Buffalo Lake

Marquette County, Wisconsin

Comprehensive Management Plan Update

March 2018

Sponsored by:

Buffalo Lake Protection & Rehabilitation District

WDNR Grant Program

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Onterra LLC
Lake Management Planning

Buffalo Lake

Marquette County, Wisconsin

Comprehensive Management Plan Update

March 2018

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Buffalo Lake Planning Committee

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Carol Deer
Ray Ducett
William Lewis
Jerry Riorday
Al Rosenthal
Bill Walkowiak

Wisconsin Dept. of Natural Resources

Ted Johnson
David Bartz

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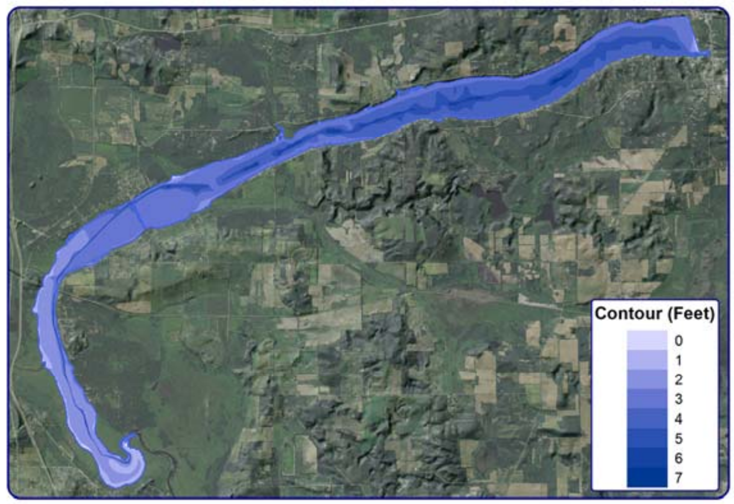
1.0 INTRODUCTION

Buffalo Lake, Marquette County, is an approximate 2,179-acre eutrophic impoundment of the Fox River with a maximum depth of 7.0 feet and a mean depth of 3.7 feet. The lake's surficial watershed encompasses approximately 402 square miles, a large portion of which is comprised of agricultural land cover. Buffalo Lake resides within the Upper Fox River Basin which drains into Lake Winnebago and ultimately to Green Bay in Lake Michigan. Studies completed in 2015 found that the lake harbors 32 native aquatic plant species, of which coontail (*Ceratophyllum demersum*) is the most abundant. Seven non-native aquatic plant species were located, including Eurasian watermilfoil and curly-leaf pondweed which were the most frequently encountered.

Lake at a Glance - Buffalo Lake

Morphology	
LakeType	Shallow, Lowland Drainage
Surface Area (Acres)	2,179 (WDNR Definition)
Max Depth (feet)	7.0
Mean Depth (feet)	3.7
Perimeter (Miles)	26.6
Shoreline Complexity	16.2
Watershed Area (Acres)	257,418
Watershed to Lake Area Ratio	115:1
Water Quality	
Trophic State	Eutrophic
Limiting Nutrient	Transitional between Phosphorus & Nitrogen
Avg Summer P (μg/L)	137
Avg Summer Chl-α (μg/L)	14
Avg Summer Secchi Depth (ft)	4.4
Summer pH	8.4
Alkalinity (mg/L as $CaCO_3$)	161
Vegetation	
Number of Native Species	32
Number of NHI-Listed Species	0
Number of Exotic Species	7
Average Conservatism	5.8
Floristic Quality	28.5
Simpson's Diversity (1-D)	0.87



NHI = Natural Heritage Inventory

Studies completed in 2004 as part of the Buffalo Lake Comprehensive Management Plan by Onterra found that the lake's aquatic plant community was dominated by the non-native plant Eurasian watermilfoil (littoral frequency of occurrence ~70%) and the lake's native plant community was indicative of degraded conditions. Following the completion of studies in 2004, numerous strategies for reducing non-native aquatic plants and enhancing the lake's native aquatic plant community were explored and presented to a steering committee comprised of Buffalo Lake Protection and Rehabilitation District (BLPRD) members. It was determined that the most feasible and cost-effective option for controlling non-native plants at the lake-wide level while enhancing the native aquatic community was through seasonal water level management. Specifically, water within Buffalo Lake was proposed to be periodically lowered from September through April in attempt to freeze/desiccate Eurasian watermilfoil and curly-leaf pondweed.

However, when the proposal for conducting winter water level management was brought to vote to the district membership, the district voted to not implement periodic water level management in Buffalo Lake as a tool to control aquatic invasive species and enhance the native aquatic plant community. To alleviate navigational issues due to surface-matted plants found throughout the majority of the lake, an aquatic plant mechanical harvesting plan was created where approximately 350 acres of the lake are harvested annually to maintain open navigational channels throughout the lake.

From the fall of 2012 through the spring of 2014, the water in Buffalo Lake was lowered to facilitate the reconstruction of the lake's dam and installation of a fish ladder. Upon refilling, anecdotal reports indicated that the Buffalo Lake's aquatic plant community had changed markedly, specifically in terms of the reduction of non-native aquatic plants. Given these perceived changes, Ted Johnson, the Wisconsin Department of Natural Resources (WDNR) lakes biologist for the region, recommended that the BLPRD reassess the lake's aquatic plant community and update the lake's management plan. The district membership voted to proceed with this management plan update.

Beyond the issue of reassessing the lake's aquatic plant community and developing strategies for future management, the BLPRD wanted to move forward with the creation of a lake management plan in order to ensure the preservation of Buffalo Lake for future generations. Through the development of a lake management plan, the BLPRD wants to assure that they are working to preserve Buffalo Lake as an ecosystem, not solely a recreational resource. Overall, the BLPRD recognized the value of gaining a better understanding of the Buffalo Lake ecosystem and its current condition. In the end, the information obtained from the studies conducted as part of the lake management plan development will help guide future BLPRD plans and programs.

This report contains the results of the comprehensive studies completed on Buffalo Lake in 2015/16 in an effort to update the lake's management plan. These studies included an assessment of Buffalo Lake's stakeholders through a stakeholder survey, the lake's water quality, watershed, shoreline, and aquatic plant community. Also included is the updated Implementation Plan which includes management goals and actions specific to Buffalo Lake's current and future management that were developed using the results of the studies by the BLPRD Planning Committee and Onterra and WDNR scientists.

The studies indicate that Buffalo Lake is currently in a eutrophic state; however, this shallow lake is aquatic-plant dominated yielding good water clarity. Studies aimed at assessing the lake's aquatic plant community revealed significant changes following the 2012-2014 water level reduction, including a >80% reduction in the occurrence of Eurasian watermilfoil and an increase in native aquatic plant species richness and diversity. One of the primary goals of this lake management plan update is to develop strategies to maintain the current lower levels of non-native aquatic plants within Buffalo Lake and prevent them from attaining the high levels observed prior to the 2012 water level reduction. The studies completed as part of this project indicate that Buffalo Lake is in a healthier state following the 2012 water level reduction, and strategies developed with the BLPRD Planning Committee on how to maintain this healthier state are discussed in the Implementation Plan.

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, the completion of a stakeholder survey, and updates within the lake group's newsletter and website. The highlights of this component are described below. Materials used during the planning process can be found in Appendix A.

Kick-off Meeting

On July 11, 2015, a project kick-off meeting was held at Montello High School to introduce the project to the general public. The meeting was advertised to district members through a one-page announcement. The approximately 20 attendees observed a presentation given by Brenton Butterfield, an aquatic ecologist with Onterra. Brenton'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

On May 23, 2016, Onterra ecologist Brenton Butterfield me with members of the BLPRD Planning Committee. In advance of this meeting, a draft copy of the Results and Discussion Sections were provided to attendees. The primary focus of this meeting was the delivery of the study results and conclusions to the committee. All study components including the aquatic plant inventories, water quality analyses, and watershed modeling were presented and discussed. Information regarding moving forward with AIS monitoring and control program was also discussed.

Planning Committee Meeting II

On July 29, 2016, Onterra ecologist Brenton Butterfield again met with the BLPRD Planning Committee to begin developing the framework for the Implementation Plan. Ted Johnson, WDNR lakes biologist, and David Bartz, WDNR fisheries biologist, were also in attendance to assist in the Implementation Plan development. The primary topic of discussion was the feasibility of completing periodic, winter water level management in the future in Buffalo Lake to control non-native aquatic plants and enhance the native aquatic plant community.

Project Wrap-up Meeting

A project Wrap-up Meeting was held at Montello High School on October 14, 2017. At this meeting, Onterra ecologist Brenton Butterfield presented the study results completed in 2015 along with the management goals and actions that were developed as part of the Implementation Plan.

Management Plan Review and Adoption Process

Prior to the first Planning Committee meeting, the results sections were sent to the all planning committee members for their review and preparation for the meeting. Following discussions at the planning meetings, Onterra staff drafted the Implementation Plan and sent it to the Planning Committee for review. Their comments were integrated into the plan, and the first official draft of the management plan was provided to the WDNR and BLPRD in September of 2016. The finalization of the plan was delayed due to transition of board members which needed to be apprised on the management goals and actions. Following a board meeting in September 2017, the board elected to move forward with Implementation Plant that was developed. In February of 2018, the board formally voted to approve the updated management plan for Buffalo Lake.

Stakeholder Survey

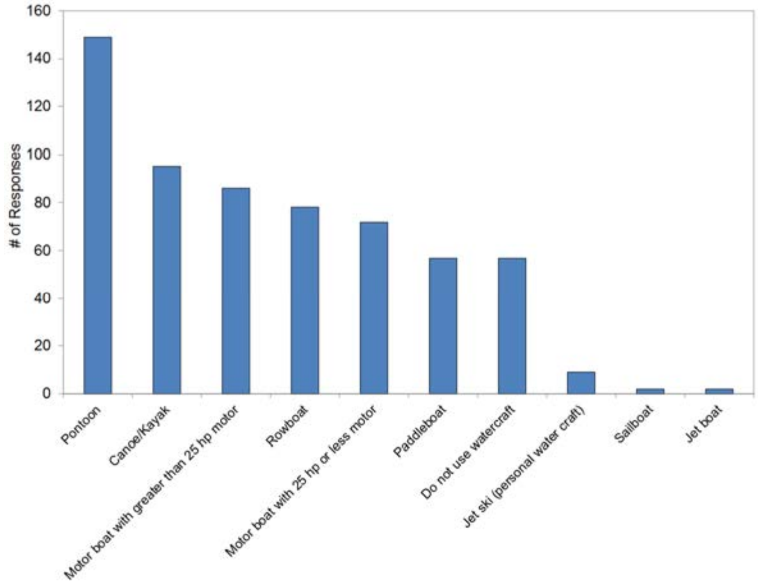
In October 2015, a seven-page, 31-question survey was mailed to 770 property owners within the Buffalo Lake Protection and Rehabilitation District. Approximately 46%, or 354 surveys were returned and the results were entered into a spreadsheet by members of the BLRPD Planning Committee. The data were summarized and analyzed by Onterra for use at the planning meetings and within the management plan. Given the relatively low response rate, the results of the stakeholder survey cannot be interpreted as being statistically representative of the population sampled. At best, the results may indicate possible trends and opinions about the stakeholder perceptions of Buffalo Lake, but cannot be stated with statistical confidence. The full survey and results can be found in Appendix B, while discussion of results is integrated within the appropriate sections of the management plan and a general summary is discussed in this section.

Of the 354 respondents, approximately 50% indicated that they use their property on Buffalo Lake on weekends throughout the year or during the summer only, 35% are year-round residents, 7% did not own property on the lake, 4% own undeveloped property, 2% indicated ‘other’ for use of their property, 1% indicated they own resort property, and 1% indicated they owned a rental property (Question #1). The subsequent sections (Water Quality, Watershed, Aquatic Plants, and Fisheries Data Integration) discuss the stakeholder survey responses with respect to these particular topics. Figures 2.0-1 and 2.0-2 highlight several other questions that were included within the survey.

The majority of survey respondents (42%) indicated that they use a pontoon boat on lake, 27% use a canoe/kayak, and 24% use a motor boat with a motor of greater than 25 horsepower (Figure 2.0-1; Question #12). The top-rated activity on Buffalo Lake among survey respondents was fishing-open water with 47% of respondents indicating this was the most important activity (Figure 2.0-1; Question #13). Relaxing/entertaining, nature viewing, and motor boating were the next top-rated activities amongst survey respondents on Buffalo Lake, respectively.

When asked to rate the factors that are currently negatively impacting Buffalo Lake, the majority of survey respondents indicated that excessive aquatic plant growth (excluding algae) was having the greatest negative impact on the lake, followed by algae blooms, aquatic invasive species introduction, and silt runoff into the lake (Figure 2.0-2; Question #19). Similarly, when asked to rank their top three concerns regarding Buffalo Lake, the majority of survey respondents listed excessive aquatic plant growth, water quality degradation, aquatic invasive species introduction, and loss of native aquatic/fish habitat (Figure 2.0-2; Question #20).

Question #12: What types of watercraft do you currently use on Buffalo Lake?



Question #13: Please rank up to three activities that are important reasons for owning your property on or near Buffalo Lake.

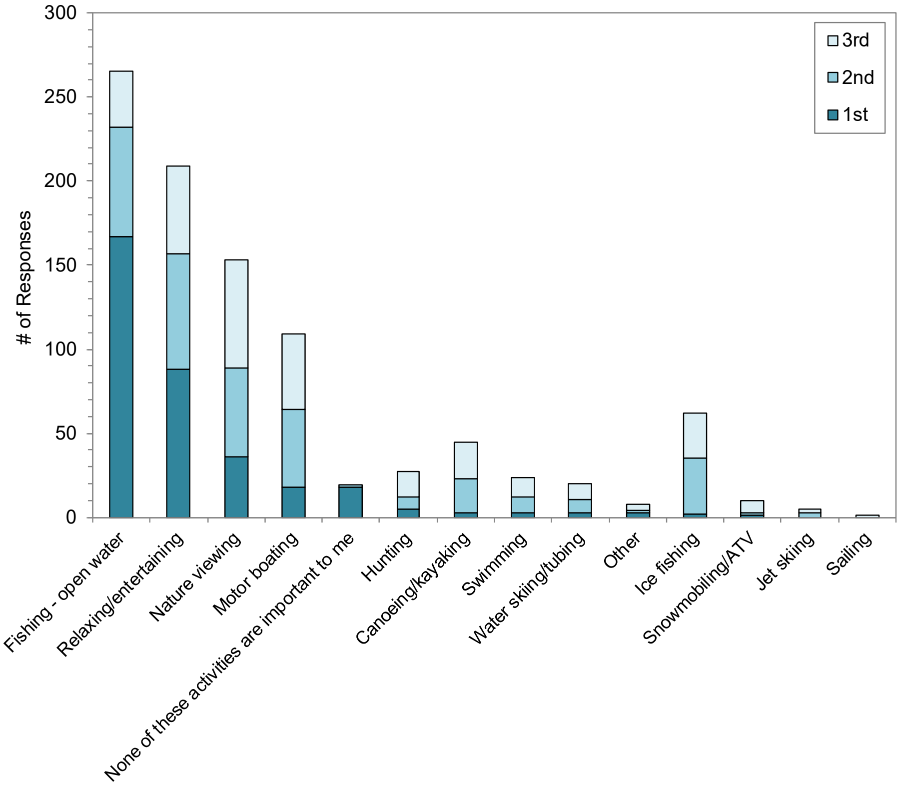
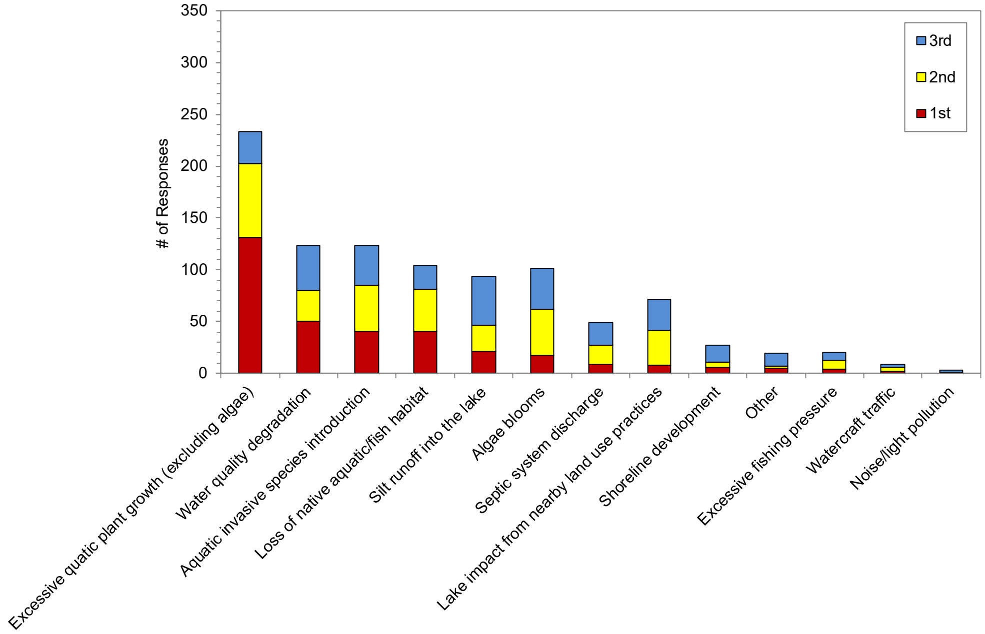


Figure 2.0-1. Select survey responses from the Buffalo Lake stakeholder survey. Created using responses from 354 survey respondents of 770 sent surveys. Additional questions and responses can be found in Appendix B.

Question #19: To what level do you believe each of the following factors may currently be negatively impacting Buffalo Lake?



Question #20: From the list below, please rank your top three concerns regarding Buffalo Lake.

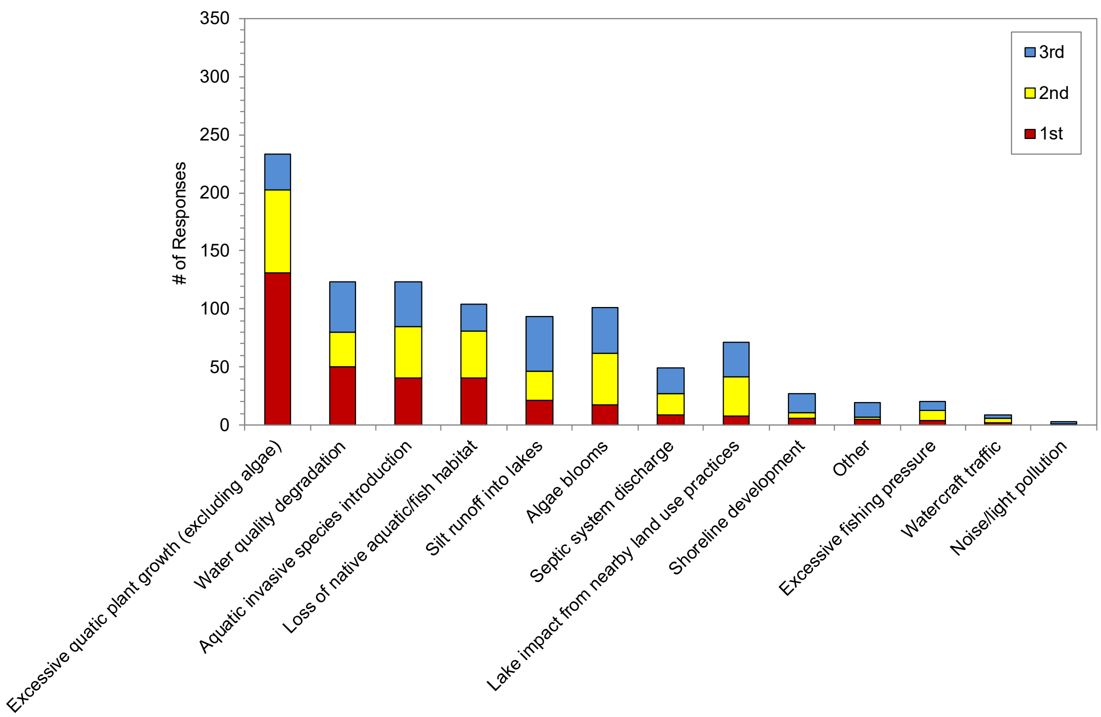


Figure 2.0-2. Select survey responses from the Buffalo Lake stakeholder survey continued. Created using responses from 354 survey respondents of 770 sent surveys. Additional questions and responses can be found in Appendix B.

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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 Encof 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 Buffalo Lake is compared to other lakes in the state with similar characteristics as well as to lakes within the Southeast Wisconsin Till Plains ecoregion (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 Buffalo 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 phytoplankton 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 clearer understanding of the lake's trophic state while facilitating clearer long-term tracking. Carlson (1977) presented a trophic state index that gained great acceptance among lake managers.

Limiting Nutrient

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

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

Temperature and Dissolved Oxygen Profiles

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

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

Dissolved oxygen is essential in the metabolism of nearly every organism that exists within a lake. For instance, 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.

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.

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 Buffalo 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, and 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 four square miles.
> >
> > Lowland drainage lakes have a watershed of greater than four square miles.

Because Buffalo Lake possesses numerous tributary inlets and an outlet, has a watershed that is greater than four square miles in area, and is relatively shallow, Buffalo Lake is classified as a shallow (mixed), lowland drainage lake (Category 4 on Figure 3.1-1).

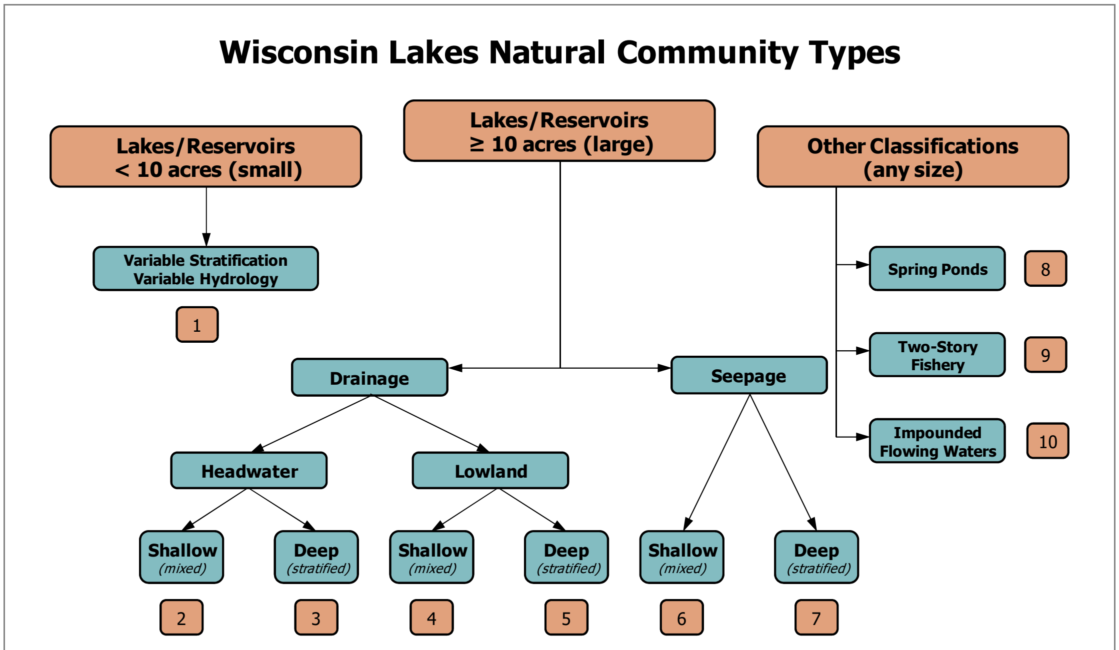


Figure 3.1-1. Wisconsin Lake Natural Communities. Buffalo Lake is classified as a shallow, lowland drainage lake (class 4). Adapted from WDNR 2013A.

Garrison, et. al (2008) developed state-wide median values for total phosphorus, chlorophyll-*a*, and Secchi disk transparency for six of the lake classifications. While 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. Buffalo Lake's watershed straddles the boundary between the North Central Hardwood Forests (NCHF) and the Southeastern Wisconsin Till Plains (SWTP) ecoregions; however, greater than 70% of the watershed acreage falls within the SWTP ecoregion, and the water quality of Buffalo Lake will be compared to other lakes within the SWTP ecoregion (Figure 3.1-2).

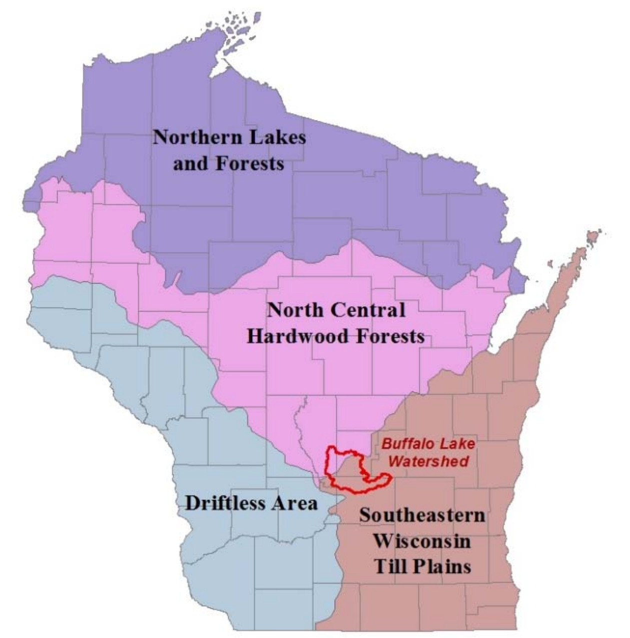


Figure 3.1-2. Location of Buffalo Lake's watershed within the ecoregions of Wisconsin. After Nichols 1999.

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 Buffalo Lake are displayed in Figures 3.1-4 - 3.1-6. Please note that the data in these graphs represent concentrations 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. While near-bottom total phosphorus concentrations are typically collected, data collected in 2004 indicated that phosphorus concentrations were similar at the near-surface and near-bottom given Buffalo Lake's shallow nature, and thus, near-bottom samples were not collected in 2015/16.

Buffalo Lake Water Quality Results

Long-term Trends

It is often difficult to determine the status of a lake's water quality purely through observation. Anecdotal accounts of a lake "getting better" or "getting worse" can be difficult to judge because a) a lake's water quality may fluctuate from year to year based upon environmental conditions such as precipitation, and b) differences in observation and perception of water quality can differ greatly from person to person. It is best to analyze the water quality of a lake through scientific data as this gives a concrete indication as to the health of the lake, and whether its health has deteriorated or improved. Further, by looking at data for similar lakes regionally and statewide, one can determine what the status of the lake is by comparison.

In a stakeholder survey sent out to BLPRD members, approximately 33% describe Buffalo Lake's current water quality as *excellent* to *good*, 34% describe it as *fair*, 28% describe it as *poor* to *very poor*, and 5% were *unsure* (Appendix B, Question # 14; Figure 3.1-3). When asked how water quality has changed in Buffalo Lake since first visiting the lake, approximately 32% of respondents indicated water quality has *remained the same*, 40% indicated water quality has *severely* or *somewhat degraded*, 21% indicated water quality has *somewhat* or *greatly improved*, and 7% were *unsure* (Question #15; Figure 3.1-3).

Buffalo Lake contains 22 established sampling locations within the lake where at least some type of lake data have been recorded historically (Table 3.1-1). Nine of these 22 sampling locations have historical lake nutrient and water quality data that are applicable for analyses, and these data are discussed within this report. Traditionally, water quality samples are collected from the lake's deepest location, and in 2015, a new sampling location named the *Deepest Spot* was created after this area was found to be approximately one foot deeper than the original *Deep Hole* sampling location (Map 2). Water quality samples collected by Onterra ecologists in 2015 and 2016 were collected from the Deepest Spot sampling location.

The available historical water quality data from the nine sampling locations were divided into three main datasets based upon their location within the lake. Data from the Center Site, East End, and At Montello sampling locations were combined into a dataset termed *Lower-Lake*, data from the Deepest Spot, At West End, and Deep Hole sampling locations were combined into a dataset termed *Mid-Lake,* and data from the Cth D Causeway, At Packwaukee, and At Trestle sampling locations were combined into a dataset termed *Upper-Lake*. Most of the historical data that are available and the data collected in 2015 and 2016 were collected from the Mid-Lake sampling locations, and these data are the primary focus for analyses.

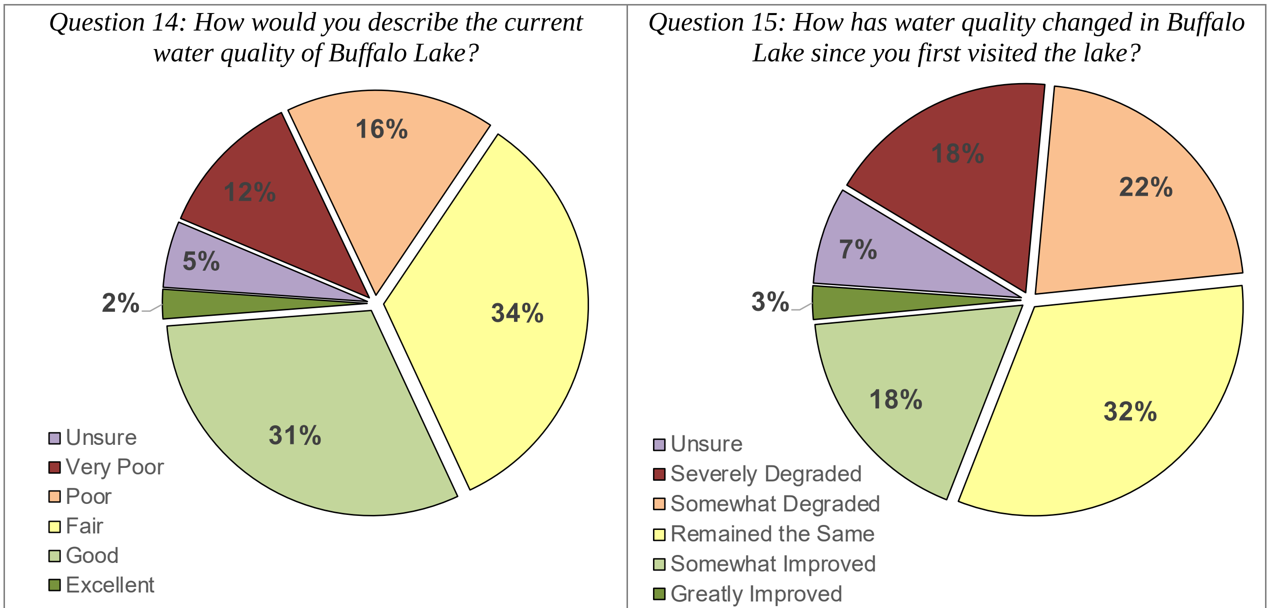


Figure 3.1-3. Buffalo Lake stakeholder survey responses regarding the lake's current and historical water quality. Created using responses from 345 (question 14) and 347 (question 15) respondents.

Table 3.1-1. Buffalo Lake water quality monitoring stations and available water quality data. Information obtained from WDNR Surface Water Data Viewer and Surface Water Integrated Monitoring System (SWIMS). Monitoring locations can be found on Map 2.

Station Name	Station STORET #	Years with Applicable Data	Applicable Data Available
Access at Montello	1001440	NA	NA
At East End	393134	1999, 2000, 2001, 2007, 2008, 2009	TP, Chl-α, Secchi
At Endeavor	10019249	NA	NA
At Montello	393015	1995	TP, Chl-α, Secchi
At Packwaukee	393016	1995	TP, Chl-α, Secchi
At Trestle	393019	1995	TP, Chl-α, Secchi
At West End	393135	1999, 2000, 2001, 2007, 2008, 2009	TP, Chl-α, Secchi
Buffalo Lake Inlet	10032458	NA	NA
Center Site	393133	1999, 2000, 2001, 2007, 2008, 2009	TP, Chl-α, Secchi
County Hwy D and Freedom Rd	10019586	NA	NA
Cth D Causeway	10007698	2007, 2014	TP, Chl-α, Secchi
Deep Hole	393122	1973, 1974, 1975, 1980, 1991, 1993, 1994, 1997, 2004, 2005, 2015	TP, Chl-α, Secchi
Deepest Spot	10014660	2015, 2016	TP, Chl-α, Secchi
DS Hwy D Bridge	10038070	NA	NA
East End	10038606	NA	NA
Fox River at Buffalo Lake	074	NA	NA
Montello Dam Up	10022807	NA	NA
Mouth of Fox River	393028	NA	NA
North Side Beach & Launch	10042005	NA	NA
Ox Creek Confluence	10038607	NA	NA
Sth 22 Brg Montello	393006	NA	NA
West End of Dam	393148	NA	NA

TP = Total Phosphorus; Chl-α = Chlorophyll-α

Total Phosphorus

In 2015, the average growing season and average summer near-surface total phosphorus concentration in Buffalo Lake were 91 and 111 µg/L, respectively (Figure 3.1-4a). The causes of higher phosphorus concentrations during the summer are discussed in the subsequent section, *Seasonal Water Quality Dynamics in Buffalo Lake*. Near-surface total phosphorus concentrations from the Mid-Lake sampling locations in Buffalo Lake are available from 1973-1974, 1991, 1993-1994, 1997, 1999-2001, 2004, and 2015. Total phosphorus concentrations in 2015 were slightly lower than the weighted average growing season (115 µg/L) and summer (137 µg/L) weighted average of available historical data.

Summer data are used when comparing lakes to one another, and Buffalo's weighted summer average near-surface total phosphorus concentration from the Mid-Lake sampling locations is 137 µg/L. This concentration falls within the *poor* category for shallow, lowland drainage lakes in Wisconsin and is approximately four and six times higher than the median concentrations for shallow, lowland drainage lakes state-wide and for all lakes within the SWTP ecoregion, respectively. Apart from the higher total phosphorus concentrations measured in 1973, there are no discernable trends (positive or negative) over time among the available total phosphorus data from the Mid-Lake sampling locations in Buffalo Lake.

Total phosphorus data are from the Lower-Lake sampling locations are available from 1995 and 1999-2001 (Figure 3.1-4b). The total phosphorus concentrations measured at these locations are slightly lower than the concentrations measured at the Mid-Lake sampling locations during this same time period, but are overall similar and fall within the *poor* category for shallow, lowland drainage lakes. Total phosphorus data from the Upper-Lake sampling locations are available from 1995 and 2014, with average growing season concentrations of 120 and 130 µg/L, respectively. These concentrations are not significantly different with those measured at the Mid-Lake and Lower-Lake sampling locations. As is discussed further in the *Seasonal Water Quality Dynamics in Buffalo Lake* and *Buffalo Lake Watershed* sections, the high concentrations of phosphorus in Buffalo Lake are not unexpected given the composition and size of its watershed and the lake's morphology.

Chlorophyll-α

As discussed, chlorophyll-*a* is a measure of free-floating algal biomass within a lake and is usually positively correlated with total phosphorus concentrations. However, chlorophyll-*a* concentrations in Buffalo Lake are significantly lower than predicted given the concentrations of phosphorus, and the reasons for this are discussed in the next section, *Seasonal Water Quality Dynamics in Buffalo Lake*. Chlorophyll-*a* concentrations are available from the Mid-Lake sampling locations in Buffalo Lake from 1980, 1991, 1993-1994, 1999-2001, 2004, and 2015 (Figure 3.1-5a). Average annual growing season chlorophyll-*a* concentrations range from 33.8 µg/L in 2000 to 14.8 µg/L in 2015. Summer chlorophyll-*a* concentrations in 2015 fell in the *excellent* category for shallow, lowland drainage lakes with an average value of 8.4 µg/L. The weighted summer chlorophyll-*a* concentration for all available data from the Mid-Lake sampling locations is 14.0 µg/L, which falls into the *good* category for shallow, lowland drainage lakes in Wisconsin. Buffalo Lake's average summer chlorophyll-*a* concentration is only slightly higher than the median concentration for other shallow, lowland drainage lakes in Wisconsin.

Chlorophyll-*a* concentrations at the Lower-Lake sampling locations are available from 1995 and 1999-2001, and the annual averages at these locations are similar to those collected from the Mid-Lake sampling locations during the same time period. (Figure 3.1-5b). Chlorophyll-*a* concentrations from the Upper-Lake sampling locations are available from 1995 and 2014, with growing season averages of 18.8 and 12.4 µg/L, respectively. Overall, the available historical chlorophyll-*a* data indicate that concentrations are not significantly different between the Upper-Lake, Mid-Lake, and Lower-Lake sampling locations.

Secchi Disk Transparency

Secchi disk transparency is a measure of water clarity. At the Mid-Lake sampling locations in Buffalo Lake, Secchi disk transparency data are available from 1973-1974, 1990-1991, 1993-1994, 2004, 2007, 2009, and 2015 (Figure 3.1-6a). In 2015, the average growing season and summer Secchi disk transparency values were relatively similar at around 4.5 feet, falling into the *good* category for shallow, lowland drainage lakes in Wisconsin. The weighted average summer Secchi disk transparency value using all available data from the Mid-Lake sampling locations is 4.4 feet, which falls into the *good* category for shallow, lowland drainage lakes in Wisconsin.

While the available historical data from the Mid-Lake sampling locations appear to show that water clarity is lower at present when compared to the early 1990s and prior, the data collected in 2007 and 2009 are lacking data from later in the summer when clarity tends to be highest in Buffalo Lake. In addition, the Secchi disk transparency from 2009 is represented by just a single measurement collected in June of that year. Secchi disk transparency data collected in 2015 are more comparable to clarity measurements collected in the 1970s and 1990s. It cannot be determined if water clarity has declined, increased, or remained stable over the time period for which historical water clarity data are available from Buffalo Lake.

Secchi disk transparency data are available from the Buffalo Lake Lower-Lake sampling locations from 1995 and 2007-2009 (Figure 3.1-6b). Of the available data from the Mid-Lake and Lower-Lake sampling locations, data were only collected at both locations in 2007 and 2009. However, as discussed, the data from 2007 are lacking late-summer measurements while only one measurement was collected from each location in 2009. Given the available data, a comparison of water clarity between the Mid-Lake and Lower-Lake sampling locations cannot be made. Secchi disk transparency data are available from the Upper-Lake locations from 1995 only, and the growing season average clarity for that location was 3.0 feet.

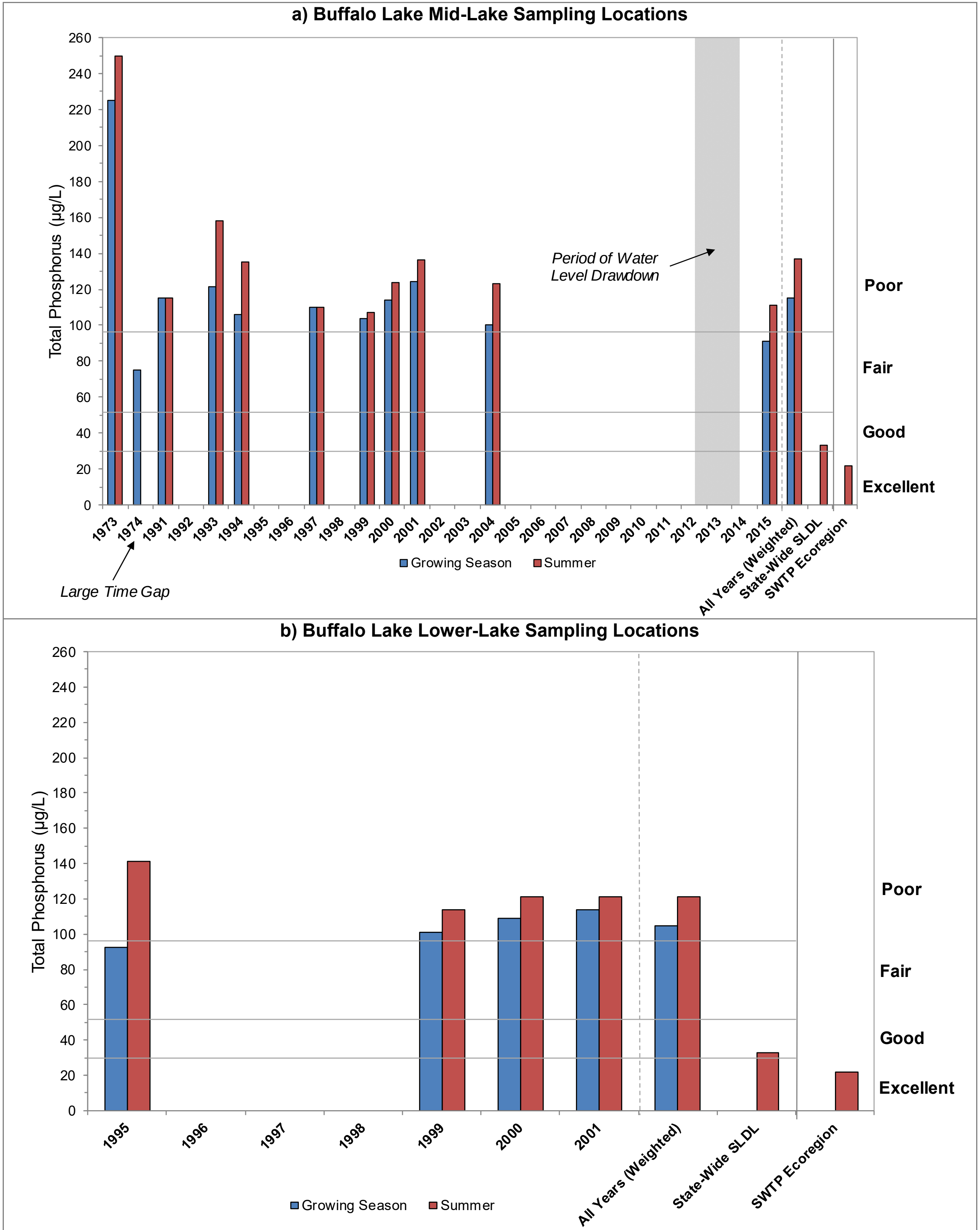


Figure 3.1-4. Buffalo Lake average annual near-surface total phosphorus concentrations measured from Mid-Lake sampling locations (a) and Lower-Lake sampling locations (b). Also displayed are the median near-surface total phosphorus concentrations for state-wide shallow, lowland drainage lakes (SLDL) and Southeastern Wisconsin Till Plain (SWTP) ecoregion lakes. Water Quality Index values adapted from WDNR PUB WT-913.

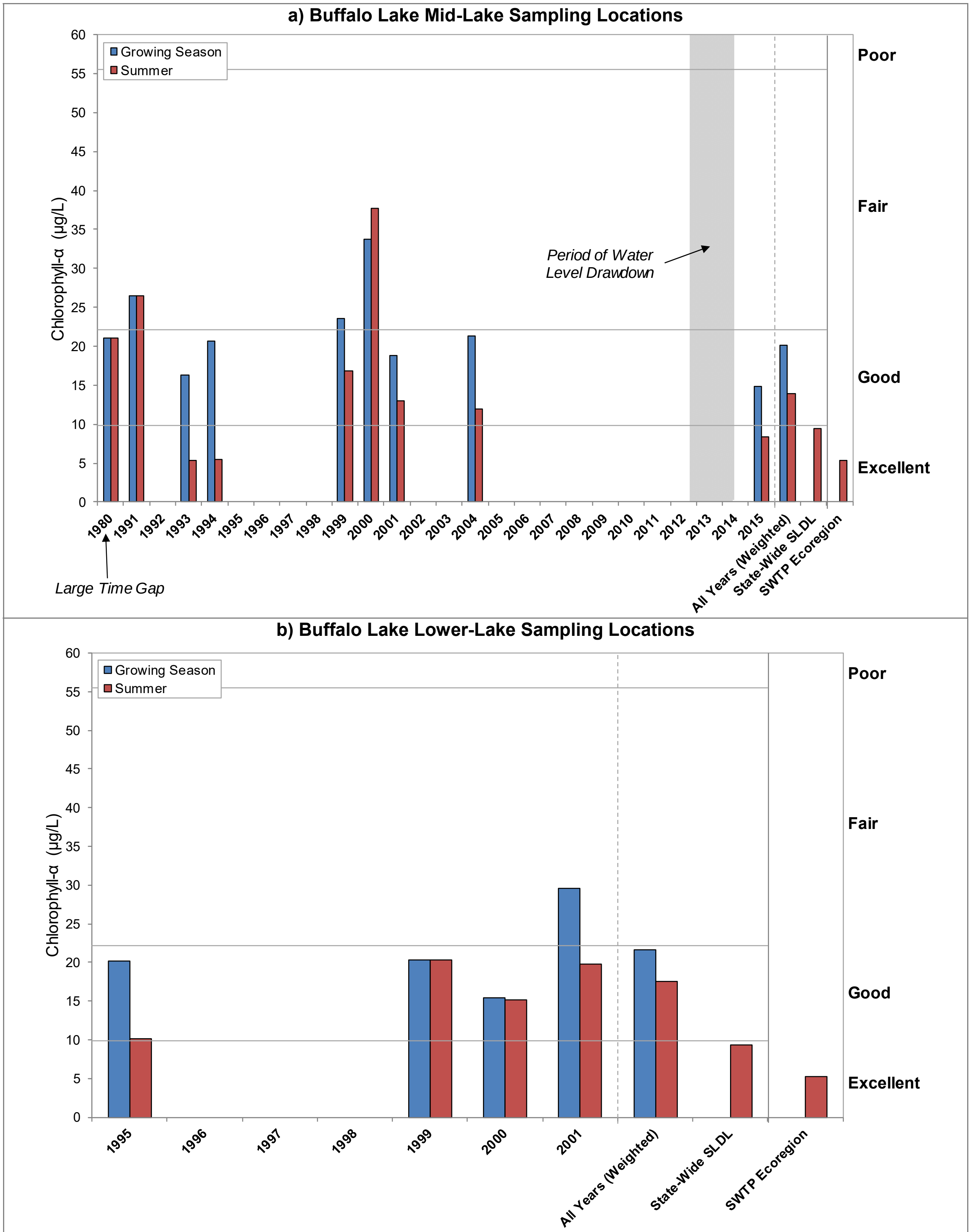


Figure 3.1-5. Buffalo Lake average annual chlorophyll-α concentrations measured from the Mid-Lake sampling locations (a) and the Lower-Lake sampling locations (b). Also displayed are the median chlorophyll-α concentrations for state-wide shallow, lowland drainage lakes (SLDL) and Southeastern Wisconsin Till Plain (SWTP) ecoregion lakes. Water Quality Index values adapted from WDNR PUB WT-913.

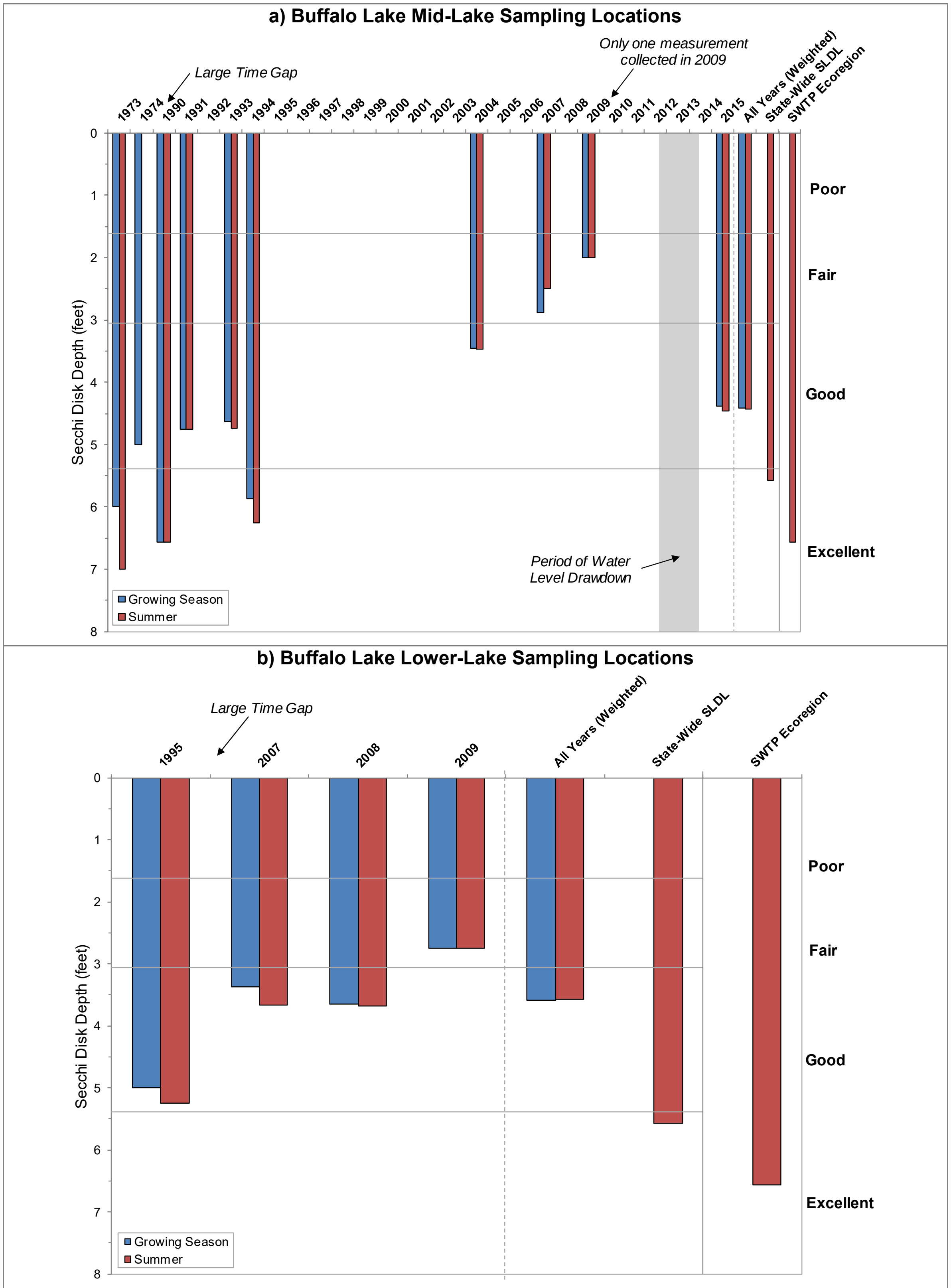


Figure 3.1-6. Buffalo Lake average annual Secchi disk transparency measured from the Mid-Lake sampling locations (a) and the Lower-Lake sampling locations (b). Also displayed are median Secchi disk transparency values for state-wide shallow, lowland drainage lakes (SLDL) and Southeastern Wisconsin Till Plain (SWTP) ecoregion lakes. Water Quality Index values adapted from WDNR PUB WT-913.

Seasonal Water Quality Dynamics in Buffalo Lake

As is discussed in the previous section, historical water quality data from Buffalo Lake are rather limited making it difficult to determine if any long-term trends in water quality are occurring. From the data that are available, no apparent trends over time were detected. However, the data collected in 2015, along with available water quality data from the Mid-Lake sampling locations, do indicate a recurring, annual seasonal pattern in Buffalo Lake's water quality. Figure 3.1-7 displays monthly average values from April-September for total phosphorus, chlorophyll-*a*, and Secchi disk transparency using all available data from the Mid-Lake sampling locations. These data show that total phosphorus concentrations increase during the open-water season, reaching a maximum concentration in July before declining again into the fall. In contrast, chlorophyll-*a* concentrations are highest in the spring and reach a minimum concentration in mid-summer. Water clarity is lowest in the spring and increases over the summer, with the highest clarity occurring in August.

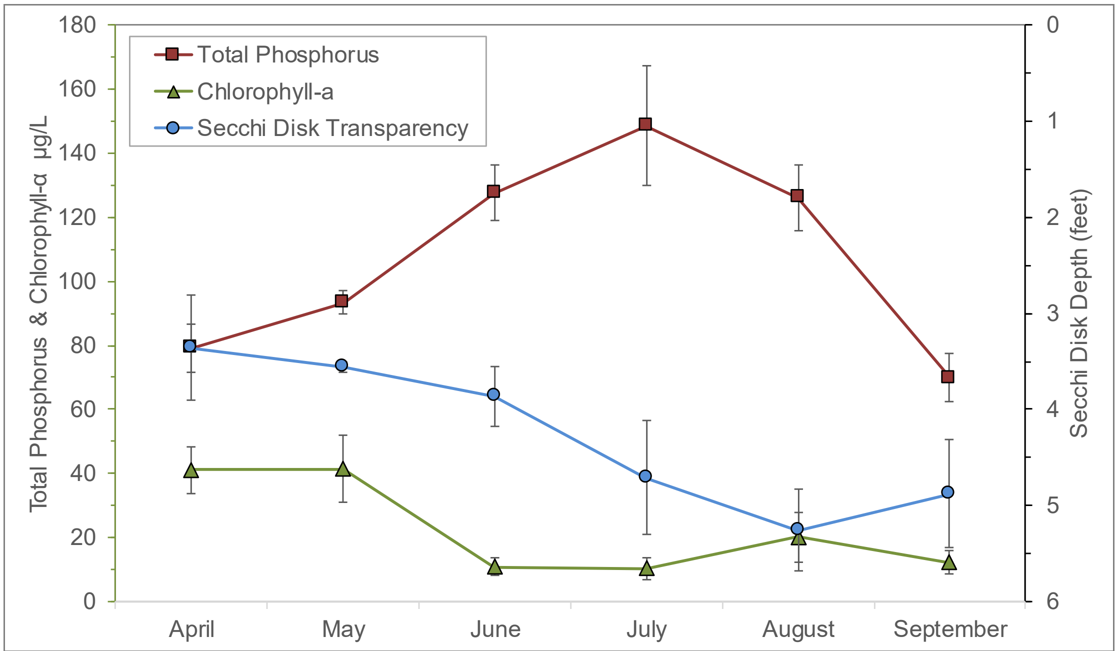


Figure 3.1-7. Buffalo Lake average monthly total phosphorus, chlorophyll-α, and Secchi disk transparency. Bars represent one standard error. Created using available data from Mid-Lake sampling locations. Data from 1973 and 1974 were not included.

Water quality data collected in 2015 also followed this same general pattern (Figure 3.1-8). On average, total phosphorus concentrations increase from an average of 79 µg/L in April to 149 µg/L in July before declining back to an average of 70 µg/L in September. This recurring pattern of increasing phosphorus concentrations over the course of the growing season is an indication that *internal nutrient loading* is likely occurring, a phenomenon often observed in shallow lakes. Lakes typically act as phosphorus 'sinks', meaning that less phosphorus leaves the lake than the amount that entered from its watershed. Most of the phosphorus that enters a lake tends to eventually become bound within bottom sediments. Typically, phosphorus concentrations tend to be higher in the spring when precipitation and runoff are higher, lower in the summer as phytoplankton consume phosphorus, die, and sink to the bottom, and higher again in the fall with increased precipitation and runoff. Internal nutrient loading, or internal nutrient recycling, involves the release of phosphorus once bound in the lake sediment back into the overlying water column.

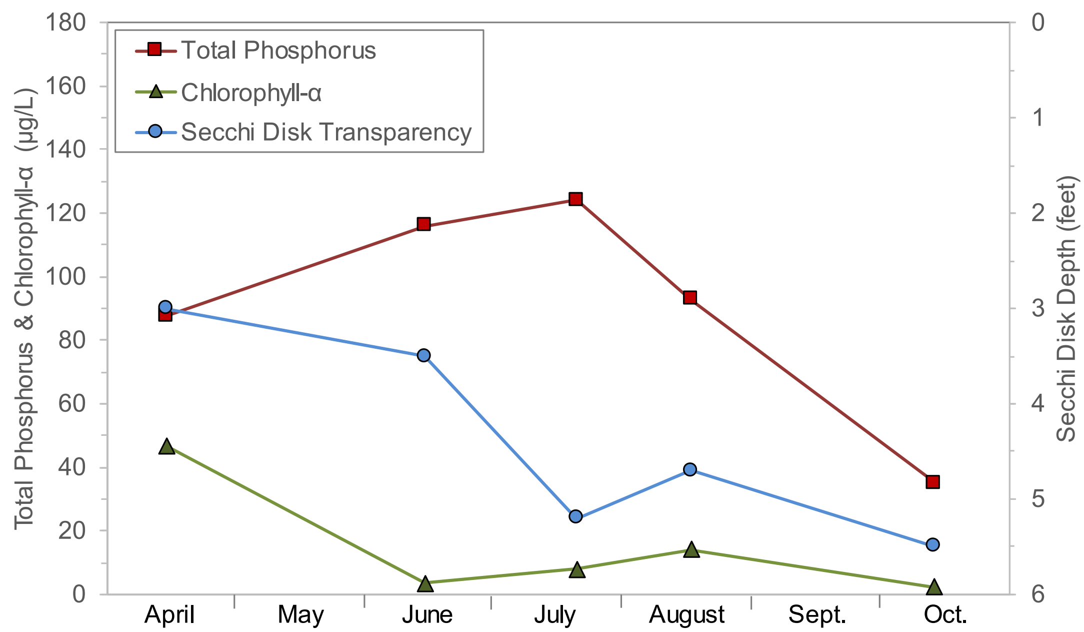


Figure 3.1-8. Buffalo Lake 2015 total phosphorus, chlorophyll-α, and Secchi disk transparency. Created using data collected from the Deepest Spot sampling location (Map 2).

The release of phosphorus from bottom sediments into the overlying water occurs under two primary environmental conditions: 1) anoxia and/or 2) elevated water pH. In the presence of oxygen, phosphorus remains bound to ferric iron within the sediment. When the overlying water becomes anoxic, or devoid of oxygen, the iron is reduced to ferrous iron and the bond with phosphorus is broken resulting in both iron and phosphorus being 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 (the hypolimnion) and the warmer, less dense layer of water at the surface (the epilimnion), prevents these layers from mixing together. Consequently, oxygen depleted through sediment oxygen demand, or the removal of oxygen consumption through biological activity within the sediments, is not replaced via atmospheric diffusion and anoxic conditions result.

Phosphorus can also be released from bottom sediments into the overlying water when water pH becomes elevated to 9.0 or above. The pH scale ranges from 0 to 14 and is an indicator of the concentration of hydrogen (H+) within the lake's water and is an index of the lake's acidity. Water with a pH value of 7.0 has equal amounts of hydrogen ions and hydroxide ions (OH-) and is considered neutral. Water with a pH of less than 7.0 has a higher concentration of hydrogen ions and is acidic, and water with a pH of greater than 7.0 has lower hydrogen ion concentrations and is 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 found in some acid bog lakes and higher than 8.4 in some marl lakes and highly productive lakes (Shaw and Nimphius 1985).

> **Macrophytes** are larger aquatic plants that can be seen with the naked eye, and include flowering plants such as pondweeds and milfoils and macroalgae like muskgrasses among others.

Carbon dioxide dissolves in and reacts with lake water to form carbonic acid which lowers the water's pH. However, during the day, photosynthesizing phytoplankton and *macrophytes* consume carbon dioxide and water pH rises. When phytoplankton and/or macrophytes become overly abundant they have the capacity to raise a lake's pH to 9.0 or greater during the day. When pH reaches these levels, the tendancy of phosphorus to remain bound within the sediment is reduced, and phosphorus can be released from sediment under these conditions even in the presence of oxygen (Solim and Wanganeo 2009).

In Buffalo Lake, it is believed that phosphorus is being released from bottom sediments during the summer due to anoxia, and possibly elevated pH. However, anoxic conditions in Buffalo Lake are not resulting from thermal stratification, but are likely arising from a different process. Buffalo Lake is shallow with a large surface area, and thus is classified as a polymictic lake based on the Osgood Index. The Osgood Index predicts the probability that a lake will remain stratified during the summer, and uses an equation that relates the lake's mean depth to its surface area (equation below). Lakes with an Osgood Index of less than 4.0 are deemed polymictic, and given Buffalo Lake's large surface area relative to its shallow depth, it has a low Osgood Index of only 0.4. This low Osgood Index value indicates that Buffalo Lake rarely, if ever, thermally stratifies during the summer.

$$Buffalo\ Lake\ Osgood\ Index\ (0.4) = \frac{Buffalo\ Lake\ Mean\ Depth\ (1.1\ m)}{\sqrt{Buffalo\ Lake\ Area\ (9.0\ km^2)}}$$

The temperature and dissolved oxygen data collected in 2015 show that Buffalo Lake's temperature and dissolved oxygen were uniform throughout the water column during every sampling event, an indication that the lake was not thermally stratified. While the development of anoxia due to thermal stratification is likely not occurring in Buffalo Lake, it is believed that anoxia is likely developing at the sediment-water interface within areas of dense aquatic plant growth, and consequently, phosphorus is being released from bottom sediments in these areas. Studies involving aquatic plants and sediment phosphorus release have found that some aquatic plants with deep root systems, like wild celery (*Vallisneria americana*), oxygenate the sediments and prevent phosphorus release, while others with shallow root systems such as common waterweed (*Elodea canadensis*) and Eurasian watermilfoil (*Myriophyllum spicatum*), or those with no root systems, like coontail (*Ceratophyllum demersum*), caused reductions in oxygen at the sediment-water interface and increased the release of phosphorus into the water (Wigand et al. 1997; Boros et al. 2011; Dai et al. 2015).

Wigand et al. 1997 found that when the water column was occupied by 80-100% coverage of these shallow-rooted aquatic plants, phosphorus was released from bottom sediments. The researchers believed that the dense growth of aquatic plants reduces mixing of oxygen down into the water column, and their shallow root systems were not able to replenish oxygen at the same rate it was being depleted. In addition, they also indicated that shading by dense aquatic plant growth prevents the growth of algae along the bottom, which have been shown to increase oxygen within the sediment-water interface. Buffalo Lake contains many areas with dense aquatic plant growth, and the 2015 whole-lake point-intercept survey found that 46% of the aquatic plant community is comprised of coontail and common waterweed, plants that have been shown to cause phosphorus release from bottom sediments in areas with dense growth.

Elevated pH has also been shown to cause the release of phosphorus from bottom sediments. However, in 2015, the highest pH recorded in Buffalo Lake was 8.4, indicating that elevated pH is likely not a significant contributor to phosphorus release from bottom sediments. However, it is possible that pH may become elevated to higher levels than what was measured within areas of dense aquatic plant growth during the day when photosynthetic rates of macrophytes are high.

The non-native plant curly-leaf pondweed naturally senesces (dies-back) in early-July. Decaying curly-leaf pondweed plants have been documented to release phosphorus into the water, and studies have shown that the senescence of large populations of curly-leaf pondweed can significantly increase phosphorus concentrations. It is likely that a portion of the increase in phosphorus observed during the summer in Buffalo Lake is due to senescence of the curly-leaf pondweed population. However, without conducting biomass and phosphorus content analysis of the curly-leaf pondweed population in Buffalo Lake, it is not possible to quantify how much phosphorus is contributed from curly-leaf pondweed senescence.

Sediment resuspension from wind and/or benthivorous fish (i.e. common carp) has also been shown to cause phosphorus concentrations to increase during the growing season in shallow lakes. However, total suspended solids measured during the summer of 2015 in Buffalo Lake were low at 2.0 mg/L and water clarity was high, indicating that the majority of the measured increase in phosphorus was likely not a result of sediment resuspension. Aquatic plants have been shown to greatly reduce sediment resuspension caused by wind- and boater-induced water movement (Horppila and Nurminen 2003). As is discussed further in this report, while the dense growth of coontail and common waterweed (among others) in Buffalo Lake is likely causing the observed increases in phosphorus during the summer, the benefits these plants provide to the lake outweigh their effects on the lake’s phosphorus concentrations.

As discussed in the previous section, phosphorus is the nutrient that limits and regulates the growth of algae in the majority of Wisconsin’s lakes. As phosphorus increases, chlorophyll-*a* concentrations also tend to increase. On average, phosphorus concentrations in Buffalo Lake nearly double from early spring to mid-summer. Based upon Buffalo Lake’s average summer total phosphorus concentration of 115 µg/L, it is predicted that Buffalo Lake’s average summer chlorophyll-*a* concentration should be 84 µg/L, or six times higher than the measured average summer value. Despite increasing phosphorus concentrations over the course of the summer, chlorophyll-*a* concentrations decline. The failure of chlorophyll-*a* concentrations to respond to increasing phosphorus concentrations in Buffalo Lake indicates that another factor other than phosphorus is limiting the growth of phytoplankton.

Nitrogen is second to phosphorus in terms of its importance in regulating the growth of phytoplankton, and in some Wisconsin lakes, nitrogen is the nutrient that is in shortest supply and thus limits the growth of phytoplankton. To determine whether phosphorus or nitrogen is 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 numerous different forms of nitrogen which are delivered to Wisconsin's lakes. Nitrogen enters waterbodies through precipitation, fixation from the atmosphere by cyanobacteria, surface inflow including fertilizers and animal wastes from agricultural areas, groundwater, and sewage treatment plants or septic systems (Wetzel 2001). 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 organism that have the ability to convert atmospheric nitrogen into a usable form.

In Buffalo Lake, nitrogen concentrations are highest in the spring, likely a result of higher runoff from agricultural lands within the watershed. During this time, the nitrogen to phosphorus ratio is greater than 20:1, indicating that phosphorus is the limiting nutrient (Figure 3.1-9). While phosphorus concentrations are at their lowest in Buffalo Lake during the spring, these concentrations are still relatively high, and consequently, given the ample amount of nitrogen, phytoplankton growth is also at its highest.

Progressing into summer as phosphorus concentrations increase, nitrogen concentrations decline. The same processes that cause phosphorus to be released from bottom sediments within areas of dense aquatic plant growth also facilitate *denitrification*, a process by which microbes convert nitrate back to nitrogen gas which is then lost to the atmosphere. Denitrification rates are also high within wetlands, and the wetlands within Buffalo Lake's watershed likely also reduce the amount of nitrogen being delivered into the lake during the summer. While increasing phosphorus concentrations alone can lower the nitrogen to phosphorus ratio, the decline in the nitrogen to phosphorus ratio during the summer in Buffalo Lake is primarily driven by the large decline in nitrogen. By June, the nitrogen to phosphorus ratio in Buffalo Lake falls below 10:1 indicating a transition to nitrogen limitation, and the lake remains nitrogen-limited through the remainder of the growing season (Figure 3.1-9). This seasonal change between phosphorus- and nitrogen-limitation have been observed in other shallow lakes around the world (Moss et al. 2013).

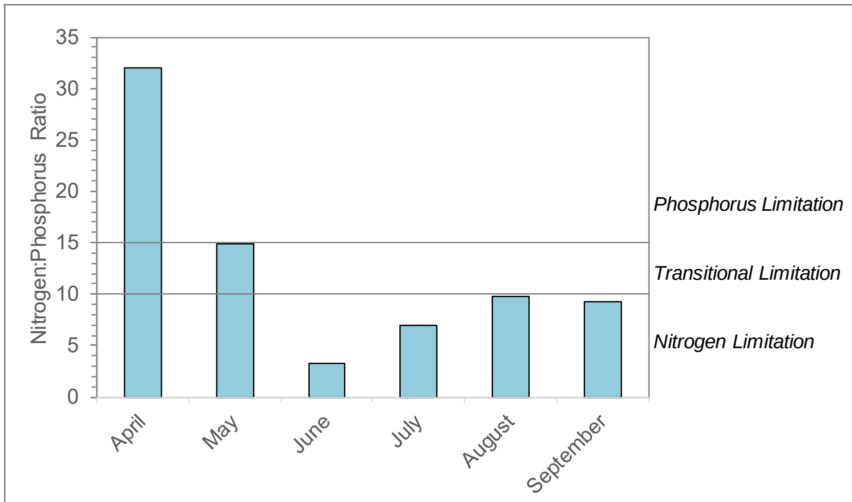


Figure 3.1-9. Buffalo Lake monthly average total nitrogen to total phosphorus ratios. Created using available data from the Mid-Lake sampling locations. Data from 1973 and 1974 were not included.

Phytoplankton growth in Buffalo Lake does not respond to increasing phosphorus concentrations during the summer because there is a limited amount of nitrogen as a result of the processes previously discussed. While low nitrogen concentrations will limit the growth of most phytoplankton, cyanobacteria (blue-green algae) have the ability to fix or utilize atmospheric nitrogen when bio-available nitrogen within the water is low. This competitive advantage often leads to blue-green algae blooms in nitrogen-limited lakes. However, as the chlorophyll-*a* data indicate, phytoplankton abundance including blue-green algae is relatively low during the summer in Buffalo Lake.

Despite the ability of blue-green algae to access atmospheric nitrogen, their growth in Buffalo Lake during the summer is likely limited by zooplankton, small planktonic crustaceans which feed upon phytoplankton. Zooplankton utilize aquatic plants as a refuge from predatory fish, and the abundance of aquatic plants in Buffalo Lake likely allow for a robust zooplankton community which feed upon and limit the growth of blue-green algae and other phytoplankton (Moss et al. 2013). Without aquatic plants, predation upon zooplankton by fish would be higher and the ability of zooplankton to maintain lower phytoplankton abundance in Buffalo Lake would be diminished.

In addition to providing habitat for zooplankton, the aquatic plant community in Buffalo Lake also contributes to reducing phytoplankton growth by directly absorbing nutrients from the water. Coontail and common waterweed, the most abundant plants in Buffalo Lake, obtain the majority of their nutrients directly from the water making these nutrients unavailable to free-floating algae (Gross et al. 2003). The leaves and stems of aquatic plants also provide habitat for periphyton, a mixture of algae and other microbes which attach to aquatic plants and obtain nutrients from the water. Coontail, among other aquatic plants, has also been shown to release allelochemicals which inhibit the growth of phytoplankton (Gross et al. 2013).

As phytoplankton growth declines over the course of the summer in Buffalo Lake, water clarity increases (Figure 3.1-7 and 3.1-8). Secchi disk transparency in Buffalo Lake is lowest in the spring with an average of approximately 3.5 feet, and increases over the summer reaching a maximum of approximately 5.0 feet in July and August. Water clarity is influenced by particulate substances such as phytoplankton and suspended sediments, but it is also influenced by dissolved compounds within the water as well. *True color* measures the amount of light scattered and absorbed by organic materials dissolved within the water. Lakes with larger watersheds typically have higher amounts of dissolved organic materials which originate from decomposing plant material delivered from forests and wetlands within the watershed. At higher concentrations, these compounds give the water a tea-like color and reduce water clarity.

In 2015, true color was measured in Buffalo Lake during the spring and mid-summer, with values of 60 and 40 Standard Units (SU), respectively. These values indicate that Buffalo Lake's water can be described as *lightly tea-colored* to *tea-colored* (UNH Center for Freshwater Biology 2014), and that the lake's water clarity is influenced by both phytoplankton and these dissolved organic compounds. The true color values from Buffalo Lake fall within the low to medium range for true color for drainage lakes in Wisconsin (Lillie and Mason 1983).

Buffalo Lake Trophic State

Figure 3.1-10 contains the weighted average Trophic State Index (TSI) values for each year with available data from the Mid-Lake sampling locations in Buffalo Lake. The TSI values are calculated with annual average summer month Secchi disk, chlorophyll-*a*, and total phosphorus values. In general, the best values to use in judging a lake's trophic state are chlorophyll-*a* and total phosphorus, as water clarity can be influenced by other factors such as dissolved organic compounds and abiotic suspended materials. If the TSI values calculated using total phosphorus, chlorophyll-*a*, and Secchi disk transparency are similar to one another, it is an indication that these three parameters a highly correlated with one another.

The weighted TSI value for total phosphorus from Buffalo Lake falls into the hypereutrophic category and is higher than the weighted average TSI values for chlorophyll-a and Secchi disk transparency, which fall into the lower eutrophic category. The lower TSI value for chlorophyll-a when compared to total phosphorus is another indication of nitrogen limitation in Buffalo Lake. In addition, the slightly higher TSI value for Secchi disk transparency when compared to chlorophyll-a is an indicator that water clarity is also reduced by another factor other than algae, likely the dissolved organic compounds discussed earlier. Hypereutrophic lakes are characterized by having excessive nutrients and algae, and low water clarity. While the TSI value for total phosphorus falls in the hypereutrophic category in Buffalo Lake, nitrogen regulates primary productivity. Therefore, the TSI for chlorophyll-*a* is the best indicator of Buffalo Lake's trophic state and indicates Buffalo Lake is in a eutrophic state.

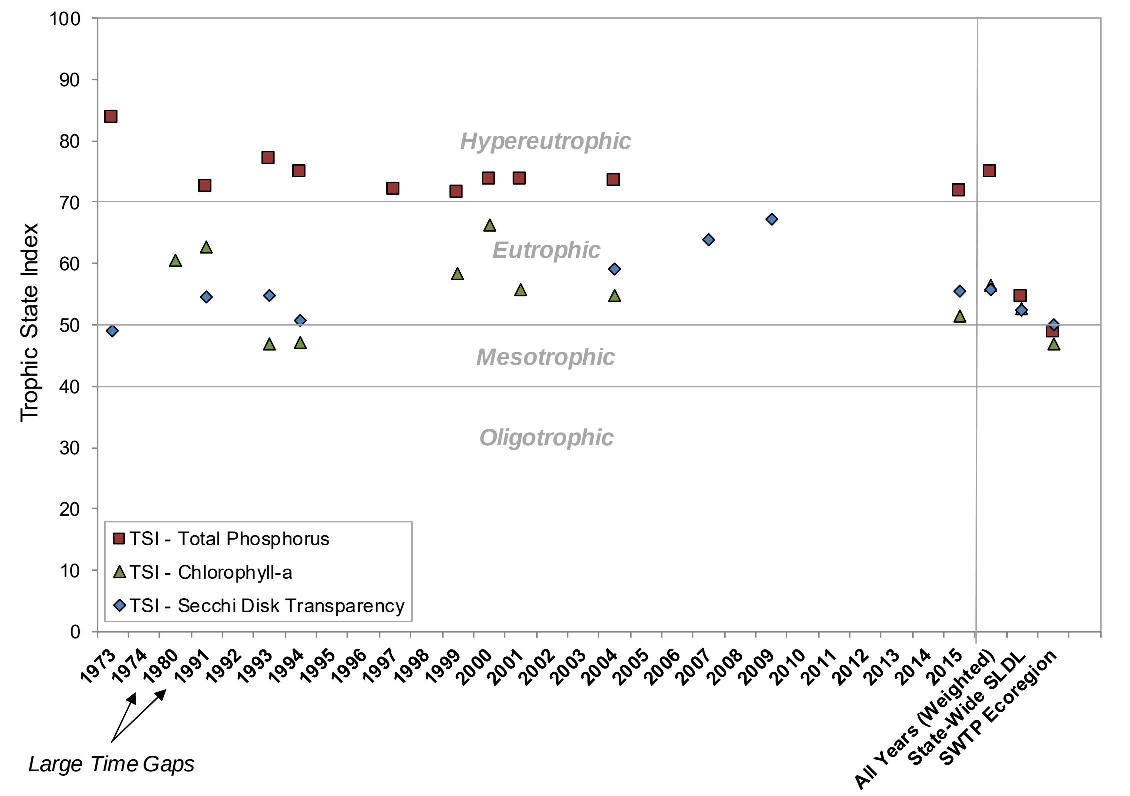


Figure 3.1-10. Buffalo Lake, state-wide shallow lowland drainage lakes (SLDL), and Southeastern Wisconsin Till Plains (SWTP) ecoregion Trophic State Index values. Values calculated with summer month surface sample data from Mid-Lake sampling locations using WDNR PUB-WT-193.

Shallow Lakes and Alternative Stable States

Shallow lakes are considered to exist in one of two general stable states: a turbid (low clarity) state 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 predate upon 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. 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 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 phytoplankton 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.

Buffalo 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 Buffalo 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. And while it is believed the dense aquatic plant growth is the cause of increasing phosphorus concentrations during the summer, they also facilitate the decline of nitrogen which results in nitrogen limitation. The nitrogen-limited conditions prevent phytoplankton growth despite high concentrations of phosphorus. Additionally, these plants provide habitat for zooplankton which prevent the nitrogen-fixing blue-green algae from becoming overly abundant.

Dissolved Oxygen and Temperature in Buffalo Lake

As mentioned previously, dissolved oxygen and temperature were measured during water quality sampling visits to Buffalo Lake by Onterra staff. Profiles depicting these data are displayed in Figure 3.1-11. These data indicate that given Buffalo Lake's shallow nature, the lake likely remains uniformly mixed throughout the open-water season and does not experience strong thermal stratification. In shallow, productive lakes like Buffalo Lake, dissolved oxygen can often become depleted in the winter with ice cover resulting in fish kills. On February 17, 2016, a profile collected through the ice by Onterra ecologists indicated sufficient levels of oxygen throughout the water column (>7.0 mg/L).

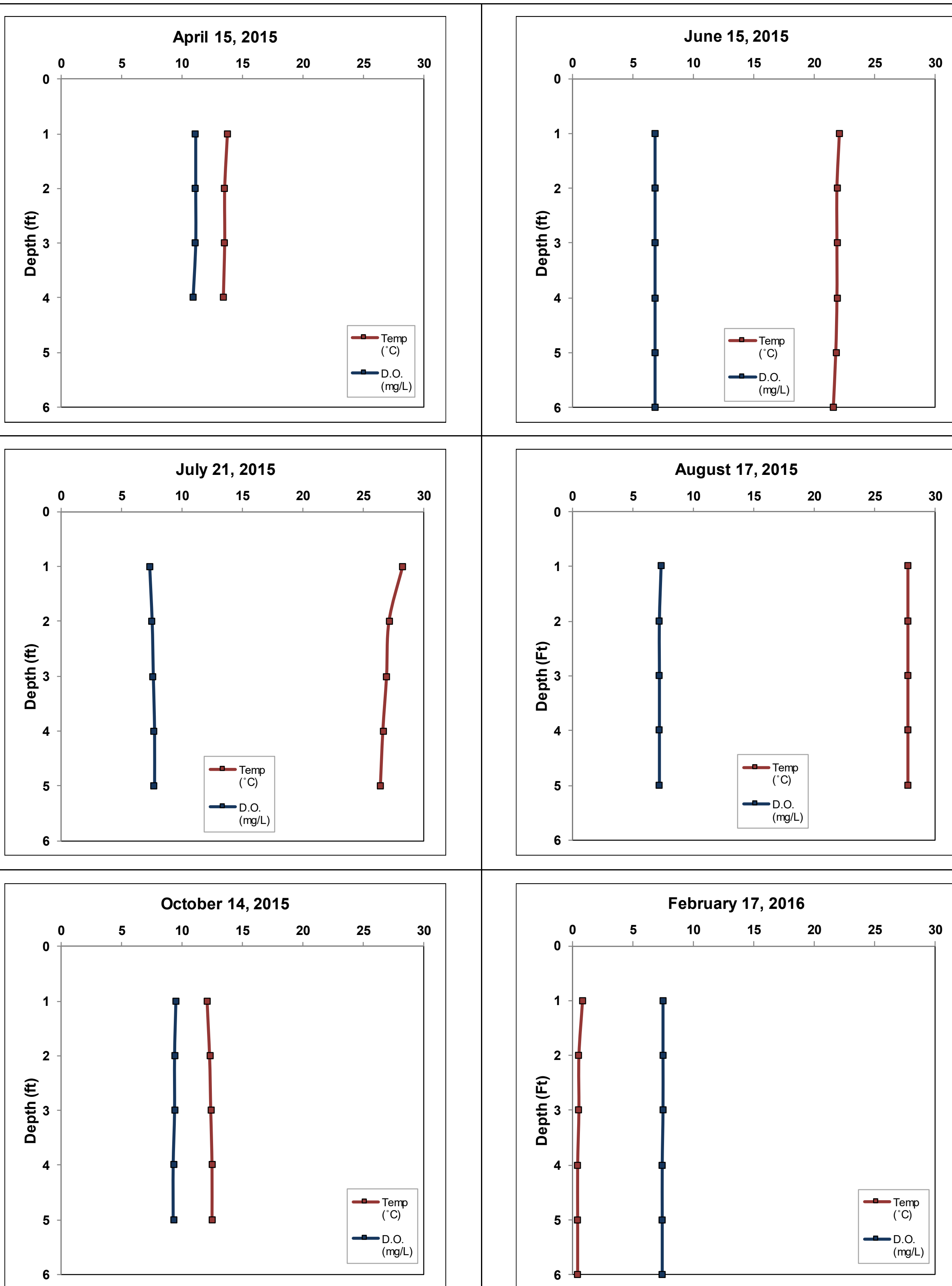


Figure 3.1-11. Buffalo Lake 2015-16 temperature and dissolved oxygen profiles. Data collected from Deepest Spot sampling location (Map 2).

Additional Water Quality Data Collected at Buffalo Lake

The previous sections were centered on lake eutrophication. However, parameters other than water clarity, nutrients, and chlorophyll-*a* were collected as part of the project. These other parameters were collected to increase the understanding of Buffalo Lake's water quality and are recommended as a part of the WDNR long-term lake trends monitoring protocol. These parameters include pH, alkalinity, calcium, and total suspended solids. Buffalo Lake's pH was discussed earlier regarding internal nutrient loading, and the definition for pH can be found in the earlier section, *Seasonal Water Quality Dynamics in Buffalo Lake*. In lakes with a pH of 6.5 and lower, the spawning of certain fish species such as walleye becomes inhibited (Shaw and Nimphius 1985). The pH of the water in Buffalo Lake was found to be alkaline with values ranging 8.1 to 8.4 in 2015.

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 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 average near-surface alkalinity in Buffalo Lake was measured at 161 (mg/L as $CaCO_3$), indicating that the lake has a substantial capacity to resist fluctuations in pH and has a low sensitivity to acid rain.

Like associated pH and alkalinity, the concentration of calcium within a lake's water depends on the geology of the lake's watershed. Recently, the combination of calcium concentration and pH has been used to determine what lakes can support zebra mussel populations if they are introduced. The commonly accepted pH range for zebra mussels is 7.0 to 9.0, and Buffalo Lake's pH falls inside of this range. Lakes with calcium concentrations of less than 12 mg/L are considered to have very low susceptibility to zebra mussel establishment. In 2015, calcium concentrations were measured in Buffalo Lake in spring and mid-summer, and the average concentration was 37.1 mg/L. The concentration of calcium in Buffalo Lake indicates the lake has *high susceptibility* to zebra mussel establishment if they are introduced. Onterra ecologists conducted plankton tows at three locations in Buffalo Lake in 2015 that underwent analysis for zebra mussel veligers, or the larval stage which is planktonic and their results were negative for the presence of veligers. Onterra ecologists did not observe any adult zebra mussels (alive or dead) during the surveys on Buffalo Lake in 2015.

Total suspended solids (TSS) are a measure of inorganic and organic particles suspended in the water, and include everything from algae to clay particles. High TSS creates low water clarity, and prevents light from penetrating into the water to support aquatic plant growth. Total suspended solids were measured in Buffalo Lake in spring, mid-summer, and fall in 2015. Total suspended solids were highest in spring with a value of 10.4 mg/L. This higher value was likely due to the higher amounts of algae growing in the lake at this time of year as well as higher amounts of suspended sediments due to increased runoff and the lack of aquatic vegetation. With a reduction in algae and the growth of aquatic vegetation, total suspended solids were low in mid-summer with a value of 2.0 mg/L, and were also relatively low in the fall with a value of 4.6 mg/L.

303(d) List Impairment Listing

The 303(d) list is listing of waterbodies that do not meet water quality standards under the Clean Water Act that needs to be submitted to the Environmental Protection Agency every two years by the state. Buffalo Lake was first placed on the 303(d) list and listed as impaired in 1998. Buffalo Lake is listed as impaired due to contamination of fish tissue by mercury and polychlorinated biphenyls (PCBs).

While mercury is found naturally in the environment due to volcanic eruptions and weathering of rocks, the majority of the mercury found in Wisconsin's waterbodies is the result of coal-fired power plants and the release of mercury into the atmosphere. Mercury is deposited into lakes, rivers, and streams through precipitation and the deposition of dust particles where it converted into its mobile and harmful form, methylmercury. Methylmercury becomes stored in bodies of aquatic animals, and concentrations tend to be highest in those species at the top of the food chain. In humans, mercury affects the nervous system and is of special concern for unborn children, infants, and children.

Polychlorinated biphenyls are man-made organic chemicals once used in various industries, and their use has been banned since 1979. However, PCBs continue to persist in certain waterbodies where they were discharged because they breakdown slowly. Like mercury, PCBs accumulate within aquatic organisms, and concentrations are often highest in top predatory species. These chemicals have been associated with birth defects, reproductive function, and cancer. The WDNR has guidelines for safe-eating of fish in Wisconsin's waterbodies. The guidelines for Buffalo Lake can be found in Table 3.1-2 below.

Table 3.1-2. Fish consumption advisories for Buffalo Lake. Adapted from WDNR website http://dnr.wi.gov/FCSExternalAdvQry/FishAdvisorySrch.aspx. Accessed April 18, 2016.

Women up to age 50 (child bearing age) and children (under age 15) may safely eat:	
1 Meal Per Week	Black Crappie, Bluegill and Sunfish, Bullheads, Inland Trout, Yellow Perch
1 Meal Per Month	Bass, Catfish, Pike, Walleye, all other species and sizes
6 Meals Per Year	Carp
Do Not Eat	Muskies

All Men (15 and older) and older women (50 and older) may safely eat:	
Unrestricted	Bullheads, Inland Trout
1 Meal Per Week	Bass, Black Crappie, Bluegill and Sunfish, Catfish, Pike, Walleye, Yellow Perch, all other species and sizes
1 Meal Per Month	Muskies
6 Meals Per Year	Carp

3.2 Watershed Assessment

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

Buffalo Lake Watershed Assessment

The surface water drainage basin, or watershed, for Buffalo Lake encompasses approximately 257,418 acres (402 square miles) across Marquette, Columbia, Adams, and Green Lake counties, yielding a watershed to lake area ratio of 115:1 (Figure 3.2-1; Map 3). In other words, approximately 115 acres of land drains to every one acre of Buffalo Lake. The WiLMS modeling indicates that Buffalo Lake's water residence time is approximately 14.6 days, or the water within the lake is completely replaced (flushing rate) every 14.6 days or 25 times per year.

Total phosphorus data are available from four lakes within Buffalo Lake's watershed, and for modeling purposes the watershed was divided into five main subwatersheds: Buffalo Lake's direct or local watershed, the Williams Lake subwatershed, the Ennis Lake subwatershed, the Mason Lake subwatershed, and the Swan Lake subwatershed (Figure 3.2-1; Map 3). Approximately 75% of Buffalo Lake's watershed is comprised of its direct watershed, 16% is comprised of the Swan Lake subwatershed, 8% is comprises of the Mason Lake subwatershed, 1% is comprised of the Williams Lake subwatershed, and <1% is comprised of the Ennis Lake subwatershed (Figure 3.2-2).

Land cover data indicates that approximately 41% (78,852 acres) of Buffalo Lake's direct watershed is comprised of row crop agriculture, 27% (52,872 acres) is comprised of forests, 19% (35,991 acres) is comprised of forested and non-forested wetlands, 10% (19,816 acres) is comprised of pasture/grass, 2% (3,056 acres) is comprised of rural residential areas, 1% (2,227 acres) is comprised of Buffalo Lake's surface, <1% (694 acres) is comprised of urban areas of medium density, and <1% (263 acres) is comprised of urban areas of high density (Figure 3.2-2). Like Buffalo Lake's direct watershed, the majority of the land cover within the subwatershed basins for Swan Lake, Mason Lake, Williams Lake, and Ennis Lake are comprised of row crop agriculture and forests.

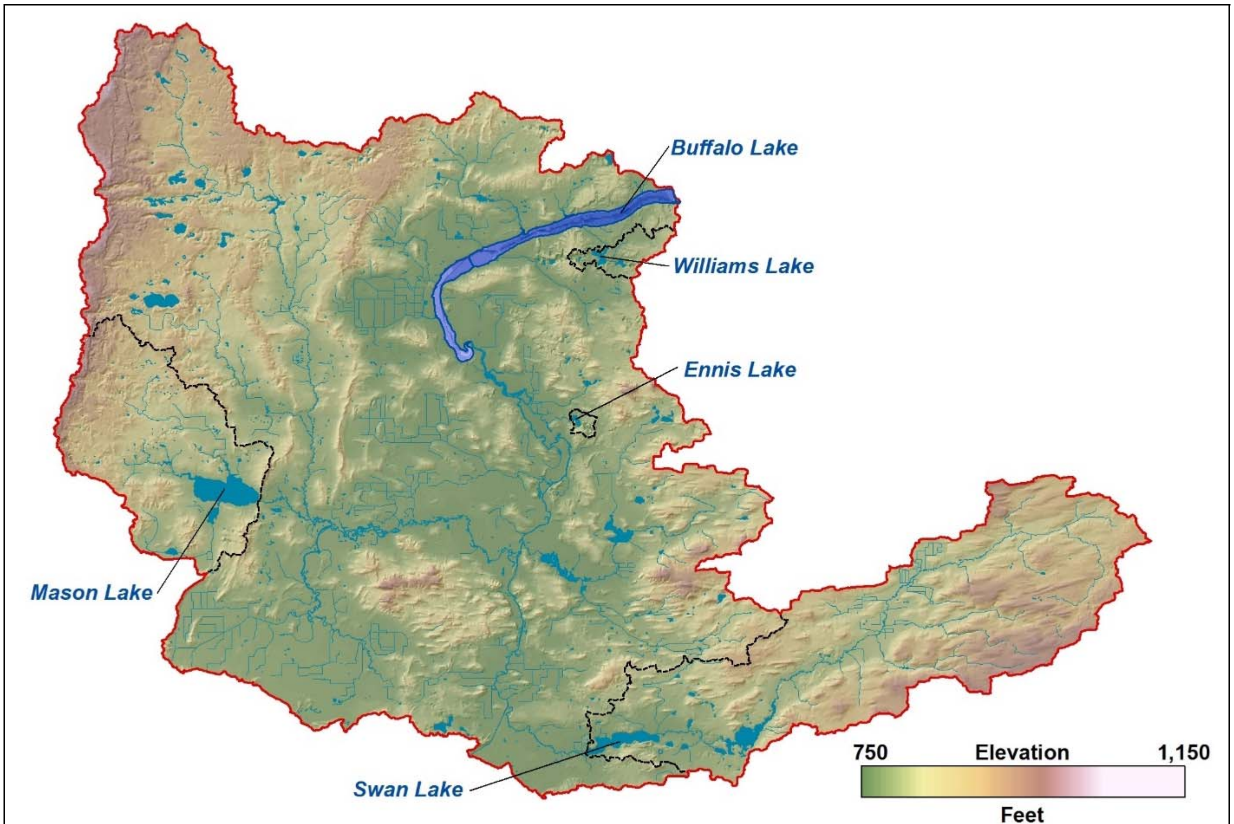


Figure 3.2-1. Buffalo Lake watershed used in WiLMS modeling. Red outline represents Buffalo Lake entire watershed; dashed black lines represent subwatersheds of lakes used in modeling.

Using the land cover types and their acreages within Buffalo Lake's direct watershed along with the estimated outflow of phosphorus from the four subwatersheds, WiLMS was utilized to estimate the annual potential phosphorus load delivered to Buffalo Lake from its watershed. In addition, using data obtained from the 2015 stakeholder survey of BLPRD members, an estimate of phosphorus loading to the lake from septic systems was also incorporated into the model. The model estimated that a total of 91,240 pounds of phosphorus are delivered to Buffalo Lake from its watershed on an annual basis (Figure 3.2-3).

Of the 91,240 estimated pounds of phosphorus being delivered to Buffalo Lake annually, the majority (77%) is estimated to originate from areas of row crop agriculture within Buffalo Lake's direct watershed, 6% from areas of pasture/grass, 5% from forests, 4% from the Swan Lake subwatershed, 4% from wetlands, 3% from the Mason Lake subwatershed, 1% from atmospheric deposition directly onto Buffalo Lake's surface, <1% from urban areas, <1% from rural residential areas, <1% from septic systems on property adjacent to Buffalo Lake, and <1% for the both the Williams Lake and Ennis Lake subwatersheds (Figure 3.1-3).

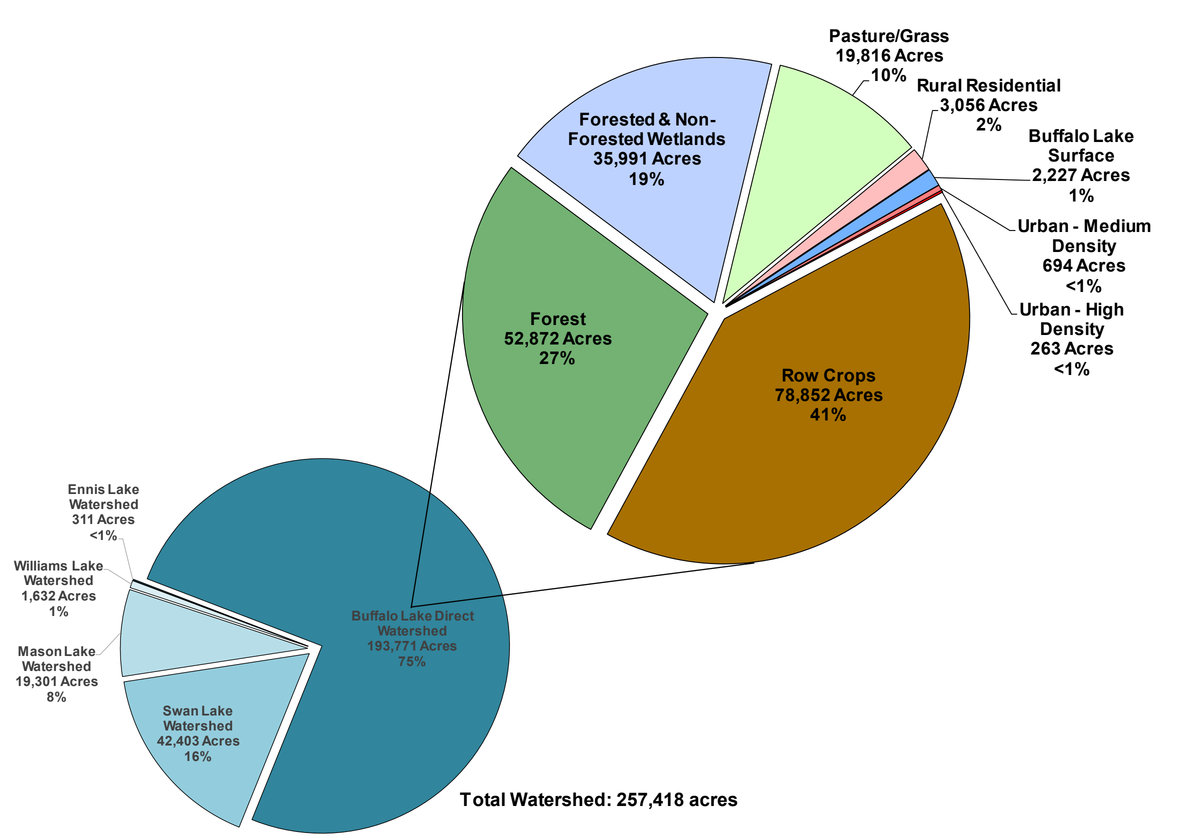


Figure 3.2-2. Buffalo Lake direct watershed land cover types in acres. Based upon National Land Cover Database (NLCD – Fry et. al 2011). Spatial distribution of land cover types is displayed on Map 3.

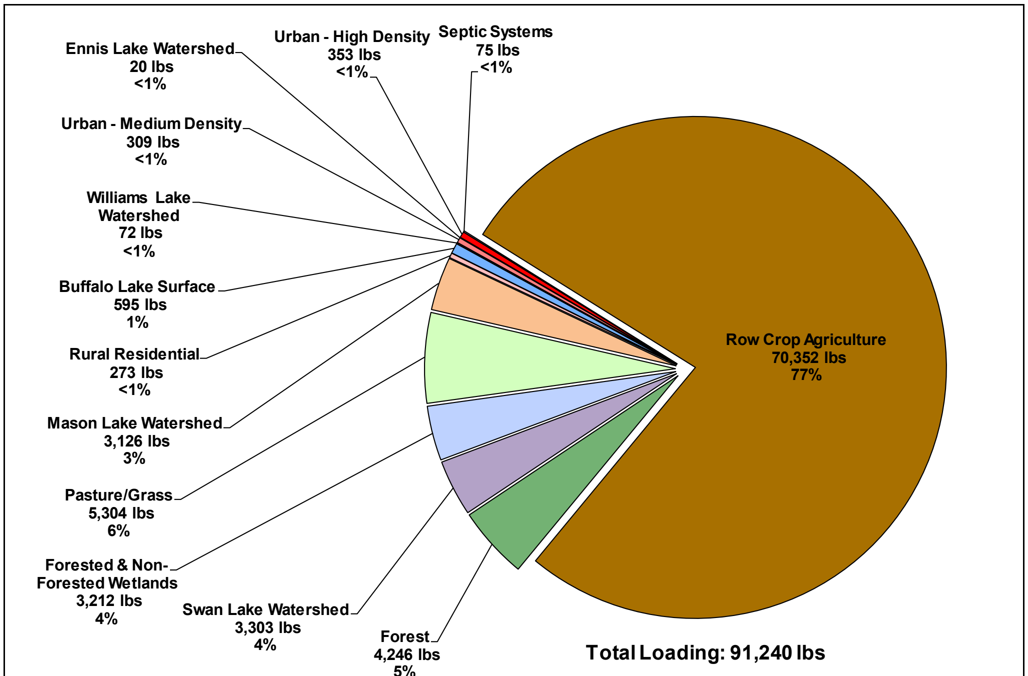


Figure 3.2-3. Buffalo Lake estimated potential annual phosphorus loading. Based upon Wisconsin Lake Modeling Suite (WiLMS) estimates.

Using the estimated annual potential phosphorus load, WiLMS predicts that Buffalo Lake should have an in-lake growing season mean total phosphorus concentration of 103 μg/L, which is only 12 μg/L lower than the weighted average growing season total phosphorus concentration of 115 μg/L calculated from available data. The predicted phosphorus concentration is also similar to the measured growing season mean total phosphorus concentration of 91 μg/L measured in 2015. However, the WiLMS estimated phosphorus loading may be slightly overestimated as a portion of Buffalo Lake's phosphorus originates from the release of phosphorus from bottom sediments (internal phosphorus loading) from processes discussed in the *Water Quality* section. However, this model indicates that the largest fraction of phosphorus (and likely nitrogen) originates from agricultural lands within Buffalo Lake's direct or local watershed. The similarity between the WiLMS predicted growing season total phosphorus and measured growing season total phosphorus concentrations in Buffalo Lake is an indication that there are no significant unaccounted sources of phosphorus being delivered to Buffalo Lake.

Currently, the WDNR is developing a Total Maximum Daily Load (TMDL) for waterbodies within the Upper Fox River Watershed including Buffalo Lake. The Clean Water Act established the term TMDL, which is the maximum amount of a given pollutant (e.g. phosphorus) that a waterbody can receive and still meet defined water quality standards. The Clean Water Act requires that the WDNR provides the Environmental Protection Agency with a list of waterbodies in Wisconsin that do not meet water quality standards under the Clean Water Act, or waterbodies that considered to be impaired. As was discussed in the *Water Quality Section*, Buffalo Lake is currently listed as impaired for PCB and mercury contamination. The TMDL being developed for the Upper Fox River Watershed will identify sources of pollutants such as phosphorus and sediments and determine actions to be taken to reduce these pollutants.

Studies conducted as part of the development for the Buffalo Lake Comprehensive Management Plan (Onterra 2006) illustrated that even if 100% of Buffalo Lake's watershed was forested, the lake would still receive sufficient nutrients to be a eutrophic system and support a high biomass of aquatic plants. Buffalo Lake is nitrogen-limited throughout the majority of the growing season, and to reduce algal growth through phosphorus limitation (nitrogen:phosphorus ratio >15:1) would require that summer phosphorus concentrations be reduced below 50 μg/L, or greater than 66% from the current concentration. To achieve this level of phosphorus reduction, WiLMS modeling indicates that an unrealistic restoration of 75% of row crop agriculture and pasture/grass to forest within Buffalo Lake's direct watershed (~74,000 acres) would need to occur.

As discussed in the *Water Quality* section, the relatively low nitrogen concentrations measured in Buffalo Lake during the summer are believed to be a result of loss to the atmosphere through high rates of denitrification brought about by warm, anoxic sediments within areas of dense aquatic plant growth. High rates of denitrification likely also occur in wetlands within Buffalo Lake's watershed and aid in reducing the amount of nitrogen flowing into the lake in the summer. Preservation/restoration of wetlands within Buffalo Lake's watershed will help reduce excess nitrogen and other pollutant inputs to Buffalo Lake. Reducing the use of lawn fertilizers along lakeshore properties will also aid in reducing nitrogen inputs to Buffalo Lake. Maintaining a healthy native aquatic plant community will also ensure that nitrogen-fixing cyanobacteria also remain low in Buffalo Lake.

Buffalo Lake Water Levels

A number of respondents to the 2015 stakeholder survey sent to BLPRD members indicated they had concerns regarding water levels in Buffalo Lake following the completion of the new dam in 2014. The majority of these comments indicated that many Buffalo Lake stakeholders believe water levels were lower following the construction of the new dam. According to WDNR dam engineers, the new dam was constructed to maintain the same maximum water level of 769.5 feet that the previous dam maintained. However, during periods of lower rainfall and consequently lower flow, the river surface elevation will drop below the maximum water level of 769.5 feet. Monthly precipitation data in the two years following the water level drawdown show that rainfall during the open water season in 2014 was below average in May and July, while rainfall was below average during June, July, and August of 2015 (Figure 3.2-4). These lower rainfall totals may have resulted in the perceived lower water levels during these months in Buffalo Lake.

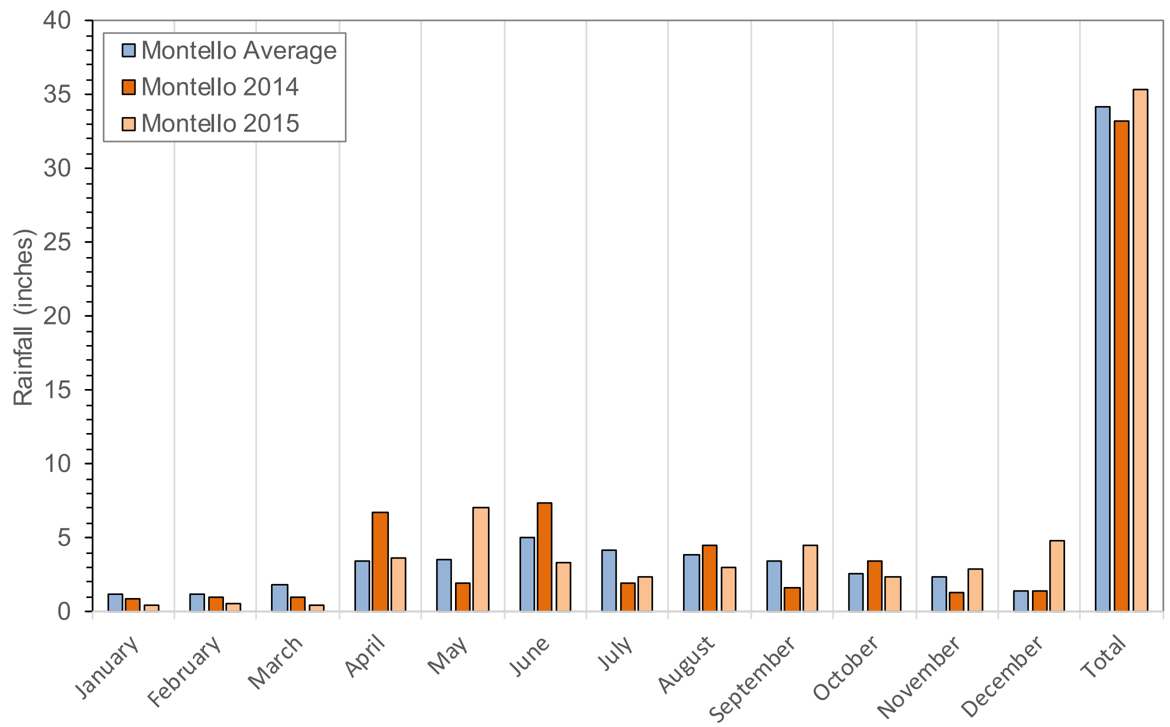


Figure 3.2-4. Montello 2014 and 2015 monthly rainfall totals. Created using data obtained from National Oceanic and Atmospheric Administration (2016).

The WDNR conducted acoustic surveys before and after the water level drawdown, and these data indicate that Buffalo Lake's mean depth increased by approximately 0.6 feet following the drawdown (Ted Johnson personal comm. 2016). However, some areas of the lake, specifically near the County D Causeway, saw sediment accumulation during the drawdown and as a result are now slightly shallower.

The BLPRD also expressed concerns about high capacity wells within Buffalo Lake's watershed and their potential impact to water levels on Buffalo Lake. According to Wisconsin NR 812.07, high capacity wells are defined as a well system of one or more wells that have an approved pump capacity of 70 or more gallons per minute. Construction, reconstruction, and operation of high capacity wells requires WDNR approval, and high capacity well owners are required to report the amount of water withdrawn on an annual basis. Studies completed in the central sands region have indicated water withdrawal from high capacity wells has significantly lowered the groundwater table in many areas, and consequently has artificially lowered the water level of a number of lakes and streams.

The lakes, streams, and wetlands that have experienced reduced water levels attributed to high capacity well pumping are waterbodies which rely almost entirely on groundwater. Drainage lakes and impoundments, like Buffalo Lake, drain large areas of land and the majority of their water originates from surface water. Water withdrawal data were obtained from the WDNR for high capacity wells within Buffalo Lake's watershed from 2011-2014. The locations of these wells cannot be publicized due to privacy reasons, but the database indicates that the number of reporting wells within Buffalo Lake's watershed ranged from 68 in 2011 to 111 in 2014. The total amount of water withdrawn annually from these wells ranged from 1.5 billion gallons in 2011 to 1.9 billion gallons in 2013.

To put the annual water withdrawal from high capacity wells within Buffalo Lake's watershed in perspective, average precipitation data used in the WiLMS modeling estimates that on average, approximately 65 billion gallons of water are loaded to Buffalo Lake from its watershed annually. The amount of water withdrawn from high capacity wells within Buffalo Lake's watershed from 2011-2014 equates to approximately 2.4-3.0% of the total amount of water loaded to the lake annually. Figure 3.2-5 displays the 2014 monthly water withdrawal amounts from high capacity wells within Buffalo Lake's watershed compared to estimated monthly hydraulic loads calculated using rainfall data recorded at Montello. While the flow data that are needed to calculate changes in Buffalo Lake's water level are not available, the 2014 high capacity well withdrawal data compared to the estimated hydraulic load indicate that it is highly unlikely that high capacity wells within Buffalo Lake's watershed are impacting the lake's water levels.

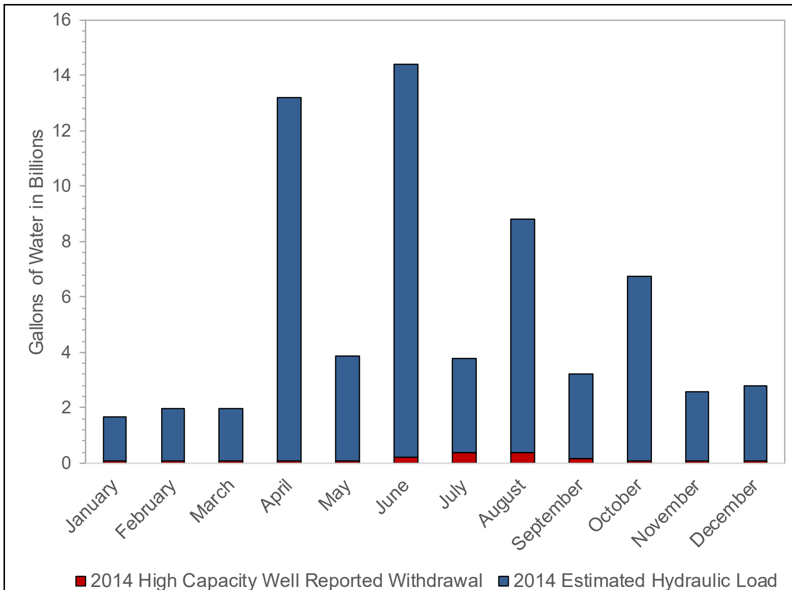


Figure 3.2-5. Buffalo Lake 2014 monthly estimated hydraulic load and 2014 reported monthly high capacity well withdrawal amounts. Hydraulic loads calculated using recorded Montello rainfall data obtained from the National Oceanic and Atmospheric Administration (2016). High capacity well data provided by the WDNR.

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 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 congregate on open lawns where their view of potential predators is unobstructed. 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 stricter shoreland ordinances. Passed in February of 2010, a revised 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 of their own. The revised NR 115 was once again examined in 2012 after some Wisconsin counties identified some provisions that were unclear or challenging to implement. The revisions proposed through Board Order WT-06-12 went into effect in December of 2013. These policy regulations require each county a ordinances for vegetation removal on shorelands, impervious surface standards, nonconforming structures and establishing mitigation requirements for development. Minimum requirements for each of these categories are as follows:

- Vegetation Removal: For the first 35 feet of property (shoreland zone), no vegetation removal is permitted except for: sound forestry practices on larger pieces of land, access and viewing corridors (may not exceed the lesser of 30 percent of the shoreline frontage), invasive species removal, or damaged, diseased, or dying vegetation. No permit is required for removal of vegetation that meets any of the above criteria. Vegetation removed must be replaced by replanting in the same area (native species only).

- Impervious surface standards: The amount of impervious surface is restricted to 15% of the total lot size, on lots that are entirely within 300 feet of the ordinary high-water mark of the waterbody. A county may allow more than 15% impervious surface on a residential lot provided that the county issues a permit and that an approved mitigation plan is implemented by the property owner. Counties may develop an ordinance, providing higher impervious surface standards, for highly developed shorelines.

- Nonconforming structures: Nonconforming structures are structures that were lawfully placed when constructed but do not comply with distance of water setback. Originally, structures within 75 ft of the shoreline had limitations on structural repair and expansion. New 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 no other build-able location exists within 35-75 feet, dependent on the county.
  - Construction may occur if mitigation measures are included either within the footprint or beyond 75 feet.
  - Vertical expansion cannot exceed 35 feet

- Mitigation requirements: New 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, dependent on the county.

- For county-specific requirements on this topic, it is recommended that lake property owners contact the county's regulations/zoning department.

Wisconsin Act 31

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

Wisconsin Act 55

In July of 2015 with the passing of the state budget, the State of Wisconsin passed Wisconsin Act 55 which modified shoreland zoning provisions. Specifically, Act 55 removed authority from counties to enforce shoreland zoning ordinances that are more restrictive than the state's minimum standards contained in NR 115. Counties that had shoreland zoning ordinances that were more restrictive than state standards are no longer able to enforce those more restrictive standards. While county governments, countywide lake and river associations, individual lake associations, and lake districts across Wisconsin have moved to challenge Act 55, the Wisconsin Legislature finished its session in November of 2015 and did not take any action on shoreland zoning.

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 from developed shorelands 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.

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 3.3-1. Example of a bio-log restoration site.

In recent years, many lakefront property owners have realized increased aesthetics, fisheries, property values, and water quality by restoring portions of their shoreland to mimic its unaltered state. An area of shore restored to its natural condition, both in the water and on shore, is commonly called a shoreland buffer zone. The shoreland buffer zone creates or restores the ecological habitat and benefits lost by traditional suburban landscaping. Simply not mowing within the buffer zone does wonders to restore some of the shoreland's natural function. Enhancement activities also include additions of submergent, emergent, and floating-leaf plants within the lake itself. These additions can provide greater species diversity and may compete against exotic species.

Cost

The cost of native, aquatic, and shoreland plant restorations is highly variable and depends on the size of the restoration area, the depth of buffer zone required to be restored, the existing plant density, the planting density required, the species planted, and the type of planting (e.g. seeds, bare-roots, plugs, live-stakes) being conducted. Other sites may require erosion control stabilization measures, which could be as simple as using erosion control blankets and plants and/or seeds or more extensive techniques such as geotextile bags (vegetated retaining walls), geogrids (vegetated soil lifts), or bio-logs (see above picture). Some of these erosion control techniques may reduce the need for rip-rap or seawalls which are sterile environments that do not allow for plant growth or natural shorelines.

Questions about rip-rap or seawalls should be directed to the local Wisconsin DNR Water Resources Management Specialist. Other measures possibly required include protective measures used to guard newly planted area from wildlife predation, wave-action, and erosion, such as fencing, erosion control matting, and animal deterrent sprays. One of the most important aspects of planting is maintaining moisture levels. This is done by watering regularly for the first two years until plants establish themselves, using soil amendments (i.e., peat, compost) while planting, and using mulch to help retain moisture.

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

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

- Spring planting timeframe.
- 100' of shoreline.
- An upland buffer zone depth of 35'.
- An access and viewing corridor 30' x 35' free of planting (recreation area).
- Planting area of upland buffer zone 2- 35' x 35' areas
- Site is assumed to need little invasive species removal prior to restoration.
- Site has only turf grass (no existing trees or shrubs), a moderate slope, sandy-loam soils, and partial shade.
- Trees and shrubs planted at a density of 1 tree/100 sq ft and 2 shrubs/100 sq ft, therefore, 24 native trees and 48 native shrubs would need to be planted.
- Turf grass would be removed by hand.
- A native seed mix is used in bare areas of the upland buffer zone.
- An aquatic zone with shallow-water 2 - 5' x 35' areas.
- Plant spacing for the aquatic zone would be 3 feet.
- Each site would need 70' of erosion control fabric to protect plants and sediment near the shoreland (the remainder of the site would be mulched).
- Soil amendment (peat, compost) would be needed during planting.
- There is no hard-armor (rip-rap or seawall) that would need to be removed.
- The property owner would maintain the site for weed control and watering.

Advantages	Disadvantages
• Improves the aquatic ecosystem through species diversification and habitat enhancement. • