watermilfoil, HWM), curly-leaf pondweed (CLP), narrow-leaved cattail, and reed canary grass (Table 3.4-1). The populations of these non-native plants in Little Green Lake are discussed in detail in the subsequent Non-Native Aquatic Plants Subsection. Table 3.4-1 also includes the list of aquatic plant species which have been documented during annual surveys completed since 2005. A comparison of the 2016 aquatic plant survey data to these historical datasets is discussed later in this section.

Lakes in Wisconsin vary in their morphology, water chemistry, substrate composition, recreational use, and management, and all of these factors influence aquatic plant community composition. Like terrestrial plants, different aquatic plant species are adapted to grow in certain substrate types; some species are only found growing in soft substrates, others only in sandy/rocky areas, and some can be found growing in either. The combination of both soft sediments and areas of harder substrates creates different habitat types for aquatic plants and generally leads to a higher number of aquatic plant species within the lake. In July 2016, Onterra completed an acoustic survey on Little Green Lake which records water depth, aquatic plant bio-volume, and substrate hardness.

On average, the hardest substrates (sand/rock/gravel) in Little Green Lake were found in shallower areas of the lake between 1 and 9 feet (Figure 3.4-2). Substrate hardness declined rapidly between 9 and 18 feet, and surprisingly, the softest sediments were located between 18-

20 feet while average hardness increased again in the deepest area of the lake between 21-27 feet. The deepest area of the lake typically contains the softest sediments, and the increase in substrate hardness in the deepest areas of Little Green Lake are believed to be due to the aeration system installed in 2003. The water movement generated by the aeration system has likely resulted in a combination of increased decomposition and redistribution of organic sediments within this area.

Table 3.4-1. Aquatic plant species located on Little Green Lake during 2016 surveys.

Growth Form	Scientific Name	Common Name	Coefficient of Conservatism (C)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Emergent	*Bolboschoenus fluviatilis*	River bulrush	5												I
	Phalaris arundinacea	Reed canary grass	Exotic												I
	Schoenoplectus tabernaemontani	Softstem bulrush	4												I
	Sparganium eurycarpum	Common bur-reed	5					I							I
	Typha angustifolia	Narrow-leaved cattail	Exotic					I							I
FL	*Nuphar variegata*	Spatterdock	6			I		I							I
	Nymphaea odorata	White water lily	6			I	I	I							I
Submergent	*Ceratophyllum demersum*	Coontail	3	X	X	X	X	X	X	X	X	X	X	X	X
	Chara spp.	Muskgrasses	7	X	X	X	X	X	X	X	X	X	X	X	X
	Elodea canadensis & E. nuttallii	Common & slender waterweed	N/A	X	X	X	X	X	X	X	X	X	X	X	X
	Heteranthera dubia	Water stargrass	6					X	X	X	X	X			X
	Myriophyllum sibiricum	Northern watermilfoil	7			X	X	X	X						
	Myriophyllum sibiricum X *spicatum*	Hybrid watermilfoil	Exotic	X	X	X	X	X	X	X	X	X	X	X	X
	Najas flexilis	Slender naiad	6		X		X	X	X			X	X	X	X
	Najas guadalupensis	Southern naiad	7											X	
	Potamogeton crispus	Curly-leaf pondweed	Exotic	X	X	X	X	X	X	X	X	X	X	X	X
	Potamogeton foliosus	Leafy pondweed	6									X	X	X	X
	Stuckenia pectinata	Sago pondweed	3	X	X	X	X	X	X	X	X	X	X	X	X
	Vallisneria americana	Wild celery	6										X		
FF	*Lemna minor*	Lesser duckweed	5		X	X	X	X	X	X	X	X	X		
	Lemna trisulca	Forked duckweed	6	X	X	X	X	X	X	X	X	X	X	X	X
	Lemna turionifera	Turion duckweed	2												X
	Wolffia spp.	Watermeal spp.	N/A												X

FL = Floating-leaf; FF = Free-floating
X = Located on rake during point-intercept survey; I = Incidentally located

The acoustic survey also recorded aquatic plant bio-volume throughout the entire lake. Aquatic plant bio-volume is the percentage of the water column that is occupied by aquatic plants. The 2016 aquatic plant bio-volume data are displayed in Figure 3.4-3. Areas where aquatic plants occupy most or all of the water column are indicated in red while areas of little to no aquatic plant growth are displayed in blue. The majority of aquatic plant growth in Little Green Lake is located in shallower areas of the lake, with the highest aquatic plant bio-volume occurring between 2.0 and 6.0 feet of water. As is discussed in the Water Quality Section (Section 3.1), water clarity in Little Green Lake is low and aquatic plants are restricted to shallower areas where light availability is highest. During the 2016 whole-lake point-intercept survey, aquatic plants were recorded growing to a maximum depth of 11 feet. The 2016 acoustic survey found that approximately 35% of Little Green Lake contained aquatic vegetation.

While the acoustic mapping is an excellent survey for understanding the distribution and levels of aquatic plant growth throughout the lake, this survey does not determine what aquatic plant species comprise the aquatic plant community. Whole-lake point-intercept surveys are used to quantify the abundance of individual plant species within the lake. Of the 182 point-intercept sampling locations that fell at or shallower than the maximum depth of plant growth (the littoral zone) in 2016, approximately 52% contained aquatic vegetation. Aquatic plant rake fullness data collected in 2016 indicates that 28% of the 182 sampling locations contained vegetation with a total rake fullness rating (TRF) of 1, 13% had a TRF rating of 2, and 11% had a TRF rating of 3 (Figure 3.4-3). The TRF data indicates that where aquatic plants are present in Little Green Lake they occur in moderate density.

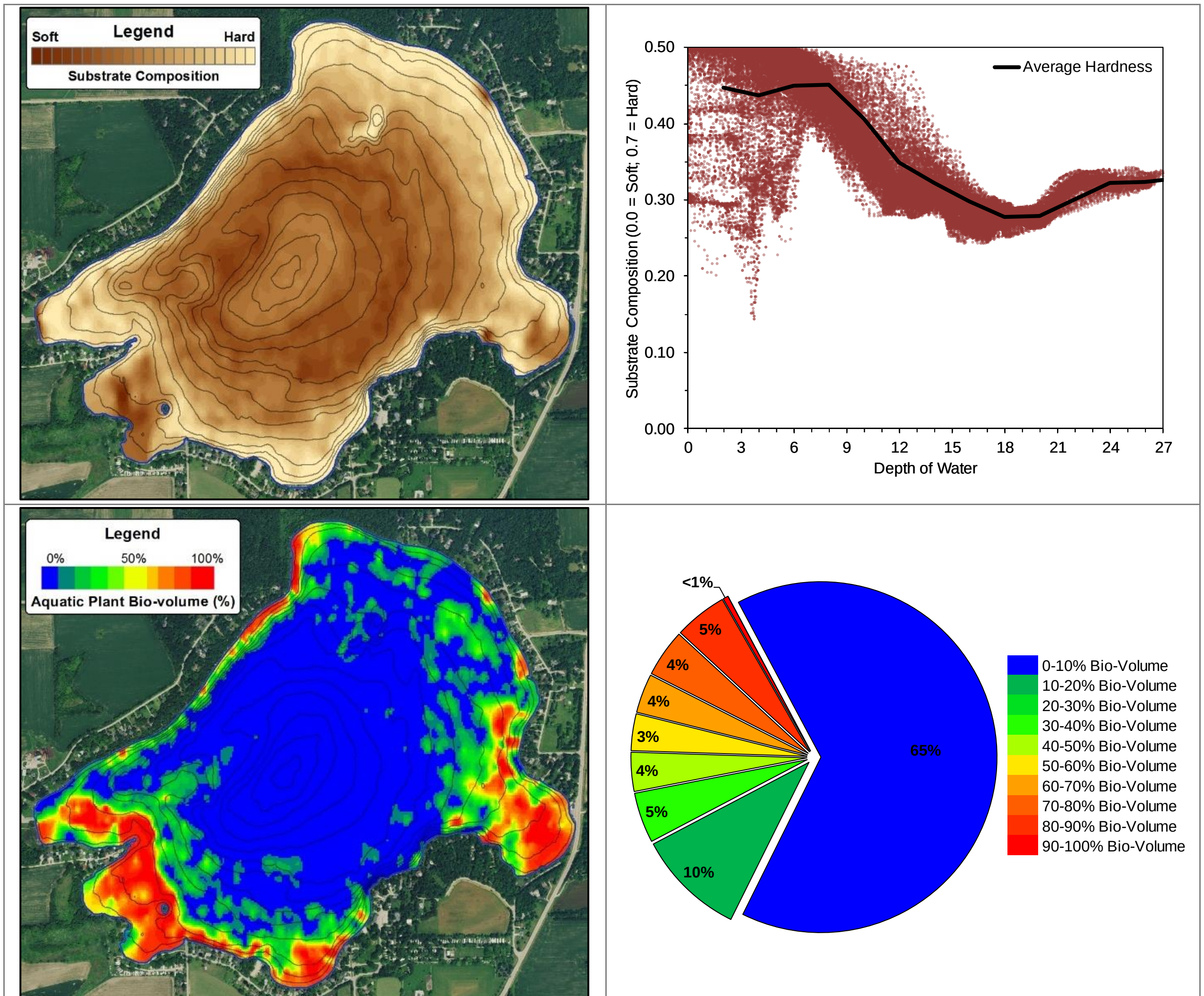


Figure 3.4-2. Little Green Lake spatial distribution of substrate hardness (top left), substrate hardness across water depth (top right), spatial distribution of aquatic plant bio-volume (bottom left), and proportion of aquatic plant bio-volume (bottom right). Contours represent 2-foot intervals. Individual data points on substrate hardness chart are displayed in red. Created using data from July 2016 acoustic survey.

Of the 19 aquatic plant species located during the 2016 surveys, 10 species were physically sampled on the rake during the point-intercept survey while the remaining nine species were located *incidentally*. An incidentally-located species means the plant was not directly sampled on the rake during the point-intercept survey but was observed in the lake by Onterra ecologists and was recorded/collected. The majority of incidentally-located plants typically include emergent species growing along the lake's margins and submersed species that are relatively rare within the lake's plant community. Of the 10 species encountered on the rake in 2016, HWM, coontail, and forked duckweed were the three-most frequently encountered (Figure 3.4-4).

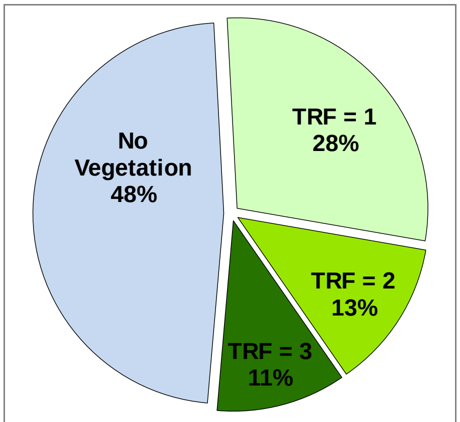


Figure 3.4-3. Little Green Lake 2016 aquatic plant total rake fullness (TRF) ratings within the littoral zone. Created using data from 2016 whole-lake point-intercept survey. N = 182.

As stated earlier, HWM and other non-native aquatic plant populations in Little Green Lake are discussed in the subsequent Non-Native Aquatic Plant Subsection. Coontail, arguably the most common aquatic plant in Wisconsin, was the second-most frequently encountered aquatic plant in Little Green Lake with a littoral frequency of occurrence of 29% (Figure 3.4-4). It was most abundant between 3.0 and 5.0 feet of water. Unlike most of the submersed plants found in Wisconsin, coontail does not produce true roots and is often found growing entangled amongst other aquatic plants or matted at the surface. Because it lacks true roots, coontail derives most of its nutrients directly from the water (Gross et al. 2013). This ability in combination with a tolerance for low-light conditions allows coontail to become more abundant in eutrophic waterbodies with higher nutrients and low water clarity. Coontail has the capacity to form dense beds which mat on the surface, and this was observed in some areas of Little Green Lake in the summer of 2016.

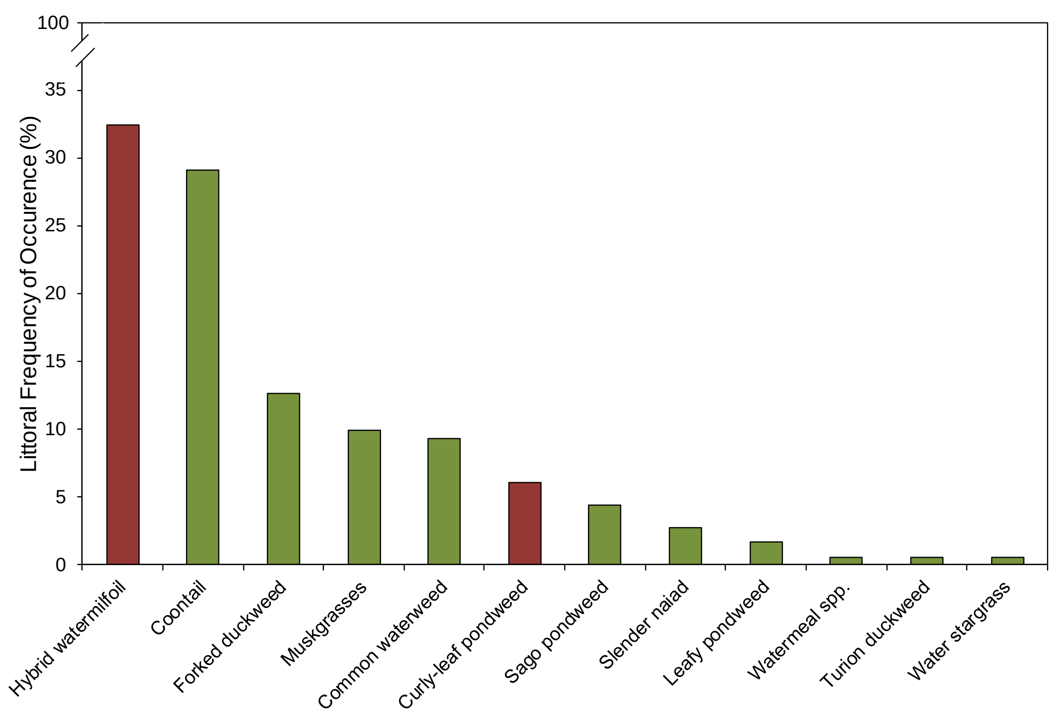


Figure 3.4-4. Littoral frequency of occurrence of aquatic plant species in Little Green Lake. Exotic species indicated with red. Created using data from 2016 whole-lake point-intercept survey.

The third-most frequently encountered aquatic plant in 2016 was forked duckweed with a littoral frequency of occurrence of 13% (Figure 3.4-4). Like the other six species of duckweed found in

Wisconsin, forked duckweed is rootless and is found free-floating within the water; however, forked duckweed is found growing below the surface as opposed to floating like the other duckweed species. Like coontail, forked duckweed obtains all of its nutrients directly from the water and is only found in waters with sufficient nutrients to sustain its growth. It can be found growing along the bottom or entangled amongst rooted aquatic plants. In Little Green Lake, forked duckweed was primarily located in shallower areas in the southeastern area of the lake.

Aquatic plant point-intercept datasets from Little Green Lake are also available annually from 2005-2015, and the methodology and sampling locations were the same as the survey completed in 2016. These historical datasets can be statistically compared to determine if any significant changes in the overall occurrence of vegetation or in species' abundance have occurred over this time period. Simple linear regression of the recorded maximum depth of plant growth over this time period showed a statistically valid (p-value = 0.008; R^2 = 0.521) decreasing trend in the maximum depth of plant growth (Figure 3.4-5). Since 2005, the recorded maximum depth of aquatic plant growth has been declining by approximately 0.5 feet per year.

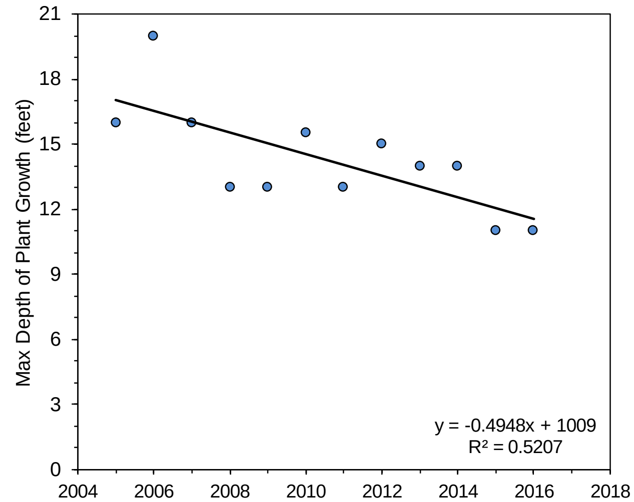


Figure 3.4-5. Recorded maximum depth of aquatic plant growth in Little Green Lake from 2005-2016. Created using data from annual whole-lake point-intercept surveys.

Simple linear regression of the lake-wide occurrence of vegetation in Little Green Lake also showed a statistically valid decline in vegetation occurrence (p-value = 0.024; R^2 = 0.415) over the period from 2005-2016, with vegetation occurrence declining at a rate of approximately 2% per year (Figure 3.4-6). Survey data from 2006 showed the highest lake-wide frequency of occurrence within the dataset and as a result may skew the trendline (solid) on Figure 3.4-6; therefore, for clarity, a trendline was also created that did not utilize the 2006 data (dashed), which, while not as steep, still indicates a decline in overall occurrence. Partitioning the data into native versus non-native plants indicates that the proportion of sampling locations containing native aquatic plants has declined while the proportion of sampling locations containing non-native plants has increased (Figure 3.4-6). While the overall occurrence of vegetation has declined, the proportion of the plant community comprised of non-native aquatic plants has increased.

As is discussed further in this section, approximately half of the point-intercept surveys completed from 2005-2016 were conducted prior to the senescence of the CLP population (June) while the other half were completed post-senescence (July). To determine if the changes in recorded maximum depth and frequency of occurrence of vegetation from 2005-2016 were the result of survey timing (pre- or post-CLP senescence), the recorded maximum depth of aquatic plant growth was examined separately in surveys completed in June and surveys completed in July. This showed that the recorded maximum depth of aquatic plant growth and occurrence of vegetation still declined over time in surveys completed in June and in the surveys completed in

July, indicating that these changes observed from 2005-2016 are not a result of the presence of CLP and survey timing.

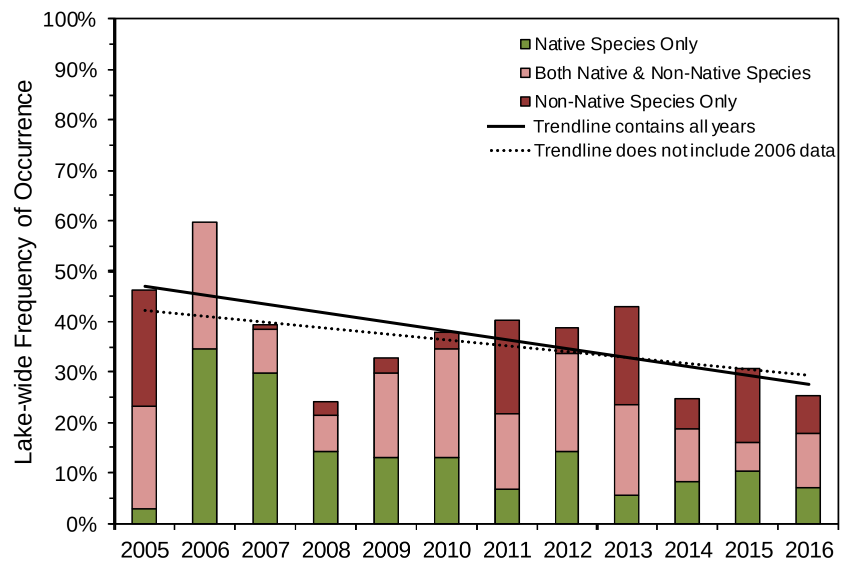


Figure 3.4-6. Frequency of occurrence of aquatic vegetation in Little Green Lake from 2005-2016. Created using data from 2005-2016 whole-lake point-intercept surveys. N = 377.

Secchi disk transparency data collected from 2005-2016 do not indicate any significant changes or trends in decreasing water clarity over the same time period, indicating that decreasing light availability is likely not the reason for reductions in aquatic plant occurrence over this period. As is discussed within the subsequent Non-Native Aquatic Plants Subsection, aquatic plant management, in terms of herbicide applications and mechanical harvesting, have been occurring annually on Little Green Lake for many years (see Little Green Lake Treatment History Subsection below). In most years from 2005-2016, a spring application of both 2,4-D and endothall has occurred in Little Green Lake in an effort to reduce CLP and HWM. The combined use of these two herbicides is known to be at least additive, or potentially synergistic, and have greater impacts than either herbicide used alone at the same concentration. The treatment record from 2005-2016 indicates that in many of the years, the amount of herbicide applied was likely sufficient to have lake-wide impacts to Little Green Lake's native aquatic plant populations. In most years, the calculated lake-wide herbicide concentrations may have been sub-lethal to HWM and CLP outside of where the herbicide was directly applied but may still have had collateral impacts to more sensitive native aquatic plant species that occurred in the lake at the time.

Certain native aquatic plant species such as common waterweed in Little Green Lake have been shown to be susceptible to the combined use of 2,4-D and endothall. Common and slender waterweed have been recorded in Little Green Lake, and due to their morphological similarity, their occurrences have been combined for comparison analysis. The point-intercept data show that the occurrence of common/slender waterweed in Little Green Lake has been highly variable from 2005-2016, but simple linear regression indicates a statistically valid decreasing trend in occurrence over time (p-value = 0.043; Figure 3.4-7). Since 2013, the littoral occurrence of common/slender waterweed has been below 10% compared to an average of 33% from 2005-

2012. Of the four most frequently encountered native aquatic plants in Little Green Lake, common/slender waterweed has shown the largest decline in occurrence over this time period.

It is believed that the recurring annual herbicide treatments on Little Green Lake are the likely cause of decreasing aquatic plant abundance, particularly of the common/slender waterweed population. Onterra's experience monitoring treatments is that plants growing in deeper water can be more susceptible to herbicide treatments given the increased environmental stresses (i.e. decreased light availability) when these plants are recovering following herbicide application. As discussed, the recorded maximum depth of plant growth has been declining in Little Green Lake indicating aquatic plant occurrence in deeper water has been declining despite no indications of decreasing water clarity.

Of the other native aquatic plant species found in Little Green Lake, coontail has seen a slight decreasing trend in littoral occurrence from 2005-2016 while forked duckweed has seen a slight increasing trend in littoral occurrence (Figure 3.4-7). The littoral occurrence of muskgrasses remained relatively stable from 2005-2014 but has increased in occurrence in 2015 and 2016. Northern watermilfoil was recorded during the whole-lake point-intercept surveys in 2007, 2008, 2009, and 2010, and within these years ranged in occurrence from 5.8% to 0.8%. However, northern watermilfoil has not been recorded in the lake since 2010 and was not observed by Onterra ecologists during any of the surveys in 2016. It is possible that the plants recorded as northern watermilfoil in these years were actually HWM or that this species has been reduced to below detectable levels from competition of aquatic invasive species and/or the herbicide management program.

The littoral occurrence of HWM has ranged from 46.1% in 2005 to 6.5% in 2007 with an average occurrence of 23% (Figure 3.4-7). Hybrid watermilfoil's littoral occurrence in 2016 of 32% ended a trend of declining occurrence since 2012 and represented a 152% increase in occurrence compared to 2015. Simple linear regression indicates that no statistically valid trend (positive or negative) in HWM occurrence has occurred from 2005-2016. Despite recurring herbicide treatments, these data indicate that they have not been effective at controlling Little Green Lake's HWM population beyond seasonal control.

The occurrence of CLP has been highly variable from 2005 to 2016, ranging from 56.3% in 2013 to 2.6% in 2006 (Figure 3.4-7). As discussed earlier, CLP naturally senesces in early summer and a portion of the surveys were completed in June (pre-senescence) while the other portion was conducted in July (post-senescence). Separating the datasets between those completed in June and July indicates that the surveys completed in June had the highest recorded occurrences of CLP, corresponding with its peak growth. In contrast, surveys completed in July had lower recorded occurrences of CLP indicating these surveys were completed following the population's natural senescence. Analysis of the survey data collected in June from 2005-2016 indicates that the occurrence of CLP in Little Green Lake when it is at or near its peak growth has remained very high and largely unchanged over this time period.

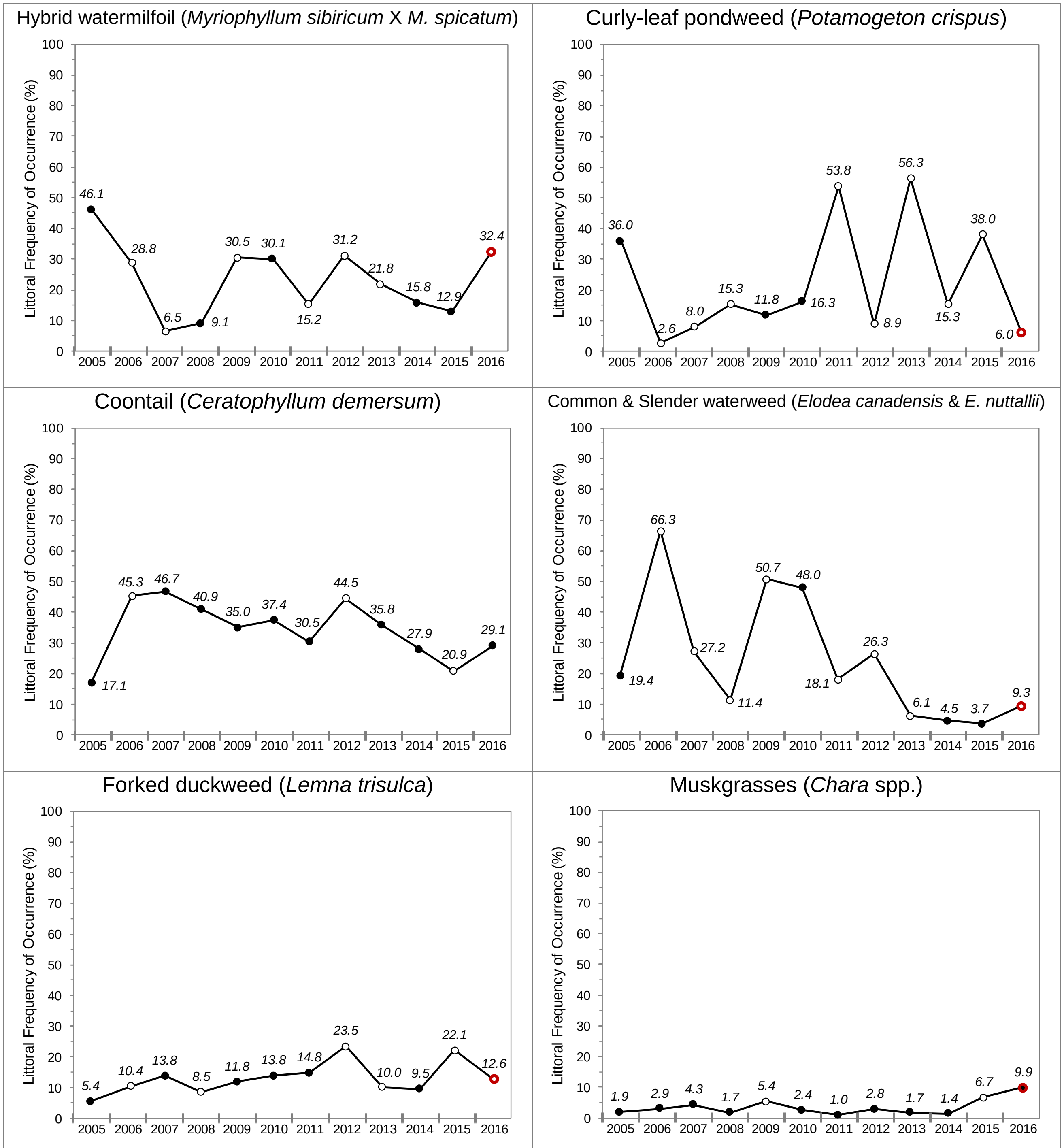


Figure 3.4-7. Littoral frequency of occurrence of select native aquatic plant species in Little Green Lake from 2010-2016. Open circle indicates a statistically valid change in occurrence from the previous survey (Chi-Square α = 0.05). Circle outlined with red indicates 2016 littoral occurrence was statistically different from littoral occurrence in 2005 (Chi-Square α = 0.05). Species displayed had a littoral occurrence of at least 5% in one of the three surveys. Created using data from 2005-2016 whole-lake point-intercept surveys.

The calculations used for the Floristic Quality Index (FQI) for a lake's aquatic plant community are based on the aquatic plant species that were encountered on the rake during the point-intercept survey and does not include incidental species. For example, while 15 native aquatic plant species were located in Little Green Lake during the 2016 surveys, 10 were encountered on the rake during the point-intercept survey. The native aquatic plant species located on the rake during the point-intercept surveys from 2005 to 2016 and their conservatism values were used to calculate the FQI for each year. Native plant species richness has ranged from 5 in 2005 to 10 in 2016 with an average of 8 species (Figure 3.4-8). Native plant species richness in Little Green Lake falls below the median values for other lakes within the SWTP ecoregion (15) and lakes throughout Wisconsin (19).

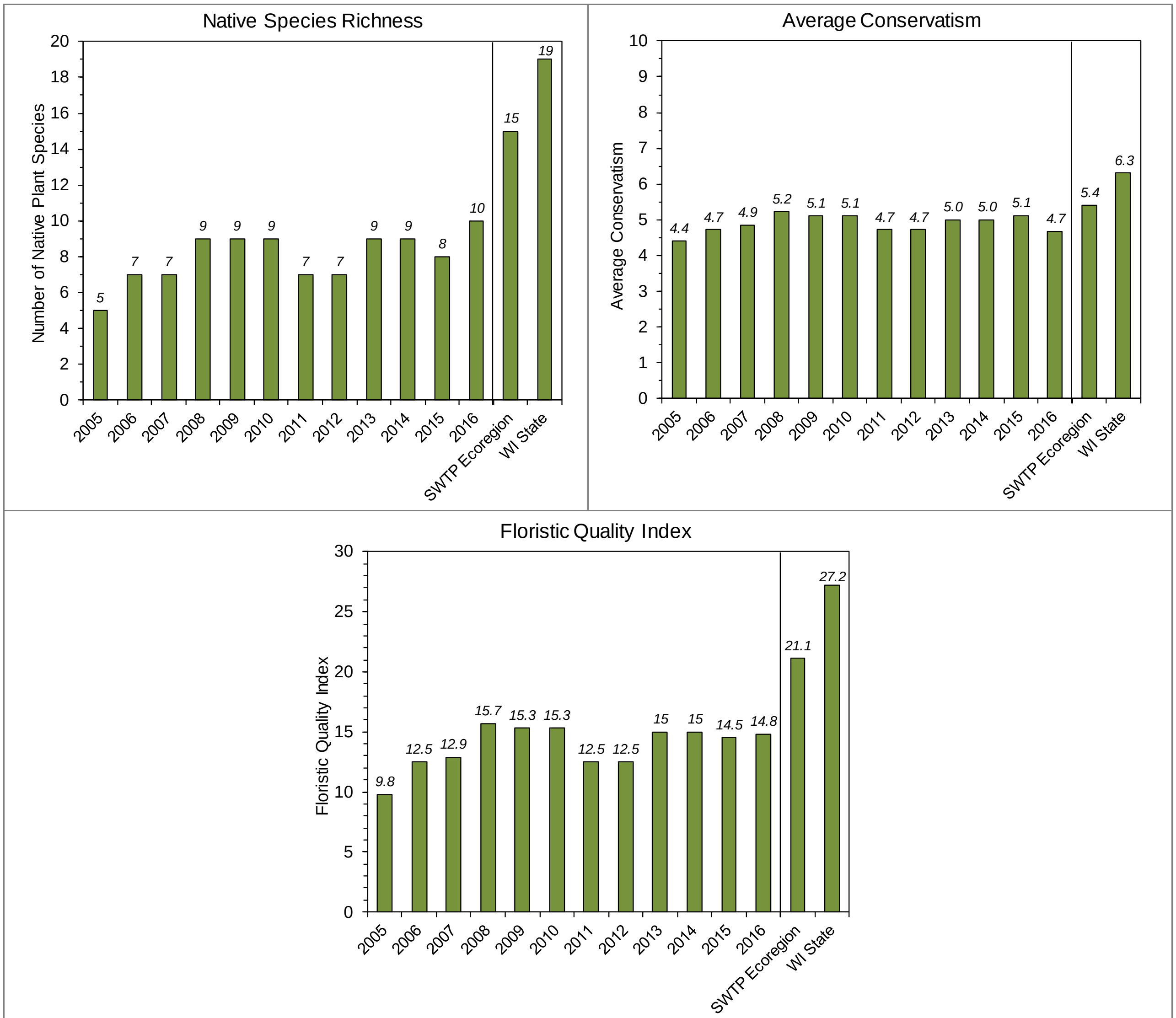


Figure 3.4-8. Little Green Lake Floristic Quality Assessment. Created using data from 2005-2016 whole-lake point-intercept surveys. Regional and state medians calculated with Onterra and WDNR data. Analysis follows Nichols 1999.

Average species conservatism has ranged from 4.4 in 20015 to 5.2 in 2008 with an average of 4.9, falling below the median values for lakes in the SWTP ecoregion (5.4) and the state (6.3) (Figure 3.4-8). Using Little Green Lake's annual species richness and average conservatism to calculate the annual FQI yielded values ranging from 9.8 in 2005 to 15.7 in 2008 and an average of 13.8 (Figure 3.4-8). The FQI values for Little Green Lake's aquatic plant community fall below median values for other lakes in the SWTP ecoregion (21.1) and lakes throughout Wisconsin (27.2). When compared to other lakes in the region and the state, Little Green Lake has a lower number of native aquatic plant species and a lower number of conservative species, or species that are sensitive to environmental degradation. Overall, the FQI analysis indicates that the native plant community of Little Green Lake is of lower quality when compared to other regional lakes and lakes throughout the state. The plant species which are most tolerant of the high-nutrient, turbid conditions found in Little Green Lake (e.g. coontail and forked duckweed) are able to persist. The low species richness and low conservatism is an indication of a highly degraded aquatic plant community, and an indication of poor water quality conditions.

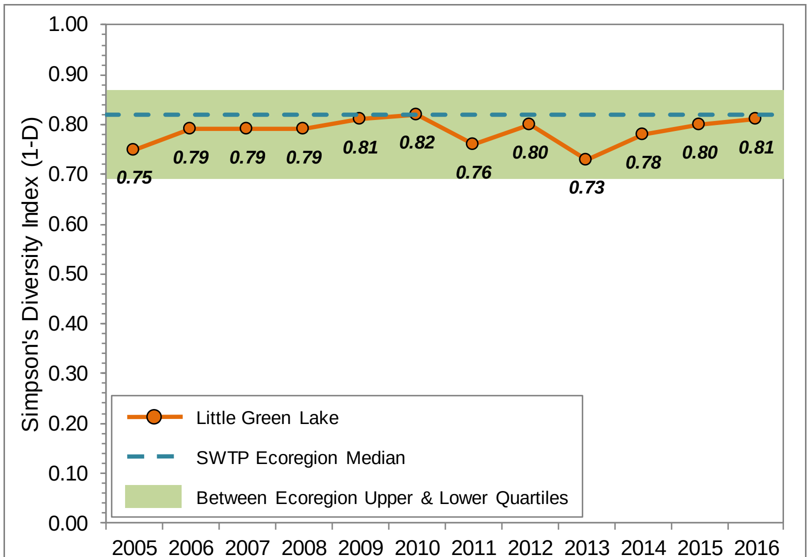


Figure 3.4-9. Little Green Lake 2005-2016 Simpson's Diversity Index. Created using data from 2005-2016 whole-lake point-intercept surveys.

While a method for characterizing diversity values of fair, poor, etc. does not exist, lakes within the same ecoregion may be compared to provide an idea of how Little Green Lake's diversity value ranks. Using data collected by Onterra and WDNR Science Services, quartiles were calculated for 77 lakes within the SWTP Ecoregion (Figure 3.4-9). Using the data collected from the 2005-2016 whole-lake point-intercept surveys, Little Green Lake's aquatic plant species diversity ranged from 0.73 in 2013 to 0.82 in 2010 with an average of 0.79. Aquatic plant species diversity was 0.81 in 2016. The average species diversity value of 0.79 falls just below the median value for lakes within the SWTP ecoregion, indicating relatively low species diversity.

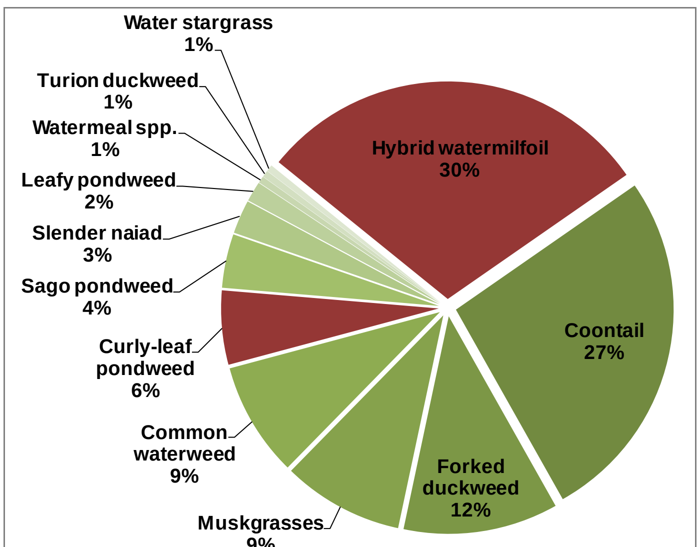


Figure 3.4-10. Relative frequency of occurrence of aquatic plant species in Little Green Lake in 2016. Exotic species indicated with red. Created using data from 2016 whole-lake point-intercept survey.

As explained earlier in the Primer on Data Analysis and Data Interpretation Section, the littoral frequency of occurrence analysis allows for an understanding of how often each of the plants is located during the point-intercept survey. Because each sampling location may contain numerous plant species, relative frequency of occurrence is one tool to evaluate how often each plant species is found in relation to all other species found (composition of population). For instance, while hybrid watermilfoil was found at 32% of the sampling locations in Little Green Lake in 2016, its relative frequency of occurrence was approximately 30%. Explained another way, if 100 plants were randomly sampled from Little Green Lake, 30 of them would be hybrid watermilfoil. Looking at relative frequency of occurrence (Figure 3.4-10), 69% of the plant community in Little Green Lake in 2016 was comprised of just three species: hybrid watermilfoil, coontail, and forked duckweed. The dominance of the plant community by a few species yields lower species diversity.

The 2016 emergent and floating-leaf aquatic plant mapping survey revealed that approximately 3.2 acres (0.6% of the lake) contained emergent and floating-leaf aquatic plant communities comprised of seven species, two of which are non-native (Table 3.4-2 and Map 5). The largest communities, primarily dominated by narrow-leaved cattail and white water lily, were located in the bays in the southwestern area of the lake as well as within the bay on the east end of the lake. An approximate 0.2-acre colony of spatterdock was present in the bay on the east side of the lake. This was the only location within Little Green Lake where this species was present.

These communities also stabilize lake substrate and shoreland areas by dampening wave action from wind and watercraft. Because the community map represents a 'snapshot' of the important emergent and floating-leaf plant communities, a replication of this survey in the future will provide a valuable understanding of the dynamics of these communities within Little Green Lake. This is important because these communities are often negatively affected by recreational use and shoreland development. Radomski and Goeman (2001) found a 66% reduction in vegetation coverage on developed shorelands when compared to the undeveloped shorelands in Minnesota lakes. Furthermore, they also found a significant reduction in abundance and size of northern pike (*Esox lucius*), bluegill (*Lepomis macrochirus*), and pumpkinseed (*Lepomis gibbosus*) associated with these developed shorelands.

Table 3.4-2. Little Green Lake acres of plant community types. Created from September 2016 community mapping survey.

Aquatic Plant Community	Acres
Emergent	1.6
Floating-leaf	1.6
Mixed Emergent & Floating-leaf	0.0
Total	**3.2**

Non-native Plants in Little Green Lake

Reed Canary Grass

Reed canary grass (*Phalaris arundinacea*) is a large, coarse perennial grass that can reach three to six feet in height. Often difficult to distinguish from native grasses, this species forms dense, highly productive stands that vigorously outcompete native species. Unlike native grasses, few wildlife species utilize the grass as a food source, and the stems grow too densely to provide cover for small mammals and waterfowl. It grows best in moist soils such as wetlands, marshes, stream banks and lake shorelines.

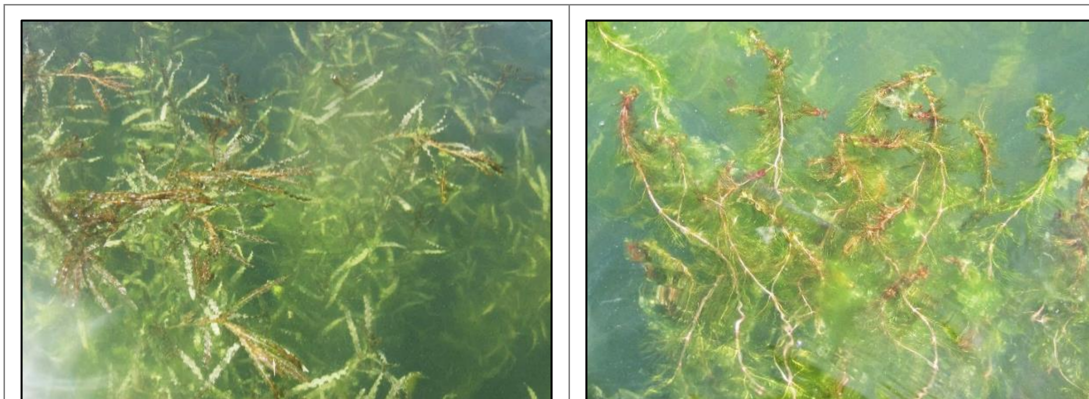
Reed canary grass is difficult to eradicate; at the time of this writing there is no commonly accepted control method. This plant is quite resilient to herbicide applications. Small, discrete patches have been covered by black plastic to reduce growth for an entire season. However, the species must be monitored because rhizomes may spread out beyond the plastic. Reed canary grass was located in a number of locations along Little Green Lake's shoreline in 2016 (Map 5).

Narrow-leaved Cattail

Narrow-leaved cattail (*Typha angustifolia*) is a non-native wetland plant introduced to North America from Europe and is widespread throughout wetland areas across Wisconsin. Like other non-native, invasive species, narrow-leaved cattail is aggressive and often forms dense monotypic stands which displace native wetland plants. Current control methods for narrow-leaved cattail include maintaining higher water levels to flood the plants, hand or mechanical harvesting followed by flooding, controlled burning, and chemical control using 2,4-D or glyphosate. Narrow-leaved cattail was one of the most abundant emergent plants along Little Green Lake's shoreline in 2016 (Map 5).

Curly-leaf Pondweed

Curly-leaf pondweed (CLP – Photograph 3.4-5) was officially documented in Little Green Lake by the WDNR in 2005; however, a report by Northern Environmental indicated CLP was the second-most abundant plant recorded in the lake during a 1994 survey indicating that CLP has been present in the lake for some time. Onterra ecologists completed an Early-Season AIS Survey on Little Green Lake on May 26, 2016 to locate and map areas of CLP. During this survey, a total of 258 acres of colonized CLP was located (Figure 3.4-11). Of the 258 acres, approximately 166 acres (64%) was delineated with a density rating of dominant or greater, while the remaining 36% was comprised of colonies delineated as scattered or highly scattered. The largest areas of surface-matted CLP were located in the southwest and northwest portions of the lake in approximately 4.0-5.0 feet of water.



Photograph 3.4-5. Curly-leaf pondweed (left) and hybrid watermilfoil (right), two non-native, invasive aquatic plants found in Little Green Lake. Photo credit Onterra, 2016.

As is discussed in the previous section, of the surveys completed in June from 2005-2016 indicate that the occurrence of CLP has not changed significantly over this period and it remains one of the dominant aquatic plants in Little Green Lake during the early part of the growing season. Despite recurring annual endothall treatments, these data indicate that the treatments have been ineffective at reducing the CLP population on a lake-wide basis over time. However, lake-wide control was not the intention of the annual treatments in recent years; instead, the annual treatments were conducted by the district strictly to reduce nuisance conditions created in some areas by CLP.

If lake-wide control, or better put, a significant reduction of the CLP population in Little Green Lake were the goal, a much different control strategy would need to be utilized. Traditionally, lake-wide control strategies of established populations of CLP consists of repeated annual herbicide treatments utilizing endothall conducted in May/June. The treatment strategy is to kill each year's plants before they are able to produce turions; therefore, little or no additional turions are added to the 'turion bank' during the control program. After multiple years of treatment, the turion bank in the sediment is depleted and the CLP population decreases significantly. Normally a control strategy for an established population includes 5-7 years of treatments of the same area. For Little Green Lake specifically, the control strategy would need to be initiated on a lake-wide basis because CLP occurs lake-wide.

In the Water Quality Section (3.1), the impact of internal nutrient loading is discussed in depth. Overall, internal loading makes up a little over half of Little Green Lake's phosphorus load and because phosphorus is most frequently the limiting nutrient in the lake, it is the nutrient that fuels the lake's nuisance algae blooms. One internal source of phosphorus in Little Green Lake is from decaying macrophytes. While most plants senesce in the fall, CLP dies back in mid-summer and has the potential to release significant phosphorus into the water column which spurs algal production. Little Green Lake has a dense population of CLP, as discussed above, and when it senesces mid-summer, that event has the potential to release over 900 pounds of phosphorus into the lake. This could equate to approximately half of the annual internal load contributed to Little Green Lake's nutrient budget. Clearly, in a system like Little Green Lake, where water quality is a real concern, reducing large sources of phosphorus to the system is important; therefore, reducing the amount of CLP in the lake as a whole, would be important to improving water quality. This concept was the driving factor in developing an experimental treatment program for CLP on Little Green Lake that started in spring 2017.

During the spring of 2017, the LGLPRD, with the guidance of Onterra, conducted an experimental treatment of CLP to test whether or not whole-lake, early-season CLP treatments may be applicable on Little Green Lake.

