Grand Lake

Green Lake County, Wisconsin

Comprehensive Management Plan

June 2019

Sponsored by:

Green Lake County &

Grand Lake Improvement Association LTD

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Onterra LLC
Lake Management Planning

Grand Lake

Green Lake County, Wisconsin

Comprehensive Management Plan

June 2019

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Acknowledgements

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

Grand Lake Planning Committee

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Kathy Medick	Michelle McHugo	Richard Murray
Jack Meyers	Bill McMullin	Sara Wilson
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1.0 INTRODUCTION

Grand Lake, Green Lake, is a 253-acre lowland, drainage lake with a maximum depth of 8 feet and a mean depth of two feet. This eutrophic lake has a relatively large watershed when compared to the size of the lake. Grand Lake contains 18 native plant species, of which coontail is the most common plant. Three exotic plant species are known to exist in Grand Lake.

Field Survey Notes

Water extremely clear, plant communities easy to see. Cattails dominate a portion of the lake, near the inlet. Northern and southern iris present along lake shore.

Photograph 1.0-1 Grand Lake, Green Lake County

Lake at a Glance – Grand Lake	
Morphology	
Acreage	253
Maximum Depth (ft)	8
Mean Depth (ft)	2
Shoreline Complexity	5.8
Vegetation	
Curly-leaf Survey Date	September 6, 2016
Comprehensive Survey Date	September 9, 2016
Number of Native Species	18
Threatened/Special Concern Species	-
Exotic Plant Species	Giant reed, Eurasian water milfoil & Curly-leaf pondweed
Simpson's Diversity	0.75
Average Conservatism	5.4
Water Quality	
Trophic State	Hypereutrophic
Limiting Nutrient	Nitrogen
Water Acidity (pH)	7.9
Sensitivity to Acid Rain	Low
Watershed to Lake Area Ratio	247:1

Grand Lake is an impoundment of the Grand River and the dam is maintained by a local feed mill operator as a source of power. The Grand River is listed as a ASNRI Endangered, Threatened, or Special Concern Area. The Village of Kingston (population 326 during 2010 census) borders over half of the lake. The village owns over 1,500 feet of lake shoreline, including a public park that occupies 500 feet or shoreline and provides public fishing access. Grand Lake has a single public boat launch, which supports parking for 10 vehicle-trailer stalls. Two resorts are located on the lake. Locals claim the lake used to have good angling opportunity; however, siltation and carp combined to decrease the recreational value of the impoundment. Efforts have been taken in the past (1960's) to reduce rough fish populations in the lake, but they have rebounded since. Both curly-leaf pondweed (CLP) and Eurasian water milfoil (EWM) were discovered in Grand Lake in 2008 and verified to be scattered throughout the lake by a survey completed in 2013 by Golden Sands RC&D. The Wisconsin Department of Natural Resources currently lists the lake as being in "Fair" condition, meeting the management criteria for recreational use (fishing and swimming). However, an initial look on the SWIMS databases for the historical water quality for Grand Lake reveals that no previous water quality data has been collected on this system.

The Grand Lake Improvement Association LTD (GLIA) was formed in 2016 to work with stakeholders to further the progress of Grand Lake.

2.0 STAKEHOLDER PARTICIPATION

Stakeholder participation is an important part of any management planning exercise. During this project, stakeholders 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 stakeholders and vice-versa. The planners educate the stakeholders 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 stakeholders 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 stakeholder survey.

The highlights of this component are described below. Materials used during the planning process can be found in Appendix A.

Kick-off Meeting

On May 5, 2016, a project kick-off meeting was held at the American Legion in Kingston, WI to introduce the project to the general public. The meeting was announced through a mailing and personal contact by GLIA board members. The approximately 25 attendees observed a presentation given by Tim Hoyman, an aquatic ecologist with Onterra. Mr. Hoyman's presentation started with an educational component regarding general lake ecology and ended with a detailed description of the project including opportunities for stakeholders to be involved. The presentation was followed by a question and answer session.

Planning Committee Meeting I

The first planning meeting was held on March 14, 2017 and included a detailed presentation of the results of the studies completed on Grand Lake and historical data that was compiled for the lake. Prior to the meeting, the report sections were provided to the committee members for their review.

Planning Committee Meeting II

The second planning meeting was held with the Grand Lake committee on May 4, 2017. This meeting included a brief review of the study conclusions, a detailed discussion regarding the use of herbicides in the aquatic environment, and the use of water level drawdowns in lake management. During this meeting, the group was led through a brainstorming session aimed at developing a list of challenges facing Grand Lake and facing GLIA in managing the lake. That list was refined and several *management goals* were developed along with potential *management actions* that would aid in the lake group meeting those goals. Together, the goals and actions developed during this meeting represented the implementation plan framework used to create the full implementation plan found at the end of this document.

Planning Committee Meeting III

On June 20, 2017, the GLIA Planning Committee met for the final time with Onterra staff to discuss the draft implementation plan, learn more specifics regarding a possible Grand Lake water level drawdown, and to develop an agenda for the Wrap-up Meeting later that summer.

Project Wrap-up Meeting

The Grand Lake Management Planning Project Wrap-up Meeting was held on Saturday, July 29, 2017. At the meeting, Tim Hoyman from Onterra delivered a 75-minute presentation discussing the project results and conclusions along with an outline of the draft implementation plan. Approximately 30 minutes were spent answering questions from the meeting attendees.

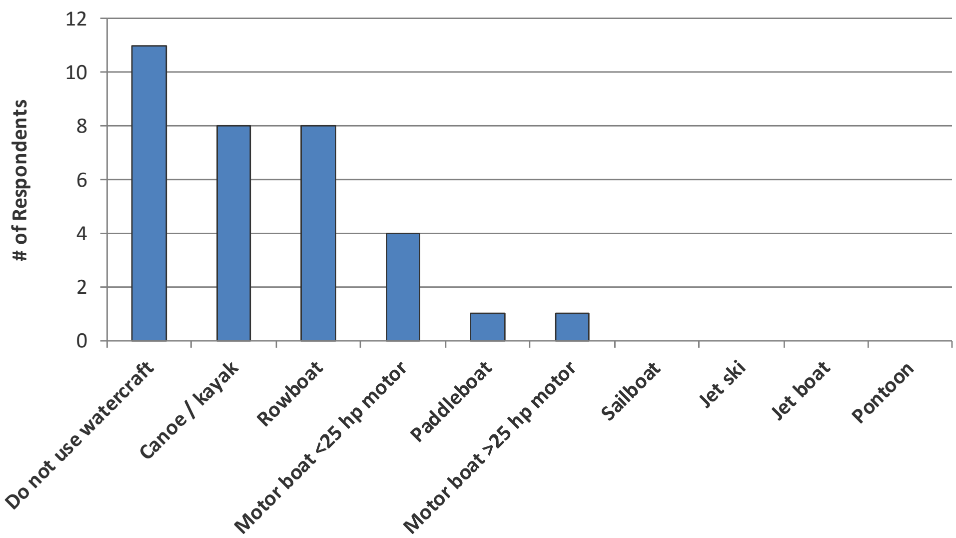
Stakeholder Survey

During November 2016, a seven-page, 31-question survey was mailed to 44 riparian property owners on or near Grand Lake. Fifty-eight percent of the surveys were returned and those results were entered into Survey Monkey by a Grand Lake Planning Committee member. 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 Stakeholder Survey, much was learned about the people that use and care for Grand Lake. The majority of stakeholders (71%) are year-round residents, while 8.3% visit on weekends through the year and 12.5% have undeveloped property on Grand Lake. 43% of stakeholders have owned their property for over 25 years, and 43% have owned their property for 15 years or less.

The following sections (Water Quality, Watershed, Aquatic Plants and Fisheries Data Integration) discuss the stakeholder survey data with respect these particular topics. Figures 2.0-1 and 2.0-2 highlight several other questions found within this survey. Eleven of survey respondents indicated that they do not use watercraft on Grand Lake while another 16 responded that they use either a canoe/kayak or rowboat, or a combination of these two vessels on Grand Lake (Question 10). Paddleboats were also a popular option. As seen on Question 11, boating is not one of the top activities that Grand Lake stakeholders participate in but fishing is, with two of the three top reasons people own their property on Grand Lake being fishing related. Algae blooms, excessive aquatic plant growth and water quality degradation were the top three choices as factors potentially impacting Grand Lake negatively (Question 23) and those three were also the top three concerns that survey respondents had for Grand Lake (Question 24).

Question 14: What types of watercraft do you currently use on the lake?



Question 17: Please rank up to three activities that are important reasons for owning your property on or near the lake.

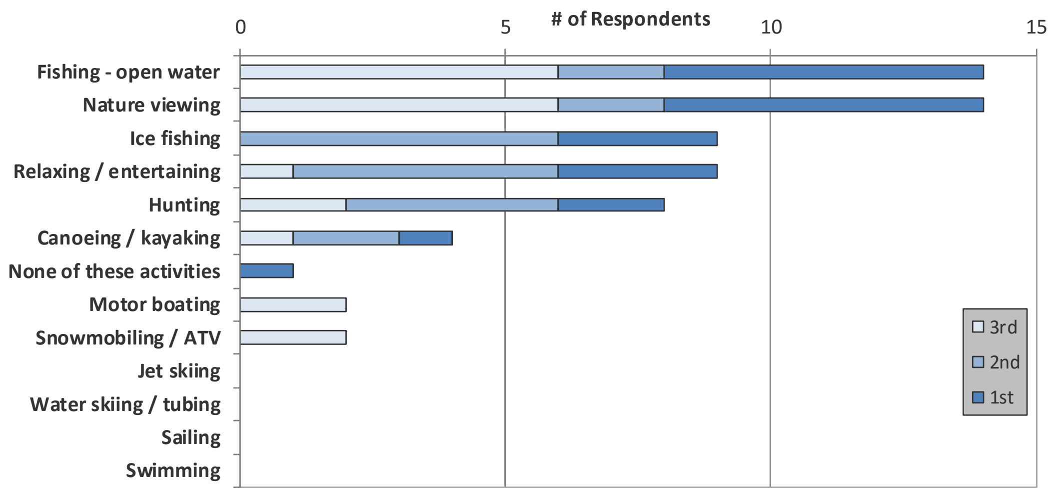
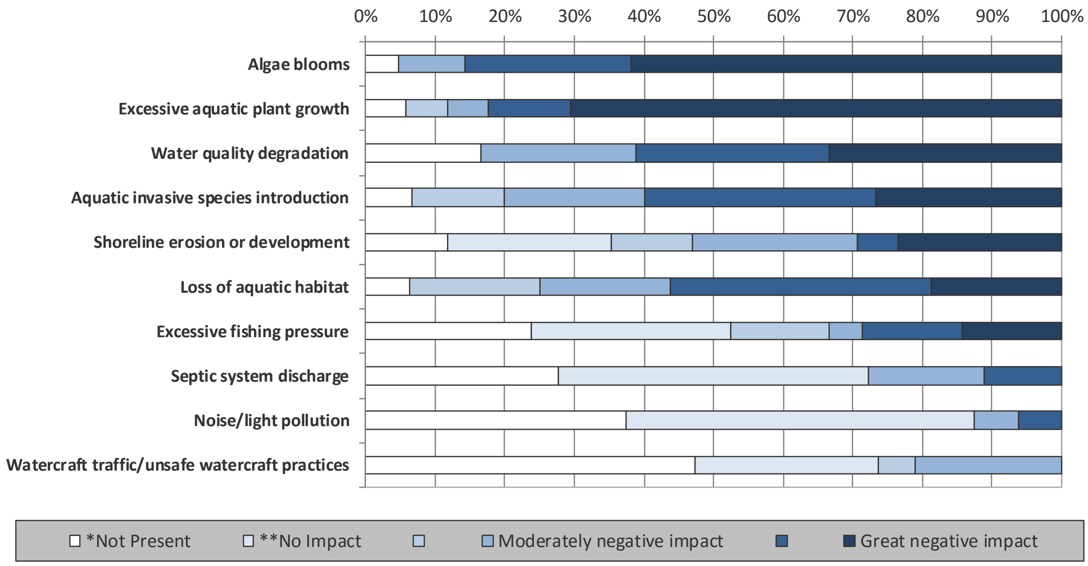


Figure 2.0-1. Select survey responses from the Grand Lake Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

Question 23: To what level do you believe these factors may be negatively impacting Grand Lake?



Question 24: Please rank your top three concerns regarding Grand Lake.

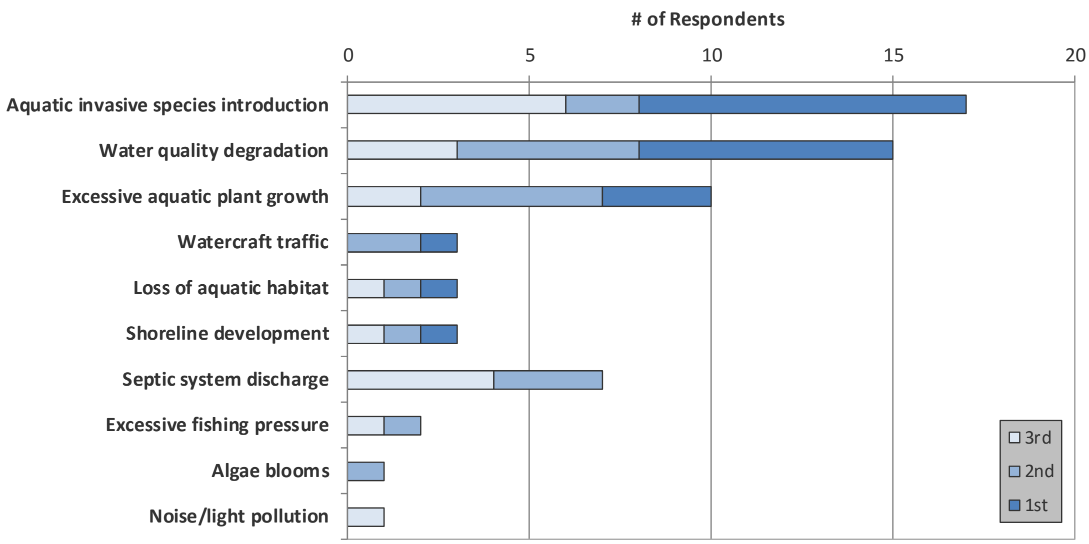


Figure 2.0-2. Select survey responses from the Grand Lake Stakeholder Survey, continued. Additional questions and response charts may be found in Appendix B.

3.0 RESULTS & DISCUSSION

3.1 Lake Water Quality

Primer on 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 Grand 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 Grand 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

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.

> 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.

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.

Dissolved oxygen is essential in the metabolism of nearly every organism that exists within a lake. For instance, fishkills 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 process that occur within a lake. Internal nutrient loading is an excellent example that is described below.

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.

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 to the water column throughout the growing season. In lakes that 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 algae blooms the following spring. Further, anoxic conditions under the winter ice in both polymictic and dimictic lakes can add large 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 algae 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 2014 Consolidated Assessment and Listing Methodology* (WDNR 2013A) 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 Grand 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, large watershed and hydrology, Grand Lake is classified as a shallow (mixed) lowland drainage lake (category 4 on Figure 3.1-1).

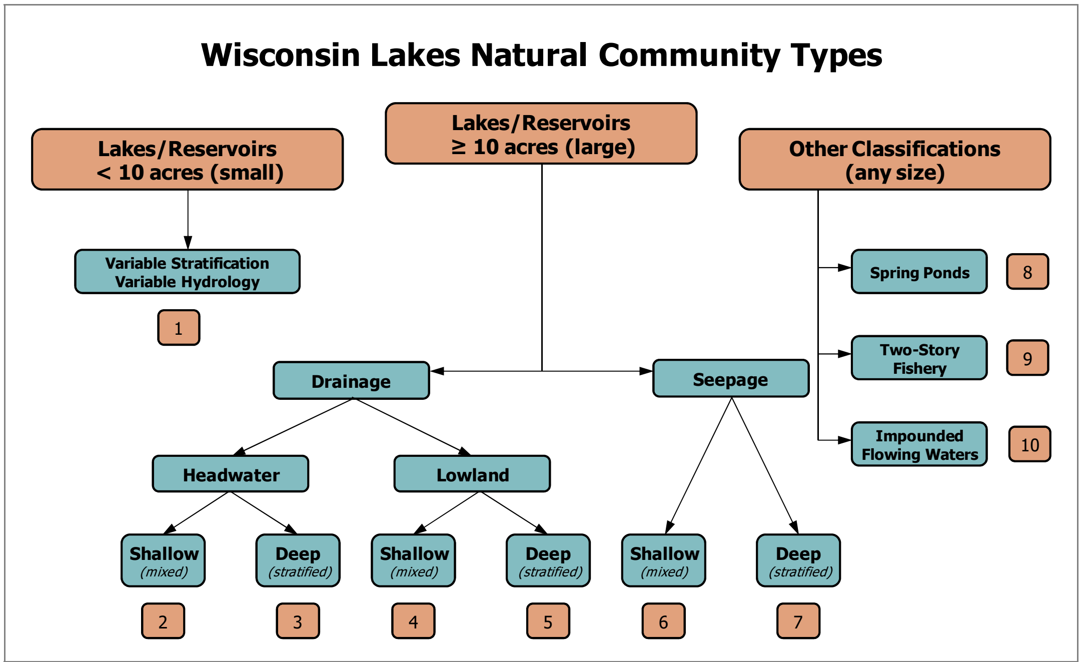


Figure 3.1-1. Wisconsin Lake Natural Communities. Adapted from WDNR 2013A.

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. Grand Lake is within the Southeastern Wisconsin Till Plains (SWTP) 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 Grand Lake are displayed in Figures 3.1-3 - 3.1-8. 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. Typically, water samples are also collected form near-bottom waters (3 feet above the bottom). Due to the shallow nature of Grand Lake, the near-bottom sample would have been collected at a similar depth as the near-surface sample (3 feet below the surface). Therefore, only near-surface samples were collected at the two sampling sites used during this project.

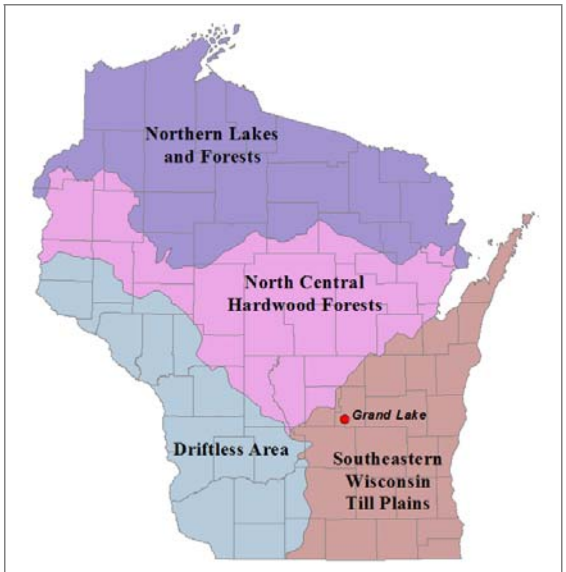


Figure 3.1-2. Location of Grand Lake within the ecoregions of Wisconsin. After Nichols 1999.

Grand Lake Water Quality Analysis

Historical water quality data are not available from Grand Lake; therefore, the studies completed in 2016 represent the first assessment of the lake's water quality. This lack of historical data makes long-term trend analyses impossible, but an understanding of the lake's current state can be discerned from the 2016 water quality data collection. The data collected in 2016 can be compared against median values for lakes within the SWTP ecoregion and lakes throughout Wisconsin.

In most instances, it is standard protocol to collect water quality data from the deepest location within a lake and in most impounded systems, the deepest location is usually located just upstream of the dam. However, in Grand Lake, the deepest location (deep hole) is located in southwest corner of the lake, far upstream from the dam (Map 1). Derek Kavanaugh, Green Lake County Conservation Department, expressed concerns during the design of this project that the water quality conditions at the deep hole were likely not representative of water quality conditions throughout the majority of the lake. Because of this, in addition to collecting water quality samples from the deep hole location, water quality samples were also collected at a site located in the downstream portion of the lake closer to the dam (Map 1). As is discussed further in this section, water quality conditions were quite different between the two sampling locations and conditions immediately surrounding the deep hole location are not believed to be representative of conditions throughout the majority of the lake. Therefore, water quality data collected from the near-dam location are used to draw overall conclusions regarding the current state of Grand Lake's water quality.

Total Phosphorus

Total phosphorus concentrations were measured five times at both sampling locations over the course of the 2016 growing season (Figure 3.1-3). In April, total phosphorous concentrations at the deep hole and near-dam sampling locations were similar. However, by June total phosphorus concentrations between the two locations deviated significantly. Total phosphorus concentrations at the deep hole locations showed a general decline over the course of the summer while concentrations at the near-dam location increased markedly.

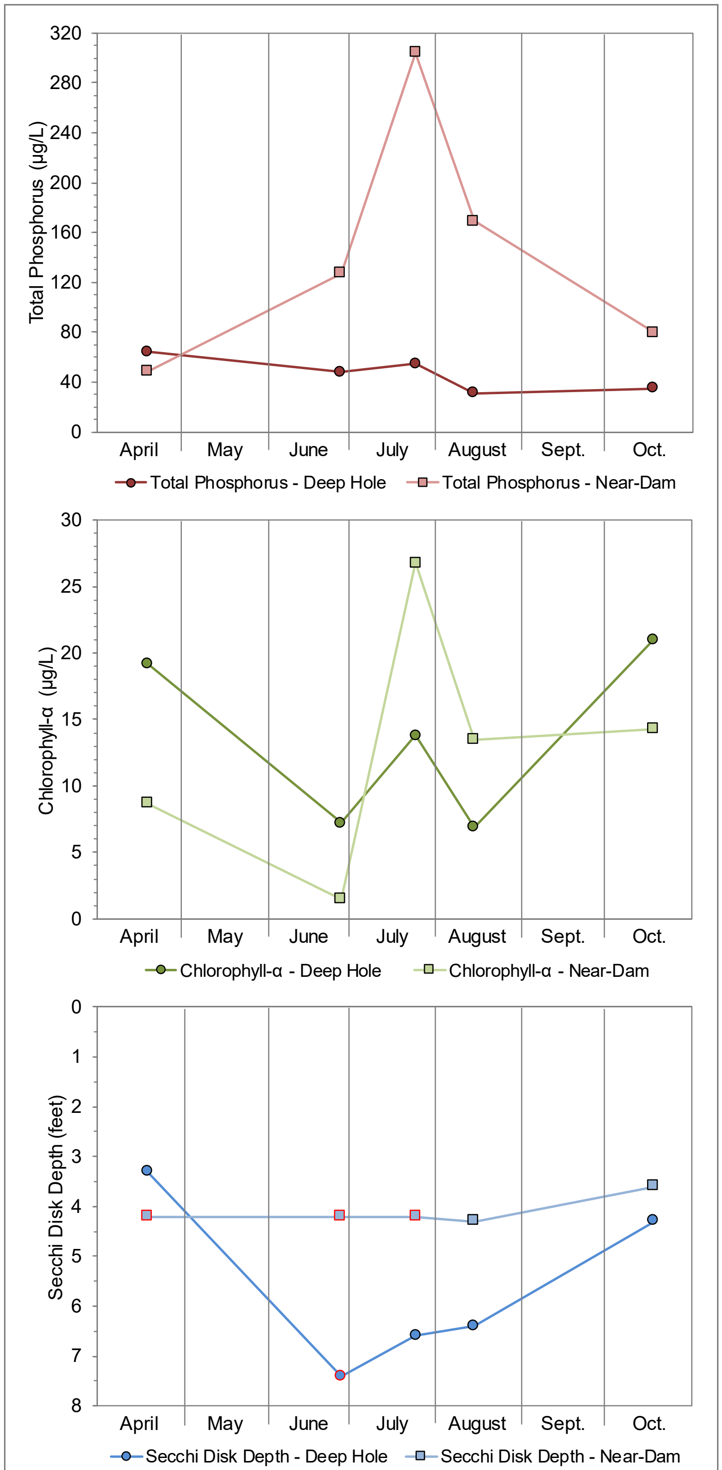


Figure 3.1-3. Grand Lake 2016 total phosphorus (top), chlorophyll-α (middle), and Secchi disk depth (bottom) from the deep hole and near-dam sampling locations. Secchi disk depth markers outlined with red indicate measurements hit the lake bottom.

Total phosphorus concentrations at the near-dam sampling location increased from 48.2 µg/L in April to 304 µg/L in July before declining back to 79.6 µg/L in October. Increases in total phosphorus concentrations over the growing season at this site are likely not attributed to increased phosphorus loading from Grand Lake's watershed and the Grand River.

In the Grand River, an inverse relationship between stream flow and total phosphorus concentrations are observed. When flow decreases in the stream, it is likely that the water resides in the stream long enough for phosphorus to be released from the sediment into the water, resulting in higher total phosphorus concentrations. Without flow data, it cannot be determined how the concentrations of phosphorus measured within the Grand River translate to the amount of phosphorus being loaded to Grand Lake. Total phosphorus concentrations in the Grand River were measured at two monitoring stations in 2012 and 2013, one monitoring station approximately one mile downstream from the Kingston Dam and one upstream from Grand Lake in the City of Markesan. Precipitation data from Markesan reveals that June of 2012 saw little rainfall, likely resulting in low streamflow reflected by high total phosphorus concentrations of 359 µg/L and 521 µg/L at the Kingston and Markesan monitoring stations, respectively (Figure 3.1-4). This reasoning is supported by flows that were measured in the Fox River at Princeton. Flows were low normal from mid-June through most of the summer. Flows were much higher in 2013 when phosphorus values at Kingston and Markesan were much lower. Following a large precipitation event, measured total phosphorus concentrations decreased at both sites in August and September of 2012. A rain event following a dry period with low stream flow would flush the water and phosphorus to the lake; however, it would be a very small percentage of the annual load to the lake. Again, this indicates that increasing total phosphorus concentrations measured in Grand Lake at the near-dam sampling location are likely not a result of increased phosphorus loading from the watershed.

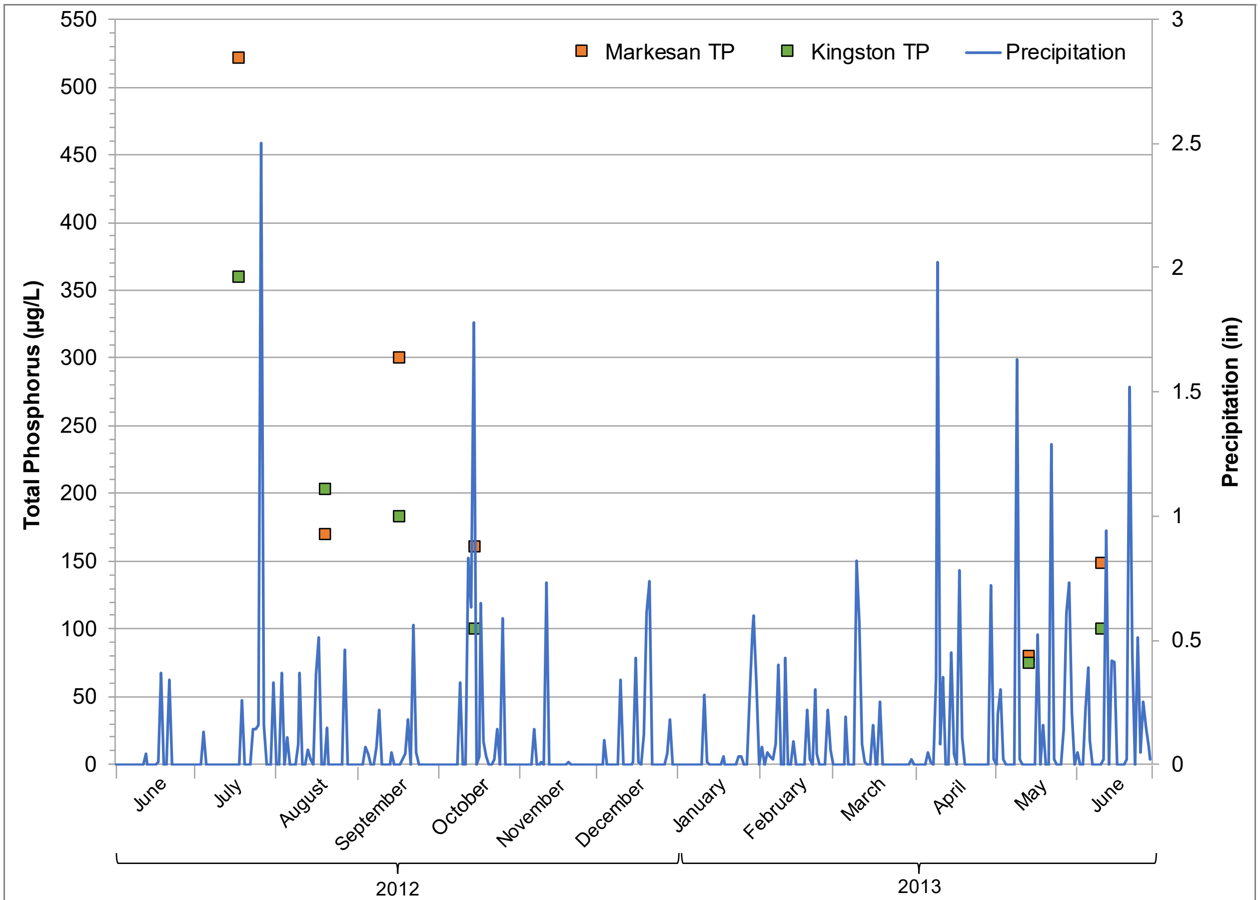


Figure 3.1-4. Grand river measured total phosphorus concentrations at the downstream Kingston monitoring station and the upstream Markesan monitoring station and precipitation. Precipitation data from Markesan Station GHCND:USC00475096 retrieved from NOAA Climate Data Online.

This trend of increasing phosphorus concentrations over the course of the growing season is an indication that internal nutrient loading is occurring, a phenomenon often observed in shallow lakes. Lakes typically act as phosphorus sinks, meaning that through chemical, physical, and biological processes, phosphorus settles to the bottom of the lake, so less phosphorus leaves the lake than enters it. In general, phosphorus concentrations tend to be higher early in the growing season following spring rains and snowmelt and then begin to decline over the course of the summer as precipitation decreases and phytoplankton consume phosphorus, die, and sink to the bottom. Come fall, phosphorus concentrations tend to increase again with fall mixing and increased precipitation. The atypical pattern of increasing phosphorus over the growing season at the Grand Lake near-dam site has been observed in other shallow lakes which experience internal nutrient loading (Moss et al. 2013).

The release of phosphorus from bottom sediments into the overlying water occurs primarily under two environmental conditions: 1) anoxia and/or 2) elevated water pH. In the presence of oxygen, phosphorus remains bound to ferric iron (Fe^{3+})within the sediment. When the overlying water becomes anoxic, or devoid of oxygen, the iron is reduced to ferrous iron (Fe^{2+}) which is soluble in water unlike ferric iron. Both iron and phosphorus are then released into the water (Pettersson 1998). Anoxia typically develops following stratification, or the formation of distinct layers of water based on temperature and density. The density gradient between the cold, dense layer of water near the bottom and the warmer, less dense layer of water at the surface prevents these layers from mixing together. Consequently, oxygen depleted through sediment oxygen demand, or the removal of oxygen through biological activity, is not replaced via atmospheric diffusion and anoxic conditions result. However, as is discussed further, the development of anoxic conditions in Grand Lake in 2016 were not the result of thermal stratification.

In shallow lakes, wind-induced sediment resuspension can also contribute to increases in phosphorus within the water column. Total suspended solids were measured on two occasions from the near-dam site in Grand Lake in 2016 and indicate that suspended particulates within the water column including both sediments and phytoplankton are low. While Grand Lake is shallow and mainly comprised of soft sediments, the lake's relatively small surface area and abundance of aquatic plants likely inhibits significant sediment resuspension from wind. Aquatic plants have been shown to greatly reduce sediment resuspension caused by wind- and boater-induced water movement (Horppila and Nurminen 2003). Benthivorous fish species in high abundance, such as the non-native common carp, can also contribute to internal nutrient loading through their excretion and by resuspending bottom sediments, flipping a shallow lake from a clear state to a turbid state. A recent study completed by the WDNR in Grand Lake, indicated the current carp population to be small, and given the lakes relatively high water clarity and abundance of macrophytes, the carp do not appear to be having a detectable impact on the lake. The carp population of Grand Lake will be discussed in detail within the Aquatic Invasive Species Section.

Aquatic plant surveys in 2016 indicated that the majority of Grand Lake contains dense populations of the non-native aquatic plant curly-leaf pondweed. Curly-leaf pondweed naturally senesces (dies-back) in early summer with warming water temperatures. The senescence of curly-leaf pondweed populations has been shown to release a significant amount of phosphorus into the water from decomposing plant tissues (Leoni et al. 2016). The increase in total phosphorus concentrations at the near-dam location in late-June likely represent the release of phosphorus from senescing curly-leaf pondweed. The oxygen profile collected in late-June indicated oxic conditions throughout the water column, so phosphorus release from bottom sediments was likely minimal at this time (Figure 3.1-7).

As is detailed in the section below on Dissolved Oxygen and Temperature in Grand Lake, by late-July 2016, the majority of the water column at the near-dam location, with the exception of the first few inches near the surface, had become anoxic and total phosphorus concentrations increased to 304 µg/L (Figure 3.1-7). At that time, temperature was relatively uniform throughout the water column an indication that development of anoxic conditions was not the result of thermal stratification. The development of anoxic conditions at the near-dam location is believed to the result of a combination of interacting factors.

First, the decomposition of senescing curly-leaf pondweed plants in early summer likely results in a more rapid depletion of oxygen (high biological oxygen demand). Second, despite Grand Lake's shallow nature, the development of a thick blanket of duckweed (*Lemna* and *Wolffia*), coontail (*Ceratophyllum demersum*), and common waterweed (*Elodea canadensis*) in summer inhibits wind-induced mixing of the water column and oxygen replenishment from the atmosphere. Third, these surface matted plants have been shown to reduce light availability in the water beneath them by 99%, diminishing growth and oxygen output of submersed plants (Parr et al. 2002). The majority of the plant growth in Grand Lake occurs in immediate surface waters. Further, the majority of the oxygen produced by duckweed has been shown to be released to the atmosphere and not into the underlying water (Janse and Van Puijenbroek 1998). The combination of senescing curly-leaf pondweed and the effects caused by the development of surface-matted plants in Grand Lake allow the rate of oxygen depletion from decomposition to exceed that of oxygen replenishment which brings about the anoxic conditions. Under anoxic conditions, phosphorus (and other nutrients) are released from bottom sediments and result in the high concentrations of phosphorus measured in July and August.

Additional evidence that the high phosphorus concentrations in summer measured at the near-dam location were mainly the result of internal loading were the high concentrations of soluble reactive phosphorus (SRP) and ammonia nitrogen. Soluble reactive phosphorus (dissolved phosphorus) is a measure of orthophosphate, the soluble form that is most available for uptake by plant cells and the form of phosphorus released from sediments under anoxic conditions. Total phosphorus is a measure of all forms of phosphorus, including SRP and phosphorus bound to sediment particles or within plant and animal cells (particulate phosphorus). Soluble reactive phosphorus within surface waters is rapidly incorporated into phytoplankton, meaning it is generally found in concentrations that are low (Wetzel 2001). However, concentrations of SRP in Grand Lake increased from 3.2 µg/L in April to 127 µg/L in July. The high concentration of SRP measured in July is an indication that this phosphorus was originating from internal loading, and that light limitation from duckweed was likely inhibiting its uptake by phytoplankton. Similarly, ammonia, like phosphorus, accumulates in the sediment under oxic conditions and can be released from the sediments under anoxic conditions. Like SRP, ammonia concentrations in Grand Lake increased from 30.8 µg/L in April to 147 µg/L in July, an indication it was originating from anoxic bottom sediments.

As discussed, elevated pH can also lead to the release of phosphorus from bottom sediments. In late-July, Grand Lake's pH was measured at 7.9, indicating phosphorus release due to elevated pH was likely not occurring. Elevated pH levels occur when the rate of photosynthesis and consumption of carbon dioxide within the water is high. While there is certainly a high rate of photosynthesis occurring in Grand Lake during the summer, most of the photosynthesis is carried out by duckweed right at the surface, and duckweed obtain their carbon dioxide from the atmosphere as opposed to the water. In short, the pH in Grand Lake did not increase significantly in 2016 because the mats of duckweed diminished light and the uptake of carbon dioxide from the water by phytoplankton and submersed aquatic plants for photosynthesis.

Using the total phosphorus data measured at the near-dam location in 2016 and the water residence time estimated from watershed modeling (see Watershed Section), it is estimated that approximately 570 pounds of phosphorus originated from internal loading in Grand Lake between April and August. While this may not seem like a significant amount of phosphorus when compared to the 38,000 plus pounds that enters the lake annually from the watershed, it actually is because this load is being added to the lake during a very low flow period. Ultimately, this keeps the phosphorus in the lake so it can be used by algae and macrophytes, especially non-rooted macrophyte species like common waterweed and coontail. By October, with cooler water temperatures, the observed growth of duckweed on the surface was less and biological decomposition was likely lower leading to oxic conditions being found throughout the water column. With the return of oxic conditions, internal nutrient loading subsided and phosphorus concentrations declined to 80 µg/L (Figure 3.1-3).

As stated previously, while total phosphorous concentrations significantly increased over the summer at the near-dam sampling location, total phosphorous concentrations decreased over the growing season at the deep hole sampling location (Figure 3.1-3). Temperature profiles collected at this location indicate the water remained thermally stratified over the course of the growing season, with a strong thermal gradient between surface and bottom waters. Water approximately 2.0 feet from the bottom averaged 11°C (52°F) over the course of the summer compared to 26°C (79°F) at the surface. In late-July, a 10°C difference (18°F) was measured between 3.0 and 4.0 feet of water. This sharp contrast in temperature across a small change in depth is unusual, even in deep stratified lakes.

Given the deep hole area of Grand Lake is relatively shallow at approximately 7.0 feet, this area was anticipated to be thoroughly mixed and be of relatively uniform temperature during the summer. The strong thermal stratification observed within the deep hole area in 2016 is believed to be a combination between the deep holes sheltered location, and thick aquatic plant growth which inhibits mixing

Total phosphorus concentrations measured at the deep hole location did not increase like those measured at the near-dam site and were approximately 4.5 times lower than those measured at the near-dam location. Oxygen profiles indicate that the entire water column at the deep hole location remained oxic throughout the growing season despite remaining thermally stratified (Figure 3.1-6). Water clarity was good enough that there was sufficient light throughout the water column to support photosynthesis. This photosynthesis produced enough oxygen to prevent anoxia, even in the bottom waters. It was observed that the deep hole location largely remained free of surface-matted duckweed during the summer, allowing light to penetrate into the water. With available light, submersed aquatic plants and benthic algae were able to photosynthesize and provide oxygen to the water within this area. With oxic conditions, internal nutrient loading does not appear to be significant within the deep hole area. This also suggests that phosphorus levels at the deep hole site are not impacted by the phosphorus from internal loading in other areas of the lake. The deep hole location likely acts as an important refuge for fish and other aquatic life when anoxic conditions develop throughout the main portion of the lake in mid-summer.

In 2016, the average growing season total phosphorous concentrations in Grand Lake at the deep hole and near-dam sampling locations were 47 and 146 µg/L, respectively (Figure 3.1-4). The average summer total phosphorous concentrations at the deep hole and near-dam sampling locations were 44 and 200 µg/L, respectively. As mentioned previously, conditions measured at the deep hole location likely represent conditions within this immediate area and conditions at the near-dam location are likely representative of the majority of the lake. The average summer total phosphorus concentration measured at the near-dam site falls within the *poor* category for shallow lowland drainage lakes in Wisconsin and is approximately nine times higher than the median concentration for lakes within the SWTP ecoregion.

Chlorophyll-α

As discussed in the *Primer* section, chlorophyll-*a* is a measure of free-floating algal biomass within a lake and is usually positively correlated with total phosphorus concentrations. As will be discussed in the section on Grand Lake Trophic State, measured chlorophyll-*a* concentrations in Grand Lake increased with measured phosphorus concentrations at both the deep hole and near-dam sampling locations (Figure 3.1-3), but chlorophyll-*a* concentrations were lower than predicted at both sites given the concentrations of phosphorus. The lower ratio of chlorophyll-*a* to total phosphorus indicates that another factor(s) other than phosphorus is limiting the growth of phytoplankton in Grand Lake.

As is discussed in the Limiting Nutrient of Grand Lake Section, the ratio of total nitrogen to total phosphorus is utilized to determine which of these two nutrients is limiting phytoplankton growth. Data collected at the deep hole location indicate phosphorus was the limiting nutrient over the course of the growing season. Despite this, chlorophyll-*a* concentrations were still lower than predicted. It is believed two primary factors other than phosphorus are regulating phytoplankton production in the deep hole location: 1) the abundance of aquatic macrophytes and 2) the high concentration of calcium.

Aquatic macrophytes provide zooplankton, small free-floating animals, with refuge from predatory fish. Zooplankton feed on phytoplankton and the abundance of aquatic plants in Grand Lake likely allows for a robust zooplankton community which graze and limit the growth of phytoplankton (Moss et al. 2013). Concentrations of calcium measured in Grand Lake in 2016 were found to be high. Dissolved calcium can reach concentrations at which no additional calcium can be dissolved (saturation point). When this happens, the calcium combines with carbonate forming calcium carbonate, or marl, and it precipitates out of the water. The precipitation of calcium carbonate also absorbs phosphorus, making it unusable by phytoplankton.

The nitrogen and phosphorus concentrations measured at the near-dam site indicate that nitrogen and phosphorus are present in high enough concentrations to produce more chlorophyll-*a* than was observed. It appears that in mid-summer the abundance of duckweed floating on the surface is reducing light penetration to the point where nutrients are not controlling algal abundance but instead light is the controlling factor. There are large amounts of dissolved forms of nitrogen and phosphorus which is a further indication that nutrients are not controlling algal growth.

In 2016, the average growing season chlorophyll-*a* concentrations in Grand Lake at the deep hole and near-dam sampling locations were 14 and 13 µg/L, respectively (Figure 3.1-4). The average summer chlorophyll-*a* concentrations at the deep hole and near-dam sampling locations were 9 and 14 µg/L, respectively. The average summer chlorophyll-*a* concentration measured at the near-dam site falls within the *good* category for shallow lowland drainage lakes in Wisconsin and is approximately three times higher than the median concentration for lakes within the SWTP ecoregion.

Water Clarity

Water clarity was measured using a Secchi disk at both the deep hole and near-dam sampling locations in 2016 (Figure 3.1-3). At the deep hole site, water clarity was lower in the spring and increased in the summer, likely corresponding to the growth of aquatic plants which reduced sediment resuspension and increased zooplankton grazing on phytoplankton. This may have happened at the near-dam site but the improvement in water clarity could not quantified because the Secchi disk was visible on the bottom in early summer. At the deep hole location, the Secchi disk measurement hit bottom during the June sampling event, indicating that water clarity exceeded the maximum depth of sampling location (7.1 feet). Because this measurement hit bottom, it cannot be included within the summer average. Water clarity at the deep hole location declined slightly in July and August to approximately 6.5 feet and declined further to 4.3 feet in October. Despite the exclusion of the June measurement which hit bottom, the average summer Secchi disk depth at the deep hole location fell within the *excellent* category for shallow lowland drainage lakes in Wisconsin and is nearly identical to the median value for lakes within the SWTP ecoregion (Figure 3.1-4)

The near-dam site is shallower and Secchi disk measurements hit bottom on three of the five sampling events (Figure 3.1-3). However, water clarity can be predicted using chlorophyll-*a* concentrations (Carlson 1977). Using the chlorophyll-*a* concentrations measured at the near-dam site, average predicted summer water clarity was 4.2 feet, falling into the *good* category for shallow lowland drainage lakes in Wisconsin and approximately 1.5 times lower than lakes within the SWTP ecoregion.

Water clarity is not only influenced by particulates such as phytoplankton and suspended sediments, but it is also influenced by dissolved compounds and elements within the water. *True color* is a measure of the amount of light absorbed by materials dissolved within the water once all of the suspended material has been filtered out. Lakes with watersheds which drain large areas of wetlands and/or coniferous forests typically have higher amounts of dissolved organic materials which originate from decomposing plant material. At higher concentrations, these compounds give the water a tea-like color and reduce water clarity. Color was measured in Grand Lake at the near-dam site during the spring and mid-summer, with values of 15 and 30 Standard Units (SU), respectively. These values indicate that Grand Lake's water can be described as *slightly to lightly tea-colored* (UNH Center for Freshwater Biology 2014), and that the lake's water clarity is primarily influenced by phytoplankton and suspended sediments.

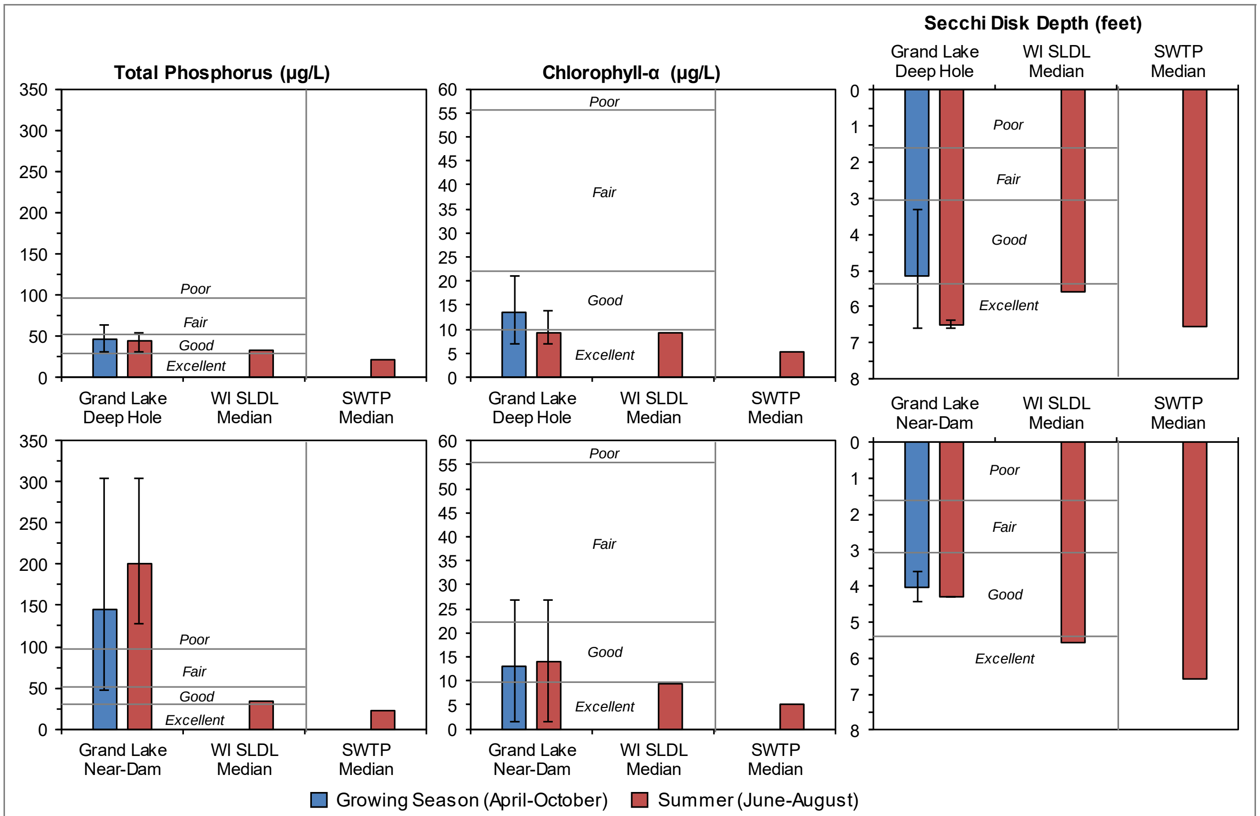


Figure 3.1-4. Grand Lake 2016 average total phosphorus, chlorophyll-α, and Secchi disk depth measured at the deep hole (top) and near-dam (bottom) sampling locations. Thin lines with caps represent minimum and maximum values. Secchi disk measurements hit bottom on one occasion at the deep hole and three occasions at the near-dam location. SLDL = Shallow, Lowland Drainage Lakes; SWTP = Southeast Wisconsin Till Plains.

Limiting Nutrient in Grand Lake

Nitrogen is second to phosphorus in terms of the nutrient of importance in regulating the growth of phytoplankton. While phosphorus limits the growth of phytoplankton in the majority of Wisconsin's lakes, some are nitrogen limited. To determine whether phosphorus or nitrogen is the nutrient limiting phytoplankton growth in a lake, lake managers look at the ratio of total nitrogen to total phosphorus. If this ratio is greater than 15:1, the lake is considered to be phosphorus-limited, and if it is less than 10:1, it is considered to be nitrogen-limited. A ratio between 10 and 15:1 indicates the lake is likely transitional between phosphorus and nitrogen limitation.

There are numerous sources and forms of nitrogen which are delivered to Wisconsin's lakes. Nitrogen enters waterbodies through precipitation, fixation from the atmosphere by cyanobacteria (blue-green algae), surface inflow, and groundwater. Human activities such as fertilizer application, runoff of animal wastes, and sewerage treatment discharge can increase nitrogen inputs to waterbodies. Unlike phosphorus, nitrogen does not occur naturally within soil minerals. The majority of the earth's nitrogen occurs within the atmosphere and is unavailable to most organisms. A bio-available form of nitrogen is created by organisms that have the ability to convert atmospheric nitrogen into a usable form.

At both sampling locations, nitrogen concentrations are highest in the spring, likely a result of higher runoff from agricultural lands within the watershed. During that time, the nitrogen to phosphorus ratio is 135:1 at the near-dam location and 78:1 at the deep hole location, indicating that phosphorus was the limiting nutrient. While phosphorus concentrations are at their lowest in Grand Lake during the spring, these concentrations are still considered to be relatively high.

Phosphorous remained the limiting nutrient throughout the growing season at the deep hole sampling location. While phosphorous concentrations are much lower at the deep hole location than the near-dam location, concentrations are still relatively high, and consequently, given the ample amount of nitrogen, phytoplankton growth should be greater than measured at the deep hole location. As discussed in the previous Chlorophyll-*a* Section, other factors such as zooplankton and sequestration by calcium carbonate are likely limiting phytoplankton growth at this location.

As spring transitions into summer, phosphorus concentrations increase significantly from 48 to 304 µg/L at the near-dam site. In July, the nitrogen to phosphorous ratio declined to 5:1, which could be indicating a transition to nitrogen limitation. However, given the high concentrations of bioavailable forms of nitrogen and phosphorus, algal growth is not limited by either nutrient. ther factors such as zooplankton, sequestration by calcium carbonate, and light limitation from surface-matted plants are limiting phytoplankton growth.

Grand Lake Trophic State

Figure 3.1-5 contains Trophic State Index (TSI) values based upon the weighted average values for total phosphorus and chlorophyll-*a* measured in Grand Lake in 2016. The TSI values for Secchi disk transparency were not included because some Secchi disk measurements hit bottom on multiple occasions. In general, the best values to use in judging a lake's trophic state are chlorophyll-*a* and total phosphorus. If the TSI values calculated using total phosphorus and chlorophyll-*a* are similar to one another, it is an indication that these parameters a highly correlated.

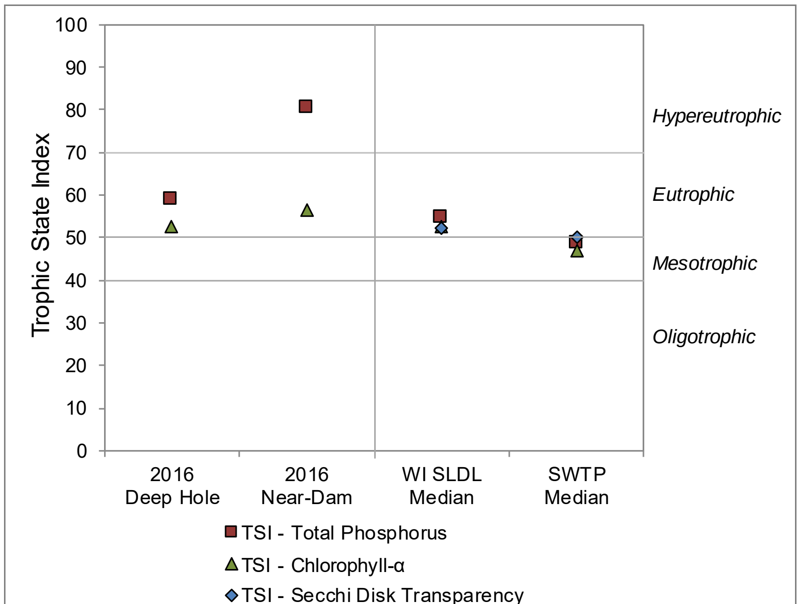


Figure 3.1-5. Grand Lake 2016 Trophic State Index values. Trophic State Index values for Secchi disk transparency were not included as multiple measurements hit the lake bottom in 2016. Values calculated with summer month sample data. SLDL = Shallow, Lowland Drainage Lakes; SWTP = Southeast Wisconsin Till Plains.

The TSI values for total phosphorus at the deep hole and near-dam location are higher than the TSI values for chlorophyll-*a* – another indication that factors other than total phosphorus are regulating phytoplankton production in Grand Lake. The TSI value for total phosphorus at the near-dam location falls within the hypereutrophic category. Hypereutrophic lakes are generally characterized as having high nutrients like Grand Lake, but also have high phytoplankton production and low water clarity. While nutrient levels are high, phytoplankton production is lower with a TSI value for chlorophyll-*a* indicating eutrophic conditions. Given much of Grand Lake's productivity is within its aquatic plant community, it is likely this system is in an upper eutrophic state. When compared to lakes in the ecoregion and the state, Grand Lake is more productive overall.

Dissolved Oxygen and Temperature in Grand Lake

As has been discussed, there were marked differences between temperature and dissolved oxygen at the deep hole and near-dam sampling locations. As shown in Figure 3.1-6, this site maintains thermal stratification throughout the growing season. Despite a maximum depth of 7 feet, the temperatures in the bottom water remained near 10°C, which could not happen if the water column destratified during the summer. Temperatures recorded at the near-dam location indicate this area did not thermally stratify as indicated by nearly uniform temperatures throughout the water column over the course of the growing season (Figure 3.1-7).

The level of dissolved oxygen within water can vary greatly and its concentration is dependent upon water temperature, atmospheric pressure, and salinity. Colder water can hold more oxygen than warmer water. The majority of the oxygen supplied to lakes is through diffusion from the atmosphere, but photosynthesizing macrophytes and algae also supply oxygen to the water. The respiration of microbes which decompose organic matter consumes oxygen within the lake. If the rate of oxygen consumption exceeds that of input from the atmosphere and photosynthesizing plants, anoxic conditions result.

When the concentration of dissolved oxygen within the water reaches equilibrium with oxygen in the atmosphere, the water is considered to be 100% saturated with oxygen. In productive lakes with abundant macrophyte and/or phytoplankton populations, oxygen can be produced at a higher rate than it can diffuse out of the water and into the atmosphere. When this occurs, dissolved oxygen concentrations exceed 100% saturation and the water is considered to be supersaturated with oxygen. If dissolved oxygen concentrations exceed 110% saturation, certain fish species may be prone to gas bubble disease where oxygen bubbles can inhibit blood flow within their vessels.

As discussed previously, water at the deep hole location remained oxygenated over the course of the five sampling events in 2016 (Figure 3.1-6). However, supersaturated conditions were present in the top 3.0 feet of water during all of the sampling events, ranging from 188% in late-July to 116% in mid-October. These conditions indicate a high-rates of photosynthesis, likely from a combination of phytoplankton, macrophytes, and the periphyton (algae) which grow on the macrophytes in this area. The cooler water temperatures at 4.0 feet and deeper at the deep hole location were never measured to be supersaturated in 2016, and the deeper waters within the deep hole area likely represent a refuge for fish in mid-summer.

Supersaturated conditions were only measured in late-June at the near-dam sampling location where the top 3.0 feet of water averaged 127% saturation. Oxygen measured in April and October at the near-dam location were near 100% saturation. The near-dam location likely has a higher rate of water movement, which may increase the rate of oxygen diffusion from the lake to the atmosphere compared to that at the deep hole location where supersaturated conditions were present. As discussed earlier, water at the near-dam location was found to be anoxic in July and August. The thick growth of duckweed and other aquatic plants at the surface likely inhibited mixing and diminished photosynthesis of aquatic plants below. The rate of oxygen depletion from decomposition exceeded that of inputs from the atmosphere and photosynthesis.

Temperature and dissolved oxygen were also measured during a sampling event through the ice in February 2017. At the deep hole location, water temperature was 3.0°C (37.4°F) just below the ice and increased to 5.3°C (41.5°F) just below the bottom (Figure 3.1-6). As mentioned previously, given the strong thermal stratification measured during the summer and the fact that near-bottom temperatures were maintained around 11°C over the course of the growing season, it was believed this was an area of groundwater inflow. However, if a significant amount of groundwater was flowing into this area the temperatures near the bottom should have been warmer than what was measured. While it cannot be said that groundwater is not flowing into the lake in the deep hole area, the winter sampling indicates that the deep hole area's sheltered location and/or dense macrophyte growth may have been more important in creating the thermally stratified conditions observed during the summer. Oxygen concentrations measured at the deep hole location were near 12 mg/L throughout the water column, indicating sufficient oxygen levels under the ice to support fish and other aquatic life.

Water temperatures measured through the ice at the near-dam site were just above freezing throughout the water column (Figure 3.1-7). Water temperature ranged from 0.6°C (33.1°F) just below the ice to 0.7°C (33.3 °F) near the bottom at 4.0 feet. This lack of thermal stratification at the near-dam location is due to this areas shallowness, and water within this area is able to continually mix in the fall up until the lake freezes. Dissolved oxygen concentrations measured at the near-dam location under the ice indicate sufficient oxygen levels were present for fish and other aquatic life. Despite the shallow, productive nature of Grand Lake, the lake is continually receiving oxygenated water from the upstream Grand River which maintains oxygenated conditions under the ice in winter.

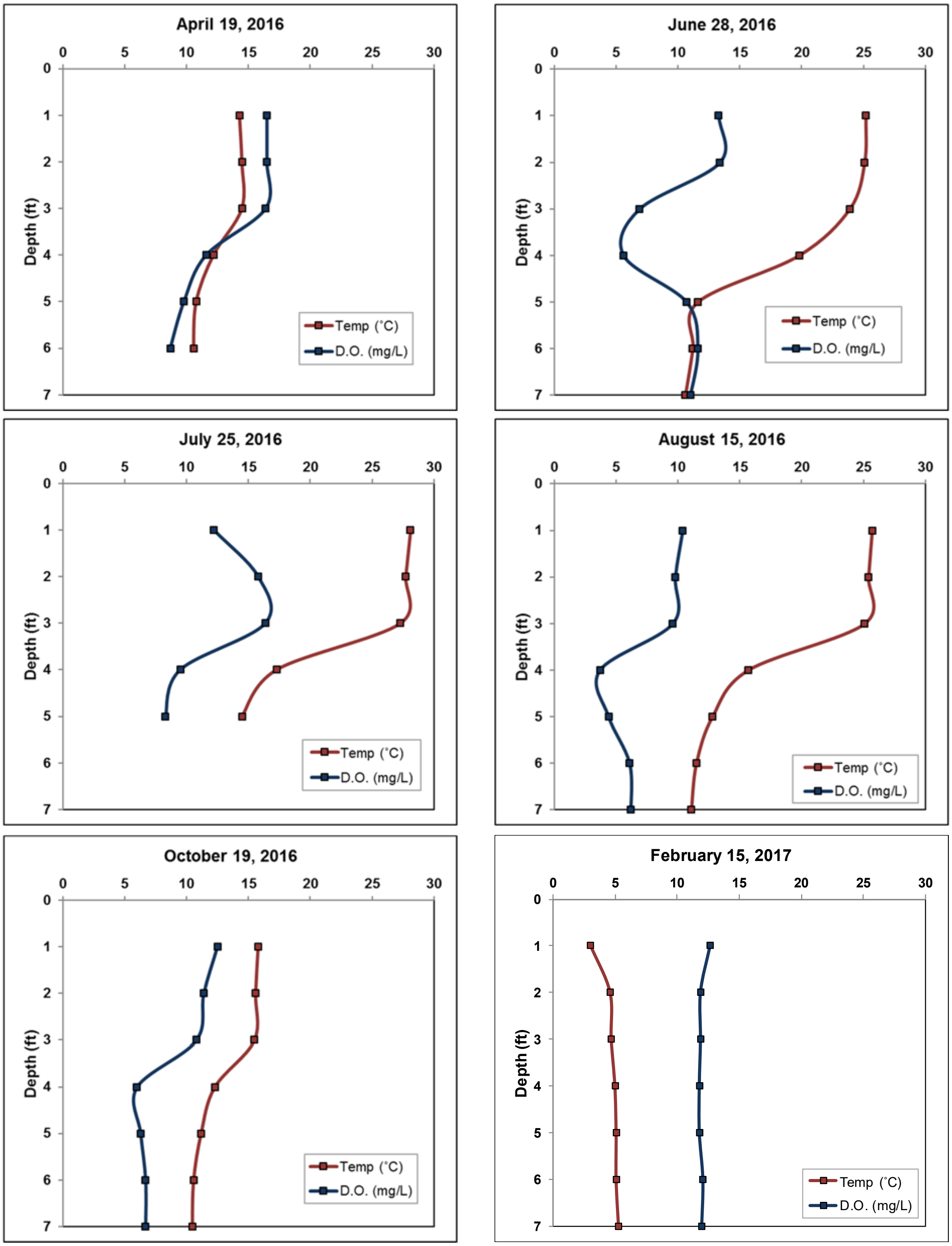


Figure 3.1-6. Temperature and dissolved oxygen profiles recorded at the deep hole sampling location in Grand Lake.

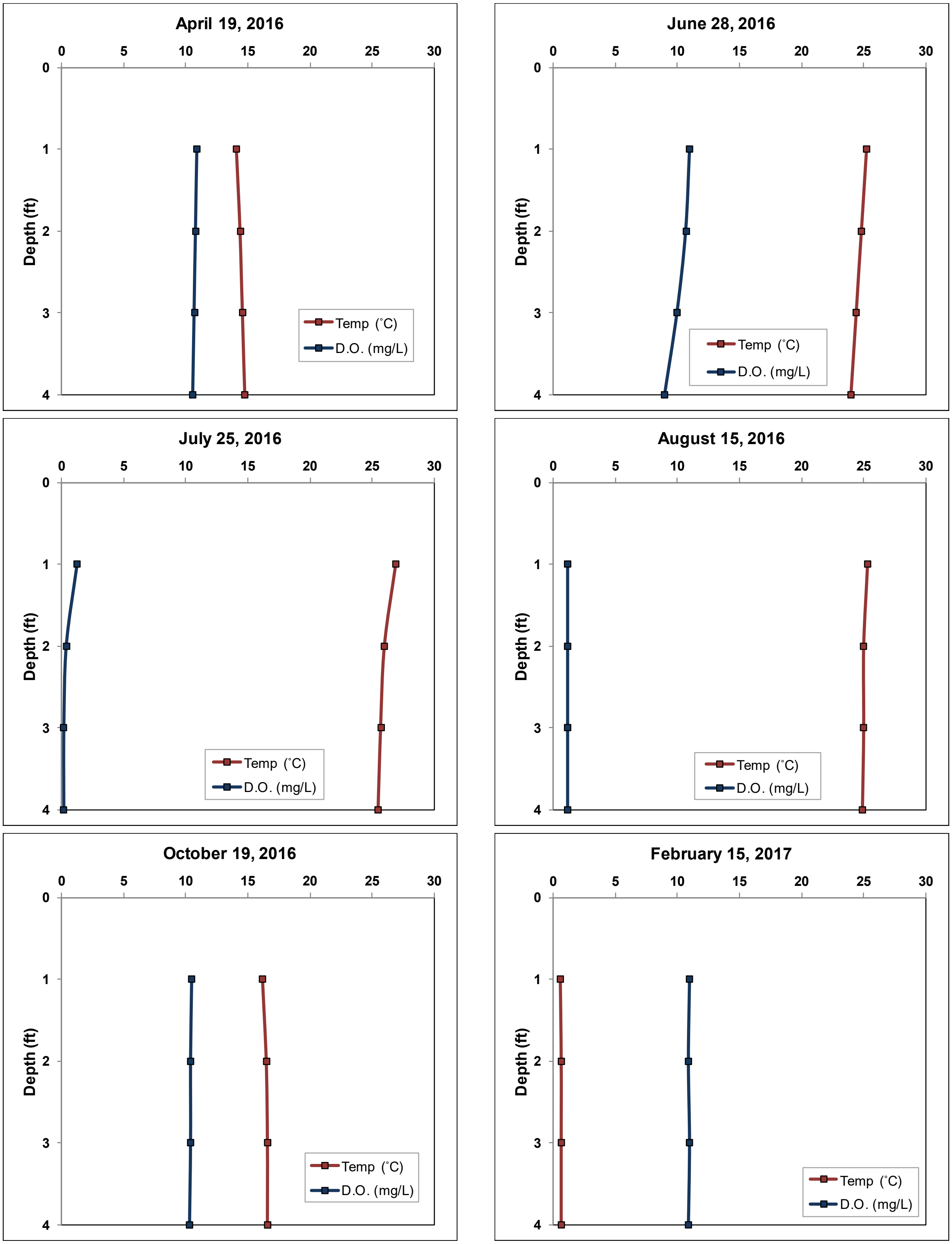


Figure 3.1-7. Temperature and dissolved oxygen profiles recorded at the near-dam location in Grand Lake.

Additional Water Quality Data Collected in Grand Lake

The previous sections centered on water quality parameters related to eutrophication. However, parameters other than water clarity, nutrients, and chlorophyll-*a* were collected as part of this project. These other parameters were collected to increase the understanding of Grand 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 at the near-dam sampling location was found to be 8.3 in April and 7.9 in July, both falling within the normal range for Wisconsin Lakes. The pH was measured at the deep hole sampling location in April and was found to be relatively high at 8.6. This elevated pH may have been the result of the high rate of photosynthesis that was occurring as indicated by supersaturated dissolved oxygen conditions discussed above. The consumption of carbon dioxide by photosynthesizing plants can raise the pH of the water during the day.

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 at the near-dam sampling location was measured in April and July and was found to be 254 and 281 (mg/L as $CaCO_3$), respectively, indicating that the lake has a substantial capacity to resist fluctuations in pH and has a low sensitivity to acid rain. The alkalinity measured at the deep hole sampling location in April was slightly lower at 207 mg/L.

Like associated pH and alkalinity, the concentration of calcium within a lake's water depends on the geology of the lake's watershed. All three of these factors can be used to determine if a lake is susceptible to zebra mussels. The calcium concentrations for the near-dam sampling location were found to be 63.1 mg/L in April and 66.0 mg/L in July. In April, the calcium concentration was found to be 40.9 mg/L at the deep hole sampling location. Both alkalinity and calcium are likely higher at the near-dam location because water draining through this area has originated from the lake's large 98-square mile watershed, while water in the deep hole location has likely originated from groundwater sources and a smaller drainage area immediately around the deep hole location.

Recently, the combination of calcium concentration and pH has been used to determine if a lake can support the non-native zebra mussel if they are ever introduced. The commonly accepted pH range for zebra mussels is 7.0 to 9.0, so Grand Lake's pH falls within this range. Zebra mussels also require a certain concentration of calcium within the water, and the concentrations measured in Grand Lake in 2016 in combination with a suitable pH indicate Grand Lake is highly suitable for zebra mussel establishment. Onterra ecologists conducted plankton tows at three locations in Grand Lake in 2016 that underwent analysis for detecting zebra mussel veligers, their planktonic larval stage. This analysis was negative for the presence of zebra mussel veligers and Onterra ecologists did not observe any adult zebra mussels during the 2016 surveys. However, the upstream waterbodies of Lake Emily and Little Green Lake and nearby Green Lake have confirmed populations of zebra mussels, and Grand Lake users should familiarize themselves with identification of this non-native mussel in the event they are introduced.

Shallow Lakes and Alternative Stable States

Shallow lakes are considered to exist in one of two general stable states: a turbid state (low clarity) dominated by phytoplankton and containing little submersed aquatic vegetation, or a clear state dominated by submersed aquatic vegetation and lower phytoplankton abundance (van Nes et al. 2007). When in the clear state, aquatic vegetation reduces the suspension of bottom sediments, utilizes nutrients that would otherwise be available to phytoplankton, and provide refuge for zooplankton which eat phytoplankton. The aquatic plant community plays a vital role in maintaining this clear-water state. Once a lake transitions from a clear to turbid state, it is highly difficult to return it back to a clear state.

A number of factors which can lead to the loss of aquatic vegetation often cause shallow lakes to transition from the clear to turbid state. Excessive nutrient loading can lead to increased phytoplankton abundance, reductions in water clarity, and a reduction in aquatic plant habitat. As aquatic vegetation declines, bottom sediments become more susceptible to wind-induced sediments resuspension and water clarity declines further. While nutrient levels are very high in Grand Lake, the aquatic plant community likely supports a robust zooplankton community, which feed on phytoplankton. Light limitation from surface matting aquatic plants is also likely limiting phytoplankton growth. Both factors aid Grand Lake in maintaining a clear state dominated by submersed aquatic vegetation.

The stabilization of water levels in shallow lakes can also lead to declines in aquatic vegetation as many species require natural, annual fluctuations for their persistence and reproduction. Studies have also documented declines in submersed aquatic vegetation and increases in nutrients and suspended solids, and a shift from a clear, submersed aquatic plant-dominated state to a turbid, phytoplankton-dominated state following the introduction of the non-native common carp (*Cyprinus carpio*) (Bajer and Sorensen 2015).

Common carp have been confirmed within Grand Lake, but as a very small population. Common carp foraging behavior 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). The water clarity was high in 2016 and the lake was dominated by submersed aquatic plants implying the common carp population is, not greatly affecting the water quality.

Grand Lake's shallow nature in combination with nutrient-rich sediments and water creates ideal conditions for excessive aquatic plant growth. However, these plants are essential for maintaining Grand Lake's current clear-water state, and a loss of aquatic plants would result in the lake transitioning to a phytoplankton-dominated state with low water clarity as a result of phytoplankton blooms and sediment resuspension.

Stakeholder Survey Response Regarding Water Quality

As discussed in section 2.0, the stakeholder survey asks many questions pertaining to perception of the lake and how it may have changed over the years. Figure 3.1-9 displays the responses of Grand Lake stakeholders to questions regarding the current water quality of Grand Lake and how it has changed since they first visited the lake. When asked how they would describe the current water quality of Grand Lake, there was a nearly even split amongst respondents between very poor, poor, fair, and good. This relatively even distribution of responses across a perception of water quality ranging from very poor to good indicates that the term 'water quality' may have different meanings amongst Grand Lake stakeholders.

Those who indicated the current water quality of Grand Lake is fair or good are likely basing their perception of the lake's water quality on the clarity of the water. As discussed in the previous sections, water clarity in Grand Lake is relatively high during the summer and falls within the good category for shallow lowland drainage lakes in Wisconsin. The respondents who indicated that the current water quality in Grand Lake is very poor or poor are likely basing their perception of water quality on the excessive aquatic plant growth in the lake, and possibly mistaking the thick mats of duckweed for algae.

When asked how water quality in Grand Lake has changed since they first visited the lake, 61% indicated that water quality has somewhat or severely degraded, 22% indicated water quality has remained the same, and 17% were unsure (Figure 3.1-9). Unfortunately, historical water quality data are not available so it cannot be said if water quality in terms of phytoplankton abundance and water clarity have changed in Grand Lake over time. A water level drawdown was conducted in 1992 to facilitate the construction of the new dam, and it is likely that aquatic plant abundance was reduced within the lake following this drawdown. A water level drawdown has not been completed since and it is possible aquatic plants have increased in abundance since 1992 and may be the reason why stakeholders indicated water quality has declined. Also, curly-leaf pondweed was first documented in the lake in 2008, and the spread and increase in this aquatic plant may also account for a possible increase in aquatic plant abundance.

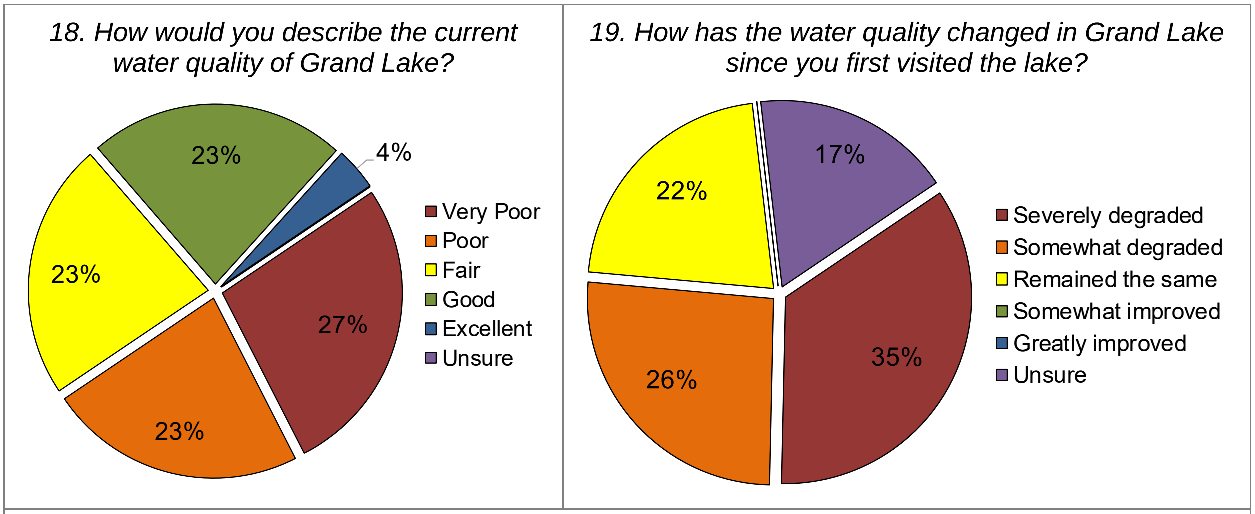


Figure 3.1-9. Grand Lake stakeholder survey response questions to questions regarding water quality. N = 23 respondents.

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 times.

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 affect 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.

Grand Lake Watershed Assessment

Grand Lake's total watershed is approximately 62,807 acres (98 square miles) across Green Lake, Fond du Lac, Columbia, and Dodge counties (Map 2). Grand Lake has a watershed to lake area ratio of 247:1. In other words, approximately 247 acres of land drains to every one acre of Grand Lake. According to WiLMS modeling, the lake's water is completely replaced approximately every 5.2 days (residence time) or 70.6 times per year (flushing rate). The lake' residence time will vary seasonally depending upon the amount of flow in the Grand River. Generally the residence is shorter during the spring and longer later in the summer.

When a lake feeds into another lake, that lake acts as a point source for the downstream lake. These lakes are modeled in series, with phosphorus outflow from the upstream lake estimated using total phosphorus concentrations and by estimating how much water is draining from the upstream lake to the downstream lake. There are two lakes within Grand Lake's watershed that were treated as point sources, Little Green Lake in Green Lake County and Lake Emily in Dodge County. For modeling purposes the lake's watershed was divided into three main subwatersheds, Grand Lake's direct watershed, the Little Green Lake subwatershed, and the Lake Emily subwatershed (Map 2). Approximately 93% of Grand Lake's watershed is composed of its direct watershed, 4% is composed of the Little Green Lake subwatershed, and 3% is composed of the Lake Emily subwatershed (Figure 3.2-1).

Typically, lakes act as a sedimentation basin and through chemical, physical, and biological processes, phosphorus is settled to the bottom of the lake. Studies that are being completed on Little Green Lake indicate that internal nutrient loading is occurring, adding phosphorus to the lake instead of acting as a sedimentation basin. Lake Emily is thought to act like a sedimentation basin, and while it is still passing some phosphorus through to Grand Lake, it is likely retaining a greater amount of phosphorus from its subwatershed.

Approximately 65.7% of Grand Lake's direct watershed is composed of row crop agriculture, 18% pasture/grass, 8.4% wetlands, 5% forest, and 2.1% rural residential areas (Figure 3.2-1). The remaining portions of the watershed are composed of Grand Lake's surface, medium density urban areas, and high density urban areas. Both the Little Green Lake subwatershed and Lake Emily subwatershed are similar to Grand Lake's direct watershed with the majority of land cover being row crop agriculture and pasture/grass.

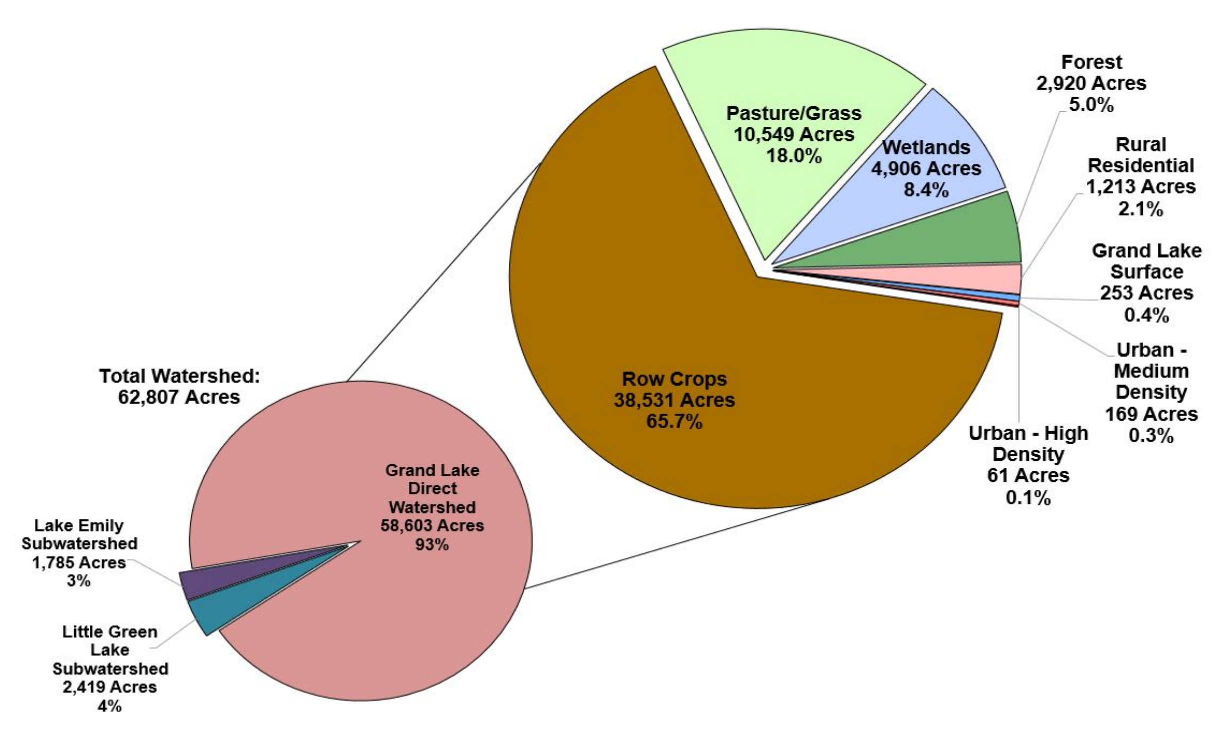


Figure 3.2-1. Grand Lake watershed land cover types in acres. Based upon National Land Cover Database (NLCD – Fry et. al 2011).

Using the landcover data described above, WiLMS was utilized to estimate the annual potential phosphorus load from Grand Lake's direct watershed, along with the estimated outflow of phosphorus from the two subwatersheds. It was estimated that approximately 38,754 pounds of phosphorus is delivered to Grand Lake from its watershed on an annual basis (Figure 3.2-3). Phosphorus loading from septic systems was also estimated using data obtained from the 2016 stakeholder survey of riparian property owners, which illustrated that only about 7 lbs, or roughly 0.02% of the annual phosphorus load is attributed to septic systems.

Of the estimated 38,754 pounds of phosphorus being delivered annually to Grand Lake, the majority, 89%, is estimated to originate from row crop agriculture within the lake's direct watershed, and 7% is from pasture/grass. The remaining phosphorus load comes from wetlands, the Little Green Lake subwatershed, forested areas, the Lake Emily subwatershed, rural residential areas, medium density urban areas, high density urban areas, Grand Lake's surface, and septic systems (Figure 3.2-2).

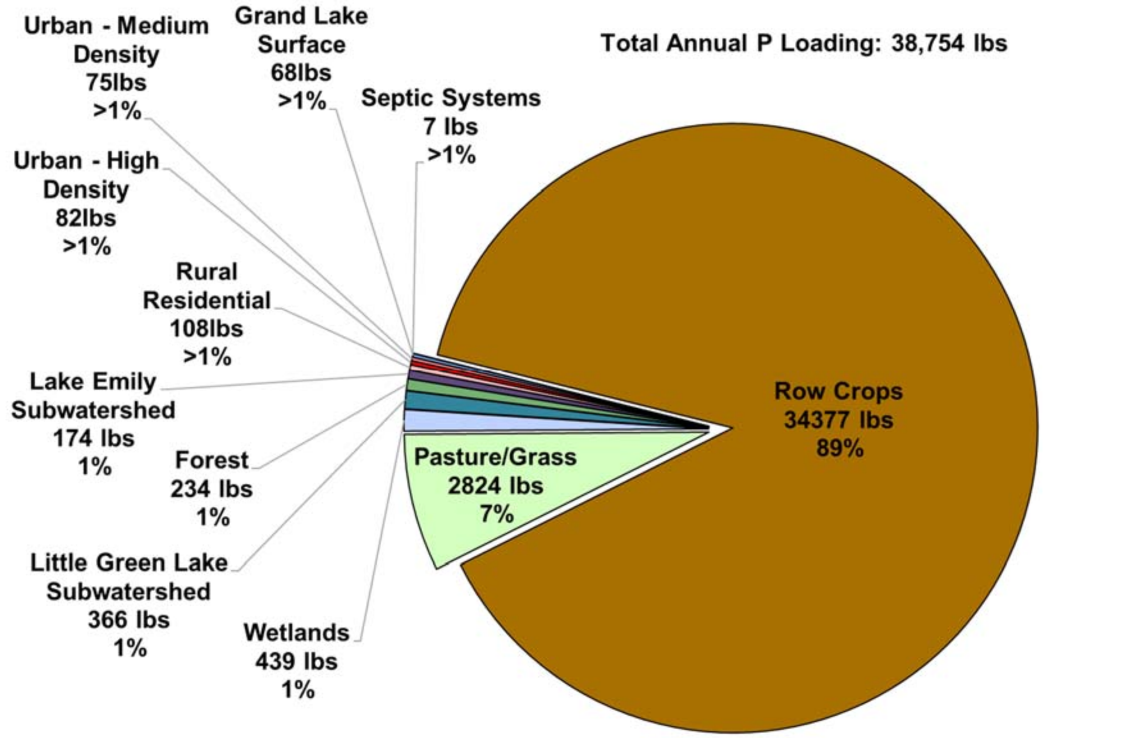


Figure 3.2-2. Grand Lake watershed phosphorus loading in pounds. Based upon Wisconsin Lake Modeling Suite (WiLMS) estimates.

Using predictive equations, WiLMS estimates that Grand Lake should have a growing season mean total phosphorus concentration of approximately 106 µg/L to 190 µg/L. The lower phosphorus concentration estimate of 106 µg/L is likely more realistic due to Grand Lake's high flushing rate and high productivity. Internal nutrient loading likely increases the growing season mean total phosphorus concentrations to around the measured 2016 growing season mean concentration of 145.6 µg/L. Internal nutrient loading is discussed in detail within the Water Quality Section 3.1.

As illustrated in the Water Quality Section, Grand Lake is highly eutrophic to hypereutrophic, meaning the lake is productive to overly productive. While a significant amount of phosphorus comes from agricultural sources within Grand Lake's watershed, it is important to remember that the watershed is tremendously large and the lake's water level is unnaturally maintained by the Kingston Dam. As discussed previously, lakes with a watershed to lake ratio of 10-15:1 or higher have so much land draining to them that regardless of land cover, sufficient phosphorus is available for the lake to be highly productive. Grand Lake has a very high watershed area to lake area ratio of 247:1, and to demonstrate the impact of a watershed of this size on the lake itself, two scenarios were developed using the WiLMS model created for the lake. The first scenario illustrates phosphorus loading if 50% of the watershed's row crop agriculture were converted to forested land and the second if 100% of row crop agriculture were converted to forested land. Currently, Grand Lake's 2016 average growing season mean total phosphorus concentration correlates to a TSI value of 78.0, which falls into the hypereutrophic category. Should 50% or 100% of the lake's direct watershed be converted to forest, it is estimated that the lake would have a TSI value of approximately 78 falling in the hypereutrophic category or 68 falling into the eutrophic category, respectively. This illustrates that even unrealistic changes within the watershed to reduce phosphorus loading would still result in Grand Lake being highly to overly productive. The management plan will need to take Grand Lakes productivity into consideration so that Grand Lake can be the best productive lake possible.

3.3 Shoreland Condition

The Importance of a Lake's Shoreland Zone

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 swimmers 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 swimmers 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).

- <u>Vegetation Removal</u>: 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).

- <u>Impervious surface standards</u>: 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.

- <u>Nonconforming structures</u>: 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

- <u>Mitigation requirements</u>: 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.

<u>Wisconsin Act 31</u>

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 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 in 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 pressured 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 nott 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. • Stakeholders 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.

Grand Lake Shoreland Zone Condition

Shoreland Development

Grand 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.

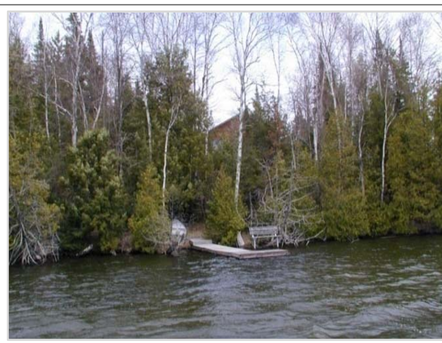
	**Urbanized**: This type of shoreline has essentially no natural habitat. Areas that are mowed or unnaturally landscaped to the water's edge and areas that are rip-rapped or include a seawall would be placed in this category.
	**Developed-Unnatural**: This category includes shorelines that have been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

Grand Lake has stretches of shoreland that fit all of the five shoreland assessment categories. In all, 4.4 miles of natural/undeveloped and developed-natural shoreland were observed during the survey (Figure 3.2-2). 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, 0.8 miles of urbanized and developed–unnatural shoreland were observed. If restoration of the Grand 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. The 2016 shoreland development survey on Grand Lake also revealed that approximately 16% (0.8 miles) of the lake's shoreline contains seawall comprised of either masonry or rip-rap (Table 3.3-1)

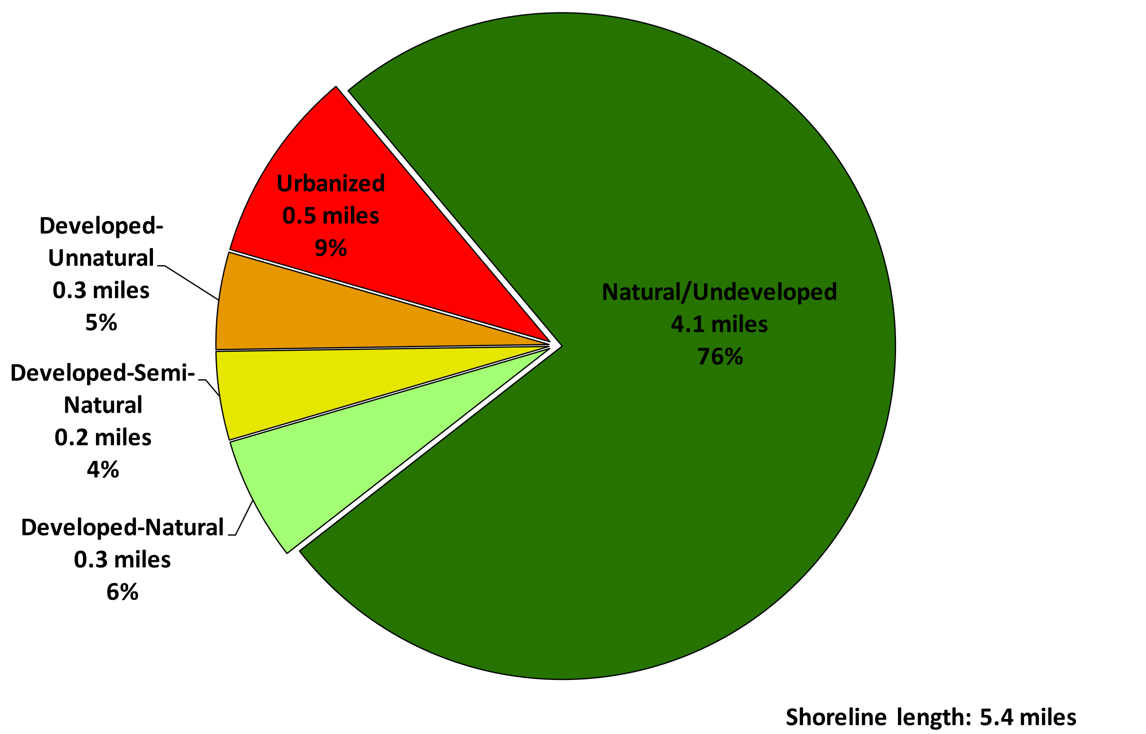


Figure 3.3-2. Grand Lake shoreland categories and total lengths. Based upon an Fall 2016 survey. Locations of these categorized shorelands can be found on Map 3.

Table 3.3-1. Grand Lake shoreland seawall categories and total lengths. Created using data from Fall 2016 shoreland development survey. Locations of these seawalls can be found on Map 3.

Modifier	Length (miles)	% Shoreline
Masonry	0.0	0%
Rip-Rap	0.8	16%
Totals	**0.8**	**16%**

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

Grand 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, 132 total pieces of coarse woody habitat were observed along 5.4 miles of shoreline, which gives Grand Lake a coarse woody habitat to shoreline mile ratio of 25:1. 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).

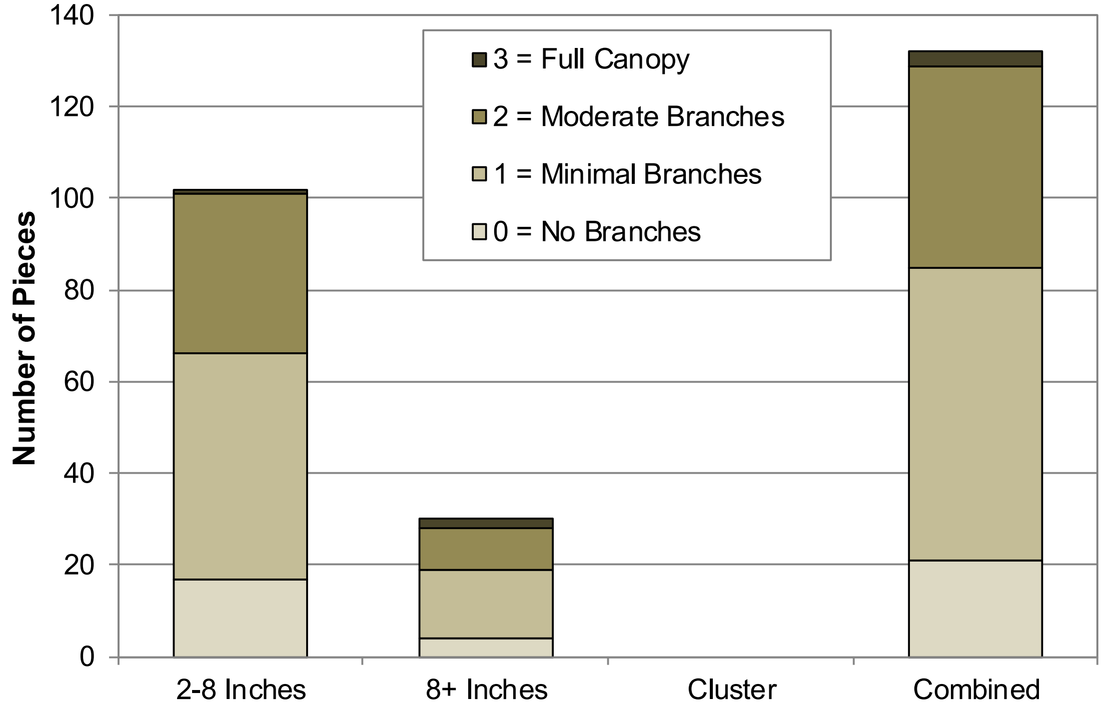


Figure 3.3-3. Grand Lake coarse woody habitat survey results. Based upon a Fall 2016 survey. Locations of Grand Lake coarse woody habitat can be found on Map 4.

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 Grand 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 Grand 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 uses. • 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

Photograph 3.4-4. Granular herbicide application.

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.

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 fishkills 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 water milfoil. Currently the milfoil weevil is not a WDNR grant-eligible method of controlling Eurasian water milfoil.

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 Grand 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 Grand 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 Grand 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 Grand 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 Grand 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 water milfoil (*Myriophyllum spicatum*; EWM) and curly-leaf pondweed (*Potamogeton crispus*; CLP) are the primary targets of this extra attention.

Eurasian water milfoil is an invasive species, native to Europe, Asia and North Africa, that has spread to most Wisconsin counties (Figure 3.4-1). Eurasian water milfoil 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 water milfoil can

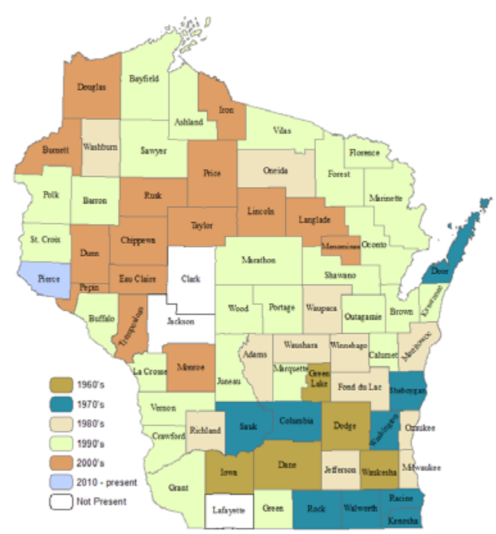


Figure 3.4-1. Spread of Eurasian water milfoil within WI counties. WDNR Data 2011 mapped by Onterra.

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

As mentioned above, numerous plant surveys were completed as a part of this project. On May 31, 2016, an Early-Season AIS Survey was completed on Grand Lake that focused upon locating and mapping occurrences of CLP. This meander-based survey revealed that the majority of Grand Lake supports dense growth of CLP, and that is it likely the dominant plant within the lake in early summer. Because of this plants effects on Grand Lakes ecology, water quality, recreation, and aesthetics, CLP is discussed in detail within the subsequent *Non-native Plants* section. Occurrences of EWM were also located during the late-May survey, and its occurrence within Grand Lake is also discussed within the *Non-native Plants* section.

The whole-lake aquatic plant point-intercept survey was conducted on Grand Lake on September 6 and 9, 2016 by Onterra while the aquatic plant community mapping survey was completed on September 9, 2016. During these surveys, 20 species of aquatic plants were located in Grand Lake (Table 3.4-1), three of which are considered non-native species: curly-leaf pondweed, Eurasian water milfoil, and giant reed (also known as common reed). These species are discussed in detail in the *Non-native Plants* section.

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

Growth Form	Scientific Name	Common Name	Coefficient of Conservatism (C)	2016 (Onterra)
Emergent	*Iris versicolor*	Northern blue flag	5	I
	Iris virginica	Southern blue flag	5	I
	Phragmites australis subsp. *australis*	Giant reed	Exotic	I
	Sagittaria latifolia	Common arrowhead	3	I
	Schoenoplectus acutus	Hardstem bulrush	5	I
	Schoenoplectus tabernaemontani	Softstem bulrush	4	I
	Typha spp.	Cattail spp.	1	I
	Zizania aquatica	Southern wild rice	8	X
Submergent	*Ceratophyllum demersum*	Coontail	3	X
	Chara spp.	Muskgrasses	7	X
	Elodea canadensis	Common waterweed	3	X
	Myriophyllum spicatum	Eurasian water milfoil	Exotic	X
	Myriophyllum verticillatum	Whorled water milfoil	8	X
	Potamogeton amplifolius	Large-leaf pondweed	7	I
	Potamogeton crispus	Curly-leaf pondweed	Exotic	X
	Potamogeton friesii	Fries' pondweed	8	X
	Potamogeton friesii X *P. zosteriformis*	Fries' X flat-stem pondweed	N/A	I
	Potamogeton nodosus	Long-leaf pondweed	5	X
	Ranunculus aquatilis	White water crowfoot	8	X
	Stuckenia pectinata	Sago pondweed	3	X
FF	*Lemna minor*	Lesser duckweed	5	X

FF = Free Floating; X = Located on rake during point-intercept survey; I = Incidental Species

Lakes in Wisconsin vary in their morphology, water chemistry, substrate composition, and recreational use, 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. During the 2016 whole-lake point-intercept survey on Grand Lake, information regarding substrate type was collected at locations sampled with a pole-mounted rake. These data indicate that over 99% of the point-intercept locations contained soft, organic sediments (Figure 3.4-2 and Map 5). As is discussed further, the lack of habitat types in terms of substrate composition is one of the factors Grand Lake supports a relatively low number of aquatic plant species.

Grand Lake is shallow with relatively high water clarity, and aquatic plants were found growing at all depths within the lake. Of the 423 total point-intercept sampling locations, 340 were sampled; the remaining 83 sampling locations were unable to be sampled due to heavy aquatic plant growth and/or shallow water and were mainly located in the southwestern portion of the lake. Of the 340 point-intercept sampling locations sampled, 84% contained aquatic vegetation (Figure 3.1-2 and Map 6), indicating the majority of the lake supports aquatic plant growth. Approximately 46% of the point-intercept locations contained aquatic vegetation with a rake fullness rating of 1, 22% contained a rake fullness rating of 2, and 16% contained a rake fullness rating of 3 (Figure 3.4-2).

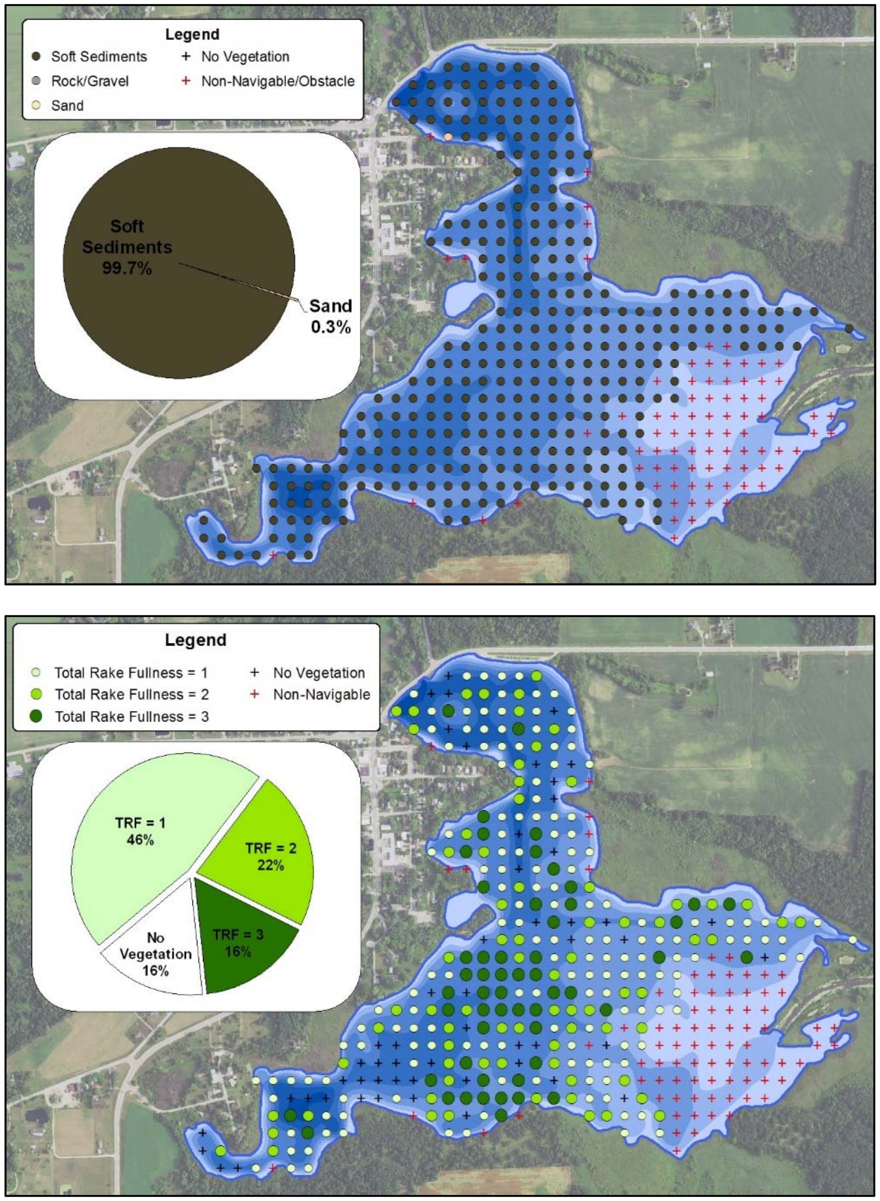


Figure 3.4-2. Grand Lake 2016 distribution of sediment types (top) and vegetation (bottom). Created using data from 2016 whole-lake point-intercept survey.

Of the 20 aquatic plant species located during the 2016 surveys, 13 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 11 species encountered on the rake in 2016, coontail, lesser duckweed, and common waterweed were the three-most frequently encountered (Figure 3.4-3).

Coontail, arguably the most common aquatic plant in Wisconsin, was the most frequently encountered aquatic plant in Grand Lake with a littoral frequency of occurrence of 60% (Figure

3.4-3). 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. Coontail has the capacity to form dense beds which mat on the surface, and this was observed in many areas throughout Grand Lake in the summer of 2016.

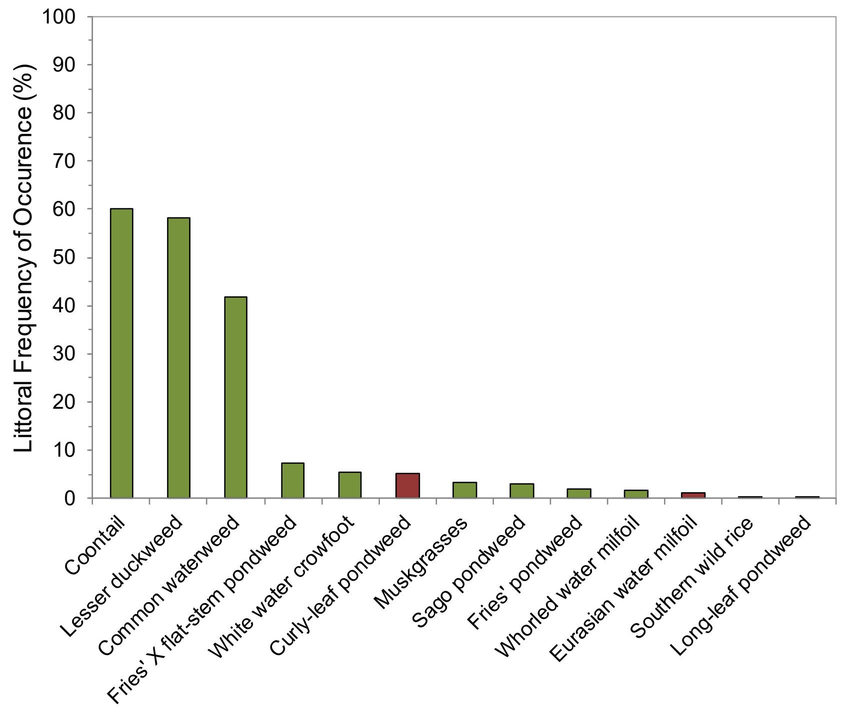


Figure 3.4-3. Littoral frequency of occurrence of aquatic plant species in Grand Lake. Exotic species indicated with red. Created using data from September 2016 whole-lake aquatic plant point-intercept survey.

Lesser duckweed was the second-most frequently encountered species in Grand Lake in 2016 with a littoral frequency occurrence of 58% (Figure 3.4-3 and Photo 3.4-5). Unlike most other aquatic plants, lesser duckweed is free-floating, unattached from the sediment and floating on the surface where it obtains nutrients directly from the water and carbon from the atmosphere (Huebert and Shay 1991). While these plants are flowering plants, they mainly reproduce vegetatively via budding. Under optimal conditions, they can double their population every 16 hours (Hasan and Chakrabarti 2009), allowing them to completely cover areas of waterbodies in a very short time. These plants cannot grow and reproduce in fast-moving water, and require areas of still or slow-moving water.

According to Hasan and Chakrabarti (2009), only a minimal amount of phosphorus within the water is required to support duckweed growth, and once this level has been reached, the concentration of nitrogen, specifically ammonia nitrogen, is main nutrient controlling the growth of duckweeds. If adequate nutrients and light are present, the remaining important factor in determining the growth rate of duckweeds is temperature (van der Heide et al. 2006). The growth rate of duckweeds is positively correlated with water temperature, and their maximum growth rate is achieved when water temperature is at 78.8°F (van der Heide et al. 2006). However, if their density or the thickness of the mat becomes too great, their growth rates decline due to self-shading (Driever et al. 2005).

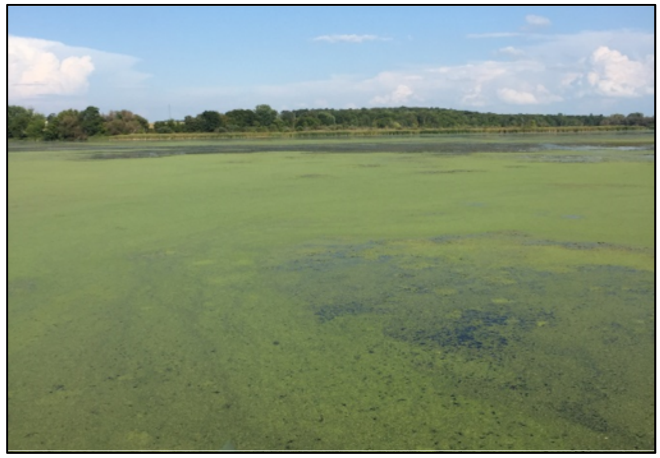


Photo 3.4-5. Thick mat of lesser duckweed (Lemna minor) growing in Grand Lake in 2016. Photo credit Onterra.

During the 2016 surveys on Grand Lake, vast blanket-like mats of duckweed were observed throughout the lake (Photo 3.4-5). The amount of duckweed present within Grand Lake is an indicator of high nutrient levels within the water, particularly ammonia nitrogen. Sources of ammonia nitrogen to lakes include fertilizers and animal wastes and release from anoxic bottom sediments. Ammonia nitrogen was detected in water quality samples collected in late-July at both the deep hole and near-dam sampling locations in 2016. Concentrations at the near-dam location were high at 147 μg/L, likely due to the anoxic conditions and release from bottom sediments. The concentration measured at the deep hole location was 41 μg/L despite the presence of oxygen at this location, and this may be an indication of agricultural runoff to this area.

All of the conditions necessary for producing excessive growth of duckweed exist within Grand Lake, including high nutrient levels (particularly ammonia nitrogen), slow-moving water, abundant sunlight, and warm water temperatures. As is discussed within the Water Quality section, the excessive growth of duckweed in Grand Lake leads to the development of anoxic conditions in summer by inhibiting mixing and reducing light availability to submersed aquatic plants.

Common waterweed, the third-most frequently-encountered aquatic plant with a littoral frequency of occurrence of 42%, is an aquatic plant species with a wide distribution across North America, and like coontail obtains the majority of its nutrients directly from the water. While common waterweed can be found growing in many of Wisconsin's waterbodies, excessive growth of common waterweed is often observed in waterbodies which receive excessive amounts of nutrients. Like coontail, it can tolerate the low light conditions found in eutrophic systems better than many other aquatic plant species. For these reasons, common waterweed has competitive advantages over other aquatic plant species that favor its growth in highly eutrophic systems such as Grand Lake.

As discussed previously, 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 17 native aquatic plant species were located in Grand Lake during the 2016 surveys, only 11 were encountered on the rake during the point-intercept survey. The native species richness for Grand Lake in 2016 (11) falls near the 25th percentile for species richness in lakes within the Southeastern Wisconsin Till Plains (SWTP) Ecoregion and below the 25th percentile for species richness in lakes throughout Wisconsin (Figure 3.4-4). As mentioned earlier, Grand Lake's low species richness is in part driven by the relatively uniform substrate composition found throughout the lake. In addition, only those species which can tolerate low-light and low-oxygen conditions (coontail and common waterweed) can persist amongst the thick mats of duckweed which develop in summer.

While Grand Lake has low native aquatic plant species richness, the average conservatism value of 5.8 for the 11 native species encountered during the 2016 point-intercept survey exceeds the 75th percentile for lakes within the SWTP ecoregion (Figure 3.4-4). This indicates that a larger proportion of the species within Grand Lake's aquatic plant community have higher conservatism values (7-8) when compared to other lakes within the ecoregion. These species with higher conservatism values include southern wild rice, muskgrasses, whorled water milfoil, Fries' pondweed, and white water crowfoot.

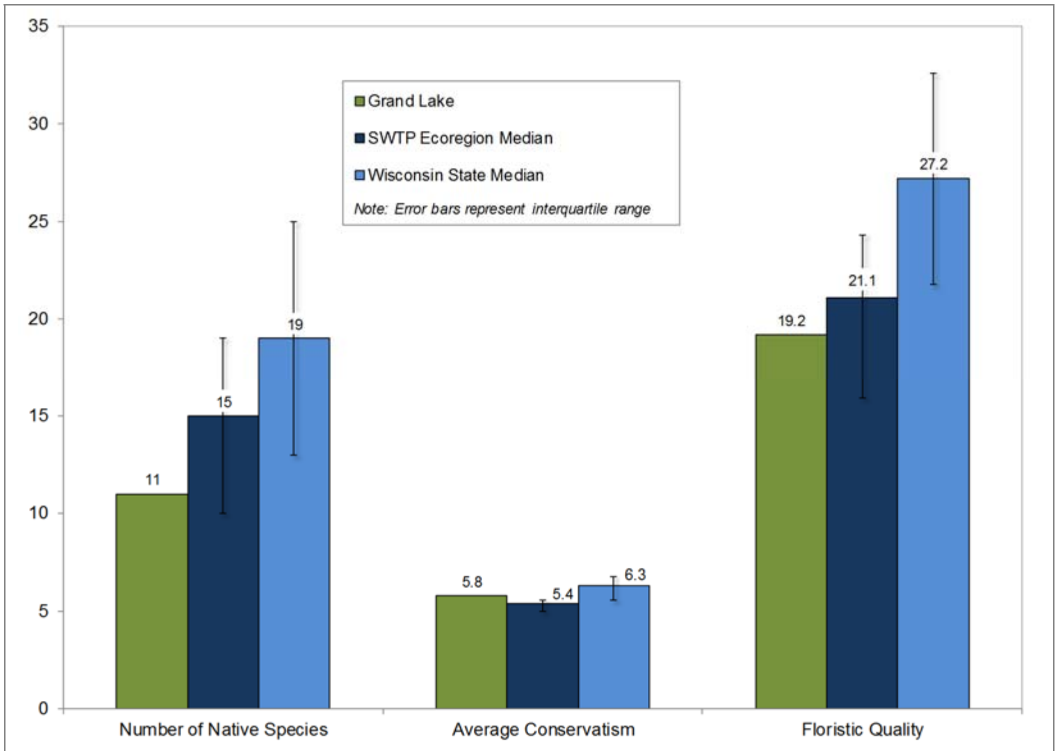


Figure 3.4-4. Grand Lake Floristic Quality Assessment. Created using data from September 2016 surveys. Analysis following Nichols (1999) where SWTP = Southeastern Wisconsin Till Plains Ecoregion.

These species are less tolerant of environmental degradation and their populations were relatively small in Grand Lake with littoral occurrences of 5% or less (Figure 3.4-3). Muskgrasses, whorled water milfoil, and Fries' pondweed were primarily encountered in the southwestern portion of the lake immediately surrounding the deep hole, while white water crowfoot occurrences expanded from the deep hole and slightly eastward. All of these species require higher water clarity, and the lack of duckweed mats within the deep hole area allows these plants adequate light availability. Grand Lake's average conservatism falls below the median value for lakes throughout Wisconsin.

While Grand Lake has higher average conservatism for the SWTP ecoregion, its lower species richness yielded a lower FQI value of 19.2 (Figure 3.4-4). Grand Lake's FQI value falls below the median values for lakes within the SWTP ecoregion and lakes throughout Wisconsin. Overall, this analysis indicates that Grand Lake's aquatic plant community is of lower quality when compared to lakes within the SWTP ecoregion and lakes throughout Wisconsin.

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 Grand 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 3.4-5). Using the data collected from the 2016 point-intercept survey, Grand Lake's aquatic plant community was found to have a Simpson's Diversity Index value of 0.75. In other words, if two individual aquatic plants were randomly sampled from Grand Lake in 2016, there would be a 75% probability that they would be different species. Grand Lake's species diversity value falls below the median values for lakes within the SWTP ecoregion and lakes throughout the state.

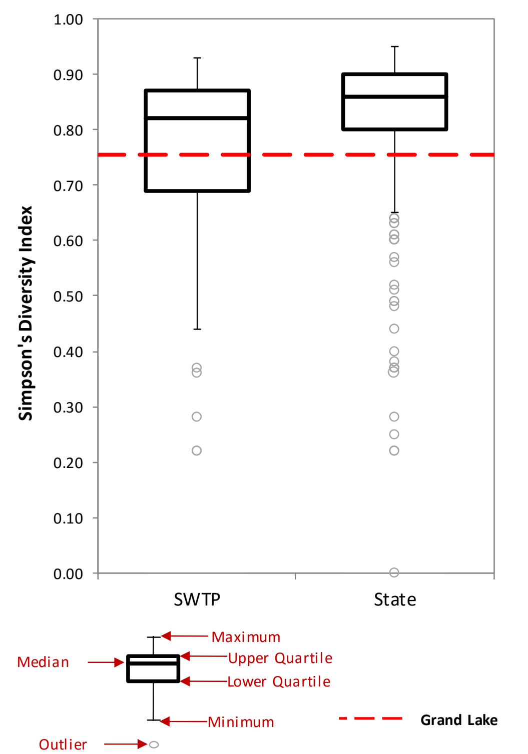


Figure 3.4-5. Grand Lake species diversity index. Created using data from September 2016 whole-lake point-intercept survey.

As explained above 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 coontail was found at 60% of the sampling locations in Grand Lake, its relative frequency of occurrence is approximately 32%. Explained another way, if 100 plants were randomly sampled from Grand Lake, 32 of them would be coontail. Looking at relative frequency of occurrence (Figure 3.4-6), approximately 84% of the plant community in Grand Lake is comprised of just three species: coontail, lesser duckweed, and common waterweed. This dominance of plant community by a small number of species yields low species diversity.

The 2016 community mapping survey revealed that approximately 51.3 acres (20%) of the 253 acre-lake contains emergent aquatic plant communities comprised of seven species (Table 3.4-2 and Map 7). The largest emergent community primarily comprised of cattails can be found in the southeastern portion of the lake in the shallow-water delta formed at the mouth of the Grand River. A larger colony of southern wild rice was also located in the southeastern portion of the lake adjacent to the large cattail colony (Map 7). One of two rice species in Wisconsin, southern wild rice is an annual emergent aquatic grass that grows in shallow water of lakes and slow-moving rivers. It is one of the largest native grass that can be found in Wisconsin.

Unlike northern wild rice which is an important human food source particularly for Native Americans, southern wild rice is not used as a human food source (Judziewicz et al. 2014). However, it is an important diet component for waterfowl, muskrats, deer, and many other species. Established wild rice plant communities can provide valuable nursery and brooding habitat for wetland bird and amphibian species as well as spawning habitat for various fish. Perhaps one of the most overlooked benefits of having established wild rice communities is their ability to utilize excessive plant nutrients, stabilize soils, and form natural wave breaks to protect shoreland areas.

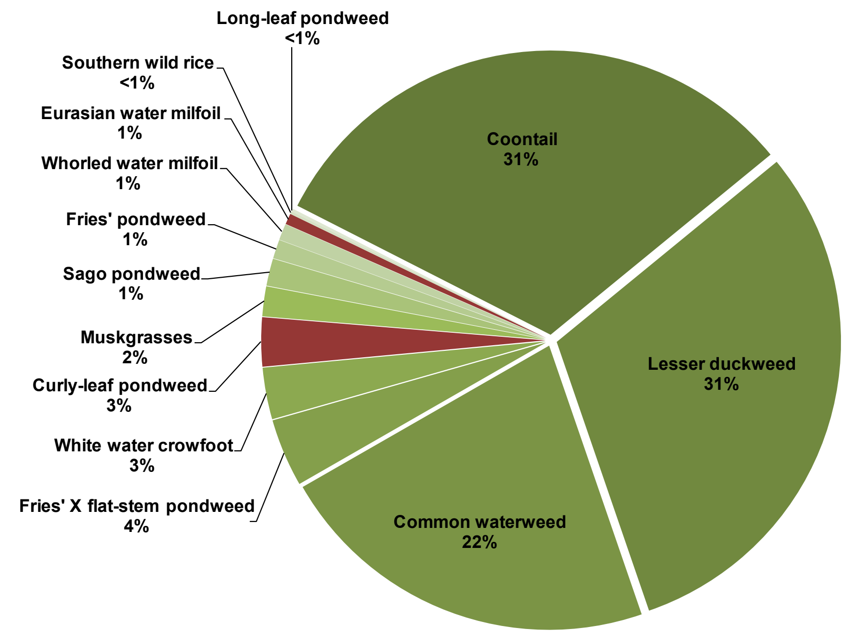


Figure 3.4-6. Relative frequency of occurrence of aquatic plant species in Grand Lake. Exotic species indicated with red. Created using data from September 2016 whole-lake point-intercept survey.

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

Plant Community	Acres
Emergent	51.3
Floating-leaf	0.0
Mixed Emergent & Floating-leaf	0.0
Total	**51.3**

Smaller emergent plant communities were found throughout near-shore areas of the lake in 2016. No floating-leaf aquatic plant species such as white water lily were located. 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 Grand 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.

Non-native Plants in Grand Lake

Curly-leaf pondweed

Curly-leaf pondweed was first documented in Grand Lake in 2008; however, given its widespread nature in 2016, it has likely been in the lake for a longer period of time. Since its discovery within the lake 2008, no management actions have been taken to control this invasive plant. During the late-May Early-Season AIS Survey in Grand Lake, Onterra ecologists mapped approximately 171 acres of CLP (Figure 3.4-7 and Map 8). Of the 171 acres, approximately 136 acres (79%) was comprised of colonies with a density rating of dominant or greater, while 77 acres (45%) was comprised of surface-matted plants.

Photograph 3.4-6. Curly-leaf pondweed, a non-native, invasive aquatic plant. Photo credit Onterra.

The southeastern portion of the lake was non-navigable due to a combination of shallow water and surface-matted plants, but the CLP population did extend into this area. As discussed earlier, CLP naturally senesces in early summer, and its littoral occurrence of 5.3% as determined from the September 2016 point-intercept survey significantly underestimates this population. If the point-intercept survey had been completed in early summer when CLP was at or near it peak growth, its littoral occurrence would most certainly have been greater than 50%.

As is discussed within the Water Quality section, it is believed that the increase observed in total phosphorus concentrations measured at the near-dam location were partially driven by the senescence and decomposition of curly-leaf pondweed in early summer. Given the large size of the CLP population in Grand Lake, it likely is a significant contributor to the internal loading in phosphorus in terms of both direct release from the plant tissues and increased biological oxygen demand from decomposing plants. The dense growth of CLP in Grand Lake likely also inhibits the growth and expansion of native aquatic plant species, and may contribute to the lower species richness found within the lake.

Eurasian water milfoil

Like CLP, EWM was first documented in Grand Lake in 2008. Mapping of EWM typically occurs in mid- to late-summer as this is when this plant is at or near is peak growth. However, given the thick mats of duckweed in Grand Lake in summer, mapping of EWM proved to be difficult. Because of this, locations of EWM mapped during the Early-Season AIS Survey are discussed here. The Early-Season AIS Survey revealed that Grand Lake contained approximately 18 acres of colonized EWM delineated as highly scattered

Photograph 3.4-7. Eurasian water milfoil, a non-native, invasive aquatic plant. Photo credit Onterra.

(Figure 3.4-7 and Map 9). While 18 acres seems substantial, highly scattered indicates the area is primarily comprised of single plant occurrences and not large, monotypic colonies. While EWM has been present within Grand Lake for at least nine years, it is not nearly as widespread or as dense as CLP.

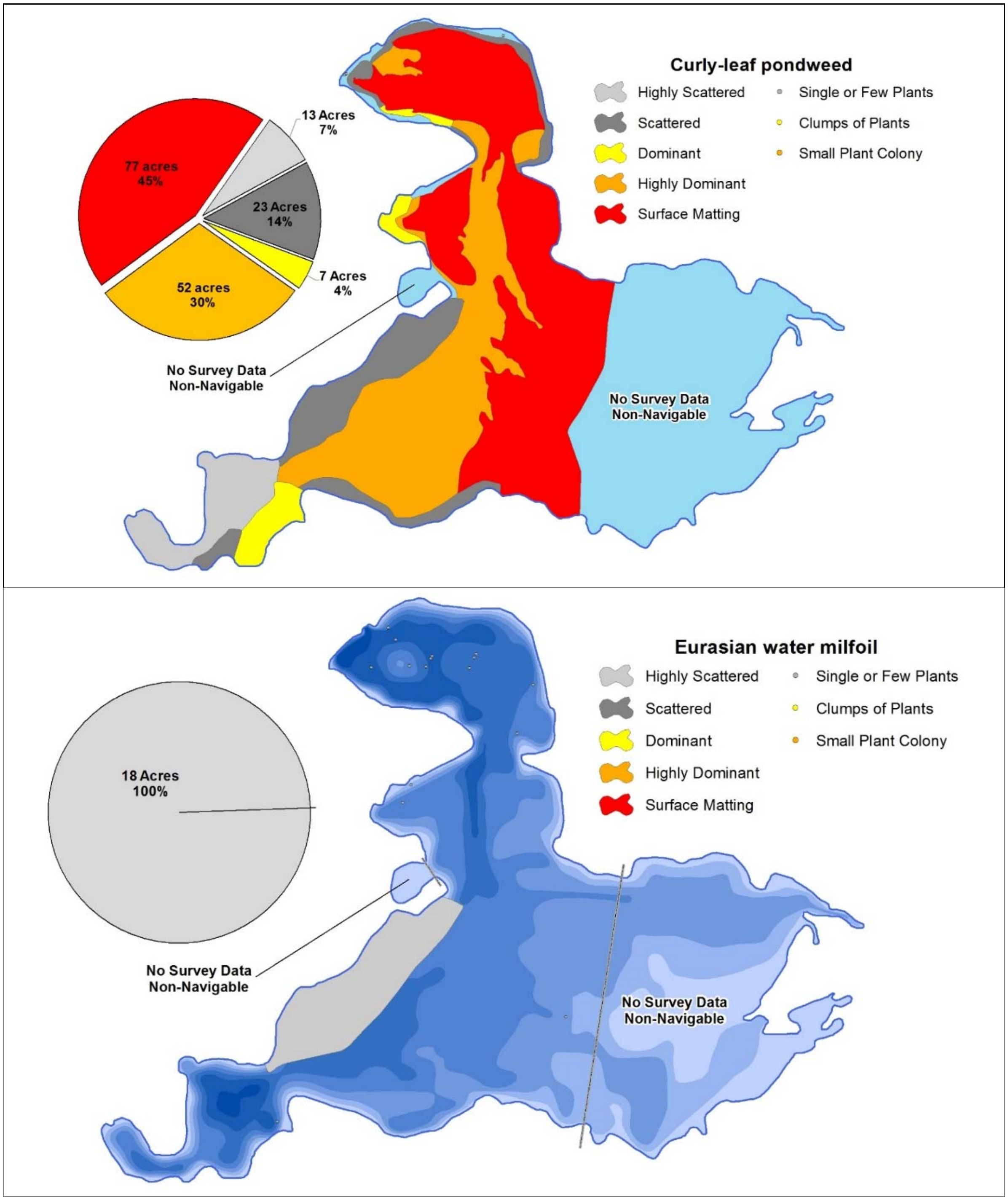


Figure 3.4-7. Grand Lake 2016 curly-leaf pondweed (top) and Eurasian water milfoil (bottom) locations. Locations mapped during survey completed on May 31, 2016.

Giant Reed (aka Phragmites)

Giant reed (*Phragmites australis* subsp. *australis*) is a tall, perennial grass that was introduced to the United States from Europe. While a native strain (*P. australis* subsp. *americanus*) of this species exists in Wisconsin, the plants located along the shorelines and in shallow water in Grand Lake are believed to be the non-native, invasive strain. Giant reed forms towering, dense colonies that overtake native vegetation and replace it with a monoculture that provides inadequate sources of food and habitat for wildlife.

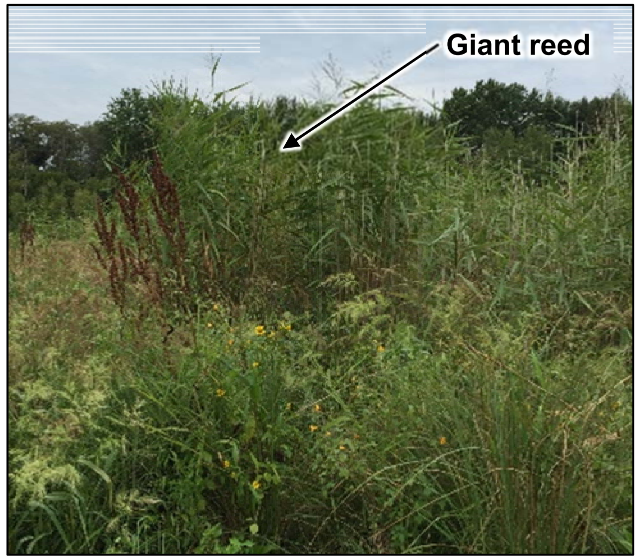


Photo 3.4-8. Colony of giant reed, a non-native invasive wetland grass growing on the shoreline of Grand Lake. Photo credit Onterra.

Two clumps of giant reed were found growing in one location along the southwestern shore of Grand Lake in 2016 (Map 7). The identification between the non-native and native strain is often difficult, and the plants found in Grand Lake had characteristics that were more indicative of the non-native strain. However, these small colonies should be continually monitored to determine if they are expanding. If continual monitoring indicates expansion, an effort should be made to remove these plants. Because this species has the capacity to displace the valuable wetland plants along the exposed shorelines, it is recommended that these plants be removed by cutting and bagging the seed heads and applying herbicide to the cut ends. This management strategy is most effective when completed in late summer or early fall when the plant is actively storing sugars and carbohydrates in its root system in preparation for over-wintering. A permit issued by the WDNR will likely be needed to place herbicide on plants that are located within the water.

Nuisance Aquatic Plant Growth in Grand Lake

When asked how often aquatic plant growth during the open water negatively impacts enjoyment of Grand Lake, the majority of stakeholder survey respondents (69%) indicated *often* or *always*, 15% indicated *sometimes*, 12% indicated *rarely*, and 4% indicated *never* (Figure 3.4-8). When asked during the past three years of the open water season which months have they been displaced from Grand Lake due to aquatic plant growth, 100% of respondents indicated July and August, 93% indicated June, 57% indicated September, 7% indicated May, and 0% indicated March, April, October, and November (Figure 3.4-8). These survey questions indicate that the majority of Grand Lake stakeholders believe recreational use of Grand Lake is hindered by excessive aquatic plant growth, and use of the lake is primarily restricted during the summer months of June, July, and August.

Onterra ecologists observed the dense growth of aquatic vegetation in Grand Lake in 2016 and found it difficult to navigate in most areas. As discussed in the previous section, Grand Lake's shallow nature, composition of primarily organic sediments, and high nutrients are all conducive for excessive aquatic plant growth. In June, CLP is at or near its peak growth, and as revealed by the 2016 Early-Season AIS Survey, is found in high densities at or near the surface throughout much of the lake. In early summer, most of the nuisance conditions are likely created by CLP. By July, the CLP population has begun to senesce and the nuisance conditions are created by surface mats of duckweed, coontail, and common waterweed. The over-abundance of duckweed, coontail, and common waterweed in Grand Lake is an indication of excessive nutrients (phosphorus and nitrogen).

Given the excessive aquatic plant growth in Grand Lake, the majority (88%) of stakeholder survey respondents indicated that they believe aquatic plant control is *definitely* or *probably* needed in Grand Lake, while 4% indicated aquatic plant control is *probably not* needed, and 8% were *unsure* (Figure 3.4-8). As is discussed in the Aquatic Plant Primer section, a number of management strategies are available for alleviating nuisance aquatic plant growth. The management strategy that will be taken to manage nuisance aquatic plant growth in Grand Lak is discussed within the Implementation Plan section.

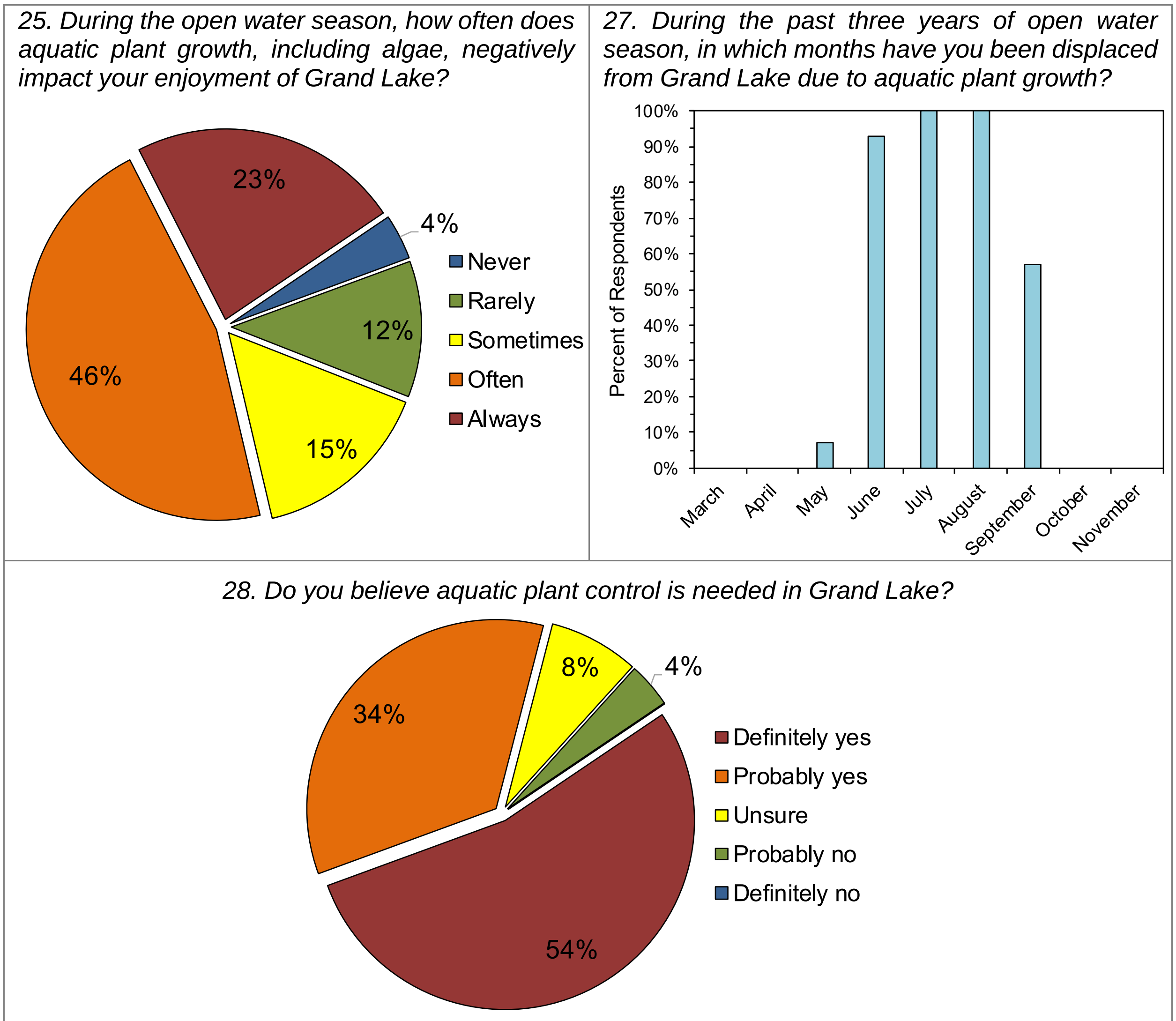


Figure 3.4-8. Grand Lake stakeholder survey response questions regarding nuisance aquatic plant growth. N = 23 respondents.

3.5 Aquatic Invasive Species in Grand Lake

As is discussed in section 2.0 Stakeholder Participation, the lake stakeholders were asked about aquatic invasive species (AIS) and their presence in Grand Lake within the anonymous stakeholder survey. Onterra and the WDNR have confirmed that there are four AIS present (Table 3.5-1).

Table 3.5-1. AIS present within Grand Lake

Type	Common name	Scientific name	Location within the report
Plants	Eurasian water milfoil	*Myriophyllum spicatum*	Section 3.4 – Aquatic Plants
	Curly-leaf pondweed	*Potamogeton crispus*	Section 3.4 – Aquatic Plants
	Giant reed	*Phragmites australis* subsp. *australis*	Section 3.4 – Aquatic Plants
Fish	Common carp	*Cyprinus carpio*	Section 3.5 – Aquatic Invasive Species

Figure 3.5-1 displays the six aquatic invasive species that Grand Lake stakeholders believe are in Grand Lake. Only the species present in Grand Lake are discussed below or within their respective locations listed in Table 3.5-1. While it is important to recognize which species stakeholders 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

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 like Beaver Dam Lake (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.

WDNR fisheries staff believe that while common carp occur in Grand Lake, their abundancies are low and at this time not impacting the lake negatively. It is speculated that Grand Lake's predator fish population is able to keep the carp population in check.

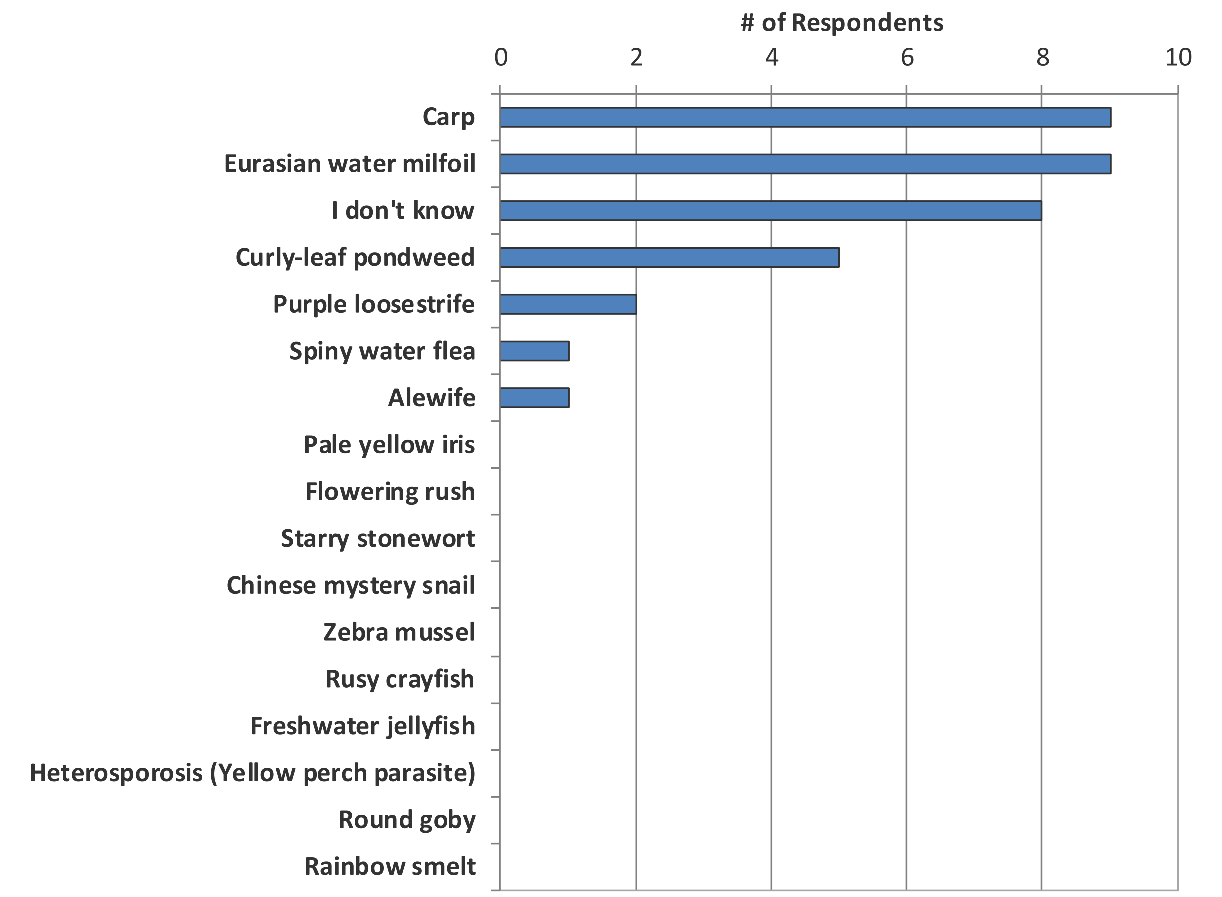


Figure 3.5-1. Stakeholder survey response Question #20. Which aquatic invasive species do you believe are in Grand Lake?

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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 Grand 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) (WDNR 2017) and personal communications with DNR Fisheries Biologist David Bartz.

Grand 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 Grand 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.

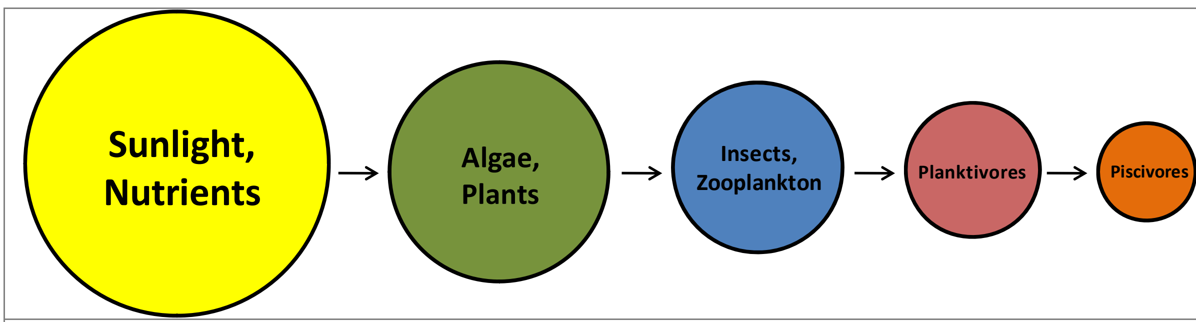

Figure 3.6-1. Aquatic food chain. Adapted from Carpenter et. al 1985.

As discussed in the Water Quality section, Grand Lake is a eutrophic system, meaning it has high nutrient content and thus relatively high primary productivity. Simply put, this means Grand 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.

Additional species that have been documented in Grand Lake include: common carp (*Cyprinus carpio*), golden shiner (*Notemigonus crysoleucas*) and white sucker (*Catostomus commersoni*).

Table 3.6-1. Gamefish present in Grand 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, othe 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
Largemouth Bass (*Micropterus salmoides*)	13	Late April - Early July	Shallow, quiet bays with emergent vegetation	Fish, amphipods, algae, crayfish and other invertebrates
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
Yellow Bullhead (*Ameiurus natalis*)	7	May - July	Heavy weeded banks, beneath logs or tree roots	Crustaceans, insect larvae, small fish, some algae
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 common passive trap used is a fyke net (Photo 3.6-1). Fish swimming towards this net along the shore or bottom will encounter the lead of the net and be diverted into the trap and through a series of funnels which direct the fish further into the net. Once reaching the end, the fisheries technicians can open the net and sort the fish captured. Fyke nets were used on Grand Lake in Spring 2014 to identify/measure species present and assess the overall fish population (Bartz 2015).

Photo 3.6-1. Fyke net positioned in the littoral zone (Photo from Kangaroo Lake WI, WDNR-2013)

The other commonly used sampling method is electroshocking. This is done, generally 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, *galvanotaxis* stimulates their nervous system and involuntarily causes them to swim toward the electrodes. When the fish are in the vicinity of the electrodes, they undergo *narcosis* (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. Electroshocking was conducted in late spring on Grand Lake to evaluate the bass and panfish populations (Bartz 2015).

Once fish are captured, using the appropriate method, data such as count, species, length, weight, sex, tag number, and aging structures may be recorded and the fish released. WDNR fisheries biologists use this data to make recommendations and informed decisions on managing the future of the fishery.

Fish Stocking

Photo 3.6-2. Fingerling Muskellunge.

To assist in meeting fisheries management goals, the WDNR may stock fingerling (Photo 3.6-2) to adult fish in a waterbody that were raised in permitted hatcheries. 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. In Grand Lake, large-scale fish toxicant treatments have occurred in 1969 and 1992 in efforts to remove rough fish such as carp and suckers (WDNR). Following these treatments, stocking efforts were undertaken to restore the fishery with more desirable species. Northern pike, walleye and largemouth bass have been historically stocked in Grand Lake and the available stocking efforts are listed below on Table 3.6-2. The last documented fish stocking activity in Grand Lake occurred in 1998.

Table 3.6-2. Stocking data available for Grand Lake (1976-1998).

Year	Species	Strain (Stock)	Age Class	# Fish Stocked
1976	Walleye	Unspecified	Fry	4,985,000
1976	Northern Pike	Unspecified	Fry	2,000,000
1979	Northern Pike	Unspecified	Fry	500,000
1993	Largemouth Bass	Unspecified	Fingerling	800
1993	Northern Pike	Unspecified	Fry	268,800
1994	Largemouth Bass	Unspecified	Fingerling	23,400
1994	Northern Pike	Unspecified	Fry	500,000
1995	Largemouth Bass	Unspecified	Fingerling	23,400
1996	Largemouth Bass	Unspecified	Fingerling	50,000
1996	Northern Pike	Unspecified	Fry	500,000
1997	Largemouth Bass	Unspecified	Large Fingerling	23,497
1997	Northern Pike	Unspecified	Large Fingerling	20,000
1997	Northern Pike	Unspecified	Fry	331,433
1998	Largemouth Bass	Unspecified	Small Fingerling	23,400

Fishing Activity

Based on data collected from the stakeholder survey (Appendix B), fishing was tied with nature viewing for the highest ranked important reason for owning property on or near Grand Lake (Question #17), ice fishing was the 2nd most important reason. Figure 3.6-2 displays the fish that Grand Lake stakeholders enjoy catching the most. These same respondents were split as to how they perceived the quality of fishing on the lake, with *fair* being the most common response (Figure 3.6-3). Approximately 75% believe that the quality of fishing has remained the same or gotten worse since they have obtained their property (Figure 3.6-4).

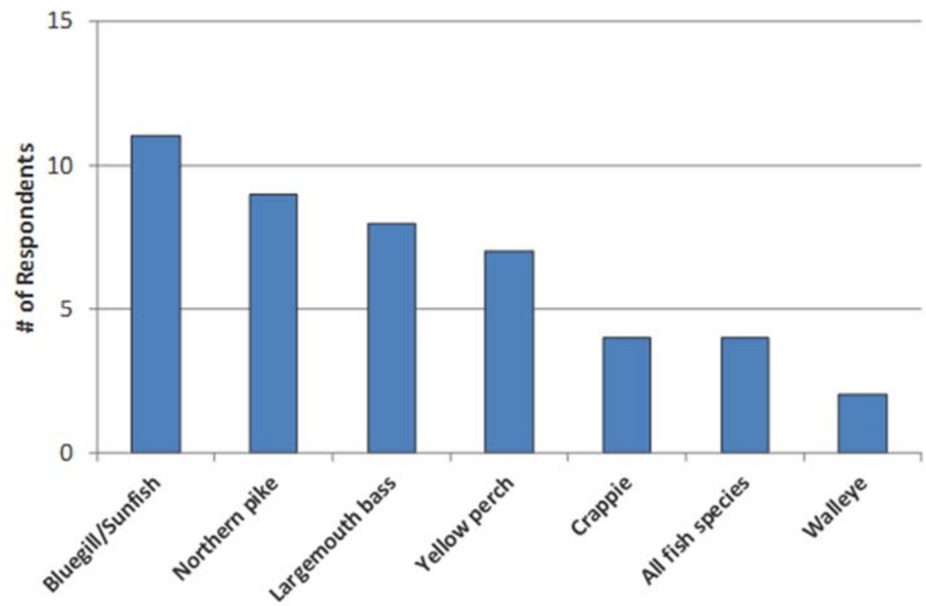

Figure 3.6-2. Stakeholder survey response Question # 11. What species of fish do you like to catch on Grand Lake?

Figure 3.6-3. Stakeholder survey response Question #12. How would you describe the current quality of fishing on Grand Lake?

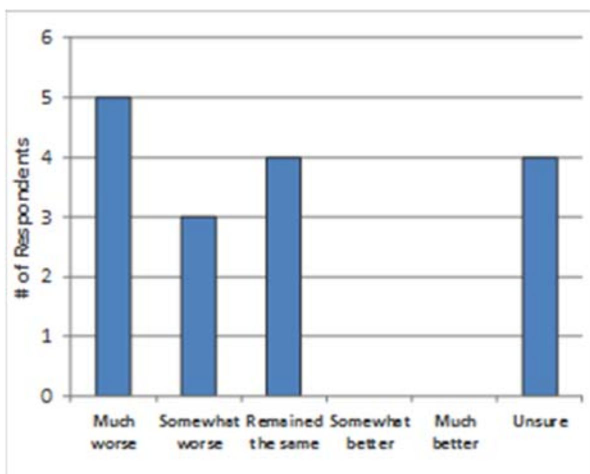

Figure 3.6-4. Stakeholder survey response Question #13. How has the quality of fishing changed on Grand Lake since you started fishing the lake?

Grand Lake Fish Habitat

Substrate Composition

Just as forest wildlife require 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/soft substrate, many aquatic plants, and coarse woody debris may produce a completely different fishery than lakes that are largely sandy/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, nearly 100% of the substrate sampled in the littoral zone of Grand Lake was composed of soft or mucky sediments.

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).

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 (WDNR 2014). 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 132 pieces of coarse woody habitat along the shores of Grand Lake, resulting in a ratio of approximately 25 pieces per mile of shoreline.

Like fish sticks, fish cribs provide the same benefits of adding woody habitat density to the lake. They are typically built using hardwood logs strapped together filled with branches inside (Photo 4). A WDNR permit may be required to install a fish crib, depending on the size and location of placement.

Grand Lake may be an excellent candidate to consider enhancing coarse woody habitat through the deployment of fish sticks or fish cribs.

Photo 3.6-3. Fish Crib Example. (Photo courtesy of Silver Lake District 2009)

Regulations and Management

The current (2016-2017) regulations for Grand Lake gamefish species is displayed in Table 4. 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 3.6-3. WDNR fishing regulations for Grand Lake (2016-2017).

Species	Season	Regulation
Panfish	Open All Year	None; Daily bag limit is 25
Largemouth bass and smallmouth bass	May 7, 2016 to March 5, 2017	14"; Daily bag limit is 5
Muskellunge and hybrids	May 7, 2016 to December 31, 2016	40"; Daily bag limit is 1
Northern pike	May 7, 2016 to March 5, 2017	26"; Daily bag limit is 2
Walleye, sauger, and hybrids	May 7, 2016 to March 5, 2017	15"; Daily bag limit is 5

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 3.6-4. 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 3.6-5. 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/)

Conclusions

Based on the most recent fisheries surveys conducted on Grand Lake in 2014, many species, including northern pike, largemouth bass, bluegill, black crappie, pumpkinseed and yellow perch have naturally reproducing populations and the fishery appears to be in stable condition (personal. communication, David Bartz 2017). Common carp, although present in the system, do not appear to be causing a significant stress on the fishery perhaps due to an adequate population of predator fish in the lake.

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 Grand Lake ecosystem.
2) Collect detailed information regarding invasive plant species within the lake, with the primary emphasis being on curly-leaf pondweed.
3) Collect sociological information from Grand Lake stakeholders 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 Grand Lake ecosystem, the folks that care about the lakes, and what needs to be completed to protect and enhance them.

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Grand Lake is a manmade aquatic ecosystem with a tremendously large watershed. Without the efforts of humans, a system like Grand Lake would not exist in nature because the basin would be eroded quickly down to the river channel and/or filled in with sediments to the level of the river channel. This is because of the large volume of water delivered annually by the 63,000-acre watershed. These facts need to be kept in mind in regards to the management of the lake as the watershed largely dictates the condition of the lake now and into the future. This does not mean that Grand Lake is unable to provide quality recreational opportunities, including fishing, waterfowl hunting, pleasure boating, and of course scenic viewing. But it does mean that there is a limit to what can be done to manage the lake's water quality and aquatic plant community. The impact of agriculture within the Grand Lake watershed is significant and has likely been largely responsible for the lake's hypereutrophic (overly productive) condition. However, watershed modeling completed during this project indicates that even if 100% of the row crop agriculture in the lake's watershed were converted to forest, the best possible landcover type, that the lake would still be eutrophic (highly productive), but likely not overly productive as it is at times currently.

Unfortunately, there are no historical water quality data available for Grand Lake, so there is no way of knowing how the lake's water quality has changed over the years. As a part of this management planning project, water quality samples were collected near the dam and at the lake's deepest spot in the southwest end of the lake. The water quality of these two sites are very different from each other with the deep-hole site being good when compared to other drainage lakes in the state and the near-dam site being poor. The deep-hole site is impacted by the tributary watershed to a much lesser degree than the near-dam site and is illustrated in the differing water quality between the two sites.

The influence of the tributary watershed is not the only factor impacting the water quality of the near-dam site and likely most of the remaining lake beyond the southwest bay. In many shallow lakes, internal loading of phosphorus plays a big role in the nutrient budget of the lake and drives algal blooms and macrophytic growth. In general, internal loading of phosphorus is the recycling of phosphorus within the lake itself, in most cases the phosphorus comes from the bottom sediments. The phosphorus can be released from the sediments due to anoxic (no oxygen) conditions brought on by thermal stratification and decomposition and by high pH levels. Carp and other bottom-feeding fish can also cause the release of phosphorus from the bottom sediments.

Grand Lake's internal nutrient loading issues are brought on in two phases and likely occur to some degree each growing season. The process begins with the heavy growth of curly-leaf pondweed beginning in the spring, followed by the plant's early senescence near the end of June. This early die-back, which is normal for curly-leaf pondweed, is followed by the decomposition of the plant's biomass. This not only consumes large amounts of oxygen in the water column, but also results in a large amount of phosphorus release from the biomass itself and the sediments due to the anoxia. This spurs the growth of the three vascular plant species that dominate the surface of the lake for the remainder of the growing season: coontail, duckweed, and common waterweed. Duckweed is never rooted to the sediments and the other two species typically are not either. Together, these species shade the majority of the lake's water column severely limiting not only rooted plant growth, but also the diffusion of atmospheric oxygen. The lack of oxygen diffusion results in anoxic conditions, likely in much of the lake, and the release of phosphorus from bottom sediments. While the amount of phosphorus released by this process into the water volume pales in comparison to what arrives from the watershed, it occurs during the lowest flows of the year, which leads to a higher impact in the lake because the phosphorus is not quickly flushed out like phosphorus that arrives from the watershed during spring runoff.

Fortunately, the high phosphorus levels in Grand Lake do not translate into massive algal blooms as they do in other shallow lakes, like nearby Puckaway and Little Green lakes. In fact, both sampling sites in Grand Lake showed good chlorophyll-*a* levels when compared to other drainage lakes in the state. This clear water is likely brought on by the shading of the three dominant plant species as discussed above. These low algal levels, as indicated by the low chlorophyll-*a* levels, bring about relatively clear water at both sites.

The early growth of curly-leaf pondweed, and subsequent growth of duckweed, coontail, and common waterweed that its death and decomposition bring on, does much to dictate the composition of the remaining aquatic plant community within and around the lake. Grand Lake's aquatic plant community, during 2016, was found to be of lower quality and diversity than most lakes in the state and ecoregion.

Grand Lake does have great potential as a recreation lake for anglers, hunters, and passive boating sports. Over three-quarters of the lake's shoreline is in a natural, undeveloped state and in areas of that shoreline that are not wetlands, there is a high occurrence of coarse woody habitat. Further, the lake supports large areas of emergent plant growth, albeit dominated by cattail.

Reducing the abundance of curly-leaf pondweed within in Grand Lake is the key to bettering the lake as a whole. As described above and within several of this plan's report sections, curly-leaf pondweed greatly impacts water quality and the aquatic plant community. While curly-leaf pondweed cannot be eradicated from Grand Lake, its abundance can be reduced, which may lead to positive changes in the lake's water quality and aquatic plant community. Two options were discussed among the planning committee to control curly-leaf pondweed; 1) extended water level drawdown, likely beginning in fall of one year, extending through the winter and next growing season, and the following winter, and 2) whole-lake, low dose herbicide treatments completed in successive years, likely seven. Both options have advantages and disadvantages to them. The drawdown would likely control curly-leaf pondweed while enhancing the emergent plant community and consolidating flocculant bottom sediments; the latter leading to greater depth and volume in the lake. However, some drawdowns have resulted in large increases in emergent plant species, which along with the loss of recreational use of the lake for approximately 18 months, is unacceptable to some lake stakeholders. Often, stakeholders are concerned that the drawdown would decimate the fishery; however, this is not typically the case with systems with large tributaries like Grand Lake that provide refuge for the fish during the action. Further, there is always an increase in quality fish habitat after a drawdown, so that leads to a healthier and more diverse fishery overall.

Photo 5.0-1 a & b. Emergent plants in Grand Lake following late 1990s drawdown. (Photos courtesy of Darin Nikolai)

Herbicide treatments for curly-leaf pondweed utilizing endothall are typically very successful if completed properly, which includes correct dosing and timing of application. However, as discussed with the planning committee during the planning process and the general public during the project wrap-up meeting, due to curly-leaf pondweed's lifecycle, to truly reduce the population, treatments must be completed annually to reduce the turion bank in the sediment and thus reduce the population. The number of annual treatments it will take to achieve the goal of significantly reducing the population is unknown, but typically it takes 5-7 years. Further, endothall is an expensive herbicide, so the cost of the annual treatments, especially when used on a whole lake scale, are high. Finally, there is always a risk of unintended environmental consequences when utilizing herbicides. Non-target species will likely be impacted, that is known. The potential risks to humans, wildlife, and fish are not completely understood because most studies completed as a part of the product registration focused upon short exposure times at high doses. The high dose/short exposure time *use pattern* is typically utilized when treating small areas of curly-leaf pondweed or other plants with endothall. However, the use pattern of the Grand Lake curly-leaf pondweed control strategy calls for a low dose of endothall sustained for a period of days. This use pattern is not as well studied; therefore, there are unknows that need to be considered when developing the herbicide treatment strategy.

After much discussion and consideration, the GLIA decided to move forward with the herbicide option over that of the drawdown. In the late 1990s, the lake was drawn down for a significant period while State Highway 44 was being reconstructed and the Kingston Dam was being updated.

While specific studies were not completed to quantify changes in the lake, many Kingston residents remember an incredible increase in emergent plants, mostly cattails with some bulrush following the drawdown (see Photos 5.0-1 a & b, above). Anecdotal observations recall these emergent plants hampering navigation and other lake uses for nearly a decade following the restoration of water levels after the construction project was complete. Many residents stated that the lake is finally back to a useable state now that the emergents have decreased to pre-drawdown levels and that they do not want to risk losing the use of the lake again because of another similar action.

The implementation plan that follows this section contains two management goals developed by the Grand Lake Improvement Association Planning Committee during the three planning meetings held as a part of this project. The first goal centers on improving the overall health of the Grand Lake ecosystem and includes an action calling for the use of herbicides to control the lake's expansive curly-leaf pondweed population. The second goal focuses upon strengthening the capacity of this newly-created organization to assure it is able to implement this plan as well as other lake-related activities well into the future.

5.0 IMPLEMENTATION PLAN

The Implementation Plan presented below was created through the collaborative efforts of the Grand Lake Improvement Association Planning Committee, Green Lake County, and ecologist/planners from Onterra. It represents the path the GLIA 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, as well as other projects, and the needs of the Grand Lake stakeholders as portrayed by the members of the Planning Committee, the returned stakeholder surveys, and numerous communications between Planning Committee members and the lake stakeholders. 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 Overall Ecological Condition of Grand Lake

The ecological health of Grand Lake is in great disrepair. Early in the growing season, the lake is highly dominated by a single exotic plant species. That plant's dominance and subsequent early summer senescence creates low aquatic plant diversity in the lake and poor water quality conditions, including likely anoxia within much of the lake's volume during the summer months.

Management Action:	Initiate volunteer-based annual water quality monitoring of Grand Lake through the WDNR Citizen Lake Monitoring Network.
Timeframe:	Initiate 2018
Facilitator:	GLIA Board of Directors
Funding Source:	The CLMN Program is funded through a grant the WDNR administers
Description:	Little historical water quality data exists for Grand Lake, making trends analysis impossible as a part of this management planning process. Creating a long-term water quality database is important in the management of any waterbody because it brings about an understanding of how the system has changed over time. It also allows the lake group to document changes in water quality brought about by management activities and initiate additional actions as needed. The Citizen Lake Monitoring Network (CLMN) is a WDNR program in which volunteers are trained to collect water quality information on their lake. The GLIA Board of Directors will recruit and coordinate volunteers to regularly collect these data. When a volunteer or group of volunteers have been selected, Ted Johnson (920-424-2104) or the appropriate WDNR/UW-Extension staff should be contacted so that the volunteers receive the appropriate training and equipment. Volunteers would start collecting solely water clarity data using a Secchi disk from the two water quality monitoring sites used during this project, four times or more each year during May, June, July, and August. A couple of years into the CLMN program, volunteers would likely start collecting water samples that would be analyzed for total

phosphorus and chlorophyll-*a*. It is also important to note that as a part of this program, the data collected are automatically added to the WDNR database and available through their Surface Water Integrated Monitoring System (SWIMS) by the volunteer.

Action Steps:

1. The GLIA Board of Directors recruits a volunteer(s) to collect water quality data four times per year on Grand Lake.
2. Volunteer(s) contact Ted Johnson (920-424-2104) to receive monitoring training and necessary collection materials.
3. Trained CLMN volunteer(s) collects data and reports results to WDNR (SWIMS database) and to district members at annual meeting.
4. The GLIA Board of Directors recruits new CLMN volunteers as needed.

Management Action: Continue monitoring curly-leaf pondweed population and aquatic plant community in Grand Lake.

Timeframe: Initiate 2019

Facilitator: Green Lake County Land Conservation Dept.

Funding Source: Green Lake County and AIS-Education, Prevention, and Planning Grants through Golden Sands Resource Conservation & Development Council, Inc.

Description: Understanding the changes in the curly-leaf pondweed population along with those of the other aquatic plants in the lake is important to understanding how to control the curly-leaf pondweed. It would also add to the little baseline data that exists for the Grand Lake aquatic plant community while assuring that the most up-to-date information is available for finalizing the control strategy described in the following management action.

Depending on available funding and staff time, Green Lake County LCD staff, with the assistance of Golden Sands RCDC staff, will monitor curly-leaf pondweed in Grand Lake by mapping the population by density biannually. The result of these surveys would be an updated map similar to Map 8 of this management plan. Further, if funding is available, these agencies will also partner to complete point-intercept plant surveys when possible with 2020 being targeted for the first survey.

Volunteers from the GLIA would be enlisted to assist with these surveys. This would keep the GLIA closely involved with monitoring the lake beyond the water quality monitoring described in the preceding action.

Following each survey, the WDNR and GLIA would be supplied with an updated map, appropriate raw data, and a brief narrative.

Action Steps: See description above.

Management Action:	Reduce and control curly-leaf pondweed population in Grand Lake.
Timeframe:	Initiate once sustainable local funding is available
Facilitator:	GLIA Board of Directors
Funding Source:	Aquatic Invasive Species Established Population Control Grant (2)
Description:	During the spring of 2016 surveys, curly-leaf pondweed was found to dominate the Grand Lake plant community (Map 8). The exceedingly abundant curly-leaf pondweed dictates the condition of the lake for the entire growing season even though the bulk of its population dies back by early July. Simply, as the plant grows vigorously during the spring and early summer, it takes up large quantities of phosphorus and acts as a growing substrate for three native species that dominate the community after the curly-leaf pondweed dies off. When the curly-leaf pondweed dies back, its decomposition releases phosphorus into the lake that is taken up by duckweeds, coontail, and common waterweed, all of which are not rooted in the lake's substrate, but instead float on the surface in a tangled mass preventing light penetration, only providing oxygen to the very upper portion of the water column, and shading plant growth below.

Removing the bulk of curly-leaf pondweed from Grand Lake's early-season plant population will likely reduce the opportunity for duckweeds, coontail, and common waterweed to dominate the system throughout the majority of the growing season. Without those plants shading the majority of the Grand Lake water column, other native plants will have the opportunity to grow.

Herbicide Control and Monitoring Strategy

Contingent Upon Stable Local Funding

The herbicide control strategy outlined below is based upon curly-leaf pondweed levels found in Grand Lake during the early summer of 2016. The description below is general in nature and would be refined within the grant application based upon the latest information. The initiation of this strategy depends on the availability of local funds to match the state funds in an AIS-EPC Grant. Once the GLIA determines that their share of the funding is stable, a grant application can be submitted and the project can begin. Overall goal of the project would be to reduce the curly-leaf pondweed population to the point that no dominant, highly dominant, or surface-matting colonies would be present the year following the 5th treatment.

Full WDNR Funding Contingent Upon Tracer-Dye Study Results

Utilizing herbicides in shallow impoundments often leads to ineffective treatments because herbicide concentrations cannot be maintained at sufficiently high concentrations for a sufficient contact time to cause target plant mortality. However, successful Eurasian watermilfoil and curly-leaf pondweed treatments utilizing herbicides have been completed on similar systems where the flow over the dam can be controlled prior to and just after the application. For instance, effect treatments of Eurasian watermilfoil have been completed in the channel upstream and downstream of the Burnt Rollway Dam that controls the water levels in the Three Lakes Chain upstream of the Eagle River Chain (controlled by the Otter Dam). In both of these treatments, which were completed years apart, water residence times are a matter of days, which brought about concern over meeting concentration-exposure times needed for an effective treatment. In both cases, water levels were lowered as much as possible in the days preceding the treatment and slowly brought up to normal by releasing the minimum flow allowed by the agreement. Both treatments resulted multiple year control of Eurasian watermilfoil.

Antigo Lakes were first treated for curly-leaf pondweed in 2013. The management planning project completed for the system a year earlier determined the system had a residence time of less than 4 days. Although water levels were lowered and slowly brought back up to normal, the 2013 treatment only met with marginal success. In 2014, 3 of the lake's 4 basins were treated for the second time except the starting doses were increased slightly to make up for the loss down stream due to flow. As a result, all three basins observed 1-5 day average endothall concentrations exceeding 0.600 ppm a.e. Curly-leaf pondweed was found to be significantly decreased as a result of the treatment.

The treatment strategy proposed for Grand Lake is outlined below. It would include controlling water levels and flow at the dam to reduce dilution brought on by the lake's estimated residency time of 5.2 days. It would also include sufficient initial dosing to extend concentration-exposure time. Still, the best method to determine if the dosing and water control strategy is appropriate is to conduct a field trial utilizing in situ dye fluorometry (sometimes referred to as rhodamine dye or tracer-dye study). The tracer-dye study on Grand Lake would be funded by a one-year WDNR grant. The results of that trial would determine if the WDNR would consider the strategy eligible for funding through the AIS-Established Population Control (AIS-EPC) Grant program. To be eligible, the tracer-dye study would need to indicate that the dosing and water control strategy would reasonably meet concentration-exposure times found in other successful treatments. If the results are not acceptable to the project partners, the GLIA will reconsider initiating a drawdown project as described in the Summary & Conclusions Section 4.0.

Monitoring Strategy

Monitoring would be completed in association with the herbicide treatments to determine impacts to curly-leaf pondweed, non-target species, and to refine the treatment strategy as needed during the course of the control project. In general, three surveys would be completed each year 1) a pretreatment survey to refine treatment areas before herbicide application and to assure that the curly-leaf pondweed population is growing and ready for treatment, 2) an early-season AIS survey completed in late June or early July to examine the lake for remaining or rebounding curly-leaf pondweed, and 3) a full point-intercept survey to quantitatively document the aquatic plant community as the project progresses. A year after the final treatment, an early-season AIS survey and point-intercept survey would be completed to assess the overall program effectiveness on the curly-leaf pondweed population and determine impacts to non-native species. Annual reports would be completed during the project, including a full report and updated control strategy during the final year of the project.

Herbicide Treatment Strategy

Map 10 displays the results of the 2016 curly-leaf pondweed mapping during the early-season AIS survey completed that year, a generalized treatment area, and the dosing information for the treatment area that would result in a calculated whole lake concentration of 0.750 ppm endothall ai (0.532 ppm ae). This dosing strategy would be adjusted annually based upon treatment area and measured concentrations following each year's application. Prior to any treatment being completed, this strategy would be modified to include the most up-to-date information and technology available and may result in a new dosing strategy for endothall or the incorporation of a totally different herbicide.

Grant Specifics

As of fall 2017, the total project cost for completing 5 annual treatments and monitoring the lake for 6 years is approximately $130,200. This estimate includes $35,000 for each treatment and $6,000 each year for monitoring and reporting. This project would be funded with two sequential AIS-EPC Grants, each likely requesting a 65% state share.. Appendix F contains an example financial plan developed for the grant project.

Action Steps: See description above.

Management Goal 2: Increase the Capacity of the Grand Lake Improvement Association to Manage Grand Lake

The Grand Lake Improvement Association was founded in 2016 and has already made great strides in building membership and communicating with those members. The management actions below will further stabilize the group and increase its ability to be the primary management entity for Grand Lake.

Management Action:	Create GLIA Communication & Education Committee
Timeframe:	Initiate 2018
Facilitator:	Board of Directors
Funding Source:	Small-Scale Planning Grant could include some aspects of initial set-up, such as training and printing.
Description:	The GLIA has created a brochure and website to provide information about the association to current and prospective members. To increase the overall capacity of the association to communicate with its members and the Village of Kingston community, the GLIA board of directors will create a standing committee made up of a single director and several association members. Once formed, the GLIA Communication and Education Committee will formulate a communication strategy for the association. Likely elements in the strategy will include:

- Multiple newsletters per year containing association news, announcements, and informational articles.
- Enhanced website design to optimize loading and access to content.
- Assembly of GLIA email list for newsletter and special announcement broadcasting.

Once the strategy is implemented, the committee will work to provide information to the membership and community. Example educational topics may include:

- Aquatic invasive species monitoring updates
- Catch and release fishing
- Littering
- Noise, air, and light pollution
- Shoreland restoration and protection
- Septic system maintenance
- Fishing Rules
- Issues concerning the dam

The committee will be responsible for reaching out to state or local agencies which can provide them with educational pamphlets, other materials or ideas, such as the UW-Extension Lakes Program. These partners may be some of those included in the table found below.

Committee members should consider attending all or a portion of the Wisconsin Lakes Partnership Convention held each spring. A wealth of knowledge regarding lake group function is available each year through presentations, workshops, and networking opportunities.

This committee would work closely with the Membership & Volunteerism Committee as each committee's goals overlap considerably.

Action Steps:

1. Recruit first committee member to act as committee chairperson.
2. Investigate if WDNR Small-Scale Lake Planning Grant would be appropriate to cover initial setup costs.
3. Establish reasonable, but flexible annual budget.
4. Committee chairperson recruits additional members with board assistance.
5. Committee chairperson reports activities and results to board and membership.

Management Action: Enhance GLIA's involvement with other entities that have a hand in managing or otherwise utilizing Grand Lake.

Timeframe: Initiate 2018

Facilitator: Board of Directors to appoint GLIA representatives.

Description: It is important that the GLIA engage with all management entities to enhance the association's understanding of common management goals and to participate in development of those goals. This also familiarizes all management entities with actions that others are taking to reduce the duplication of efforts.

Action Steps:

1. 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 Grand 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, grants, all lake activities.	Once a year, or more as necessary.	Information on updating a lake management plans, submitting grants or to seek advice on other lake issues.
	Conservation Warden (Nathan Ackerman – 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.
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 other lake issues.
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.
Manchester Rod and Gun Club	920.398.8012	Partner in managing lake and wildlife	Annually and as needed.	Possible funding raising partner and/or contributor to funding.
Village of Kingston	President (Lisa Wendt - 920.394.3710)	Supports GLIA, assists in lake management.	As needed.	Contact regarding grant applications, projects such as CBCW, village events, etc.
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.

Management Action:	Create Membership & Volunteerism standing committee of GLIA.
Timeframe:	Initiate 2017
Facilitator:	Board of Directors
Potential Grant:	Small-scale Planning Grant could include some aspects of initial set-up, such as training and printing.
Description:	Sustaining membership and volunteerism in any organization is challenging, especially in an organization that represents a population that is not consistently in the area and is there primarily to recreate and relax. Many lake associations struggle with this issue because member and volunteer recruiting is completed sporadically and on an as-needed or urgent basis. Without good management, volunteers may become underutilized. Some may have been turned off by an impersonal, tense or cold atmosphere. Volunteers want to feel good about themselves for helping out, so every effort must be made by volunteer managers to see to it that the volunteer crews enjoy their tasks and their co-volunteers. To increase and sustain association membership and volunteerism effectively and efficiently, the GLIA will create a standing committee of the association aimed at completing these tasks consistently. Committee, and other association members, should consider attending all or a portion of the Wisconsin Lakes Partnership Convention held each spring. A wealth of knowledge regarding lake group function is available each year through presentations, workshops, and networking opportunities. This committee would work closely with the Education & Communication Committee as each committee's goals overlap considerably.

Action Steps:

1. Recruit first committee member to act as committee chairperson.
2. Investigate if WDNR Small-Scale Lake Planning Grant would be appropriate to cover initial setup costs.
3. Establish reasonable, but flexible annual budget.
4. Committee chairperson recruits additional members with board assistance.
5. Committee chairperson reports activities and results to board and membership.

Management Action:	Build GLIA treasury and contingency fund.
Timeframe:	Initiate 2018
Facilitator:	Board of Directors

Description: The availability of funds is important for the future management and protection of Grand Lake. Unexpected expenses can hinder the association's ability to independently address new issues that may arise on the lake.

In order to assure the availability of funds for the future of Grand Lake's management, the GLIA will establish a treasury and contingency fund.

Fund raising events may include (preliminary list provided by Michelle Machugo):

- Art fair
- Pizza party
- Brew fest
- Wine tasting
- Movie in the park
- Soup & sandwich luncheon
- Fishing tournament
- Auction
- T-shirt sale
- Plant sale
- Popcorn sale
- Candy sale
- Chili cook off
- 50/50 raffle
- Silent auction
- Treasure chest raffle
- Eating contest
- Car wash
- Dog wash
- Farmers market
- Rummage sale
- Bake sale
- Barbeque
- Bake off
- Brat Fry
- Fish Fry
- Pie & ice cream social
- Garden walk
- Tour of homes
- Pet show
- Talent show
- Concert in the park
- Pancake breakfast
- Golf outing
- Breakfast with Santa
- Photos with Santa & holiday gift wrapping
- Car show
- Tractor show

Action Steps: See description above.

6.0 METHODS

Lake Water Quality

Baseline water quality conditions were studied to assist in identifying potential water quality problems in Grand Lake (e.g., elevated phosphorus levels, anaerobic conditions, etc.). Water quality was monitored at the deepest point in the lake that would most accurately depict the conditions of the lake (Map 1). Samples were collected with a 3-liter Van Dorn bottle at the subsurface (S) and near bottom (B). Sampling occurred once in spring, fall, and winter and three times during summer. Samples were kept cool and preserved with acid following standard protocols. All samples were shipped to the Wisconsin State Laboratory of Hygiene for analysis. The parameters measured included the following:

Parameter	Spring		June		July		August		Fall		Winter	
	S	B	S	B	S	B	S	B	S	B	S	B
Total Phosphorus	●	●	●	●	●	●	●	●	●	●	●	●
Dissolved Phosphorus	●	●			●	●					●	●
Chlorophyll a	●		●		●		●		●			
Total Kjeldahl Nitrogen	●	●			●	●					●	●
Nitrate-Nitrite Nitrogen	●	●			●	●					●	●
Ammonia Nitrogen	●	●			●	●					●	●
Laboratory Conductivity	●	●			●	●						
Laboratory pH	●	●			●	●						
Total Alkalinity	●	●			●	●						
Total Suspended Solids	●	●	●	●	●	●	●	●	●	●	●	●
Calcium	●											

In addition, during each sampling event Secchi disk transparency was recorded and a temperature, pH, conductivity, and dissolved oxygen profile was be completed using a Hydrolab DataSonde 5.

Watershed Analysis

The watershed analysis began with an accurate delineation of Grand 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 Grand Lake during a May 31, 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 Grand 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 September 6 and 9, 2016. A point spacing of 48 meters was used resulting in approximately 423 points.

Community Mapping

During the species inventory work, the aquatic vegetation community types within Grand 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 by the University of Wisconsin – Steven's Point Herbarium.

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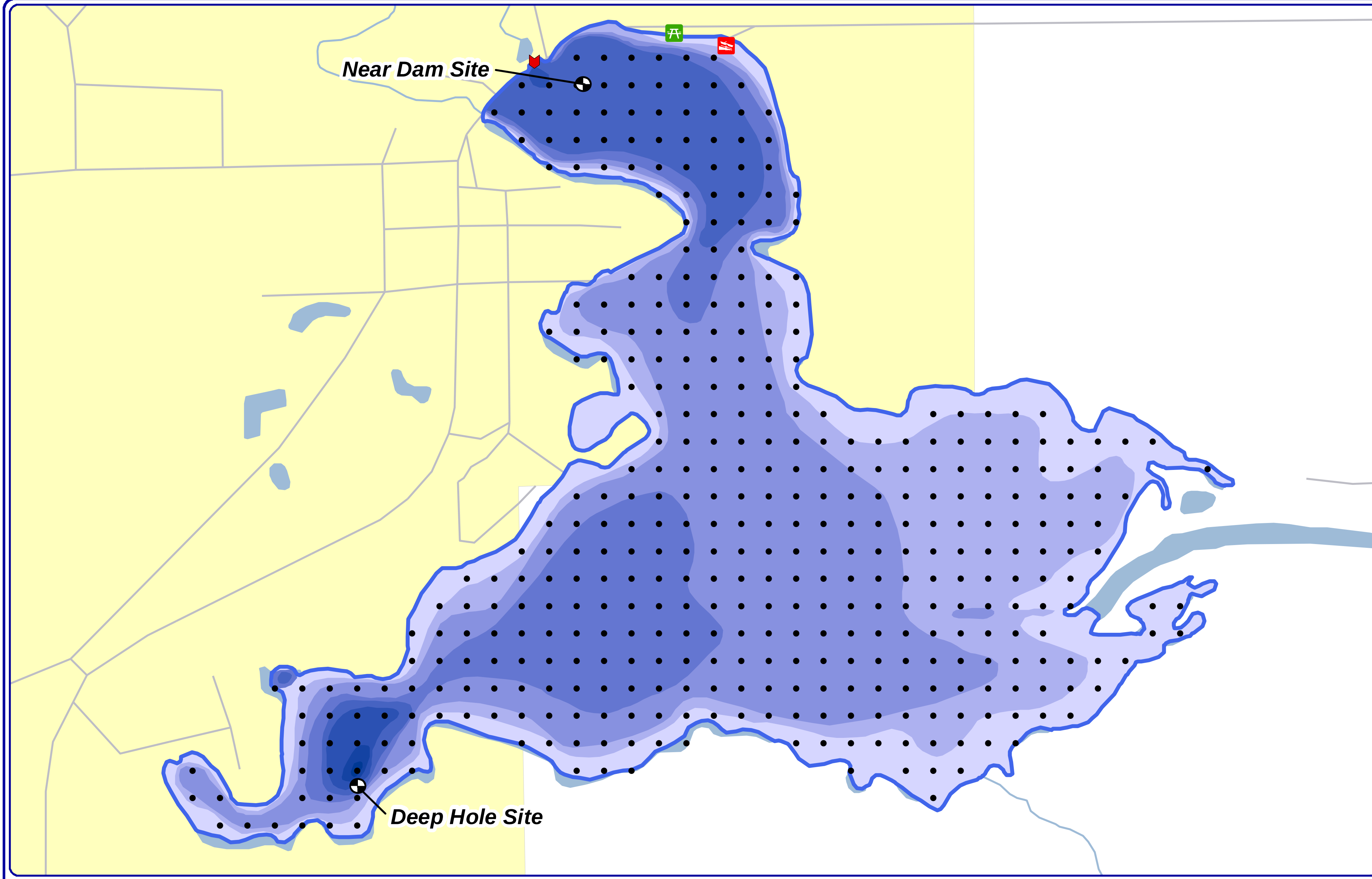


Legend

Grand Lake ~ 242 acres
WDNR Definition

Point-Intercept Survey Location
48 meter spacing, 423 total points

Village of Kingston

Public Access

Public Park

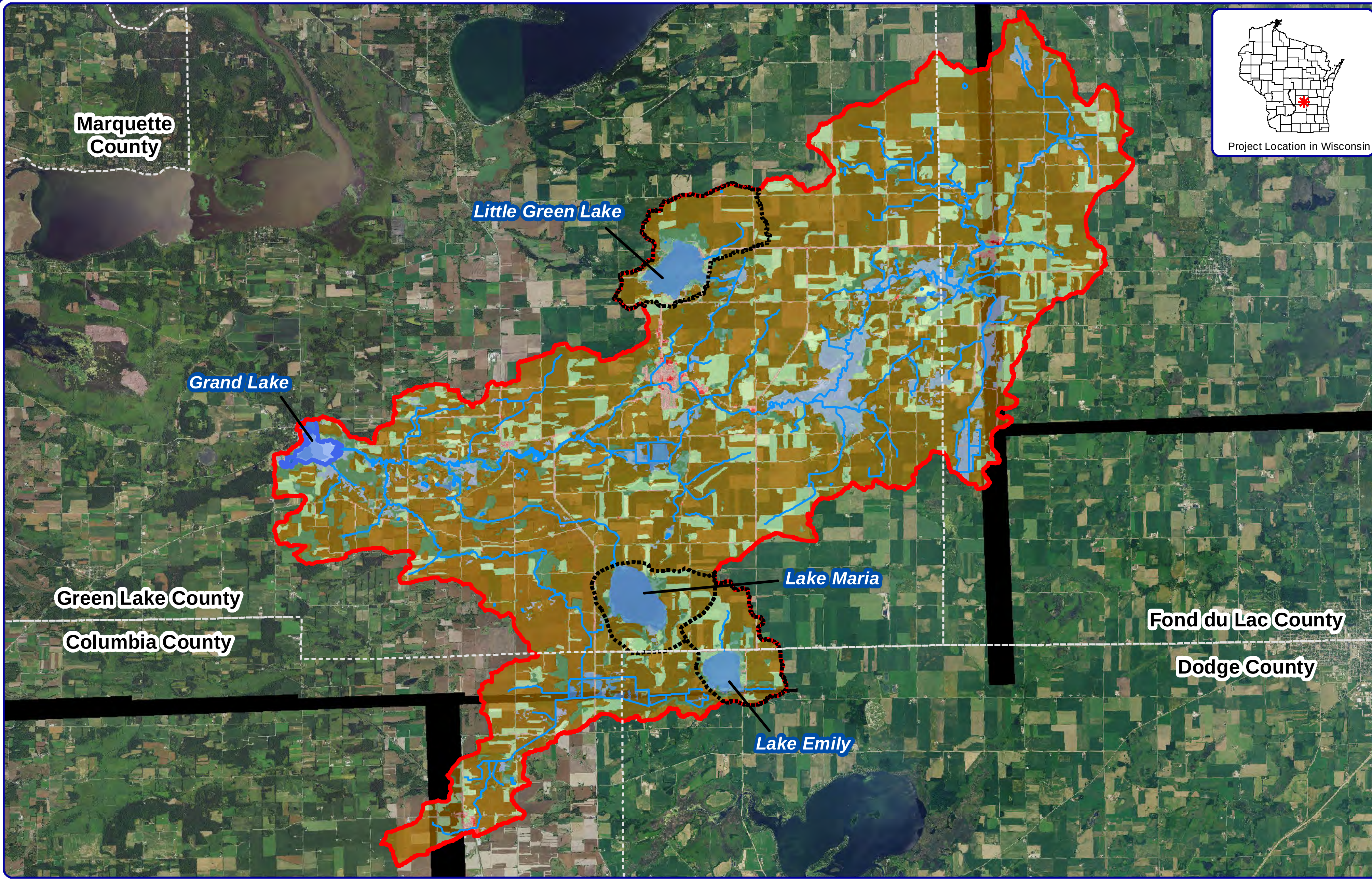
Dam Location

Water Quality Sampling Locations

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

Sources: Roads and Hydro: WDNR
Map Date: February 22, 2017
Filename: *Map1_Grand_Location.mxd*

Map 1
Grand Lake
Green Lake County, Wisconsin
Project Location & Lake Boundaries



N W E S
12,500
Feet

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

Sources:
Hydro: WDNR
Bathymetry: WDNR
Orthophotography: NAIP 2015
Land Cover: NLCD 2011
Watershed Boundaries: Onterra 2016
Map Date: January 12, 2017
Filename: Map2_Grand_WS.mxd

Legend

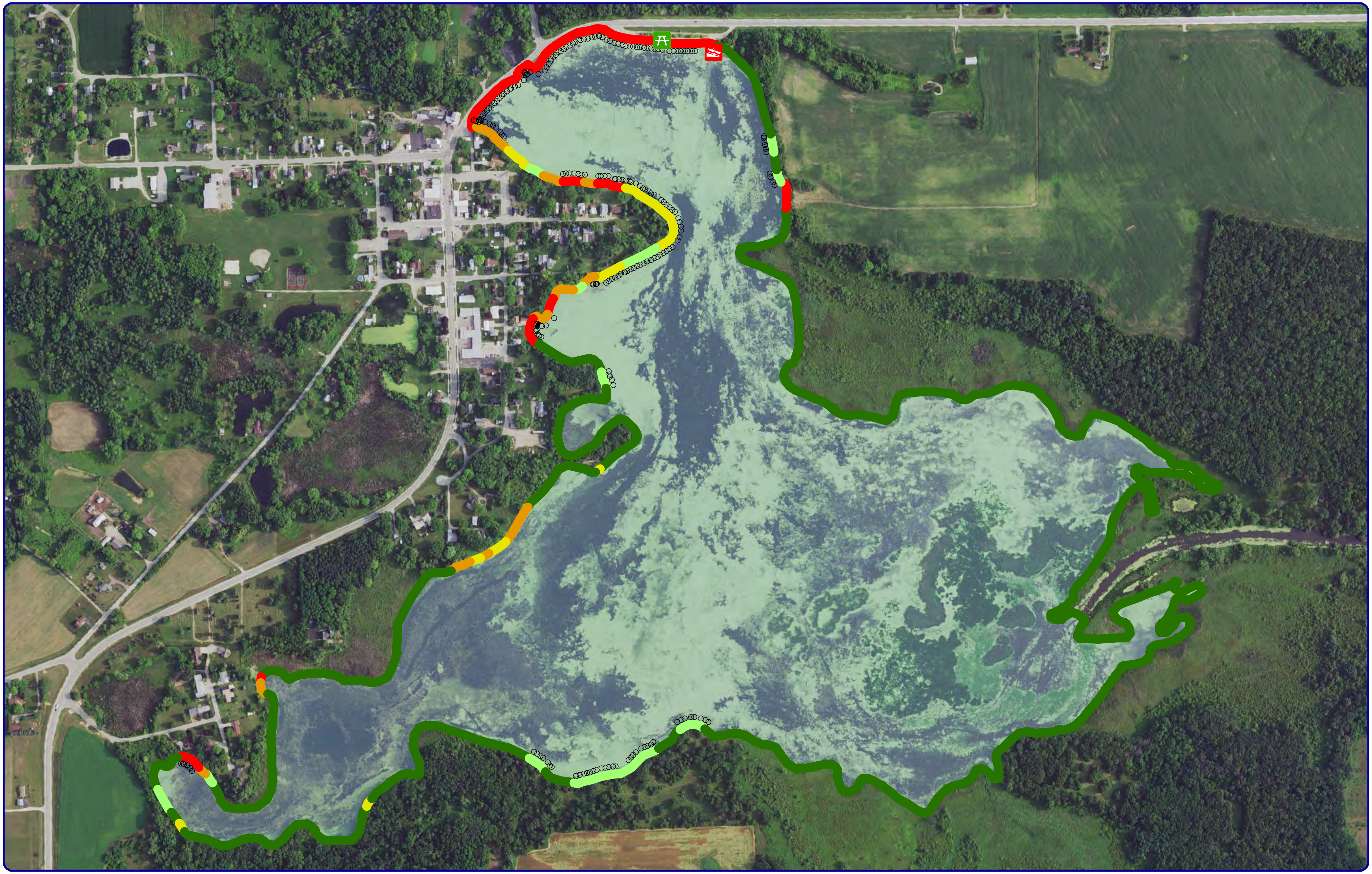
Land Cover Types

- Forest
- Forested Wetlands
- Wetlands
- Open Water
- Rural Open Space
- Pasture/Grass
- Row Crops
- Rural Residential
- Medium Density Urban
- High Density Urban
- Grand Lake Watershed Boundary
- Subwatershed Boundaries
- County Boundaries
- River/Stream

Map 2

Grand Lake
Green Lake County, Wisconsin

Watershed & Land Cover Types

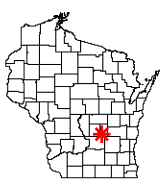


N
W E
S

750
Feet

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

Sources:
Hydro: WDNR
Orthophotograph: NAIP, 2015
Shoreland Condition: Onterra, 2016
Map Date: December 9, 2016
Filename: Grand_ShorelandCondition_2016.mxd

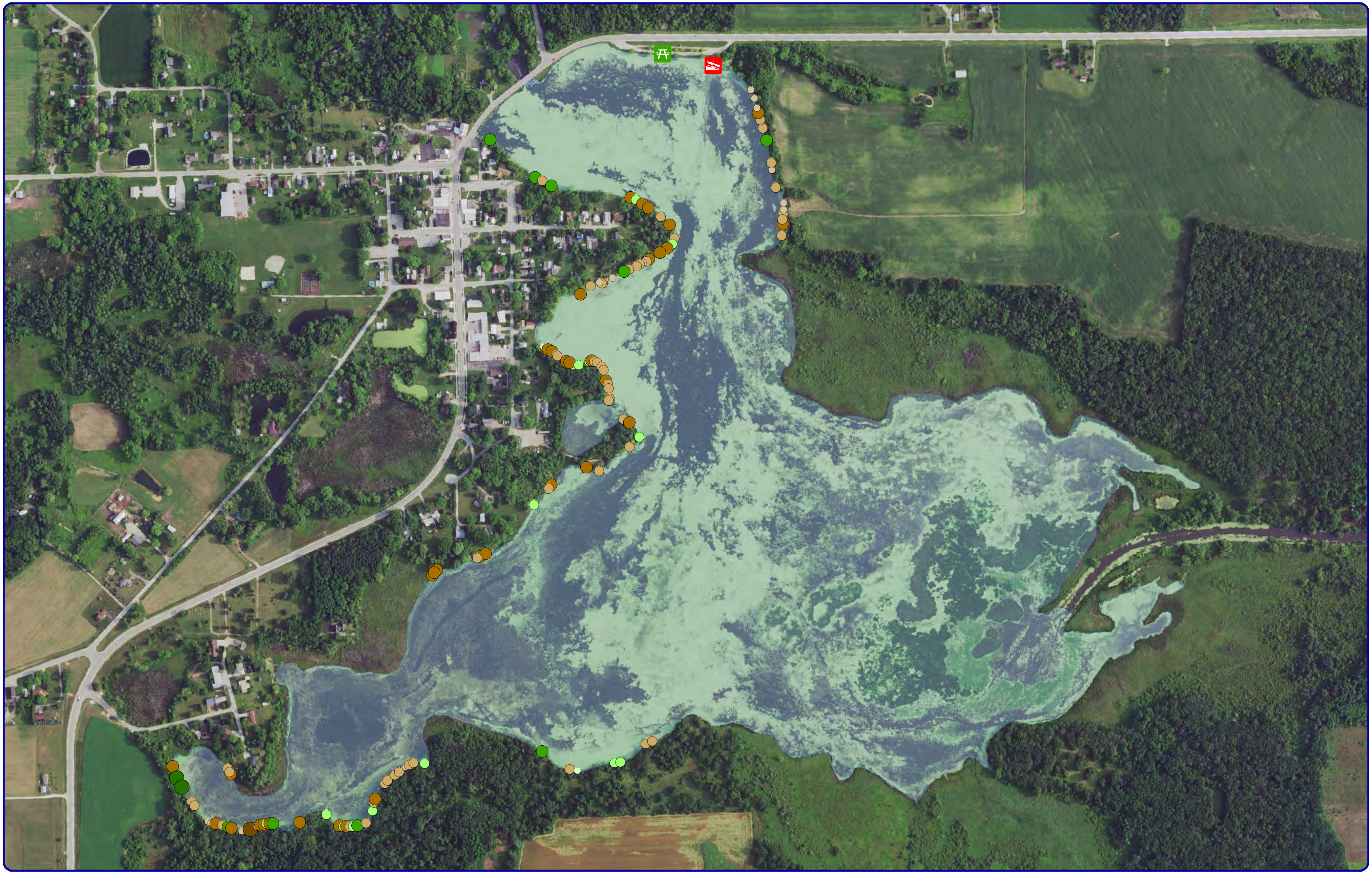

Project Location in Wisconsin

Legend

- Natural/Undeveloped
- Developed-Natural
- Developed-Semi-Natural
- Developed-Unnatural
- Urbanized

Seawall
- Masonry/Wood
- Rip-Rap

Map 3
Grand Lake
Green Lake County, Wisconsin
2016 Shoreland Assessment



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Feet

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De Pere, WI 54115
920.338.8860
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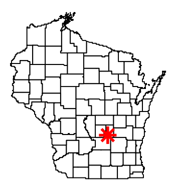
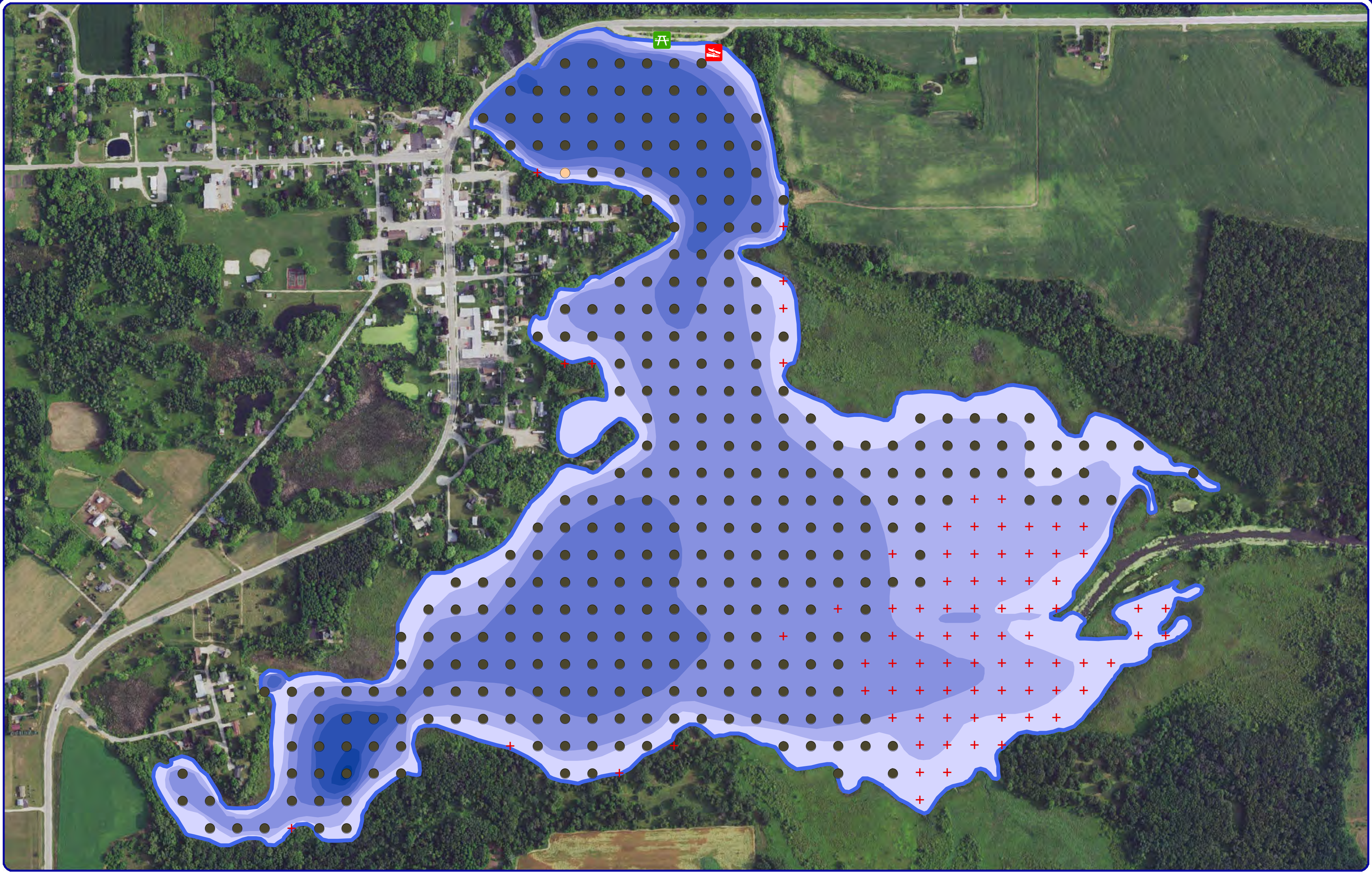
Sources:
Hydro: WDNR
Orthophotograph: NAIP, 2015
Coarse Woody Habitat: Onterra, 2016
Map Date: November 18, 2016
Filename: Map4_Grand_CWH_2016.mxd


Project Location in Wisconsin

Legend

2-8 Inch Pieces	8+ Inch Pieces	Cluster of Pieces
No Branches	No Branches	No Branches *(None)*
Minimal Branches	Minimal Branches	Minimal Branches *(None)*
Moderate Branches	Moderate Branches	Moderate Branches *(None)*
Full Canopy	Full Canopy	Full Canopy *(None)*

Map 4
Grand Lake
Green Lake County, Wisconsin
2016 Coarse Woody Habitat Survey Results



750
Feet

Onterra, LLC
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815 Prosper Road
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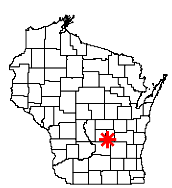
920.338.8860
www.onterra-eco.com

Sources:
Hydro and Roads: WDNR
Bathymetry: WDNR, digitized by Onterra
Aquatic Plant Survey: Onterra, 2016
Map Date: Febraury 21, 2017
Filename: Map5_Grand_SubstratePI_2016.mxd



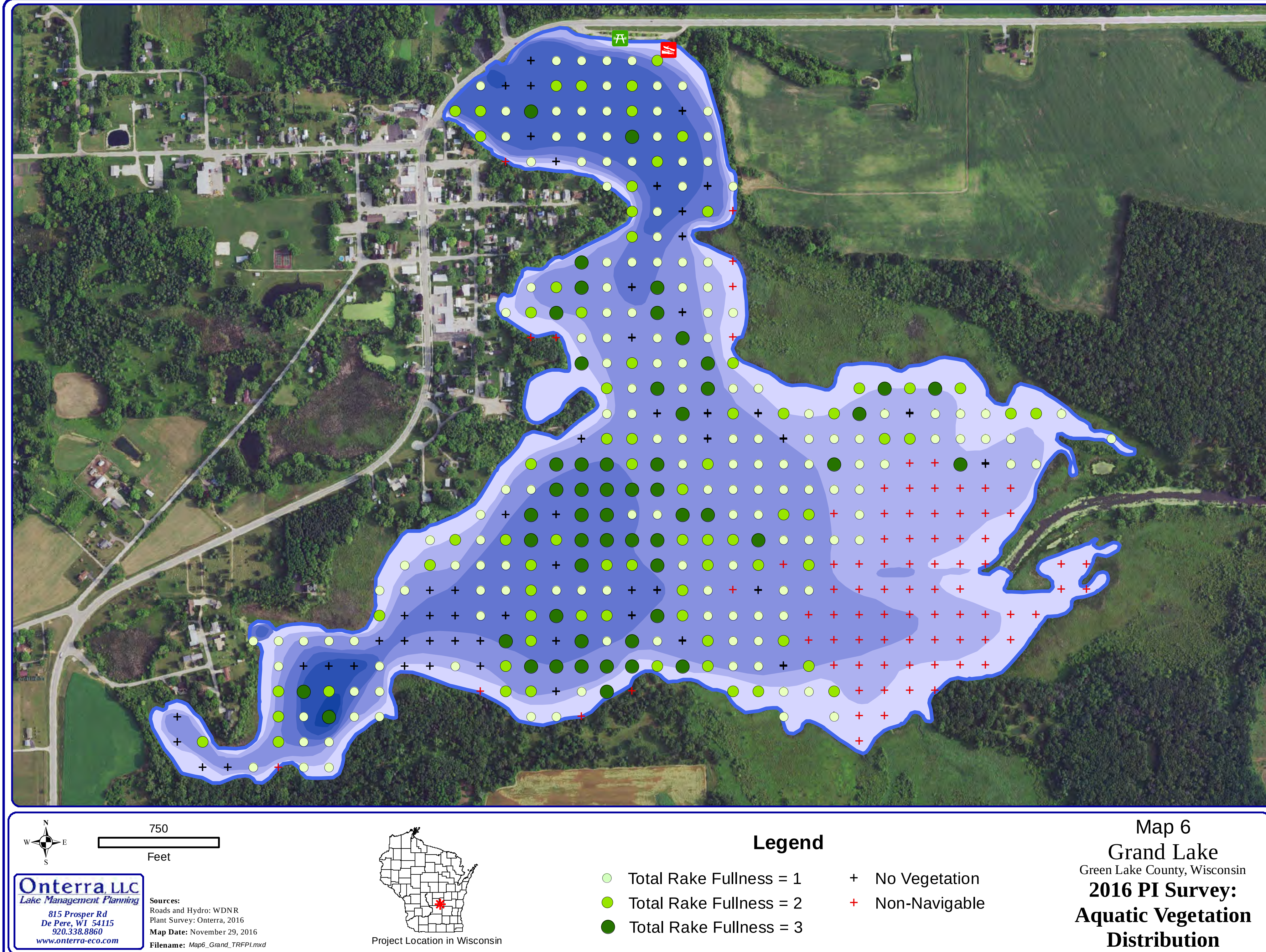
Project Location in Wisconsin

Legend

- Soft/Organic Sediments
- Rock
- Sand
- Too Deep
- Non-navigable

Map 5
Grand Lake
Green Lake County, Wisconsin

2016 PI Survey: Substrate Types



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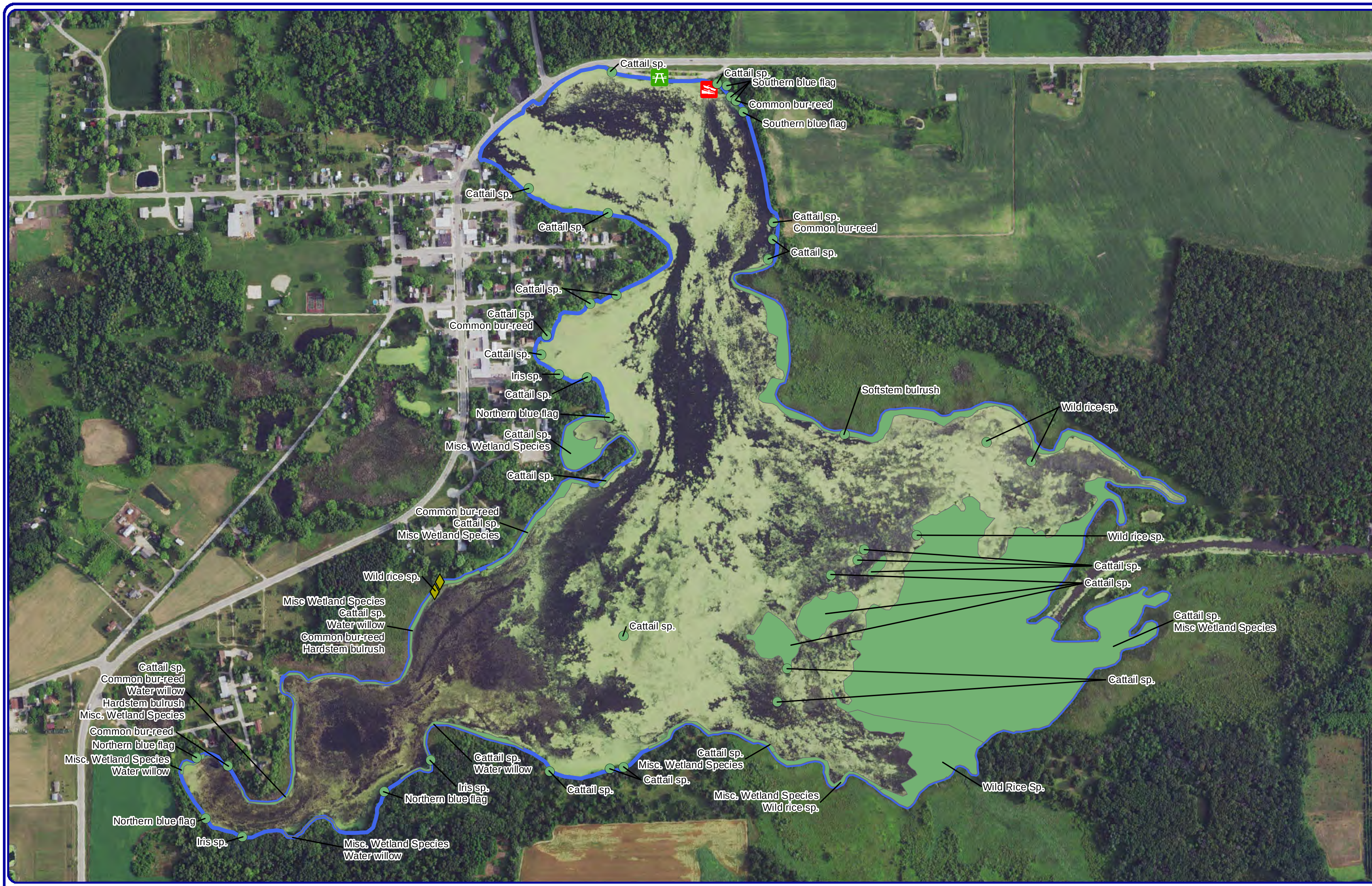
Sources:
Roads and Hydro: WDNR
Plant Survey: Onterra, 2016
Map Date: November 29, 2016
Filename: *Map6_Grand_TRFPI.mxd*

Map 6
Grand Lake
Green Lake County, Wisconsin
2016 PI Survey: Aquatic Vegetation Distribution



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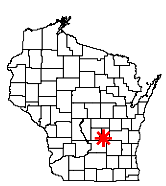
Sources:
Aquatic Plants: Onterra, 2016
Orthophotography: NAIP, 2015
Map date: February 13, 2017
Filename: Map7_Grand_Comm_2016.mxd



Extent of large map shown in red.

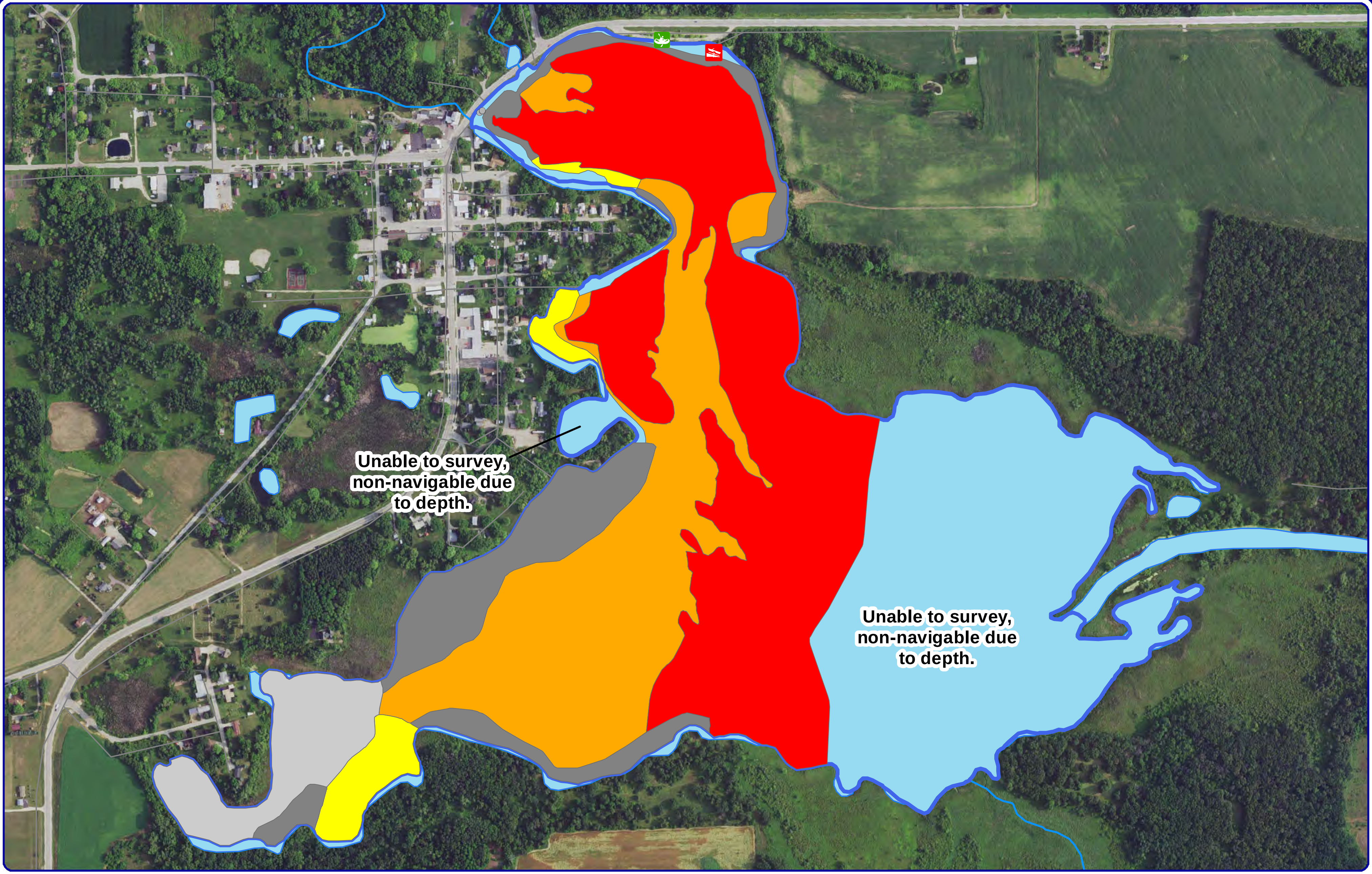
Legend

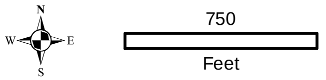
Small Plant Communities
- Emergent
- Floating-leaf
- Mixed Floating-leaf & Emergent
- Giant reed

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

Map 7
Grand Lake
Green Lake County, Wisconsin

Aquatic Plant Communities





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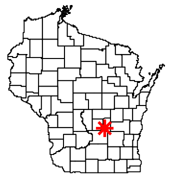
Sources:
Roads and Hydro: WDNR
EWM Survey: Onterra, 2016
Map Date: June 13, 2016
Filename: Map8_Grand_CLP_June16.mxd

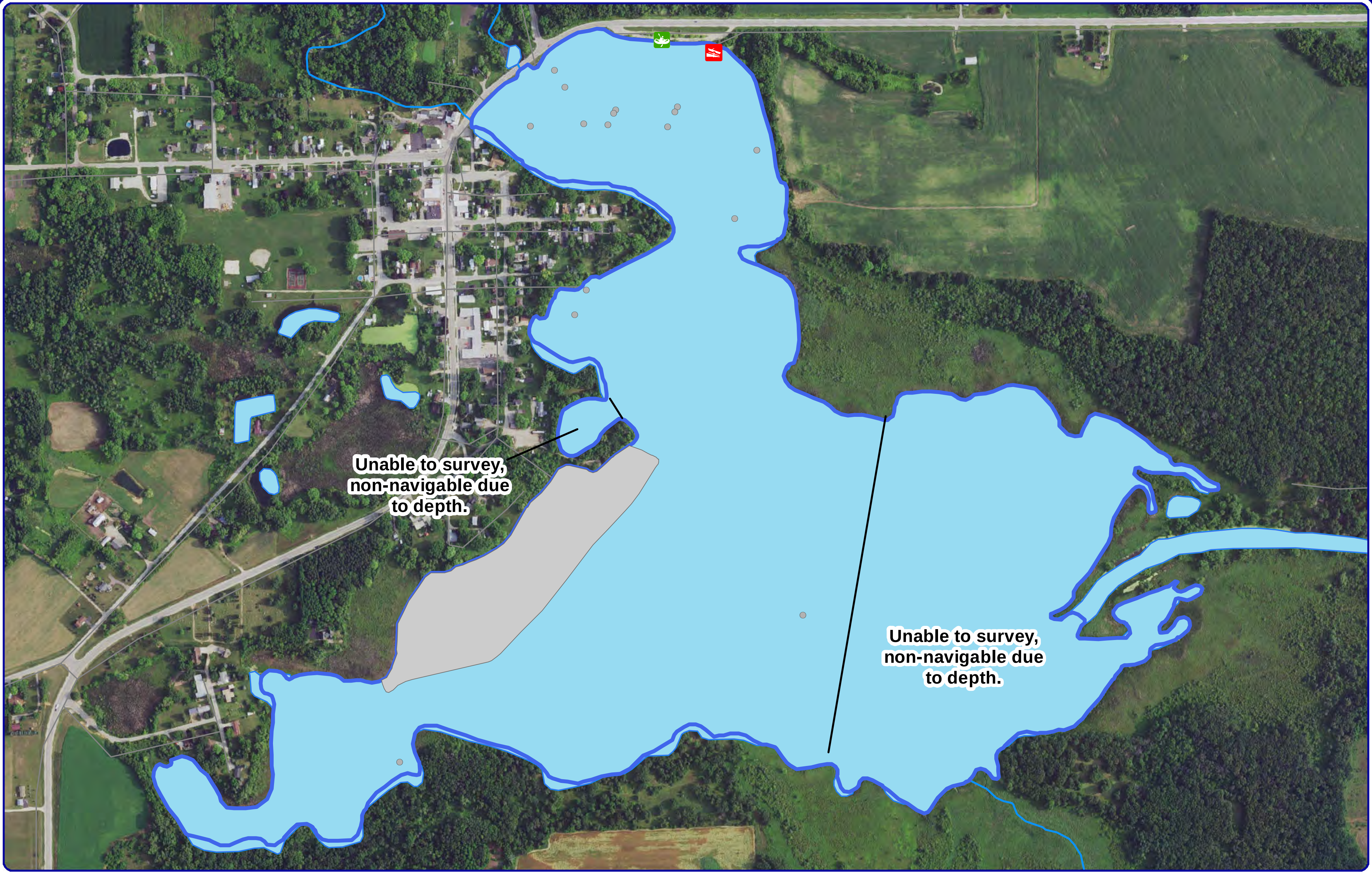


Project Location in Wisconsin

Legend

- Highly Scattered
- Scattered
- Dominant
- Highly Dominant
- Surface Matted
- Single or Few Plants
- Clump of Plants
- Small Plant Colony

Map 8
Grand Lake
Green Lake County, Wisconsin
June 2016 CLP
ESAIS Survey Results



N
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E
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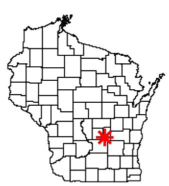
750
Feet

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

Sources:
Roads and Hydro: WDNR
EWM Survey: Onterra, 2016
Map Date: June 13, 2016
Filename: *Map9_Grand_EWM_June16.mxd*



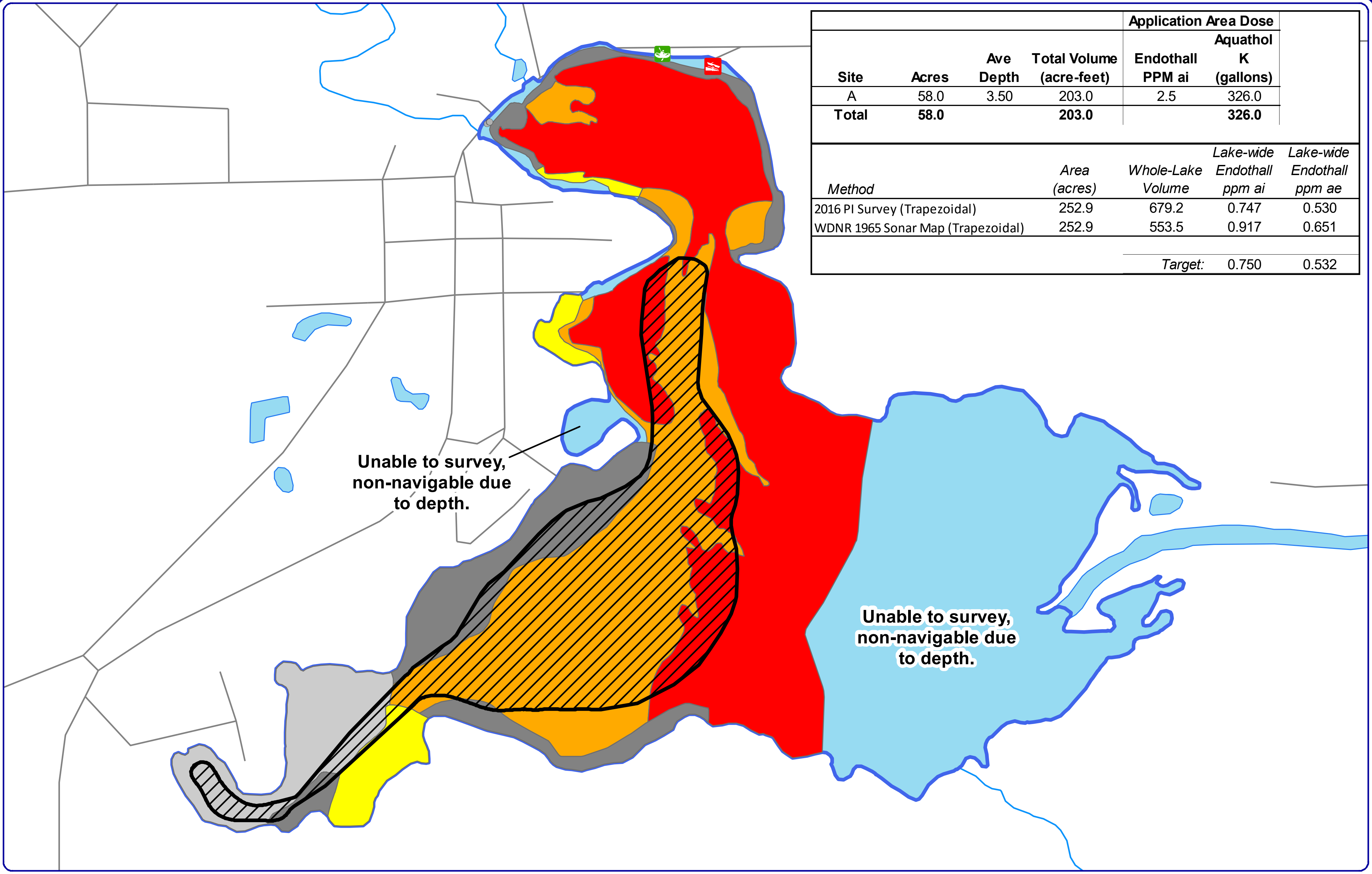
Project Location in Wisconsin

Legend

- Highly Scattered
- Scattered *(None found)*
- Dominant *(None found)*
- Highly Dominant *(None found)*
- Surface Matted *(None found)*
- Single or Few Plants
- Clump of Plants
- Small Plant Colony

Map 9
Grand Lake
Green Lake County, Wisconsin

June 2016 EWM
ESAIS Survey Results



				Application Area Dose	
Site	Acres	Ave Depth	Total Volume (acre-feet)	Endothall PPM ai	Aquathol K (gallons)
A	58.0	3.50	203.0	2.5	326.0
Total	**58.0**		**203.0**		**326.0**

Method	*Area (acres)*	*Whole-Lake Volume*	*Lake-wide Endothall ppm ai*	*Lake-wide Endothall ppm ae*
2016 PI Survey (Trapezoidal)	252.9	679.2	0.747	0.530
WDNR 1965 Sonar Map (Trapezoidal)	252.9	553.5	0.917	0.651
		Target:	0.750	0.532

N W E S

550
Feet

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

Sources:
Roads and Hydro: WDNR
CLP Survey: Onterra, 2016
Map Date: May 1, 2016 JLW
Filename: *Grand_CLP_TreatmentExample.mxd*

Project Location in Wisconsin

Legend
- Highly Scattered
- Scattered
- Dominant
- Highly Dominant
- Surface Matted
- Example CLP Treatment Area

Map 10
Grand Lake
Green Lake County, Wisconsin
CLP Treatment Example