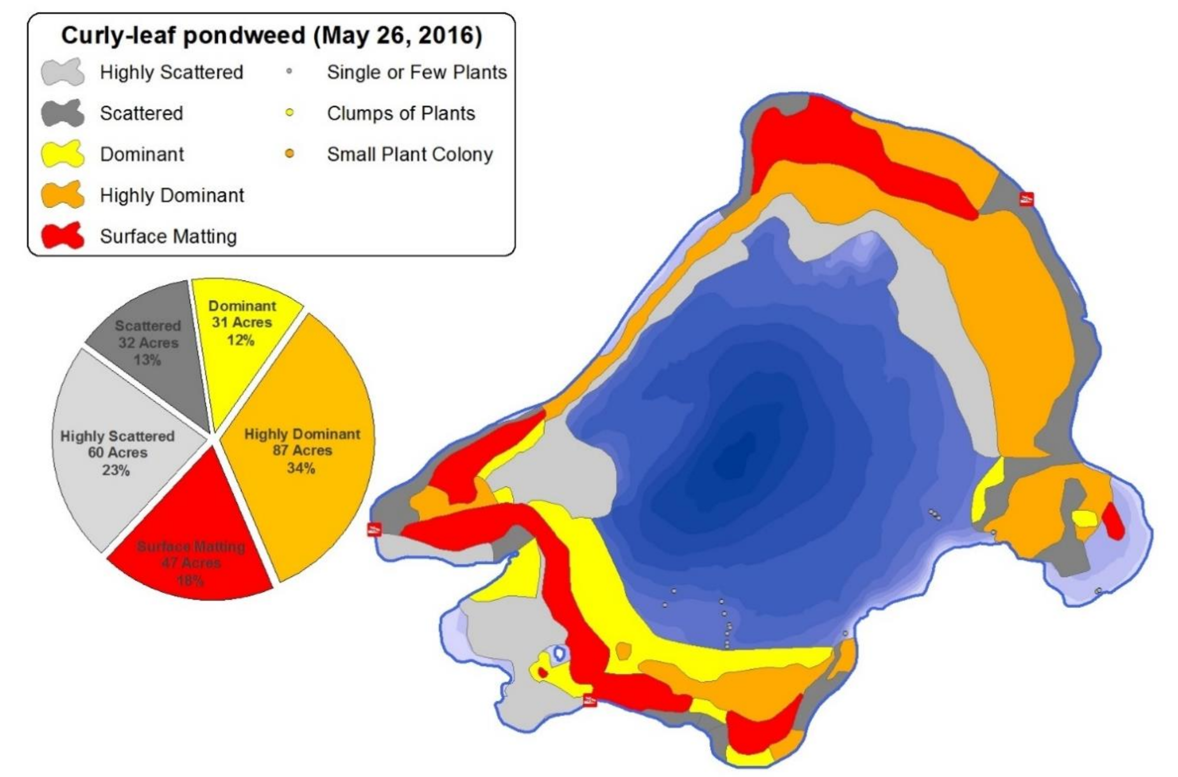


Figure 3.4-11. Little Green Lake May 2016 curly-leaf pondweed locations. Locations mapped during survey completed on May 26, 2016.

The proposed strategy included similar early-spring treatments of CLP utilizing endothall as had been used previously, with an additional larger area being added as an experimental site (Figure 3.4-12). Site A-17, which targeted roughly 20 acres of CLP in a portion of the lake known as Kearley Bay, was included to mimic a whole-lake treatment of CLP in Little Green Lake. As a part of the experimental treatment, monitoring of Little Green Lake's native and exotic plant population continued into 2017, one year beyond what was originally included in the planning project, to document changes brought on by the treatment. The additional monitoring included sampling of 20 point-intercept sub-sample sites prior to the treatment in April and several weeks after the treatment in June. These points were also sampled during the whole lake point-intercept survey completed in 2016 as a part of the management planning project; however, that survey was completed late in the summer after CLP had already senesced, so only the native plant and HWM findings are comparable with data collected in 2017. Originally, the experimental treatment was to be completed twice, once in 2017 at the district's expense, and again in 2018 under a proposed AIS-Established Population Control Grant slatted for submittal in February 2018.

				Application Area Dose						
Site	Acres	Ave Depth	Volume (acre-feet)	2,4-D PPM ae	DMAIV (gallons)	Endothall PPM ai	Aquathol K (gallons)	Diquat Gallons/acre	Diquat (ppm cation)	Diquat (gallons)
A-17	20.2	4.5	90.9			2.0	117.0			
B-17	16.0	4.0	64.0	4.0	183.0	1.5	62.0			
C-17	2.3	3.5	8.1					1.75	0.37	4.0
D-17	2.8	3.0	8.4					1.50	0.37	4.2
E-17	5.0	3.5	17.5	4.0	50.0	1.5	17.0			
Total	46.3		188.9		233.0		196.0			8.2

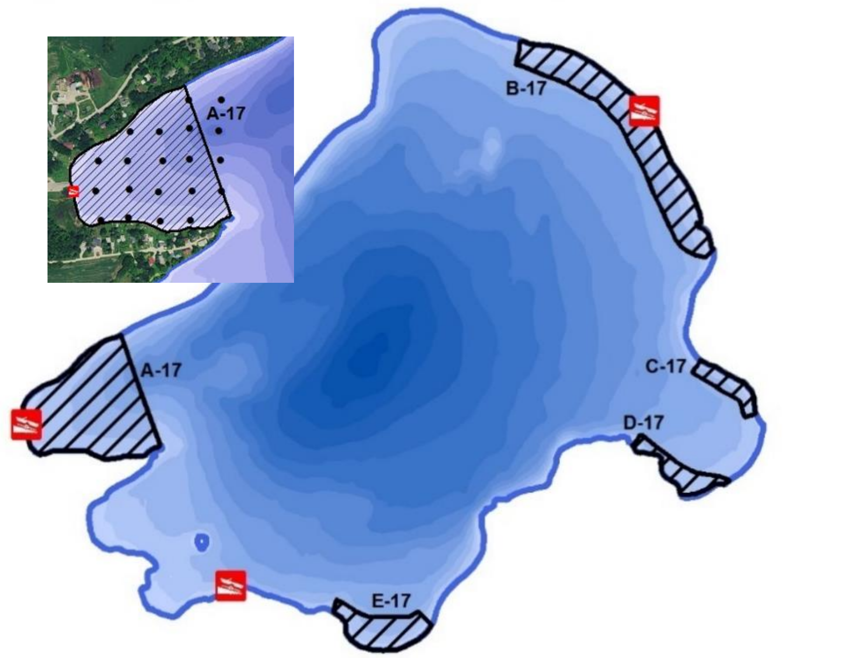


Figure 3.4-12. Little Green Lake 2017 final herbicide treatment strategy. Site A-17 was an experimental treatment site to investigate the impact of an early-season endothall treatment on curly-leaf pondweed and hybrid watermilfoil. Inset indicates location of point-intercept sub-sample locations in Site A-17.

It was expected that the early spring endothall treatments would work to significantly reduce CLP in Kearley Bay during 2017 and 2018. Monitoring also included pretreatment, Early-Season AIS Survey, and Late Summer Peak-Biomass Surveys. The results of those surveys were to be used to determine what native plants occupied the area following the expected decrease in CLP density and to document the treatment's impact on HWM in the area. Recent research has shown that in treatments conducted at colder water temperatures (roughly 55° F), endothall may act systemically and cause mortality in HWM. As mentioned above, the overarching objective of these studies were to assist in determining the applicability of completing multiple whole-lake endothall treatments in Little Green Lake to significantly lower CLP densities on a lake-wide basis. As alluded to below, based upon changes in HWM densities in Little Green Lake between early summer and late summer 2016, it was believed that the dense CLP populations dominating the lake during the early part of the growing season may be stifling the growth of HWM. And, if that were the case, the successful control of CLP through a whole-lake treatment may spur rapid expansion of the HWM population; therefore, a secondary objective of the experimental treatment on site A-17 was to determine if HWM could also be controlled with endothall and keep it from expanding in the absence of CLP.

On April 24, 2017, an Onterra field crew visited Little Green Lake to complete the pretreatment survey and collect data at the designated point-intercept sub-sample locations. Both EWM and CLP were observed throughout treatment site A-17. The sub-sample point-intercept survey completed in this area indicated EWM had a frequency of occurrence of 50% and CLP had a frequency of occurrence of 45%. The native aquatic plants, coontail and muskgrasses, were also observed within this area. The combination of a sub-sample point-intercept survey and transects with the submersible camera indicated sufficient EWM and CLP to warrant treatment within site A-17. The herbicide treatment was completed on May 3, 2017 in light wind conditions, which remained under 7 mph for at least the next 24 hours.

On June 13th, 2017, Onterra staff completed an Early-Season AIS Survey on Little Green Lake. This is a meander-based survey of the littoral zone where both CLP and HWM are mapped. In addition, the crew also completed the post-treatment sub-sample point-intercept survey within herbicide application area A-17. During the survey, aquatic plant growth (both native and non-native) was observed to be much lower than it was at approximately the same time in 2016. The survey crew did not locate CLP anywhere in the lake, even in areas outside of the herbicide application areas where CLP growth had been observed during the pre-treatment survey on April 24th. Given no CLP was located during the survey and reports from lake residents that CLP growth had been observed a couple weeks prior, this was believed to indicate that the population had already senesced. This early senescence of CLP in Little Green Lake was unexpected as Onterra crews were observing CLP growth on other area lakes during the same time. While some district members believed that the CLP senescence and generally low occurrence of native plants was brought on by the May herbicide treatment, it is highly unlikely because lake-wide concentrations would not be sufficient to kill the species of aquatic plants documented in Little Green Lake. However, precipitation in April, May, and the first part of June of 2017 were approximately 40% higher than the average for those months from 2007-2016. Secchi disk transparency data indicates that water clarity was significantly lower (3.1 feet during survey) than average for that time of year (~6-7 feet), indicating that the increased precipitation resulted in a higher amount of nutrients and sediments being delivered to the lake in spring 2017. The lower water clarity in combination with slightly higher water levels may have created stressful conditions for the CLP bringing about its early senescence and a generally low occurrence of native plants as well.

Hybrid milfoil was observed during Early-Season AIS Survey, albeit at a lower level than what was observed at the same time in 2016. The lower level of EWM observed may have been the result of the stressful conditions discussed above, the inability of the field crew to see the plants due to the low water clarity, or a combination of both. In June 2017 within treatment site A-17, 37% of the sub-sample locations contained HWM compared to 50% earlier that spring prior to treatment. Further, while the crew recorded HWM at 37% of the sampling locations, the plant was not visible from the surface in the treatment area, indicating that the HWM was low-growing and likely stressed. The crew observed a handful of single HWM plants in the bay in the southwest portion of the lake and along the northeast shore. The largest area of HWM encountered was an area of *scattered* HWM in the northwest portion of the lake. The HWM in that area was readily visible from the surface. Results of the 2017 Late-Season AIS Survey aimed at mapping HWM occurrences within the lake are discussed in the Eurasian Watermilfoil/Hybrid Watermilfoil Subsection below.

Riparians and anglers reported several dead bluegill/pumpkinseeds and bullheads in June 2017 and questioned whether or not the herbicide treatment was the cause. WDNR fisheries biologist David Bartz indicated that many area lakes were experiencing *Columnaris* bacteria outbreaks that year due to "rapidly warming water temperatures in combination with large inputs of organics (often pollen) from heavy rains, and spawning stress." Mr. Bartz indicated that the numbers of dead fish observed were low and should not to cause alarm, but he should be notified if larger numbers are observed.

As a part of the alternative analysis process, Onterra designed a 6-year project that included annual, whole-lake treatments of CLP in Little Green Lake in 2019-2022, and associated monitoring to document the results. The first phase of the 6-year project would have cost approximately $440,000, of which $200,000 would have been covered by state grants, leaving $240,000 to be covered over roughly a 3-year period by the LGLPRD. The second phase of the project would have been covered by a second state grant and was estimated to cost approximately the same as the first phase.

As elaborated on below, HWM occurrence was lower in the experimental treatment area (site A-17) immediately following the treatment and late in the growing season as well; however, the 2017 findings are confounded by the odd climatic conditions during the spring and early growing season of 2017. Therefore, the decrease in HWM seen in 2017 may have been as much the result of the climatic conditions as it was the endothall treatment. Overall, it does not appear that the early-spring treatment using endothall had the impact on HWM that was hoped for and would be sufficient to alleviate concerns of the district and Onterra regarding increased densities of HWM if the competition from CLP were removed early in the growing season. This combined with the costs elaborated on above has led the LGLPRD to not consider lake-wide CLP control on Little Green Lake for at least the next two years. The LGLPRD will monitor the lake conditions in 2018 and 2019. They plan to re-evaluate the lake-wide CLP control option in 2010 and identify funding options.

Eurasian Watermilfoil/Hybrid Watermilfoil

Eurasian watermilfoil was first documented in Little Green Lake in 1993. Exhibiting some morphological characteristics of the native northern watermilfoil, Eurasian watermilfoil samples from Little Green Lake were collected and sent by WDNR to the University of Connecticut for DNA analysis in 2006. Their results confirmed that the milfoil samples tested were HWM, a cross between EWM and the native northern watermilfoil (*M. sibiricum*). No additional samples have been tested for hybridity. Most lakes are suspected as having mixed populations of both EWM and HWM within them.

Onterra ecologists mapped locations of HWM in Little Green Lake in May 2016, September 2016, and September 2017 (3.4-13). Typically, HWM reaches its peak growth in mid- to late-summer. However, it is often up and growing early in the season and mapping it during the Early-Season AIS Survey helps to guide mapping later in the year. In May 2016, approximately 110 acres of colonized HWM was located in Little Green Lake. Of these 110 acres, approximately 20 acres (18%) were delineated as dominant or highly dominant. These denser areas of HWM were located in the southwestern and eastern portions of the lake in approximately 4.0 feet of water. The remaining 90 acres (82%) was delineated as scattered or highly scattered.

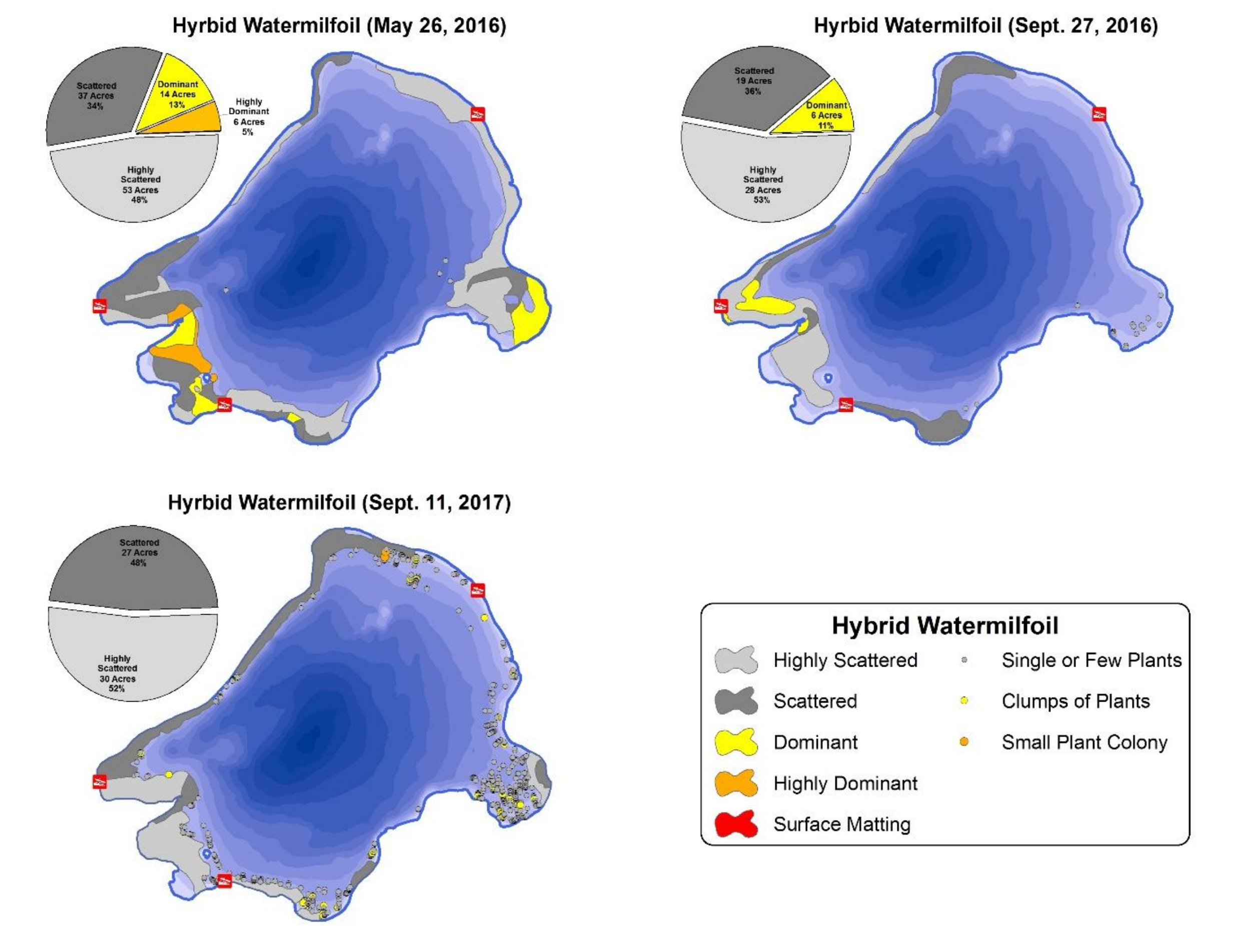


Figure 3.4-13. Little Green Lake May and September 2016 hybrid watermilfoil locations. Locations mapped during survey completed on May 26 and September 27, 2016.

When Onterra ecologists returned to Little Green Lake in September 2016 to complete the HWM Peak-Biomass Survey, they were surprised to find that colonies of HWM had declined to approximately 53 acres. Of these 53 acres, 6 acres (11%) were delineated as dominant while the remaining acreage was delineated as scattered or highly scattered. A portion of the HWM delineated as scattered within the bay on the west side of the lake in May was found to have increased do dominant in September. However, the highly dominant and dominant colonies mapped in May in southwest and eastern portions of the lake had declined to highly scattered or to single-plant occurrences.

Onterra ecologists had not noted declines in EWM/HWM populations on other lakes being surveyed at the same time in 2016. It is believed that local conditions within the lake likely contributed to the decline in HWM. In late-July 2016, a small diquat application occurred in Little Green Lake in an attempt to alleviate dense aquatic plant growth around riparian docks. This small treatment in combination with mechanical harvesting, early competition with CLP, and declining water clarity over the course of the growing season, likely contributed to the lesser amounts of HWM in September 2016 when compared to May of that year. As discussed above, one of the primary factors believed to be controlling HWM densities in Little Green Lake is the dense, early-season growth of CLP. It could be that HWM is held back by CLP early in the growing season and then is not able to expand in area and density later in the season due to the lake's typically worsening water clarity as the summer progresses. Mechanical harvesting and annual herbicide treatments likely impact HWM densities as well. However, severely lessened CLP growth through a whole lake treatment strategy, and possibly the other factors discussed here would not be able to hold back the HWM growth later in the season.

In September 2017, HWM was found in additional areas throughout Little Green Lake when compared to September 2016. Based upon surveys completed as a part of the experimental CLP treatment completed in 2017, and anecdotal information, it is believed that CLP experienced an early die-off in 2017. While the surveys did not show a marked increase in density of known areas, the additional areas outside those mapped previously may have been made possible due to the early CLP die-off.

As discussed in the previous section, the 2005-2016 point-intercept data show that while the occurrence of HWM in Little Green Lake can vary from year to year, it has not declined significantly over this period. Like CLP, it appears that the annual herbicide treatments have been largely ineffective at reducing HWM in Little Green Lake on a lake-wide basis, and like CLP, it remains one of the dominant aquatic plant species within the lake. Again, like CLP, reducing HWM on a lake-wide basis has not been the district's objective in recent years.

Background on Herbicide Application Strategies

Herbicides that target submersed plant species are directly applied to the water, either as a liquid or an encapsulated granular formulation. Factors such as water depth, water flow, treatment area size, and plant density work to dilute herbicide concentration within aquatic systems. Understanding Concentration-Exposure Times (often referred to as CETs) is an important consideration for the use of aquatic herbicides. Successful control of the target plant is achieved when it is exposed to a lethal concentration of the herbicide for a specific duration of time.

A Cooperative Research and Development Agreement between the Wisconsin Department of Natural Resources and U.S. Army Corps of Engineers Research and Development Center in conjunction with significant participation by private lake management consultants have coupled quantitative aquatic plant monitoring with in-lake herbicide concentration data to evaluate efficacy, selectivity, and longevity of chemical control strategies primarily targeting EWM/HWM implemented on a subset of Wisconsin waterbodies. Based on the preliminary findings from this research, lake managers have adopted two main treatment strategies: 1) spot treatments, and 2) large-scale (whole-lake) treatments.

Spot treatments are a type of control strategy where the herbicide is applied to a specific area (treatment site) such that when it dilutes from that area, its concentrations are insufficient to cause significant effects outside of that area. Herbicide application rates for spot treatment are formulated volumetrically, typically targeting EWM with 2,4-D at 3.0-4.0 ppm acid equivalent (ae). This means that sufficient 2,4-D is applied within the *Application Area* such that if it mixed evenly with the *Treatment Volume,* it would equal 3-4.0 ppm ae. This standard method for determining spot treatment use rates is not without flaw, as no physical barrier keeps the herbicide within the *Treatment Volume* and herbicide dissipates horizontally out of the area before reaching equilibrium (Figure 3.4-14). While lake managers may propose that a particular volumetric dose be used, such as 3.0-4.0 ppm ae, it is understood that actually achieving 3.0-4.0 ppm ae within the water column is not likely due to dissipation and other factors.

Ongoing research clearly indicates that the herbicide concentrations and exposure times of large (> 5 acres each) treatment sites are higher and longer than for small sites (Nault 2015). Research also indicates that higher herbicide concentrations and exposure times are observed in protected parts of a lake compared with open and exposed parts of the lake. Areas targeted containing water exchange (i.e. flow) are often not able to meet herbicide concentration-exposure time (CET) requirements for control.

WDNR administrative code defines large-scale treatments as those that exceed 10% of the littoral zone (NR 107.04[3]). From an ecological perspective, large-scale (whole-lake) treatments are those where the herbicide is applied to specific sites, but when the herbicide reaches equilibrium within the entire volume of water (of the lake, lake basin, or within the epilimnion of the lake or lake basin) it is at a concentration that is sufficient to cause mortality to the target plant within that entire treated volume. In regards to the WDNR's 10% littoral frequency of occurrence threshold discussed above, there is ecological basis in this standard. In general, if 10% of a lake was targeted with 2,4-D at 4.0 ppm ae, the whole-lake equilibrium concentration would be approximately 10% of that rate or 0.4 ppm ae. The target 2,4-D concentration for large-scale EWM treatments is typically between 0.250 and 0.400 ppm ae understanding that the exposure time would be dictated by herbicide degradation and be maintained for 7-14 days or longer. Therefore, spot treatments that approach 10% of a lake's area will become large-scale treatments.

Large-scale treatments have become more widely utilized by many lake managers (and public sector regulatory partners) as they impact the entire EWM/HWM population at once. This minimizes the repeated need for exposing the lake to herbicides as is required when engaged in an annual spot treatment program. Properly implemented, large-scale herbicide treatments can be highly effective, with minimal EWM, often zero, being detected for a year or two following the treatment (Figure 3.4-15, left frame). Some large-scale treatments have been effective at reducing EWM populations for 5-6 years following the application. Following the same herbicide use pattern, HWM populations were reduced the year following treatment to a lesser degree than similar pure EWM populations (Figure 3.4-15, right frame). In almost all HWM populations, rebound took less time and the rebounded populations were at much higher frequencies than EWM populations.

Predicting success (EWM control) and native plant impacts from whole-lake treatments may also be better understood than for spot treatments. Some native plants are quite resilient to this herbicide use pattern, either because they are inherently tolerant of the herbicide or they emerge later in the year than when the herbicide was active in the lake. Other species, particularly dicots, some thin-leaved pondweeds, and naiad species, can be impacted and take a number of years to recover. Often during the year of treatment, overall native plant biomass can be lessened but typically (not always) rebounds the following year. However, the preceding

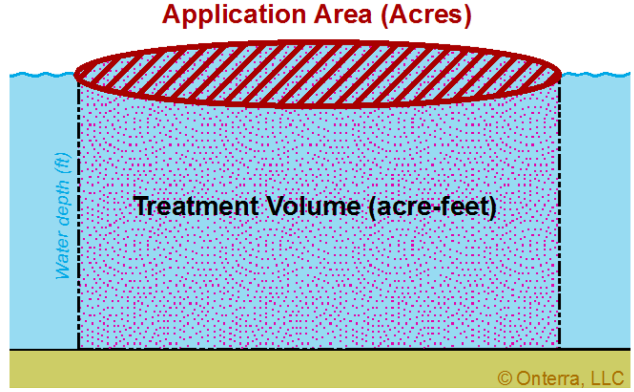


Figure 3.4-14. Herbicide Spot Treatment diagram.

statements are a bit of a generalization because some case studies have had varying levels of EWM control even at high concentration and exposure times and others case studies had collateral native plant impacts greater than would be assumed considering the concentrations and exposure times achieved.

It is also important to note that US EPA registration of aquatic herbicides typically requires organismal toxicity studies to be conducted using concentrations and exposure times consistent with spot-treatment use patterns (high concentrations, short exposure times). Therefore, only limited organismal toxicity data is available for concentrations and exposure times consistent with whole-lake treatment use patterns (low concentrations, long exposure times).

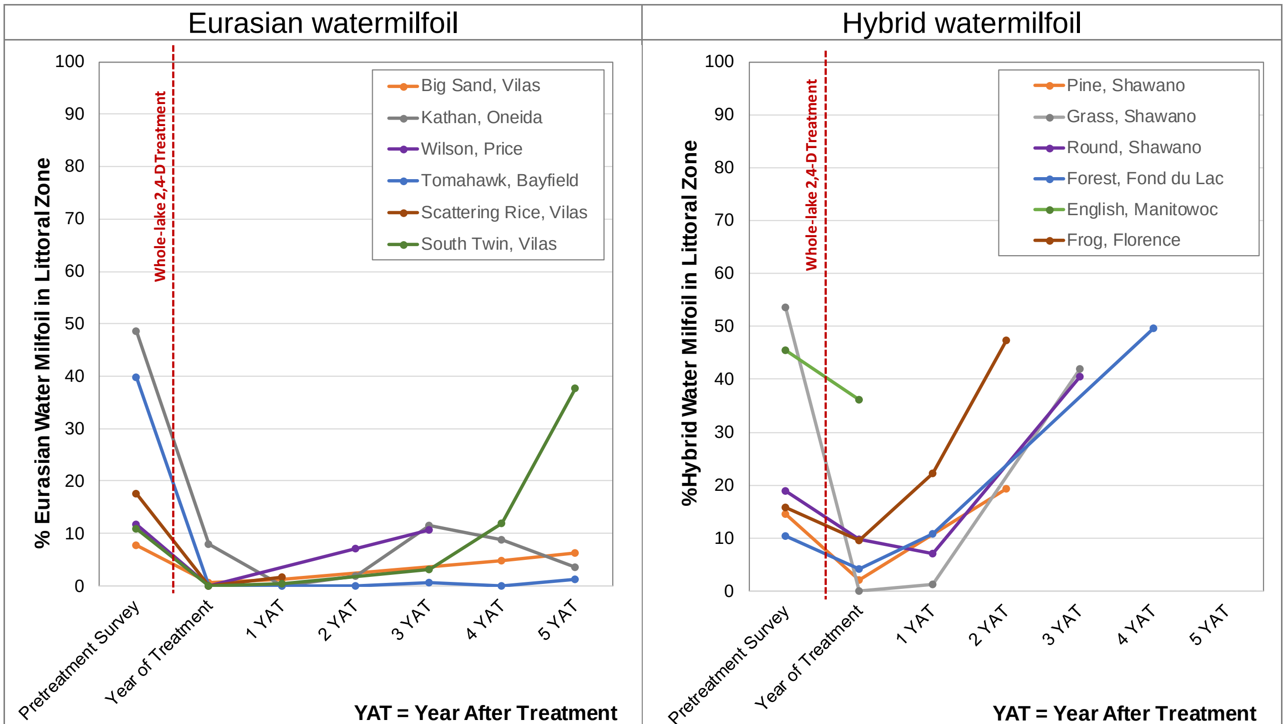


Figure 3.4-15. Littoral frequency of occurrence of invasive milfoil in lakes managed with large-scale 2,4-D treatments.

Because of their durability as a laboratory species, fathead minnows are often the subject of organismal toxicity studies. The LC50 (lethal concentration when half die) for fathead minnow exposure to 2,4-D (amine salt) has been determined to be 263 ppm ae sustained for 96 hours, a thousand times higher than fish would be exposed to in a large-scale treatment (target of approximately 0.3 ppm ae). With the assistance of a WDNR AIS-Research Grant, DeQuattro and Karasov (2015) investigated the impacts on fathead minnow of 2,4-D concentrations more relevant to what would be observed in large-scale treatments. The focus of their investigations was on reproductive toxicity and/or possible endocrine disruption potential from the herbicide.

The study revealed morphological changes in reproducing male fathead minnows, such that they had lower tubercle scores (analogous to smaller antlers on a male white-tail deer) with some 2,4-D products/use-rates and not with others. This may suggest that the "inert" carrier may be the cause, not the 2,4-D itself. At a static exposure of 0.5 ppm ae for 58 days (fish exposed for 28 days then eggs they laid were continued to be exposed for 30 more days post fertilization) uncovered a reduction in larval fathead survival from 97% to 83% at the lowest dose of one herbicide that was tested (no reduction at higher doses). While the herbicide concentrations and exposure times that caused the larval fathead minnow survival rates to decline in the study are much higher and longer than would be targeted for large-scale treatments, some 2,4-D treatments that accidentally exceeded the target rates could have approached the target concentrations tested by DeQuattro and Karasov (2015).

Little Green Lake Treatment History

Records indicate that the application of herbicides to control aquatic plants and/or algae has occurred on an annual basis since 1992. Treatment records detailing which herbicides were used and at what dosage are incomplete from 1992-2000; however, a complete record of treatments is available from 2001-2016 (Figure 3.4-16). Over this 15-year period, a combination of 2,4-D, endothall, and/or diquat have been applied to Little Green Lake in an effort to control non-native aquatic plants. The annual amount of herbicide in pounds of active ingredient ranged from 28 pounds in 2001 to 2,742 pounds in 2006 with an average of 923 pounds per year.

As discussed previously, it is postulated that the combined application of 2,4-D and endothall may have synergistic effects in terms of aquatic plant control. It is believed that the decline in native aquatic plant abundance observed from 2005-2016, particularly common/slender waterweed, is the result of recurring applications of these herbicides. And while these herbicide applications likely were at concentrations to affect aquatic plants at a lake-wide level in most years, the concentrations were not effective at longer-term control of CLP or HWM.

The concept of heterosis, or hybrid vigor, is important in regards to hybrid watermilfoil management in Little Green Lake. The root of this concept is that hybrid individuals typically have improved function compared to their pure-strain parents. Hybrid water-milfoil typically has thicker stems, is a prolific flowerer, and grows much faster than pure-strain EWM (LaRue et al. 2012). These conditions likely contribute to this plant being particularly less susceptible to biological (EnviroScience personal comm.) and chemical control strategies (Glomski and Netherland 2010, Poovey et al. 2007). As has been discussed, data gathered from large-scale 2,4-D treatments in Wisconsin from 2009-2016 suggest that treatments on lakes with populations of HWM were not as successful when compared to lakes with pure-strain EWM. In other words, it appears that some strains of HWM, but not all, are more tolerant of auxin herbicide treatments (2,4-D, triclopyr) than pure-strain EWM.

While understood in terrestrial herbicide applications for years, resistance evolution is an emerging topic amongst herbicide applicators, lake management planners, and researchers. Herbicide resistance is when a plant population develops reduced susceptibility to an herbicide over time. This occurs in a population when some of the targeted plants have an innate tolerance to the herbicide and some do not. Following a herbicide treatment, the more tolerant strains will rebound whereas the others will be controlled. Thus, the plants that re-populate the lake will be those that are more tolerant to that herbicide resulting in a more resistant population.

The past HWM control strategy initiated on Little Green Lake used 2,4-D. As discussed above, EWM is more sensitive to 2,4-D than HWM. Overtime, the relative population of EWM may have declined compared to HWM. The discussion above also indicates that some HWM strains may be more sensitive to 2,4-D than others. The strategy may have resulted in sensitive strains being removed from the population. Overall, this could have resulted in a population of 2,4-D tolerant invasive milfoil within Little Green Lake.

Nuisance Aquatic Plant Growth in Little Green Lake

A property owner survey was sent to 289 Little Green Lake property owners in 2016. Approximately 32% of the surveys were returned. Given the low response rate, the responses to the following questions regarding nuisance aquatic plant growth cannot be interpreted as being statistically representative of the population sampled. At best, the results may indicate possible trends and opinions about the respondents' perceptions of aquatic plant growth in Little Green Lake but cannot be stated with statistical confidence.

When asked how often aquatic plant growth during the open water negatively impacts enjoyment of Little Green Lake, the majority of respondents (61%) indicated *often* or *always*, 33% indicated *sometimes*, 6% indicated *rarely*, and 0% indicated *never* (Figure 3.4-17). Based on their answers to this question, when asked if aquatic plant control was needed on Little Green Lake, 89% indicated *definitely* and *probably yes*, 2% indicated *probably no*, 1% indicated *definitely no*, and 8% were *unsure* (Figure 3.4-17). The responses to these questions highlight the excessive growth of aquatic plants that occurs in certain areas of Little Green Lake and that the majority of survey respondents are in favor of some method of aquatic plant control.

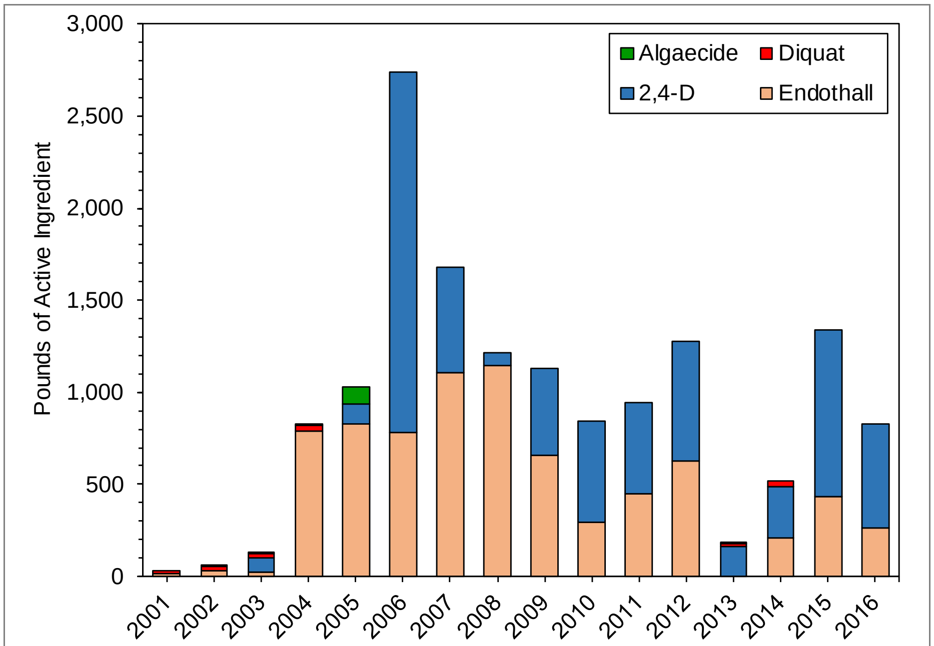
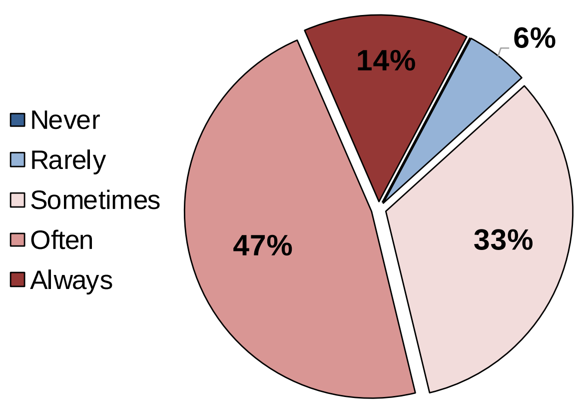


Figure 3.4-16. Little Green Lake herbicide treatment history from 2001-2016.

In 2016, Onterra ecologists observed large, surface-matted areas of CLP early in the year. Based on this plant's lifecycle, it is likely the primary species interfering with navigation and recreation on Little Green Lake in May and June. However, the nuisance conditions created by the CLP population early in the growing season had largely abated by July. During the early-July 2016 point-intercept survey, Onterra ecologists made note of the presence of nuisance aquatic plant conditions at the point-intercept sampling locations. The sampling locations where nuisance conditions were recorded were within the bay on the southwest side of the lake and within the bay on the east side of the lake. The nuisance conditions were created by a combination of surface-matted HWM and coontail.

In addition to annual herbicide treatments, the LGLPRD has been mechanically harvesting aquatic plants in select areas of Little Green Lake to create navigational lanes from shallower areas of the lake to deeper areas of open water. In 2016, the LGLPRD's harvesting permit allotted for the harvesting of navigational lanes totaling approximately 23.5 acres (Map 6). The 2016 mechanical harvesting report created by the LGLPRD indicates approximately 172,000 pounds of aquatic plants were mechanically harvested between June 1 and September 2, and the primary plants harvested included HWM, CLP, coontail, and filamentous algae. A mechanical harvesting strategy developed as part of this planning project can be found within the Implementation Plan Section (Section 5.0).

22. During the open water season, how often does aquatic plant growth, including algae, negatively impact your enjoyment of Little Green Lake?



23. Considering you answer to question 22, do you believe aquatic plant control is needed on Little Green Lake?

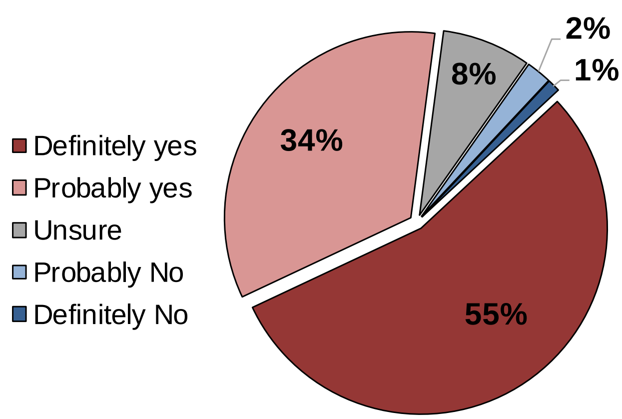


Figure 3.4-17. Little Green Lake property owner survey response questions regarding nuisance aquatic plant growth. N = 93 respondents of 289 surveys distributed.

3.5 Aquatic Invasive Species in Little Green Lake

As is discussed in section 2.0 Property Owner Participation, the lake property owners were asked about aquatic invasive species (AIS) and their presence in Little Green Lake within the anonymous stakeholder survey. Onterra and the WDNR have confirmed that there are seven AIS present (Table 3.5-1).

Table 3.5-1. AIS present within Little Green Lake

Type	Common name	Scientific name	Location within the report
Plants	Hybrid watermilfoil	*Myriophyllum sibiricum X spicatum*	Section 3.4 – Aquatic Plants
	Curly-leaf pondweed	*Potamogeton crispus*	Section 3.4 – Aquatic Plants
	Reed canary grass	*Phalaris arundinacea*	Section 3.4 – Aquatic Plants
	Narrow-leaved cattail	*Typha angustifolia*	Section 3.4 – Aquatic Plants
	Purple loosestrife	*Lythrum salicaria*	Section 3.5 – Aquatic Invasive Species
Invertebrates	Rusty crayfish	*Orconectes rusticus*	Section 3.5 – Aquatic Invasive Species
Fish	Common carp	*Cyprinus carpio*	Section 3.5 – Aquatic Invasive Species

Figure 3.5-1 displays the nine aquatic invasive species that Little Green Lake property owners believe are in Little Green Lake. Only the species present in Little Green Lake are discussed below or within their respective locations listed in Table 3.5-1. While it is important to recognize which species property owners believe to present within their lake, it is more important to share information on the species present and possible management options. More information on these invasive species or any other AIS can be found at the following links:

- http://dnr.wi.gov/topic/invasives/
- https://nas.er.usgs.gov/default.aspx
- https://www.epa.gov/greatlakes/invasive-species

Aquatic Animals

Rusty Crayfish

Rusty crayfish (*Orconectes rusticus*) are originally from the Ohio River basin and are thought to have been transferred to Wisconsin through bait buckets. These crayfish displace native crayfish and reduce aquatic plant abundance and diversity. Rusty crayfish can be identified by their large, smooth claws, varying in color from grayish-green to reddish-brown, and sometimes visible rusty spots on the sides of their shell. They are not eaten by fish that typically eat crayfish because they are more aggressive than the native crayfish. Rusty crayfish reproduce quickly but with intensive harvesting their populations can be greatly reduced within a lake.

Common Carp

Since the introduction of common carp (*Cyprinus carpio*), an invasive species which originates from Eurasia, to waterbodies in the United States and other countries around the world, numerous studies have documented the deleterious effects these fish have on lake ecosystems. Common carp can survive in a wide range of waterbody conditions, but they reach their greatest densities in shallow, eutrophic systems (Weber et al. 2011). Because of their ability to reach extreme densities, they are considered to be one of the most detrimental invasive species to waterbodies they inhabit (Weber et al. 2011).

Following the introduction of common carp to a waterbody, studies have documented declines in submersed aquatic vegetation and increases in total phosphorus and suspended solids, and a shift from a clear, submersed aquatic plant-dominated state to a turbid, algae-dominated state (Bajer and Sorensen 2015). Common carp directly increase nutrients within the water by physical resuspension of bottom sediments through foraging and spawning behavior as well as through excretion (Fischer et al. 2013). Common carp foraging behavior also creates more flocculent sediments which are more prone to resuspension from wind. In addition, sediments are also more prone to wind-induced resuspension as aquatic vegetation declines through physical uprooting and decline in light availability due to increases in water turbidity (Lin and Wu 2013). Zooplankton which feed on algae also decline as their refuge from predators within aquatic vegetation disappears. Common carp create a positive feedback mechanism: the direct physical resuspension and uprooting of vegetation indirectly increases the susceptibility of bottom sediments to wind-induced resuspension, and the increased turbidity further decreases aquatic vegetation.

Aquatic Plants

Purple loosestrife

Purple loosestrife (*Lythrum salicaria*) is a perennial herbaceous plant native to Europe and was likely brought over to North America as a garden ornamental. This plant escaped from its garden landscape into wetland environments where it is able to out-compete our native plants for space and resources. First detected in Wisconsin in the 1930's, it has now spread to 70 of the state's 72 counties. Purple loosestrife largely spreads by seed, but also can vegetatively spread from root or stem fragments.

There are a number of effective control strategies for combating this aggressive plant, including herbicide application, biological control by native beetles, and manual hand removal. At this time, hand removal by volunteers is likely the best option as it would decrease costs significantly.

Purple loosestrife was first observed on Little Green Lake in 2015 but was not found during the 2016 surveys.

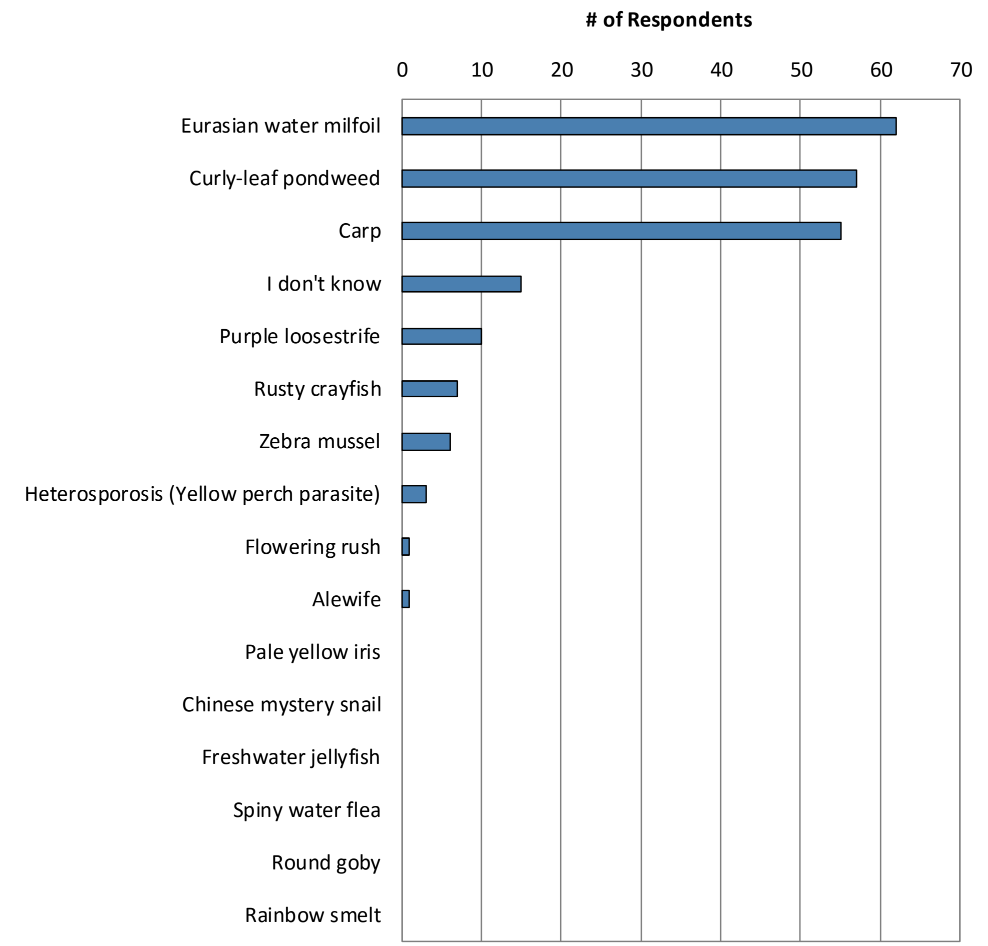


Figure 3.5-1. Property owner survey response Question #19. Which aquatic invasive species do you believe are in Little Green Lake?

3.6 Fisheries Data Integration

Fishery management is an important aspect in the comprehensive management of a lake ecosystem; therefore, a summary of available data is included here as reference. The following section is not intended to be a comprehensive plan for the lake's fishery, as those aspects are currently being conducted by the fisheries biologists overseeing Little Green Lake. The goal of this section is to provide an overview of the data that exists. Although current fish data were not collected as a part of this project, the following information was compiled based upon data available from the Wisconsin Department of Natural Resources (WDNR 2017) and personal communications with DNR Fisheries Biologist David Bartz.

Before beginning to summarize available fisheries data, historical fisheries should be taken into consideration. Historical fishery data can provide valuable information as to what the fishery was once like and is currently trending or being stocked towards. Prior to 1955, common carp and white bass were the two most common fish species within Little Green Lake (Ramaker & Associates 1997). An algae bloom in 1955 resulted in a massive fish kill and the remaining surviving fish were exposed to the fish toxicant toxaphene (Ramaker & Associates 1997). Little Green Lake was then stocked for walleye, largemouth bass and bluegill to rebuild the fishery. Another fish kill occurred in 2012 affecting an estimated 200 walleye in Lakeview Bay, the suspected cause was believed to be low dissolved oxygen from an algae bloom (personal communication, Dave Bartz).

Fish kills are typically the result of low concentrations of dissolved oxygen in the water. These low concentrations can occur when a large algae bloom begins to decay. The decaying process consumes dissolved oxygen in the water, resulting in hypoxic conditions. When large numbers of fish begin to decompose, more oxygen is depleted and a downward spiral of decreased dissolved oxygen transpires. (USGS 2017)

No carp were captured from seine netting in 1966 however a 2013 WDNR survey confirmed carp are present in Little Green Lake. Some limited carp control efforts have occurred historically in Little Green Lake; however, harvesting proved difficult with relatively low populations coupled with lower water clarity and heavy aquatic plant growth (personal comm. Dave Bartz). The common carp in Little Green Lake are believed to be in low densities and are not causing any major damage to the lake's ecology (personal comm. Dave Bartz). The population of this species will be monitored by WDNR biologists.

Little Green Lake Fishery

Energy Flow of a Fishery

When examining the fishery of a lake, it is important to remember what drives that fishery, or what is responsible for determining its mass and composition. The gamefish in Little Green Lake are supported by an underlying food chain. At the bottom of this food chain are the elements that fuel algae and plant growth – nutrients such as phosphorus and nitrogen, and sunlight. The next tier in the food chain belongs to zooplankton, which are tiny crustaceans that feed upon algae and plants, and insects. Smaller fish called planktivores feed upon zooplankton and insects, and in turn become food for larger fish species. The species at the top of the food chain are called piscivores and are the larger gamefish that are often sought after by anglers, such as bass and walleye.

A concept called energy flow describes how the biomass of piscivores is determined within a lake. Because algae and plant matter are generally small in energy content, it takes an incredible amount of this food type to support a sufficient biomass of zooplankton and insects. In turn, it takes a large biomass of zooplankton and insects to support planktivorous fish species. And finally, there must be a large planktivorous fish community to support a modest piscovorous fish community. Studies have shown that in natural ecosystems, it is largely the amount of primary productivity (algae and plant matter) that drives the rest of the producers and consumers in the aquatic food chain. This relationship is illustrated in Figure 3.6-1.

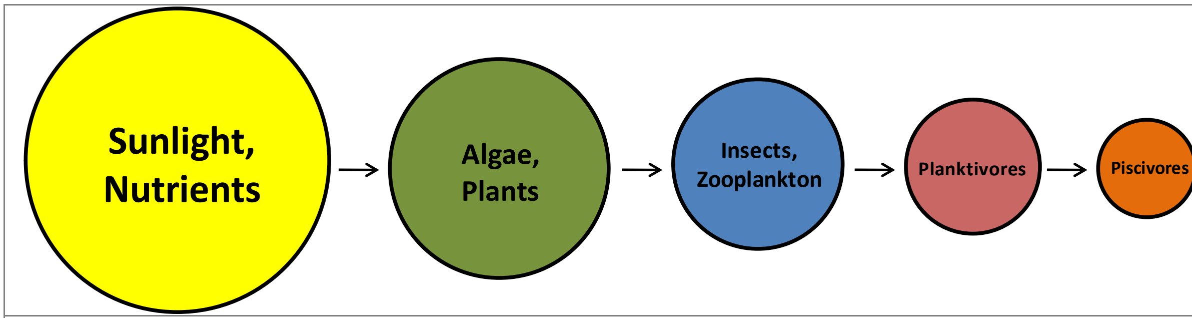


Figure 3.6-1. Aquatic food chain. Adapted from Carpenter et. al 1985.

As discussed in the Water Quality section, Little Green Lake is a eutrophic system, meaning it has high nutrient content and thus relatively high primary productivity. Simply put, this means Little Green Lake should be able to support sizable populations of predatory fish (piscivores) because the supporting food chain is relatively robust. Table 3.6-1 shows the popular game fish present in the system. Although not an exhaustive list of fish species in the lake, additional species documented in past surveys of Little Green Lake include: white sucker (*Catostomus commersoni*), common carp (*Cyprinus carpio*), fathead minnow (*Pimephales promelas*) and the golden shiner (*Notemigonus crysoleucas*).

Table 3.6-1. Gamefish present in Little Green Lake with corresponding biological information (Becker, 1983).

Common Name (*Scientific Name*)	Max Age (yrs)	Spawning Period	Spawning Habitat Requirements	Food Source
Black Bullhead (*Ameiurus melas*)	5	April - June	Matted vegetation, woody debris, overhanging banks	Amphipods, insect larvae and adults, fish, detritus, algae
Black Crappie (*Pomoxis nigromaculatus*)	7	May - June	Near *Chara* or other vegetation, over sand or fine gravel	Fish, cladocera, insect larvae, other invertebrates
Bluegill (*Lepomis macrochirus*)	11	Late May - Early August	Shallow water with sand or gravel bottom	Fish, crayfish, aquatic insects and other invertebrates
Brown Bullhead (*Ameiurus nebulosus*)	5	Late Spring - August	Sand or gravel bottom, with shelter rocks, logs, or vegetation	Insects, fish, fish eggs, mollusks and plants
Green Sunfish (*Lepomis cyanellus*)	7	Late May - Early August	Shelter with rocks, logs, and clumps of vegetation, 4 - 35 cm	Zooplankton, insects, young green sunfish and other small fish
Largemouth Bass (*Micropterus salmoides*)	13	Late April - Early July	Shallow, quiet bays with emergent vegetation	Fish, amphipods, algae, crayfish and other invertebrates
Muskellunge (*Esox masquinongy*)	30	Mid April - Mid May	Shallow bays over muck bottom with dead vegetation, 6 - 30 in.	Fish including other muskies, small mammals, shore birds, frogs
Northern Pike (*Esox lucius*)	25	Late March - Early April	Shallow, flooded marshes with emergent vegetation with fine leaves	Fish including other pike, crayfish, small mammals, water fowl, frogs
Pumpkinseed (*Lepomis gibbosus*)	12	Early May - August	Shallow warm bays 0.3 - 0.8 m, with sand or gravel bottom	Crustaceans, rotifers, mollusks, flatworms, insect larvae (terrestrial and aquatic)
Rock Bass (*Ambloplites rupestris*)	13	Late May - Early June	Bottom of course sand or gravel, 1 cm - 1 m deep	Crustaceans, insect larvae, and other invertebrates
Walleye (*Sander vitreus*)	18	Mid April - Early May	Rocky, wavewashed shallows, inlet streams on gravel bottoms	Fish, fly and other insect larvae, crayfish
Yellow Perch (*Perca flavescens*)	13	April - Early May	Sheltered areas, emergent and submergent veg	Small fish, aquatic invertebrates

Survey Methods

In order to keep the fishery of a lake healthy and stable, fisheries biologists must assess the current fish populations and trends. To begin this process, the correct sampling technique(s) must be selected to efficiently capture the desired fish species. A commonly used passive trap is a fyke net (Photograph 3.6-1). Fish swimming towards this net along the shore or bottom will encounter the lead of the net, be diverted into the trap and through a series of funnels which direct the fish further into the net. Once reaching the end, fisheries technicians can open the net, record biological characteristics, mark (usually with a fin clip) and then release the captured fish. Fyke nets were set on Little Green Lake in 2013 to assess spawning populations of walleye, northern pike and muskellunge (Bartz 2013).

The other commonly used sampling method is electroshocking (Photograph 3.6-1). This is done, often at night, by using a specialized boat fit with a generator and two electrodes installed on the front touching the water. Once a fish comes in contact with the electrical current produced, the fish involuntarily swims toward the electrodes. When the fish is in the vicinity of the electrodes, they become stunned making them easy for fisheries technicians to net and place into a livewell to recover. Contrary to what some may believe, electroshocking does not kill the fish and after being placed in the livewell fish generally recover within minutes. As with a fyke net survey, biological characteristics are recorded and any fish that has a mark (considered a recapture from the earlier fyke net survey) are also documented before the fish is released. Electroshocking was conducted on Little Green Lake in April and June 2013 to assess the walleye, bass and panfish fishery (Bartz 2013).

The mark-recapture data collected between these two surveys is placed into a statistical model to calculate the population estimate of a fish species. Fisheries biologists can then use this data to make recommendations and informed decisions on managing the fishery.

Photograph 3.6-1. Fyke net positioned in the littoral zone of a Wisconsin Lake (left) and an electroshocking boat (right).

Fish Stocking

Photograph 3.6-2. Muskellunge fingerling.

To assist in meeting fisheries management goals, the WDNR may stock fry, fingerling or adult fish in a waterbody that were raised in permitted hatcheries (Photograph 3.6-2). Stocking of a lake may be done to assist the population of a species due to a lack of natural reproduction in the system, or to otherwise enhance angling opportunities. Little Green Lake has been heavily stocked since the 1970s with muskellunge, walleye and muskellunge hybrids. Stocking efforts from 1972 to 2017 by the WDNR, Fishing Friends Forever and the LGLPRD are displayed in Tables 3.6-2 through 3.6-7. Fathead minnows and black crappie have also been stocked by Fishing Friends Forever and the LGLPRD (Appendix F). Stocking efforts of muskellunge and walleye have been successful and are likely to continue (personal comm. Bartz).

Table 3.6-2. Available WDNR stocking data of walleye for Little Green Lake (1972-2017).

Year	Species	Strain (Stock)	Age Class	# Fish Stocked	Avg Fish Length (in)
2017	Walleye	Mississippi Headwaters	Small Fingerling	16,174	1.7
2017	Walleye	Lake Michigan	Large Fingerling	3,682	8.0
2015	Walleye	Lake Michigan	Small Fingerling	16,184	1.8
2013	Walleye	Mississippi Headwaters	Small Fingerling	23,285	2.0
2011	Walleye	Lake Michigan	Small Fingerling	16,741	2.1
2009	Walleye	Lake Michigan	Small Fingerling	15,310	1.8
2007	Walleye	Mississippi Headwaters	Small Fingerling	16,415	2.1
2005	Walleye	Unspecified	Small Fingerling	24,380	1.9
2003	Walleye	Lake Michigan	Small Fingerling	27,032	2.5
2001	Walleye	Unspecified	Small Fingerling	23,300	1.6
1999	Walleye	Unspecified	Small Fingerling	25,000	1.5
1998	Walleye	Unspecified	Small Fingerling	10,000	1.7
1997	Walleye	Unspecified	Large Fingerling	20,200	2.7
1995	Walleye	Unspecified	Fingerling	26,703	2.8
1991	Walleye	Unspecified	Fingerling	12,060	3.0
1990	Walleye	Unspecified	Fingerling	21,280	3.0
1989	Walleye	Unspecified	Fingerling	23,584	2.0
1987	Walleye	Unspecified	Fingerling	72,000	2.0
1984	Walleye	Unspecified	Fingerling	24,050	3.0
1973	Walleye	Unspecified	Fry	1,500,000	
1972	Walleye	Unspecified	Fry	1,000,000	1.0

Table 3.6-3. Available WDNR stocking data of muskellunge for Little Green Lake (1972-2017).

Year	Species	Strain (Stock)	Age Class	# Fish Stocked	Avg Fish Length (in)
2017	Muskellunge	Upper Wisconsin River	Large Fingerling	932	9.3
2017	Muskellunge	Upper Wisconsin River	Small Fingerling	500	6.3
2016	Muskellunge	Upper Wisconsin River	Large Fingerling	466	10.3
2014	Muskellunge	Upper Wisconsin River	Large Fingerling	466	9.5
2013	Muskellunge	Upper Wisconsin River	Large Fingerling	466	11.4
2012	Muskellunge	Upper Wisconsin River	Large Fingerling	950	9.6
2011	Muskellunge	Upper Wisconsin River	Large Fingerling	930	9.3
2010	Muskellunge	Upper Wisconsin River	Large Fingerling	821	12.8
2009	Muskellunge	Upper Wisconsin River	Large Fingerling	931	10.2
2008	Muskellunge	Upper Wisconsin River	Large Fingerling	932	10.3
2007	Muskellunge	Upper Wisconsin River	Large Fingerling	620	13.0
2006	Muskellunge	Upper Wisconsin River	Large Fingerling	205	10.8
2005	Muskellunge	Unspecified	Large Fingerling	932	10.6
2004	Muskellunge	Unspecified	Large Fingerling	999	10.5
2003	Muskellunge	Unspecified	Large Fingerling	932	10.9
2002	Muskellunge	Unspecified	Large Fingerling	931	10.1
2001	Muskellunge	Unspecified	Large Fingerling	932	10.6
1999	Muskellunge	Unspecified	Large Fingerling	876	10.9
1996	Muskellunge	Unspecified	Fingerling	932	11.8
1993	Muskellunge	Unspecified	Fingerling	1,000	9.0
1992	Muskellunge	Unspecified	Fingerling	930	10.0
1991	Muskellunge	Unspecified	Fingerling	1,200	11.0
1990	Muskellunge	Unspecified	Fingerling	1,200	10.0
1989	Muskellunge	Unspecified	Fingerling	400	7.0
1988	Muskellunge	Unspecified	Fingerling	400	11.0
1987	Muskellunge	Unspecified	Fingerling	1,200	3.0
1986	Muskellunge	Unspecified	Fingerling	400	8.0
1985	Muskellunge	Unspecified	Fingerling	400	8.0
1984	Muskellunge	Unspecified	Fingerling	400	8.0
1983	Muskellunge	Unspecified	Fingerling	350	9.0
1982	Muskellunge	Unspecified	Fingerling	400	9.0
1981	Muskellunge	Unspecified	Fingerling	400	9.0
1980	Muskellunge	Unspecified	Fingerling	400	11.0
1979	Muskellunge	Unspecified	Fingerling	436	9.0
1978	Muskellunge	Unspecified	Fingerling	400	10.0
1977	Muskellunge	Unspecified	Fingerling	1,040	11.0
1976	Muskellunge	Unspecified	Fingerling	400	13.0
1975	Muskellunge	Unspecified	Fingerling	200	9.0
1974	Muskellunge	Unspecified	Fingerling	400	11.0
1973	Muskellunge	Unspecified	Fingerling	1,300	14.0
1972	Muskellunge	Unspecified	Fry	18,000	1.0
1972	Muskellunge	Unspecified	Fingerling	1,200	15.0

Table 3.6-4. Available WDNR stocking data of northern pike X muskellunge for Little Green Lake (1974-2002).

Year	Species	Age Class	# Fish Stocked	Avg Fish Length (in)
2002	Northern Pike x Muskellunge	Large Fingerling	1,000	10.0
2001	Northern Pike x Muskellunge	Large Fingerling	500	8.1
2000	Northern Pike x Muskellunge	Large Fingerling	1,000	8.0
1999	Northern Pike x Muskellunge	Large Fingerling	200	8.1
1988	Northern Pike x Muskellunge	Fingerling	1,600	7.5
1987	Northern Pike x Muskellunge	Fingerling	2,400	7.0
1986	Northern Pike x Muskellunge	Fingerling	800	9.0
1985	Northern Pike x Muskellunge	Fingerling	800	10.0
1984	Northern Pike x Muskellunge	Fingerling	800	8.0
1983	Northern Pike x Muskellunge	Fingerling	800	9.0
1982	Northern Pike x Muskellunge	Fingerling	800	9.0
1981	Northern Pike x Muskellunge	Fingerling	800	9.0
1980	Northern Pike x Muskellunge	Fingerling	1,600	7.5
1979	Northern Pike x Muskellunge	Fingerling	800	10.0
1978	Northern Pike x Muskellunge	Fingerling	800	9.0
1977	Northern Pike x Muskellunge	Fingerling	800	11.0
1976	Northern Pike x Muskellunge	Fingerling	826	6.0
1975	Northern Pike x Muskellunge	Fingerling	800	13.0
1974	Northern Pike x Muskellunge	Fingerling	828	11.0

Table 3.6-5. Fishing Friends Forever and LGLPRD stocking data of muskellunge for Little Green Lake (2005-2012).

Year	Species	Strain (Stock)	Age Class	# Fish Stocked	Avg Fish Length (in)
2012	Muskellunge	N/A	Large Fingerling	100	N/A
2011	Muskellunge	N/A	Large Fingerling	100	N/A
2007	Muskellunge	N/A	Large Fingerling	100	N/A
2006	Muskellunge	N/A	Large Fingerling	200	N/A
2005	Muskellunge	N/A	Large Fingerling	100	N/A

Table 3.6-6. Fishing Friends Forever and LGLPRD stocking data of northern pike for Little Green Lake (2003-2016).

Year	Species	Strain (Stock)	Age Class	# Fish Stocked	Avg Fish Length (in)
2016	Northern Pike	N/A	N/A	168	13"
2014	Northern Pike	N/A	N/A	65	12"
2010	Northern Pike	N/A	N/A	100	N/A
2008	Northern Pike	N/A	N/A	100	N/A
2006	Northern Pike	N/A	N/A	100	N/A
2005	Northern Pike	N/A	N/A	340	N/A
2004	Northern Pike	N/A	N/A	250	N/A
2003	Northern Pike	N/A	N/A	250	N/A

Table 3.6-7. Fishing Friends Forever and LGLPRD stocking data of walleye for Little Green Lake (2002-2016).

Year	Species	Strain (Stock)	Age Class	# Fish Stocked	Avg Fish Length (in)
2016	Walleye	N/A	N/A	1000	N/A
2015	Walleye	N/A	N/A	1500	5-8"
2015	Walleye	N/A	N/A	900	10-12"
2014	Walleye	N/A	N/A	775	6"
2013	Walleye	N/A	N/A	1500	N/A
2012	Walleye	N/A	N/A	1300	N/A
2011	Walleye	N/A	N/A	1,200 est	N/A
2010	Walleye	N/A	N/A	2,500 est.	N/A
2009	Walleye	N/A	N/A	306	7"
2009	Walleye	N/A	N/A	1360	6"
2009	Walleye	N/A	N/A	1500	N/A
2008	Walleye	N/A	N/A	2450	N/A
2007	Walleye	N/A	N/A	500	N/A
2006	Walleye	N/A	N/A	100	5-8"
2005	Walleye	N/A	N/A	286	11"
2005	Walleye	N/A	N/A	715	6"
2005	Walleye	N/A	N/A	1034	N/A
2004	Walleye	N/A	N/A	3400	N/A
2004	Walleye	N/A	N/A	2223	N/A
2003	Walleye	N/A	N/A	2000	N/A
2002	Walleye	N/A	N/A	875	N/A

Fish Populations and Trends

Utilizing the fish sampling techniques mentioned above and specialized formulas, WDNR fisheries biologists can estimate populations and determine trends of captured fish species. These numbers provide a standardized way to compare fish caught in different sampling years depending on gear used (fyke net or electrofishing). Data is analyzed in many ways by fisheries biologists to better understand the fishery and how it should be managed. Table 3.6-8 includes a summary of fish species and data WDNR fisheries biologists reported after a 2013 survey.

Table 3.6-8. Information reported by Fisheries Biologists after the 2013 fisheries survey on Little Green Lake. *N/A indicates not enough fish were sampled to calculate data.

Fish Species	Fish Sampled	Size Structure	Avg Length (inches)	Growth
Walleye	325	Good	20	N/A
Northern Pike	124	Fair	25.6	N/A
Muskellunge	22	N/A	38	N/A
Largemouth Bass	N/A	Good	12.4	N/A
Bluegills	N/A	Fair	5.5	Slightly Above Average
Yellow Perch	2,706	Poor	6.3	Above Average
Black Crappie	327	N/A	9.5	Slightly Above Average

Fishing Activity

Based on data collected from the property owner survey (Appendix B), fishing was the second most important reason for owning property on or near Little Green Lake (Question #14). Figure 3.6-2 displays the fish that Little Green Lake property owners enjoy catching the most. Approximately 80% of these same respondents believed that the quality of fishing on the lake was either good or fair (Figure 3.6-3). Approximately 70% of property owners who fish Little Green Lake believe panfish fishing has gotten somewhat worse or remained the same (Figure 3.6-4), and approximately 55% believe that the quality of gamefish fishing has remained the same or gotten worse since they have started fishing the lake (Figure 3.6-5).

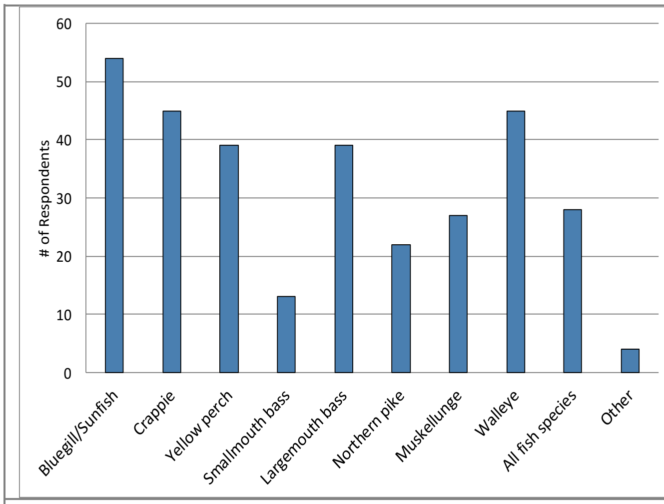


Figure 3.6-2. Property owner survey response Question #7. What species of fish do you like to catch on Little Green Lake?

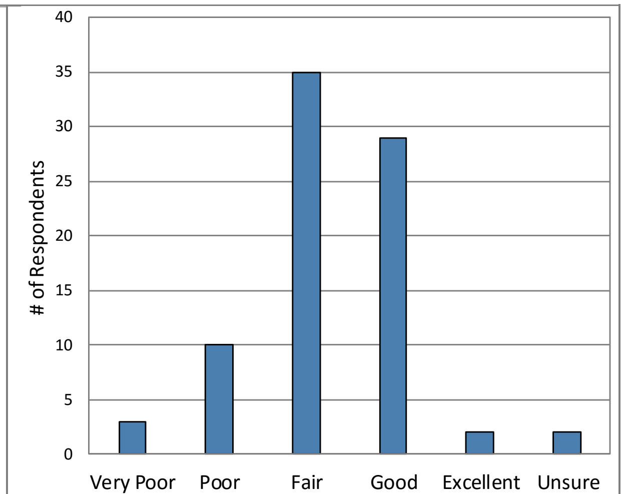


Figure 3.6-3. Property owner survey response Question #8. How would you describe the current quality of fishing on Little Green Lake?

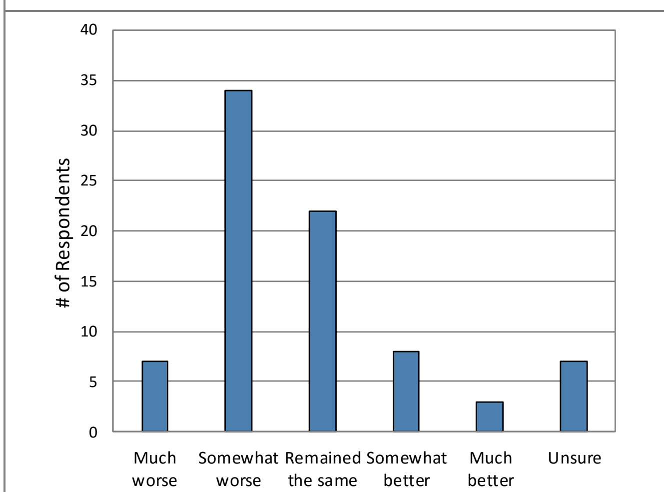


Figure 3.6-4. Property owner survey response Question #9. How was the quality of panfish (i.e. bluegill, crappie, perch) fishing changed on Little Green Lake since you started fishing the lake?

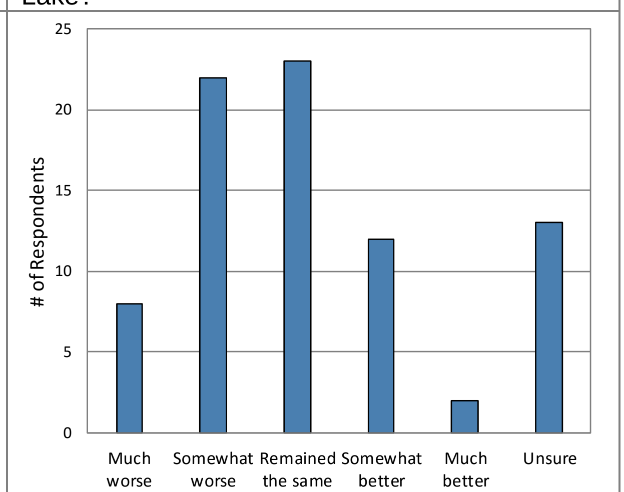


Figure 3.6-5. Property owner survey response Question #10. How was the quality of game fish (i.e. bass, walleye, northern pike, muskellunge) fishing changed on Little Green Lake since you started fishing the lake?

Little Green Lake Fish Habitat

Substrate Composition

Just as forest wildlife requires proper trees and understory growth to flourish, fish require certain substrates and habitat types to nest, spawn, escape predators, and search for prey. Lakes with primarily a silty or soft substrate, many aquatic plants, and coarse woody debris may produce a completely different fishery than lakes that are largely sandy or rocky and contain few aquatic plant species or coarse woody habitat.

Substrate and habitat are critical to fish species that do not provide parental care to their eggs. Northern pike is one species that does not provide parental care to its eggs (Becker 1983). Northern pike broadcast their eggs over woody debris and detritus, which can be found above sand or muck. This organic material suspends the eggs above the substrate, so the eggs are not buried in sediment and suffocate as a result. Walleye are another species that does not provide parental care to its eggs. Walleye preferentially spawn in areas with gravel or rock in places with moving water or wave action, which oxygenates the eggs and prevents them from getting buried in sediment. Fish that provide parental care are less selective of spawning substrates. Species such as bluegill tend to prefer a harder substrate such as rock, gravel or sandy areas if available, but have been found to spawn and care for their eggs in muck as well.

According to the point-intercept survey conducted by Onterra in 2016, 80% of the substrate sampled in the littoral zone of Little Green Lake was soft sediments, 15% was sand with the remaining 5% composed of rock substrate.

Coarse Woody Habitat & Fish Sticks Program

As discussed in the Shoreland Condition Section, the presence of coarse woody habitat is important for many stages of a fish's life cycle, including nesting or spawning, escaping predation as a juvenile, and hunting insects or smaller fish as an adult. Unfortunately, as development has increased on Wisconsin lake shorelines in the past century, this beneficial habitat has often been the first to be removed from the natural shoreland zone. Leaving these shoreland zones barren of coarse woody habitat can lead to decreased abundances and slower growth rates in fish (Sass 2006).

Photograph 3.6-3. Fish Stick Example. (Photo courtesy of WDNR 2014).

The "Fish sticks" program, outlined in the WDNR best practices manual, adds trees to the shoreland zone restoring fish habitat to critical near shore areas. Typically, every site has 3 – 5 trees which are partially or fully submerged in the water and anchored to shore. The WDNR recommends placement of the fish sticks during the winter on ice when possible to prevent adverse impacts on fish spawning or egg incubation periods. The program requires a WDNR permit and can be funded through many different sources including the WDNR, County Land & Water Conservation Departments or partner contributions. These projects are typically conducted on lakes lacking significant coarse woody habitat in the shoreland zone. A fall 2016 survey documented 96 pieces of coarse woody along the shores of

Little Green Lake, resulting in a ratio of approximately 22 pieces per mile of shoreline. Contact the local WDNR fisheries biologist to discuss the applicability of this program as it relates to the fisheries habitat goals for Little Green Lake.

Regulations and Management

Little Green Lake is a highly productive fishery and receives significant fishing pressure. Overall the lake is managed as a bass/panfish fishery with a walleye/muskellunge component and a naturally reproducing northern pike population (personal communication, Dave Bartz). Little Green Lake is on a 5-year sampling rotation with the WDNR and is scheduled for fisheries surveys in 2018 from which population estimates will derive and future management decisions may be influenced by.

Regulations for Little Green Lake gamefish species as of December 2018 are displayed in Table 3.6-9. For specific fishing regulations on all fish species, anglers should visit the WDNR website (*www. http://dnr.wi.gov/topic/fishing/regulations/hookline.html)* or visit their local bait and tackle shop to receive a free fishing pamphlet that contains this information.

Table 3.6-9. WDNR fishing regulations for Little Green Lake (As of May 2018).

Species	Daily bag limit	Length Restrictions	Season
Channel catfish	25, 25 in total, but only 24 if one flathead catfish is	None	Open All Year
Flathead catfish	1	30", but flathead catfish from 36" to 42" may not be kept	May 5, 2018 to Sept. 30, 2018
Panfish	25	None	Open All Year
Largemouth bass and smallmouth bass	5	14"	May 5, 2018 to March 3, 2019
Muskellunge and hybrids	1	40"	May 5, 2018 to December 31, 2018
Northern pike	2	26"	May 5, 2018 to March 3, 2019
Walleye, sauger, and hybrids	5	15"	May 5, 2018 to March 3, 2019
Bullheads	Unlimited	None	Open All Year

Mercury Contamination and Fish Consumption Advisories

Freshwater fish are amongst the healthiest of choices you can make for a home-cooked meal. Unfortunately, fish in some regions of Wisconsin are known to hold levels of contaminants that are harmful to human health when consumed in great abundance. The two most common contaminants are polychlorinated biphenyls (PCBs) and mercury. These contaminants may be found in very small amounts within a single fish, but their concentration may build up in your body over time if you consume many fish. Health concerns linked to these contaminants range from poor balance and problems with memory to more serious conditions such as diabetes or cancer. These contaminants, particularly mercury, may be found naturally to some degree. However, the majority of fish contamination has come from industrial practices such as coal-burning facilities, waste incinerators, paper industry effluent and others. Though environmental regulations have reduced emissions over the past few decades, these contaminants are greatly resistant to breakdown and may persist in the environment for a long time. Fortunately, the human body is able to eliminate contaminants that are consumed however this can take a long time depending upon the type of contaminant, rate of consumption, and overall diet. Therefore, guidelines are set upon the consumption of fish as a means of regulating how much contaminant could be consumed over time.

General fish consumption guidelines for Wisconsin inland waterways are presented in Figure 3.6-6. There is an elevated risk for children as they are in a stage of life where cognitive development is rapidly occurring. As mercury and PCB both locate to and impact the brain, there are greater restrictions on women who may have children or are nursing children, and also for children under 15.

Fish Consumption Guidelines for Most Wisconsin Inland Waterways

	Women of childbearing age, nursing mothers and all children under 15	Women beyond their childbearing years and men
Unrestricted*	-	Bluegill, crappies, yellow perch, sunfish, bullhead and inland trout
1 meal per week	Bluegill, crappies, yellow perch, sunfish, bullhead and inland trout	Walleye, pike, bass, catfish and all other species
1 meal per month	Walleye, pike, bass, catfish and all other species	Muskellunge
Do not eat	Muskellunge	-

**Doctors suggest that eating 1-2 servings per week of low-contaminant fish or shellfish can benefit your health. Little additional benefit is obtained by consuming more than that amount, and you should rarely eat more than 4 servings of fish within a week.*

Figure 3.6-6. Wisconsin statewide safe fish consumption guidelines. Graphic displays consumption guidance for most Wisconsin waterways. Figure adapted from WDNR website graphic (http://dnr.wi.gov/topic/fishing/consumption/)

4.0 SUMMARY AND CONCLUSIONS

The design of this project was intended to fulfill three objectives:

1) Collect baseline data to increase the general understanding of the Little Green Lake ecosystem.
2) Collect detailed information regarding invasive plant species within the lake, with the primary emphasis being on hybrid watermilfoil (HWM) and curly-leaf pondweed (CLP).
3) Collect sociological information from Little Green Lake property owners regarding their use of the lake and their thoughts pertaining to the past and current condition of the lake and its management.

The three objectives were fulfilled during the project and have led to a good understanding of the lake itself, the stakeholders that manage the lake, and what needs to be completed to continue its management.

Little Green Lake is a complicated ecosystem. Like most lakes, especially those in the southern portion of the state, its shorelands and watershed are greatly impacted by humans. The lake is not just impacted by what is occurring in and around it at this time, but also by what has happened in the past several decades. It is the cumulation of these impacts that makes the lake complicated, at least from a management standpoint.

Based upon data collected over the past three decades, the water quality of Little Green Lake would be considered fair to poor. It is currently listed as impaired by the WDNR and US Environmental Protection Agency for several reasons, including eutrophication, degraded habitat, excess algal growth, and elevated pH. These impairments center on the fact that the lake is very productive due to high levels of nutrients in the water. The high nutrient concentrations, primarily phosphorus, fuel high rates of algal growth that lower water clarity. The high nutrients also drive excessive growth of vascular plants within the lake leading to nuisance levels of native and non-native species.

As alluded to above, it is not only phosphorus that comes into the lake from its shoreland properties and watershed on an annual basis that impacts Little Green Lake's current water quality, but even more so, the phosphorus that has entered the lake over the past 100 or more years. About 49% of Little Green Lake's annual phosphorus input to the water column arrives from sources external to the lake, like shoreland properties, its drainage basin, and the atmosphere. The remaining 51% is actually recycled from within the lake through a process called internal phosphorus loading. The phosphorus being recycled again and again may have entered the lake decades earlier. In Little Green Lake, there are three sources that contribute to internal phosphorus loading: 1) anoxic bottom sediments in the lake's deep hole, 2) natural die off of CLP in mid-summer, and 3) release from anoxic sediments under dense vascular plant growth. Studies have not been completed to parse the total load between the three sources, but it is likely that release from deep-water sediments is the primary source, followed by CLP decomposition, and then release from sediments within dense plant beds.

Little Green Lake is polymictic, meaning that throughout the summer the lake goes through periods of stratification that are broken up by frequent mixing events. During stratification, high rates of bacterial decomposition in the deepest layer of water, called the hypolimnion, consume all of the oxygen. Under these anoxic conditions, phosphorus, which is typically bound to iron in the presence of oxygen, is released to the overlaying water. As a result, phosphorus concentrations in the hypolimnion can be 20 times higher than in the upper mixing layer (epilimnion) where algae grow. Some of the hypolimnetic phosphorus is entrained or mobilized to the epilimnion while the lake is still stratified; however, the bulk of the phosphorus is made available to algae during mixing events. This process can happen many times over a summer, acting as a nutrient pump transporting phosphorus out of the sediments and into the water column where it fuels excess algal growth.

In 2003, a destratification system was installed in Little Green Lake with the intent of preventing the lake from stratifying during the growing season. The use of the destratification system would prevent internal loading by keeping the full water column oxygenated. Two studies have been completed by WDNR staff to determine if the destratification system is working to improve water quality in Little Green Lake as intended. The first study compared data prior to the installation of the system with data collected while the system was in operation. The results indicated that the system was reducing but not preventing stratification and internal phosphorus loading was still occurring. The water quality was equally as poor whether the system was in operation or not. At that time, the conclusion was that because the system was not preventing internal loading, its use could be discontinued. However, members of the district felt that the water quality had improved since the system's installation, so it remained in operation.

A second set of data were collected by WDNR staff during the 2013 and 2014 growing seasons. The system was in operation during 2013 but not during 2014. Again, the data indicated that the operation of the destratification system did not prevent internal phosphorus loading as intended. These data were not fully analyzed or reported on until this management planning project.

Additionally, research in Wisconsin and around the world, has increased the understanding of the iron-phosphorus relationship and how insufficient iron in a lake can limit the effect of a destratification system that is operating correctly. Essentially, research completed on Cedar Lake in Polk County (James et al. 2015), indicated that even with a functioning destratification system, if sufficient iron does not exist in the lake, internal nutrient loading will continue and could even be worsened by the operation of the system. Sufficient iron is available in lakes with an iron:phosphorus ratio of 3.6:1 or greater.

The studies completed on Little Green Lake during 2013 and 2014 also included iron concentration analysis, which showed that iron:phosphorus ratios were often below 2.1:1 and at times lower than 1:1. In the end, this means that even with a destratification system that works to keep the lake from stratifying and forming anoxic hypolimnions, Little Green Lake would likely still experience significant internal phosphorus loading. Adding iron to the lake to bring the iron levels to sufficient levels was investigated thoroughly. The cost estimate for an iron treatment is $328,000, not including permits or monitoring. Due to a variety of factors Little Green Lake did not have any navigation or algae issues in 2017. Mechanical harvesting was not performed for the first time in at least seventeen years. For these reasons the LGLPRD has decided not to pursue an iron treatment for at least the next three years. The LGLPRD will monitor the lake conditions from 2018 to 2020. The district will re-evaluate the iron treatment option in 2021. By that time, they will know if a lake-wide CLP treatment will be pursued. Detailed information about this alternative can be found in Appendix G.

A much more commonly utilized technique for reducing internal loading of phosphorus in Wisconsin Lakes, as well as over one hundred lakes around the US, is the addition of alum (aluminum sulfate) directly to the lake. The aluminum bonds with phosphorus in the sediment and that bond remains whether oxic or anoxic conditions exist. If dosed correctly, that alum layer acts as a barrier in the sediment and significantly reduces internal phosphorus loading, typically up to 90%. Alum addition to Little Green Lake would likely be a very good alternative to reduce internal loading of phosphorus from the sediments. During the planning process, an analysis was completed to determine a rough dosing range and cost for an alum treatment on Little Green Lake. Depending on the dose required, which would be determined through sediment analysis, the cost of treating Little Green Lake with alum would range between approximately $214,000 and $430,000, not including permits and additional monitoring. Due to the same reasons related to the iron treatment option, the LGLPRD has decided not to pursue an alum treatment for at least the next three years. The LGLPRD will monitor the lake conditions from 2018 to 2020. The district will re-evaluate the aluminum sulfate treatment option in 2021. By that time, they will know if a lake-wide CLP treatment will be pursued. Detailed information regarding alum use in lakes and its potential use in Little Green Lake can be found in Appendix G.

During the summer of 2017, the five existing destratification tube lines were upgraded and a total of 1000 feet of new ½” tubing with micro-sized holes 1” apart was installed by the district. This project was completed with the intent of improving oxygenation in deeper depths of the lake, as was intended when the original destratification system was installed. As described above, iron levels in Little Green Lake may be too low to allow for sufficient phosphorus binding even if the lake does not stratify; however, the district will be continuing to regularly monitor water quality to determine if the updated system leads to improvements.

Internal loading, as described above, accounts for 51 percent of Little Green Lake’s total phosphorus budget, but external loading of phosphorus is also significant. Over the years, the Green Lake County Land Conservation Department has worked to improve the Little Green Lake watershed by completing numerous projects to reduce soil erosion from agricultural fields and increase the quality of runoff water before it reaches the lake. While all of the projects completed in the watershed likely reduced the amounts of nutrients reaching the lake, one in particular is believed to have made a significant impact. In 2009, Green Lake County created a sedimentation basin in the northern portion of the lake’s watershed (Map 2) and since that time, spring phosphorus concentrations in the lake have been shown to be lower. The LGLPRD has worked closely with the Green Lake County Land Conservation Department for many years and maintains a strong relationship with department staff. The Implementation Plan that follows includes several watershed projects that will be completed in the future.

Overall, one of the primary objectives of the Implementation Plan is to improve the ecological health of the Little Green Lake. This objective is represented in many of the goal and actions within the plan. The district has made changes to the destratification system and will monitor its effectiveness over the next several years. It is important to understand that the destratification system’s purpose is to improve water quality by destratifying the lake and preventing anoxic conditions in the near bottom waters, which would reduce internal phosphorus loading. However, as described above and within Water Quality Section 3.1, due to low iron:phosphorus ratios documented in the lake, even with successful destratification, the lake may not see improved water quality, such as lower phosphorus and chlorophyll-*a* concentrations.

Other options are discussed within this document that would likely reduce internal phosphorus loading in Little Green Lake. If the recent changes to the destratification system do not lead to improved water quality, the LGLPRD will investigate these other options. Again, the overarching goal is to improve the ecological health of Little Green Lake. Improving water quality is one aspect and is the first step. When improved water quality is realized, the lake will likely see natural increases in aquatic plant abundancies and possibly quality shown in increased floristic quality and species diversity. If this does not occur naturally, the district should move to utilize best management practices to increase the plant diversity through controlling exotic species and direct enhancement to the native population through plantings of appropriate native species. Introductions of native floating-leaf and emergent species have been completed many times statewide, so this is a definite possibility. Introduction of native submergent species is not as straight forward; still, the district should move forward with investigating current methods in those introductions.

Little Green Lake had annual aquatic plant point-intercept surveys completed from 2005 to 2016. Several important facts emerged from the analysis of these data. For instance, the general make-up of the plant population has remained much the same over the past 12 years. Many of the same species are present year after year with some fluctuation in total count, but in general, the number of native species is around 8. The native species that are present are tolerant of disturbed conditions and the lack of more sensitive species is an indication of a degraded environment. The number of native species present is considered poor compared to other lakes in the region and state. Species diversity is also considered low and has seen little change over the years.
One concerning trend found in the analysis is that the abundance of aquatic plants in the lake is decreasing. Further, there is a definite, statistically significant decrease in the maximum depth of plant growth throughout the dataset. Looking closer, the occurrence of areas where native species are found is decreasing overall, while the areas containing non-native species, like CLP and HWM are increasing. Over the timeframe of the point-intercept dataset, water clarity did not change, so it is not responsible for the decline. As is discussed in more detail within the Aquatic Plant Section 3.4, the annual use of herbicides in the lake is likely responsible for these trends.

The occurrence of CLP and HWM in the lake are high and at times cause nuisance conditions. The incredibly high biomass of CLP early in the growing season may work to actually stifle the overall growth HWM; however, its natural early die-back near the end of June also likely adds a tremendous amount of phosphorus to the system as that biomass decomposes. That released phosphorus could make up as much as half the annual internal nutrient load, and as discussed earlier, this drives much of the summer algal growth. Unfortunately, the costs to treat CLP on a lake-wide basis for several years in a row is higher than the LGLPRD is able to accept at this time.

The property owner survey conducted in 2016 identified concerns regarding the current sewer system and septic systems. The current sewer system was installed in 2003 for all properties on the south and east sides of the lake from South Kearley Road to the Lakeview Restaurant on Highway 44. The remaining properties on the north and west sides of the lake have private septic systems. Many comments were received regarding the perceived negative impact that current septic systems have on Little Green Lake water quality. There were also many comments about the original expectation that the sewer system was going to be extended to the two remaining areas of the lake. Some property owners feel the monthly costs for the current sewer system customers will go down if the system is extended to the other areas of the lake. Green Lake County requires each septic system to be inspected and pumped at least every three years. The LGLPRD receives a septic system compliance report at least annually from Green Lake County. Modeling completed as a part of this project estimates the amount of phosphorus reaching the lake from the current septic systems as negligible. Extension of the current sewer system to the two remaining areas of the lake is not warranted from a water quality risk standpoint.

The Implementation Plan presented in the next section contains management goals and actions aimed at reducing external nutrient loads, continued monitoring of lake water quality, assuring navigation and other recreational opportunities, and the dissemination of important information to district members. While the plan has not changed radically from what the LGLPRD has been doing over the past decade, the process that led to this plan increased the understanding of Little Green Lake among district members and vetted several possible actions that have been discussed around the lake for several years and could still be pursued in the next 3-4 years.

5.0 IMPLEMENTATION PLAN

The Implementation Plan presented below was created through the collaborative efforts of the Little Green Lake Protection & Rehabilitation District Planning Committee and ecologist/planners from Onterra. It represents the path the LGLPRD will follow in order to meet their lake management goals. The goals detailed within the plan are realistic and based upon the findings of the studies completed in conjunction with this planning project and the needs of the Little Green Lake stakeholders as portrayed by the members of the Planning Committee, the returned property owner surveys, and numerous communications between Planning Committee members and the lake property owners. The Implementation Plan is a living document in that it will be under constant review and adjustment depending on the condition of the lake, the availability of funds, level of volunteer involvement, and the needs of the stakeholders.

Management Goal 1: Improve Current Water Quality Conditions in Little Green Lake

Management Action:	**Monitor water quality through WDNR Citizens Lake Monitoring Network**
Timeframe:	Continuation and enhancement of current effort
Potential Grant:	Small-Scale Lake Planning Grant (2019) for additional water quality sampling
Facilitator:	Mike Ross, Current CLMN Volunteer
Description:	Monitoring water quality is an import aspect of every lake management planning activity. Collection of water quality data at regular intervals aids in the management of the lake by building a database that can be used for long-term trend analysis. Volunteers from the LGLPRD have collected Secchi disk clarities, water chemistry samples, and dissolved oxygen/temperature profiles during this project and in the past through the WDNR Citizen Lake Monitoring Network (CLMN). Stability will be added to the program by recruiting additional volunteers to keep the program fresh and to assure sampling is completed regularly if the current volunteer is unavailable. As described in the main portion of this document, the LGLPRD updated the in-lake portions of the destratification system with the intension of improving the system's ability to mix the lake. As a part of this management action, the district will collect additional water quality information over the next several years to determine if the improvements made to the destratification system, 1) prevent the lake from stratifying during the open water season, and most importantly, 2) improve water quality by reducing internal loading. The additional water quality monitoring should include the following: 1. Creation of dissolved oxygen/temperature profiles at the same multiple locations around the lake at least twice each month. 2. Collection of bottom water samples with a Van Dorn bottle for total phosphorus and total iron analysis.

	3. Addition of total iron analysis from surface samples already collected as a part of the CLMN program. If the water quality, not just oxygen conditions at depth, of Little Green Lake is not documented to improve over the next 3-4 years as a result of the updated destratification system and watershed improvements, a diagnostic/feasibility study should be completed to determine if an alum treatment or amended iron treatment should be completed on Little Green Lake (see Summary and Conclusions Section 4.0).
Action Steps:	
1.	Obtain customer identification number and set up analysis account with Wisconsin State Laboratory of Hygiene (608.224.6203).
2.	Purchase small Van Dorn sampler (http://shop.sciencefirst.com/wildco/student-water-samplers/7883-water-sampler.html) or see if the WDNR has one the district can borrow.
3.	Discuss the possibility and procedure of obtaining a Small-Scale Lake Management Planning Grant to partially fund the additional water quality sampling with the regional lakes coordinator.
4.	Report and discuss data with regional lakes coordinator annually.

Management Action:	**Work with Green Lake County Land Conservation Department to make improvements in Little Green Lake Watershed**
Timeframe:	Continuation and enhancement of current effort
Potential Grant:	Targeted Runoff Management Grants and/or Lake Protection Grants
Facilitator:	Board of Commissioners
Description:	As discussed in the Water Quality Section and the Watershed Section, the LGLPRD has partnered with the Green Lake County Land Conservation Department to complete several watershed improvement projects. As a part of this project, evidence was discovered regarding improved spring total phosphorus values in Little Green Lake that were likely brought on by the installation of a sedimentation basin in 2009. In July 2017, LGLPRD members met with Derek Kavanaugh, Green Lake County Land Conservation Department, to tour the watershed and begin planning watershed projects that would lead to improvements in Little Green Lake's water quality. A follow-up meeting was held on April 5, 2018 (Appendix H). The LGLPRD will work with Mr. Kavanaugh and the Green Lake County Land Conservation Department to create project designs, seek funding sources, and implement improvements in the watershed; including, but not limited to, the following example projects: • Improvements and rehabilitation of retention pond constructed in 2000 • Improvements and rehabilitation of retention pond constructed

	in 2009 • Correction of erosion occurring near culvert located at N3044 East Little Green Road • Investigate and determine feasibility of correcting runoff issues caused by culvert between W2120 and W2114 Melmar Dr. • Investigate possibility of creating a retention pond on vacant property south of Melmar Dr. • Determine the feasibility of resurrecting the retention pond built on the Degner property in 1992 • Investigate the feasibility, potential costs, funding, timing and benefits of improving the significant sediment building up between the road and the lake near N3041 East Little Green Road • Resolve the current water flow issue near N3044 N. Kearley Road • Explore funding opportunities for the various watershed projects • Seek opportunities for watershed farmers to greater utilize agricultural best management practices
Action Steps:	
1.	See project description.

<u>Management Action:</u>	**Continue to improve and monitor the effectiveness of the destratification system**
Timeframe:	Continuation and enhancement of current efforts over the next 3-5 years
Facilitator:	Board of Commissioners
Description:	The LGLPRD feels the operation of the destratification system is warranted to allow more opportunities to monitor its effectiveness and consider more improvement opportunities. The monitoring of the destratification system effectiveness through additional water quality analysis is covered in the first management action under Management Goal 1. During the summer of 2017, the five existing tube lines were upgraded and a total of 1,000 feet of new ½" tubing with micro-sized holes 1" apart was installed by the district. In 2016 a new 3-year lease agreement was approved between the LGLPRD and Fernwood Campground, LLC to continue to operate the existing destratification system pumphouse at its current location through December 31, 2018. In April 2018, the LGLPRD extended the lease agreement terms for two additional years through December 31, 2020. One of the lake treatment options that was analyzed during this lake management planning project was adding alum to the lake to reduce

	the amount of phosphorus that is released from the sediment during internal loading. If an alum treatment is conducted on Little Green Lake in the future the destratification system operation would need to be permanently stopped because it would no longer be needed. If an iron nitrate treatment is conducted on Little Green Lake in the future the destratification system operation would need to be continued indefinitely.
Action Steps:	
1.	Evaluate additional improvements to the destratification system.
2.	Review and analyze the results of expanded water quality testing.
3.	Determine if operation of the destratification system beyond 2020 is warranted. If operation beyond 2020 is implemented, the LGLPRD would need to explore options for longer term operation that include another lease agreement extension or constructing a new building on LGLPRD property for the destratification system.

Management Goal 2: Assure Navigation and other Recreational Opportunities on Little Green Lake

Management Action:	**Utilize mechanical harvesting to provide riparian access to open water areas of Little Green Lake**
Timeframe:	Continuation of current effort with updated harvesting map
Potential Grant:	Not applicable
Facilitator:	Board of Commissioners
Description:	The LGLPRD understands the importance of native aquatic vegetation within Little Green Lake. However, nuisance aquatic plant conditions exist in certain parts of the lake, caused aquatic invasive species (CLP and EWM/HWM) and loosely-rooted native vegetation (coontail, common waterweed, southern naiad). The LGLPRD supports the reasonable and environmentally sound actions to facilitate navigability on Little Green Lake. These actions target nuisance levels of aquatic plants in order to benefit watercraft navigation patterns. Reasonable and environmentally sound actions are those that meet WDNR regulatory and permitting requirements and do not impact anymore shoreland or lake surface area than necessary. The WDNR oversees the management of aquatic plants on inland lakes. The manual cutting and raking of native aquatic plant species within a 30-foot-wide area containing a pier, boatlift, or swim raft is exempt from a state permit provided that the cut plants are removed from the lake. However, the use of mechanized or mechanical devices requires a WDNR permit. Current management of nuisance levels of aquatic plants occurs on portions of the lake using two district-owned mechanical harvesters and beginning on June 1. Map 7 contains the 23.2 acres of Little Green Lake that will be harvested during the growing season under the WDNR permit.
Action Steps:	
1.	A new 5-year WDNR permit for mechanical harvesting with the updated harvesting map will be needed in early 2019.

Management Action:	**Conduct nuisance plant treatments using herbicides on an as-needed basis in common use areas of Little Green Lake**
Timeframe:	Continuation of current effort with updated dosing strategy
Potential Grant:	Not applicable
Facilitator:	Board of Commissioners

<table>
<tr><td align="right">Description:</td><td colspan="2">As described in the Sections 3.4 and 3.5, Little Green Lake supports nuisance levels of native and non-native aquatic plants that interfere with recreational use, including boating, swimming, and fishing. The LGLPRD utilizes limited herbicide spot treatments to relieve the nuisance brought on by these plants. The treatment areas are created by the LGLPRD's consultant each spring based upon the results of a pretreatment inspection. Once the treatment areas are created, the consultant applies for a chemical treatment permit through the WDNR.

In 2017, several areas of the lake totaling approximately 46.3 acres were treated utilizing an updated dosing strategy. A portion of that treatment, as described in the main document, was to simulate a whole-lake treatment of CLP in Kearley Bay. In 2018, 34.1 acres were treated, which did not include the experimental treatment of the entire Kearley Bay. Approximately 34 acres were also treated in 2016. The new strategy, based upon treatment area acreage, is detailed below and would be utilized in the future based upon continued success. It is expected that the total area treated in any year would be less than 35 acres. If the proposed area exceeds 35 acres, the treatment plan will be closely scrutinized by the district and the WDNR.

Treatment Areas ≥ 5 acres: 4.0 ppm ae 2,4-D / 1.5 ppm ai Endothall
Treatment Areas < 5 acres: Diquat at maximum label rate

Curly-leaf pondweed is the primary target of this control strategy in most years. The greatest benefit to the lake in terms of reduced phosphorus input from decay and longevity of nuisance relief is realized with the treatments are completed before the curly-leaf pondweed's biomass is high, such as before turion production. Therefore, these treatments will be completed early in the season, likely in May.

If treatment results are not acceptable to the LGLPRD and WDNR, the LGLPRD will seek advice on a new dosing strategy.</td></tr>
<tr><td align="right">Action Steps:</td><td colspan="2"></td></tr>
<tr><td align="right" colspan="1">1.</td><td colspan="2">Continue annual herbicide treatments in 2018 to 2020. A WDNR permit is required each year.</td></tr>
<tr><td align="right" colspan="1">2.</td><td colspan="2">Reevaluate the lake-wide CLP control option in 2020 and determine suitable funding options.</td></tr>
</table>

Management Action:	**Establish a program for aquatic invasive species (AIS) prevention**
Timeframe:	Initiate in 2018
Facilitator:	Board of Commissioners
Description:	The LGLPRD has been monitoring AIS for many years. Their primary focus over the years has been on CLP and HWM. There are new AIS threats to Wisconsin lakes every year. It is important to increase the knowledge and awareness of property owners and other users of Little Green Lake about the threats and risks of AIS. There are many programs and actions that can be pursued by the LGLPRD to improve AIS prevention and control. Assistance can be sought from several organizations including WDNR, Golden Sands Resource Conservation and Development Council, Wisconsin Lakes, Green Lake County, and the Clean Boats Clean Waters Program. Typical AIS prevention activities include boat launch signage, articles on specific AIS threats (e.g. zebra mussels, purple loosestrife, etc.), education events, tool boards, and the Clean Boats Clean Waters Program.
Action Steps:	
1.	Create an AIS Prevention and Containment Strategy/Plan, including the use of purple loosestrife and pale-yellow iris information provided by WDNR
2.	Raise awareness about the threats and risks of AIS for Little Green Lake
3.	Investigate educational and project funding opportunities through WDNR and Clean Boats Clean Waters Program.

Management Action:	**Conduct nuisance plant treatments around piers using herbicides on an as-needed basis.**
Timeframe:	Continuation of current effort
Potential Grant:	Not applicable
Facilitator:	Board of Commissioners
Description:	As described in the Sections 3.4 and 3.5, Little Green Lake supports nuisance levels of native and non-native aquatic plants that interfere with recreational use, including boating, swimming, and fishing. The LGLPRD utilizes limited herbicide spot treatments under and around piers to relieve the nuisance brought on by these plants. The treatment and permit costs are split among the property owners requesting the treatments and the permit is sponsored by the district. Only areas with nuisance levels that hinder navigation to a significant level will be treated. The existence of aquatic plants in the area

		would not be considered reason to complete a treatment. Pier area spraying was not implemented in 2017 due to the lack of navigation issues and the high cost estimates. Pier area treatment costs have risen from $35/pier in 2016 to estimated costs in 2017 and 2018 of $100 - $150/pier depending on the number of piers treated. Most property owners are not willing to pay the higher costs.
Action Steps:		
	1.	Continue to pursue lower cost solutions for pier area treatments.
	2.	Property owners will rely on hand raking to remove excess nuisance plants when herbicide treatments are not utilized.

Management Action:	**Coordinate periodic aquatic vegetation monitoring**
Timeframe:	Point-Intercept Survey every 3-5 years, Community Mapping Survey every 6-10 years
Potential Grant	Lake Management Planning Grant or AIS-Education, Prevention, & Planning Grant
Facilitator:	Board of Commissioners
Description:	A whole-lake point-intercept survey should be conducted on Little Green Lake at a minimum of once every 3-5 years. This will allow an understanding of the submergent aquatic plant community dynamics within Little Green Lake. In order to understand the dynamics of the emergent and floating-leaf aquatic plant communities in Little Green Lake, a community mapping survey would be conducted every 6-10 years. A community mapping survey has only been conducted during 2016 on Little Green Lake.
Action Steps:	
	See description above.

Management Goal 3: **Increase LGLPRD's Capacity to Communicate with Lake Property Owners and Facilitate Partnerships with Other Management Entities**

Management Action:	**Use education and communications to promote lake protection and enjoyment with property owners**
Timeframe:	Continuation of current efforts
Facilitator:	Board of Commissioners – establish an Education & Communications Committee
Description:	Education represents an effective tool to address many lake issues. Many lake organizations use periodic newsletter mailings, a website, social media, and meetings to convey information. These mediums allow for exceptional communication with district members. This level of communication is important within a management group because it facilitates the spread of important district news, educational topics, and even social happenings. Respondents to the LGLPRD's property owner survey indicated they were *fairly well informed* but not *highly informed* (Question #27, Appendix B). LGLPRD will give consideration to forming an Education & Communication Committee to connect with stakeholders and establish educational initiatives such as the following: o Aquatic invasive species identification o Basic lake ecology o Boating safety (promote existing guidelines) o Shoreline habitat restoration and protection o Fishing regulations One of the district officers would be a liaison to the committee and assure that it would continue as committee members changed. The committee would also be in charge of creating and disbursing the district newsletter and maintaining and improving the district website.
Action Steps:	
	See description above.

Management Action:	**Continue LGLPRD involvement with other entities that have responsibilities in managing Little Green Lake**
Timeframe:	Continuation of current efforts
Facilitator:	Board of Commissioners
Description:	The waters of Wisconsin belong to everyone and therefore this goal of protecting and enhancing these shared resources is also held by other entities. Some of these entities are governmental while others organizations rely on voluntary participation. It is important that the LGLPRD actively engage with all management entities to enhance the district's understanding of common management goals and to participate in the development of those goals. This also helps all management entities understand the actions that others are taking to reduce the duplication of efforts. Each entity will be specifically addressed in the table on the table below:
Action Steps:	
	See table guidelines below.

Partner	Contact Person	Role	Contact Frequency	Contact Basis
Wisconsin Department of Natural Resources	Fisheries Biologist (David Bartz – 920.787.3016)	Manages the fishery of Little Green Lake.	Once a year, or more as issues arise.	Stocking activities, scheduled surveys, survey results, volunteer opportunities for improving fishery.
	Water Resources Management Specialist (Ted Johnson – 920.424.2104)	Oversees management plans, permits, grants, all lake activities.	Once a year, or more as necessary.	Information on updating lake management plans, submitting grants/permits or to seek advice on other lake issues.
	Conservation Warden (John Schreiber – 920.369.6028)	Oversees regulations handed down by the state.	As needed. May contact WDNR Tip Line (1.800.847.9367) as needed also.	Suspected violations pertaining to recreational activity, including fishing, boating safety, ordinance violations, etc.
	Gina Laliberte (608.515.9219)	Statewide Coordinator for Blue-Green Algae	As needed.	Contact whenever a blue-green algae outbreak is suspected, or information is needed.
	Eric Evensen (920.303.5447)	Watershed Management Specialist	As needed.	Contact whenever a manure or other runoff issue is present
	Spill Hotline (800.943.0003)	Statewide hotline for any type of spill.	Only when a spill is imminent or has occurred.	Contact regarding a manure runoff issue that threatens LGL
Green Lake County	Soil Conservationist (Derek Kavanaugh – 920.294.4057)	Provide technical assistance and education.	Twice a year or more as issues arise.	Contact to report new occurrences of AIS or to seek advice on watershed and other lake issues.
	Land Use Planning & Zoning (Matt Kirkman – 920.294.4175)	Director of Land Use Planning & Zoning Dept.	Once a year or more as needed.	Contact for assistance and guidance on land use planning and zoning topics.
	Heath Department (Kathy Munsey – 920.294.4070)	County Health Officer	Once a year or more as needed.	Contact for assistance and guidance related to any suspected blue-green algae outbreaks.
Golden Sands RC&D	AIS Coordinator (Anna Cisar – 715.343.6215)	Facilitates education on AIS.	As needed	Provides AIS education, ID, and training. Contact to report new occurrences of AIS.
Fishing Friends Forever	P.O. Box 224 Markesan, WI 53946 (John Vandebrink – 920.229.5448)	Assist with fish stocking.	As needed	Additional stocking activities
City of Markesan	Clerk (Betsy Amend -920.398.3031)	Supports LGLPRD.	As needed.	Contact regarding projects such as CBCW, Soldier and Sailors Park rental, etc.
	Martin Hansen (920.398.3031)	Property Supervisor	Once a year or more as needed.	Contact regarding blue-green algae & swimming beach issues
Town of Green Lake	Dominic Machkovich – 920.229.0874	Township road maintenance and improvements	Once a year or more as needed.	Contact regarding road, culvert, and water drainage issues.

UW-Extension	Program Coordinator (Erin McFarlane – 715.346.4978)	Clean Boats Clean Waters Program	As needed.	May be contacted to set up CBCW training sessions, report data, etc.
Wisconsin Lakes	General staff (800.542.5253)	Facilitates education, networking and assistance on lake issues.	As needed. May check website (www.wisconsinlakes.org) often for updates.	May attend WL's annual conference to keep up-to-date on lake issues. WL reps can assist on grant issues, training, habitat enhancement techniques, etc.
State of Wisconsin	Joan Ballweg – 608.266.8077	State Representative – 41st District	Once a year or more as needed.	Invite to LGLPRD annual meeting, contact regarding state-level issues.

Management Goal 4: Improve Lake and Fishery Resources by Protecting and Restoring Little Green Lake Shoreland Conditions

Management Action:	**Educate property owners on the importance of shoreland condition and shoreland restoration on Little Green Lake**
Timeframe:	Initiate 2019
Facilitator:	Board of Commissioners
Description:	As discussed in the Shoreland Condition Section (3.3), the shoreland zone of a lake is highly important to the ecology of a lake. When shorelands are developed, the resulting impacts on a lake range from a loss of biological diversity to impaired water quality. Because of its proximity to the waters of the lake, even small disturbances to a natural shoreland area can produce ill effects. Over 60% of Little Green Lake's shoreline is considered completely urbanized or developed-unnatural. This severely limits shoreland habitat, but it also reduces natural buffering of shoreland runoff and allows nutrients to enter the lake. Because property owners may have little experience with or be uncertain about restoring a shoreland to its natural state, the LGLPRD has decided to take the following steps to increase shoreland restoration on Little Green Lake: 1. Educate property owners about the importance of healthy and natural shorelands. 2. Solicit 1-3 property owners to allow shoreland restoration and storm water runoff designs for their property. This would include the possible restoration of shorelands under public ownership. 3. The LGLPRD work with Green Lake County (Derek Kavanaugh) or private entity to create design work. Small-scale WDNR grants may be sought to offset design costs. 4. Designs can be shared with LGLPRD members to provide further education of shoreland restoration projects. 5. Move forward with implementing shoreland restoration per the designs that were developed for those riparians that wish to. Project funding would be available through the WDNR's Healthy Lakes Initiative Grants (see below). 6. The LGLPRD's goal would be to have at least 2 shoreland restoration sites to serve as demonstrations sites to encourage other riparians to follow same path of shoreland restoration. The WDNR's Healthy Lakes Initiative Grant program allows

	partial cost coverage for native plantings in transition areas. This reimbursable grant program is intended for relatively straightforward and simple projects. More advanced projects that require advanced engineering design may seek alternative funding opportunities, such as Lake Protection Grants or potentially through Green Lake County. • 75% state share grant with maximum award of $25,000; up to 10% state share for technical assistance • Maximum of $1,000 per 350 ft^2 of native plantings (best practice cap) • Implemented according to approved technical requirements (WDNR, County, Municipal, etc.) and complies with local shoreland zoning ordinances • Must be at least 350 ft^2 of contiguous lakeshore; 10 feet wide • Landowner must sign Conservation Commitment pledge to leave project in place and provide continued maintenance for 10 years • Additional funding opportunities for water diversion projects and rain gardens (maximum of $1,000 per practice) also available
Action Steps:	
1.	Recruit facilitator from Planning Committee or Board of Commissioners
2.	Facilitator contacts Green Lake County Land Conservation Department to gather information on initiating and conducting shoreland restoration projects. If able, the County Conservationist would be asked to speak to LGLPRD members about shoreland restoration at their annual meeting.
3.	The LGLPRD would encourage property owners that have restored their shorelines to serve as demonstration sites.

<u>Management Action:</u>	**Coordinate with WDNR and private landowners to expand coarse woody habitat in Little Green Lake**
Timeframe:	Initiate 2019
Facilitator:	Board of Commissioners
Description:	LGLPRD stakeholders must realize the complexities and capabilities of the Little Green Lake ecosystem with respect to the fishery it can produce. With this, an opportunity for education and habitat enhancement is present in order to help the ecosystem reach its maximum fishery potential. Often, property owners will remove downed trees, stumps, etc. from a shoreland area because these items may impede watercraft navigation shore-fishing or swimming. However, these naturally occurring woody pieces serve as crucial habitat for a variety of aquatic organisms, particularly

	fish. The Shoreland Condition Section (3.3) and Fisheries Data Integration Section (3.6) discuss the benefits of coarse woody habitat in detail. The WDNR's Healthy Lakes Initiative Grant allows partial cost coverage for coarse woody habitat improvements (referred to as "fish sticks"). This reimbursement grant program is described in the second Management Action of Management Goal 1.
Action Steps:	
1.	Recruit facilitator from Planning Committee or Board of Commissioners (potentially same facilitator as previous management actions).
2.	Facilitator contacts Ted Johnson (WDNR Lakes Coordinator) and Dave Bartz (WDNR Fisheries Biologist) to gather information on initiating and conducting coarse woody habitat projects.
3.	The LGLPRD will encourage property owners that have enhanced coarse woody habitat to serve as demonstration sites.

6.0 METHODS

Lake Water Quality

Baseline water quality conditions were studied to assist in identifying potential water quality problems in Little Green Lake (e.g., elevated phosphorus levels, anaerobic conditions, etc.). Water quality was monitored at the deepest point on the lake that would most accurately depict the conditions of the lake (Map 1). Samples were collected using WDNR Citizen Lake Monitoring Network (CLMN) protocols which occurred twice during the summer. In addition to the samples collected by LGLPRD members, professional water quality samples were collected at subsurface (S) and near bottom (B) depths once in spring, summer, fall and winter. Winter dissolved oxygen was determined with a calibrated probe and all samples were collected with a 3-liter Van Dorn bottle. Secchi disk transparency was also included during each visit.

All samples that required laboratory analysis were processed through the Wisconsin State Laboratory of Hygiene (SLOH). The parameters measured, sample collection timing, and designated collector are contained in the table below.

	Spring		**June**	**July**		**August**	**Fall**		**Winter**	
Parameter	**S**	**B**	**S**	**S**	**B**	**S**	**S**	**B**	**S**	**B**
Total Phosphorus	■	■	♦	■	■	♦	■	■	■	■
Dissolved Phosphorus	■	■							■	■
Chlorophyll-*a*	■		♦	■		♦	■			
Total Nitrogen	■	■	●	■		●			■	■
True Color	■			■						
Laboratory Conductivity	■	■		■	■					
Laboratory pH	■	■		■	■					
Total Alkalinity	■	■		■	■					
Hardness	■									
Total Suspended Solids	■	■					■	■		
Calcium	■									

♦ indicates samples collected as a part of the Citizen Lake Monitoring Network.
● indicates samples collected by volunteers under proposed project.
■ indicates samples collected by consultant under proposed project.

Watershed Analysis

The watershed analysis began with an accurate delineation of Little Green Lake's drainage area using U.S.G.S. topographic survey maps and base GIS data from the WDNR. The watershed delineation was then transferred to a Geographic Information System (GIS). These data, along with land cover data from the National Land Cover Database (NLCD – Fry et. al 2011) were then combined to determine the watershed land cover classifications. These data were modeled using the WDNR's Wisconsin Lake Modeling Suite (WiLMS) (Panuska and Kreider 2003)

Aquatic Vegetation

Curly-leaf Pondweed Survey

Surveys of curly-leaf pondweed were completed on Little Green Lake during a May 26, 2016 field visit, in order to correspond with the anticipated peak growth of the plant. Visual inspections were completed throughout the lake by completing a meander survey by boat.

Comprehensive Macrophyte Surveys

Comprehensive surveys of aquatic macrophytes were conducted on Little Green Lake to characterize the existing communities within the lake and include inventories of emergent, submergent, and floating-leaved aquatic plants within them. The point-intercept method as described in the Wisconsin Department of Natural Resource document, Recommended Baseline Monitoring of Aquatic Plants in Wisconsin: Sampling Design, Field and Laboratory Procedures, Data Entry, and Analysis, and Applications (WDNR PUB-SS-1068 2010) was used to complete this study on July 12, 2016. A point spacing of 70 meters was used resulting in approximately 377 points.

Community Mapping

During the species inventory work, the aquatic vegetation community types within Little Green Lake (emergent and floating-leaved vegetation) were mapped using a Trimble GeoXT Global Positioning System (GPS) with sub-meter accuracy. Furthermore, all species found during the point-intercept surveys and the community mapping surveys were recorded to provide a complete species list for the lake.

Representatives of all plant species located during the point-intercept and community mapping survey were collected and vouchered for the University of Wisconsin – Steven's Point Herbarium.

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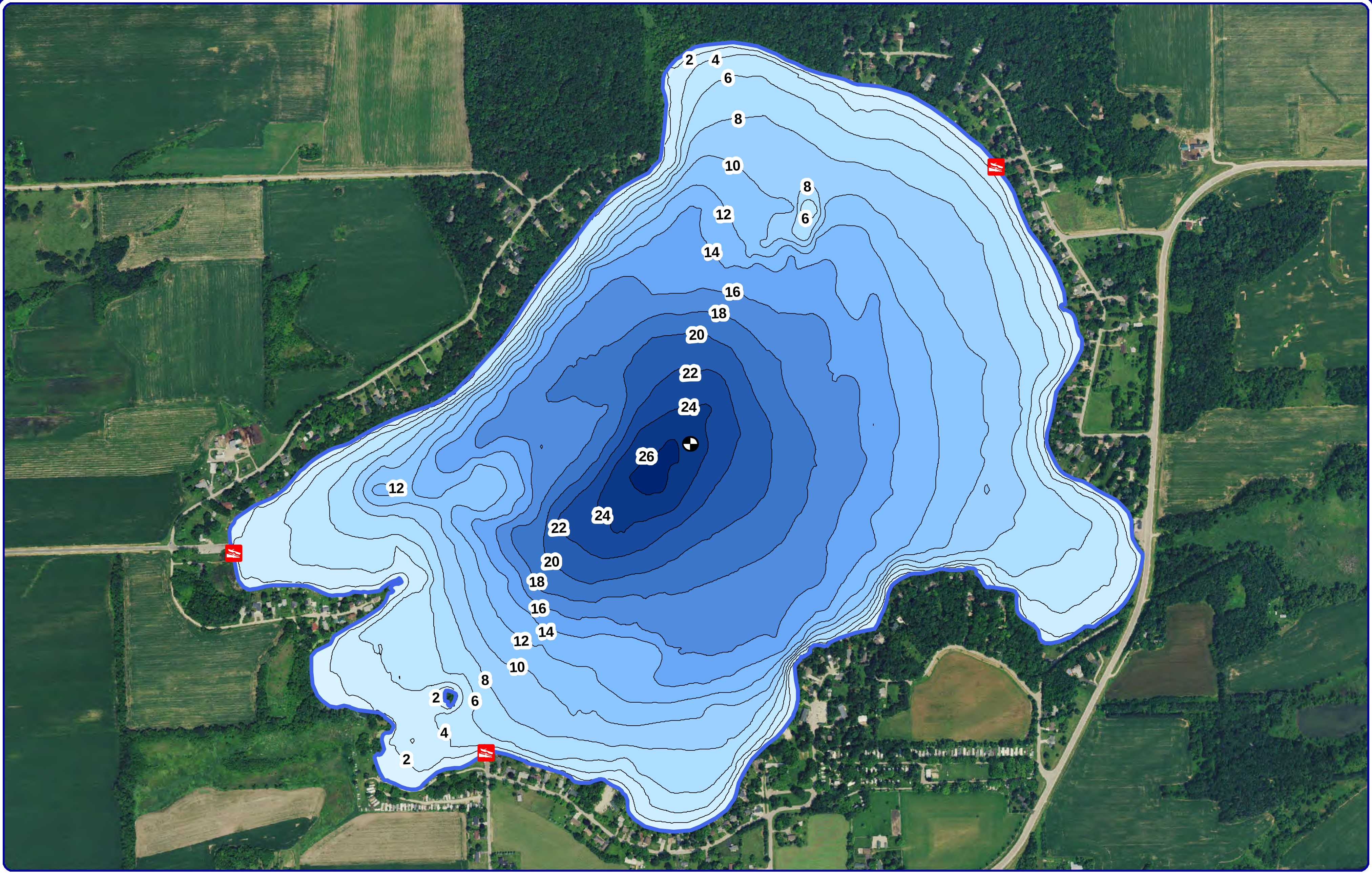
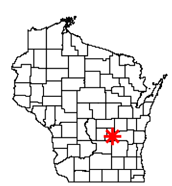


900
Feet

Onterra, LLC
Lake Management Planning
815 Prosper Road
De Pere, WI 54115
920.338.8860
www.onterra-eco.com

Sources:
Hydro: WDNR
Orthophotography: NAIP, 2015
Bathymetry: Onterra, 2016
Map Date: March 31, 2017
Filename: LittleGreen_Location.mxd



Project Location in Wisconsin

Legend

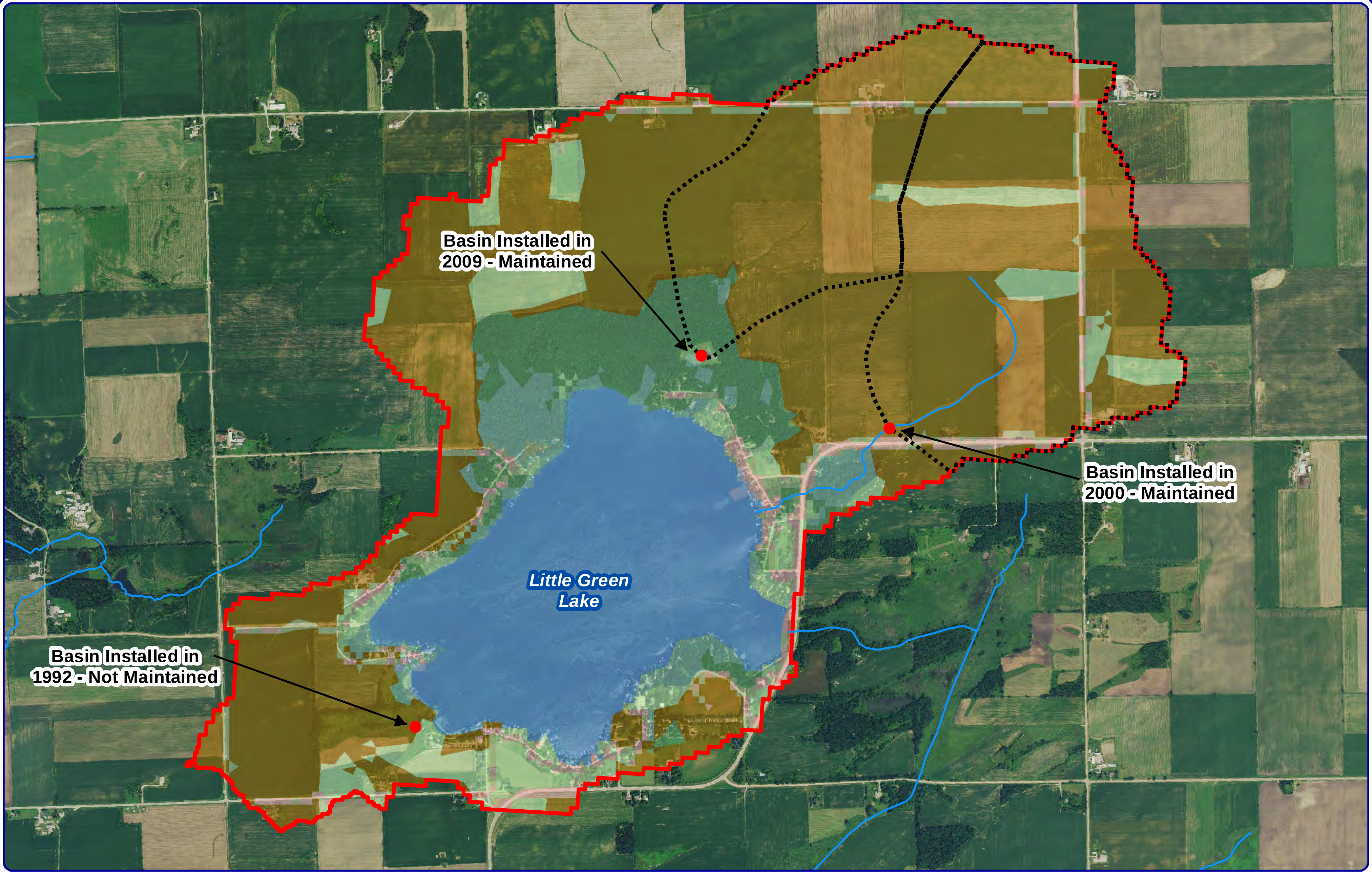
Little Green Lake ~462 acres
WDNR Definition

Public Access

Water Quality Sampling Location

Map 1
Little Green Lake
Green Lake County, Wisconsin

Project Location & Lake Boundaries



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Feet

Onterra, LLC
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Sources:
Hydro: WDNR
Bathymetry: Onterra 2016
Orthophotography: NAIP 2015
Land Cover: NLCD 2011
Watershed Boundaries: Onterra 2016
Map Date: January 18, 2017
Filename: LittleGreen_Watershed.mxd

Project Location in Wisconsin

Legend

Land Cover Types

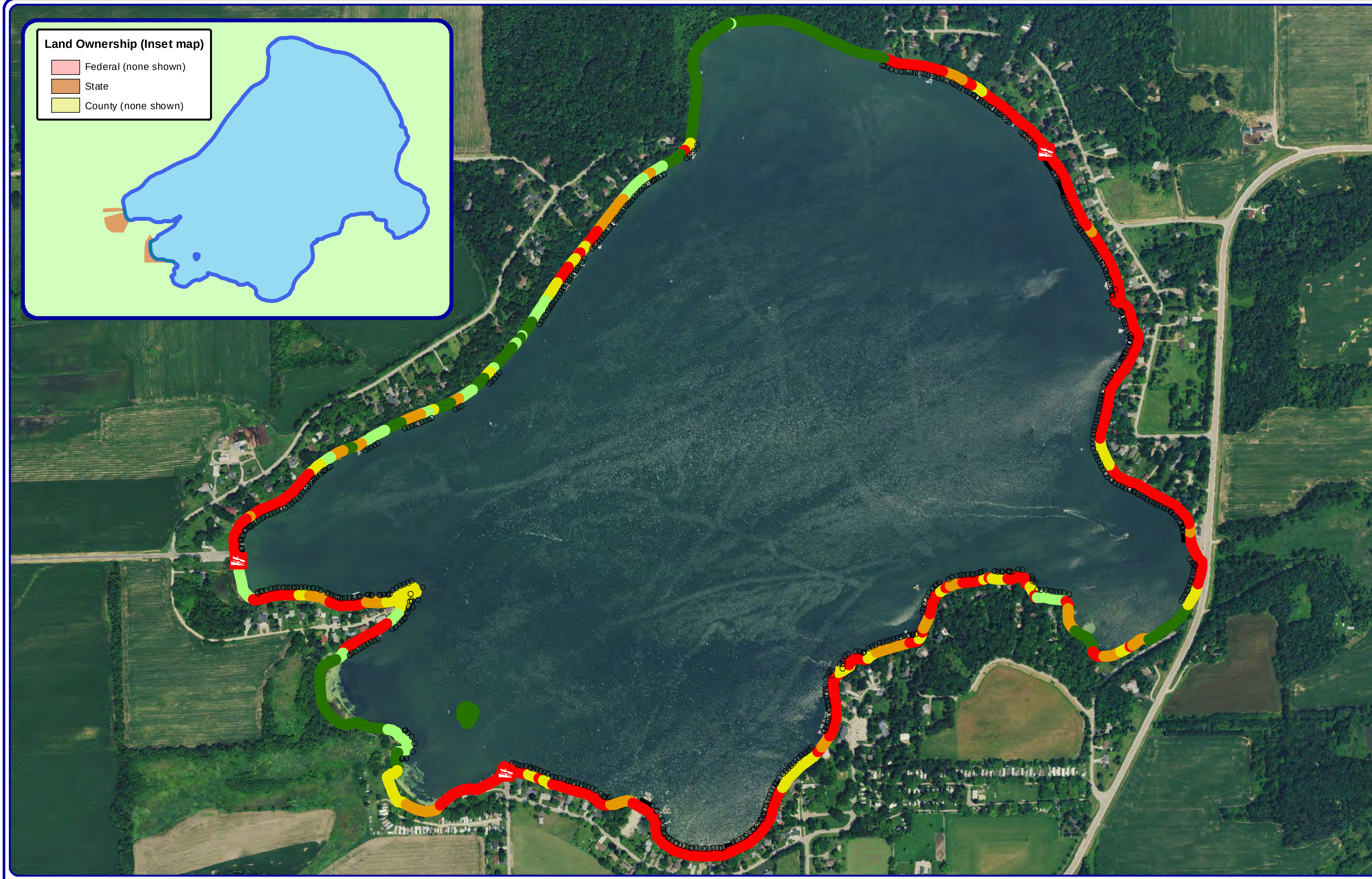
- Forest
- Forested Wetlands
- Wetlands
- Open Water
- Rural Open Space
- Pasture/Grass
- Row Crops
- Rural Residential
- Medium Density Urban

- Little Green Lake Watershed Boundary
- Sedimentation Basin Watershed Boundary
- Sedimentation Basin
- River/Stream

Map 2

Little Green Lake
Green Lake County, Wisconsin

Watershed & Land Cover Types



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920.338.8860
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Sources:
Hydro: WDNR
Orthophotography: NAIP, 2015
Shoreline Assessment: Onterra, 2016
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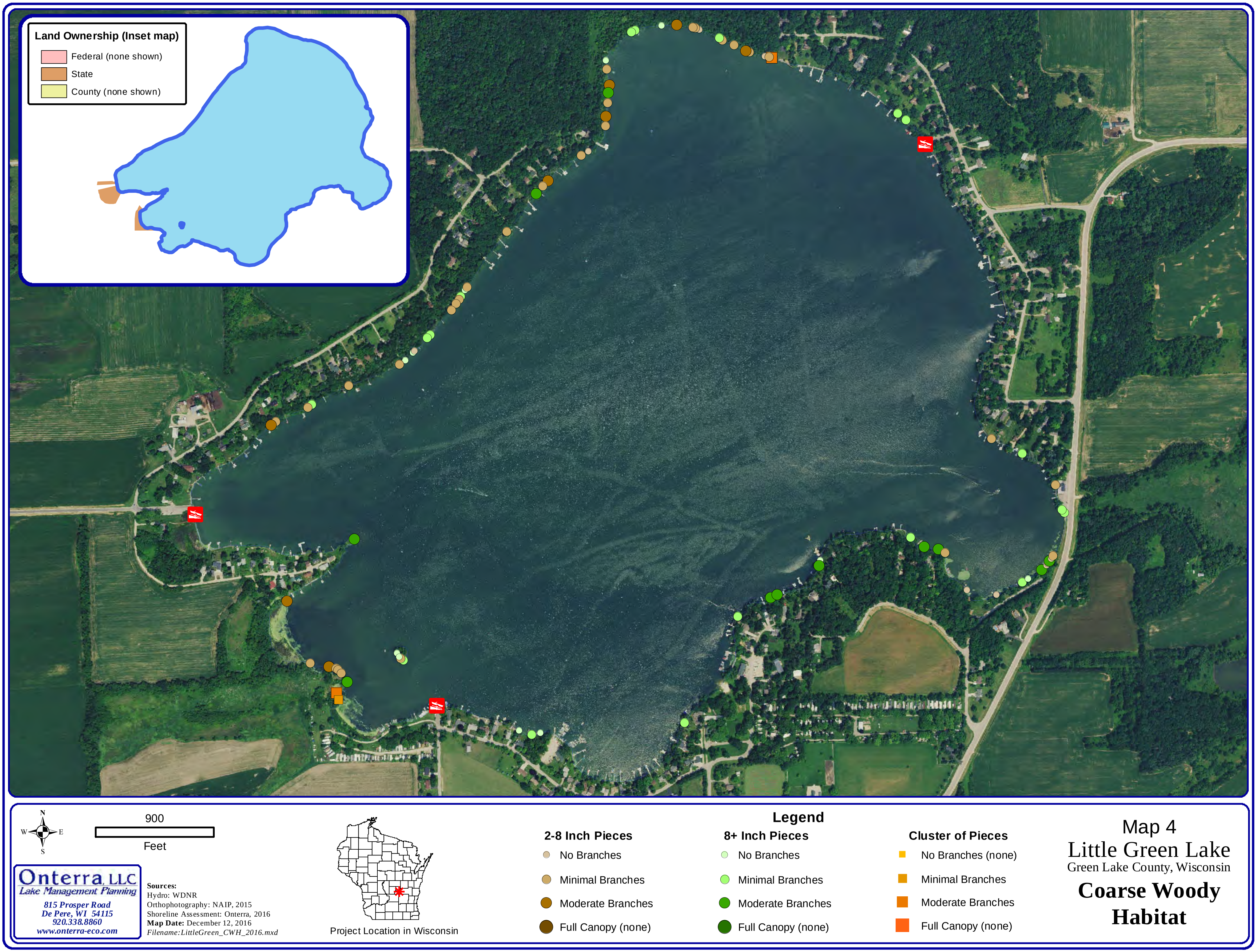
Map 3
Little Green Lake
Green Lake County, Wisconsin
2016 Shoreland Condition



Land Ownership (Inset map)
Federal (none shown)
State
County (none shown)
N
W
E
S
900
Feet
Onterra, LLC
Lake Management Planning
815 Prosper Road
De Pere, WI 54115
920.338.8860
www.onterra-eco.com
Sources:
Hydro: WDNR
Orthophotography: NAIP, 2015
Shoreline Assessment: Onterra, 2016
Map Date: December 12, 2016
Filename: LittleGreen_CWH_2016.mxd
Project Location in Wisconsin
Legend
2-8 Inch Pieces
No Branches
Minimal Branches
Moderate Branches
Full Canopy (none)
8+ Inch Pieces
No Branches
Minimal Branches
Moderate Branches
Full Canopy (none)
Cluster of Pieces
No Branches (none)
Minimal Branches
Moderate Branches
Full Canopy (none)
Map 4
Little Green Lake
Green Lake County, Wisconsin
Coarse Woody Habitat

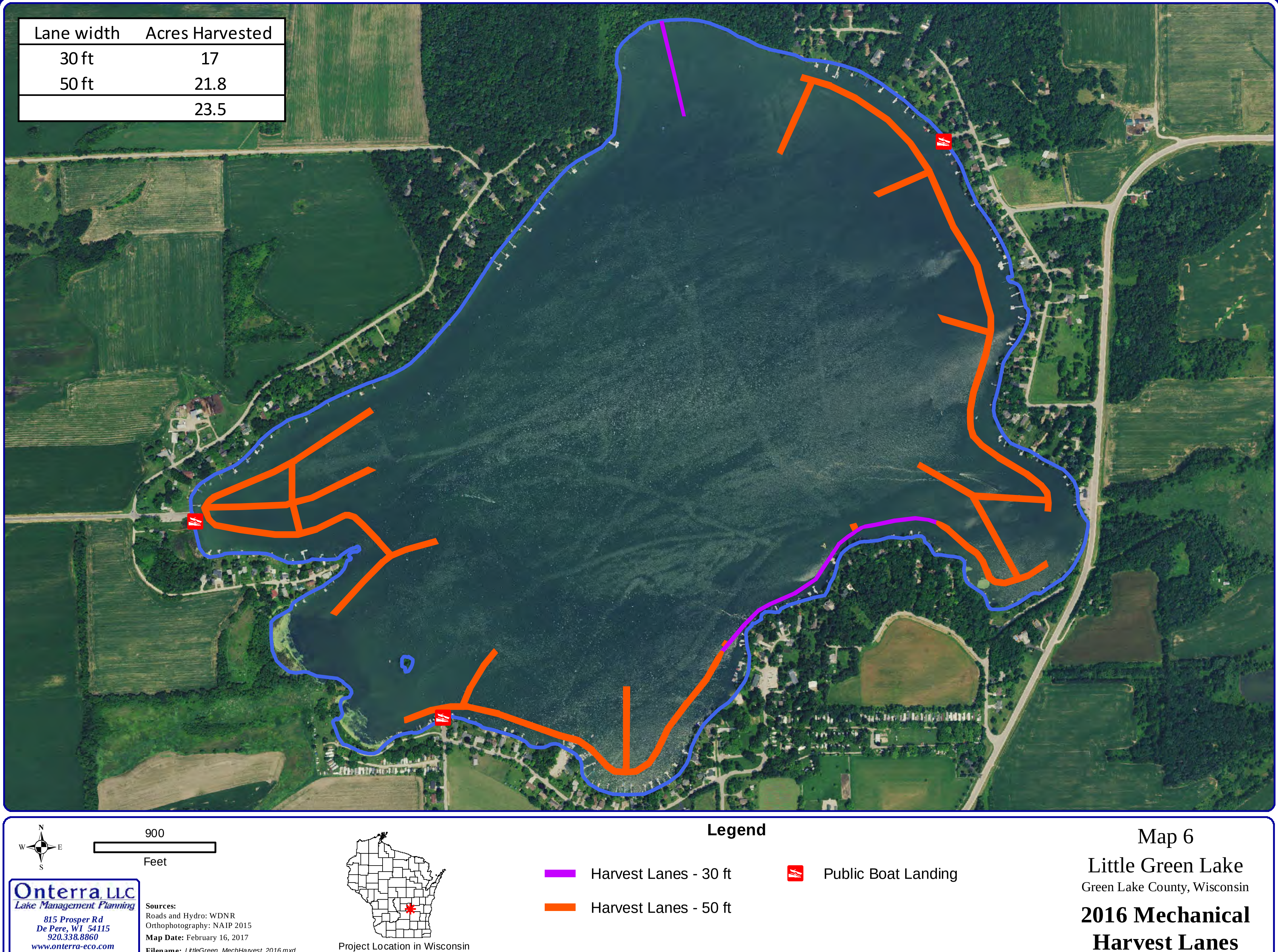
Sources:
Aquatic Plants: Onterra, 2016
Orthophotography: NAIP, 2015
Map Date: October 28, 2016
Filename: LittleGreen_Comm_2016.mxd

Legend

Small Plant Communities
- Emergent
- Floating-leaf
- Mixed Floating-leaf & Emergent

Large Plant Communities
- Emergent
- Floating-leaf
- Mixed Floating-leaf & Emergent

Map 5
Little Green Lake
Green Lake County, Wisconsin
Aquatic Plant Communities



Lane width	Acres Harvested
30 ft	17
50 ft	21.8
	23.5

Map 6
Little Green Lake
Green Lake County, Wisconsin

2016 Mechanical Harvest Lanes

Onterra, LLC
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815 Prosper Rd
De Pere, WI 54115
920.338.8860
www.onterra-eco.com

Sources:
Roads and Hydro: WDNR
Orthophotography: NAIP 2015
Map Date: February 16, 2017
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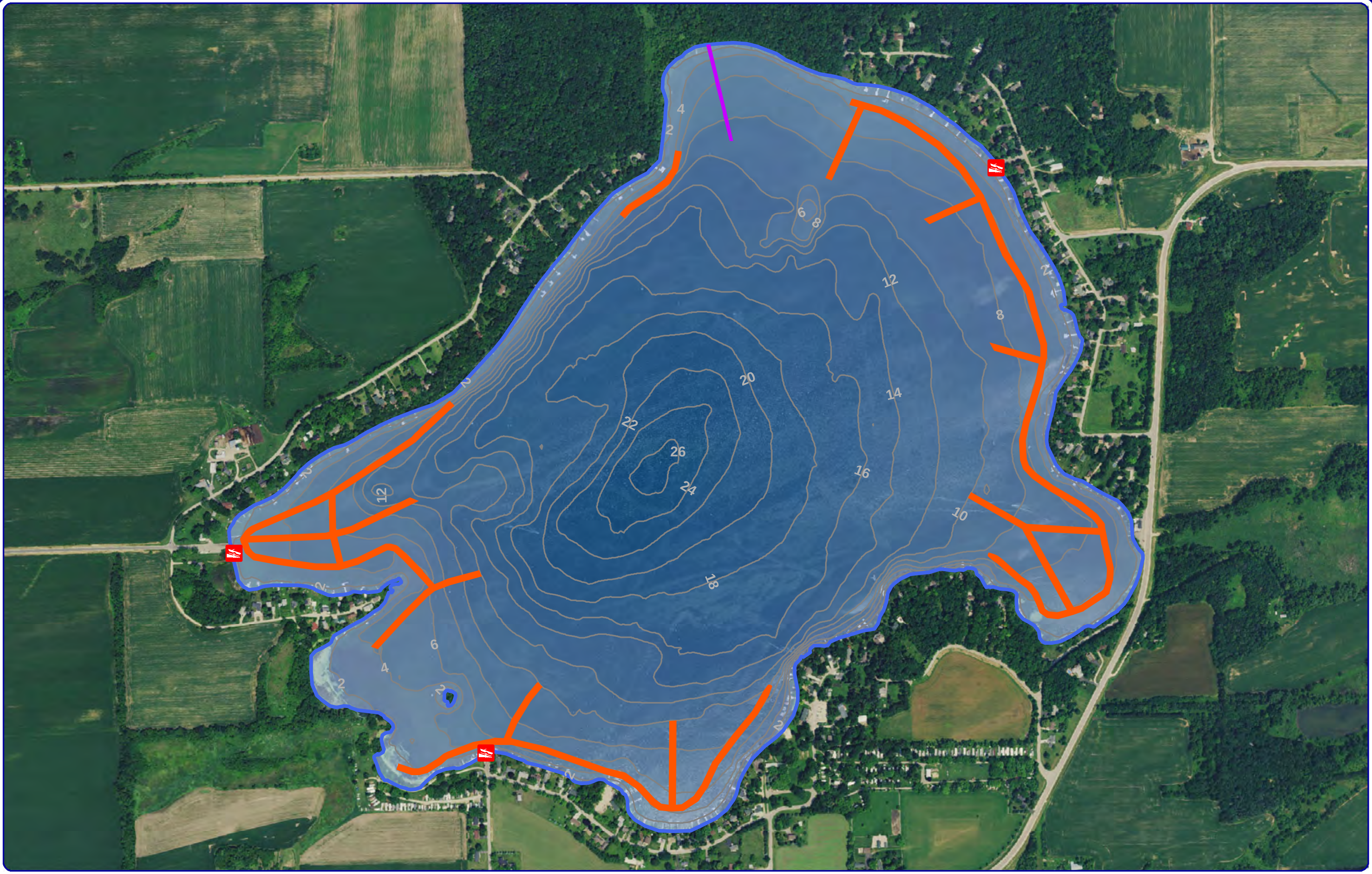

N
W E
S

900
Feet

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Lake Management Planning
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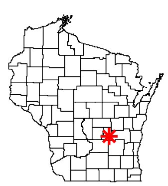
De Pere, WI 54115
920.338.8860
www.onterra-eco.com

Sources:
Roads and Hydro: WDNR
Orthophotography: NAIP 2015
Map Date: March 28, 2018 JLW
Filename: *LittleGreen_MechHarvest_2018.mxd*



Project Location in Wisconsin

Legend

Harvest Lanes - 50 ft
(22.7 acres)

Harvest Lanes - 30 ft
(0.5 acres)

Public Boat Landing

Map 7
Little Green Lake
Green Lake County, Wisconsin
Mechanical Harvest Lanes
(Updated 2018)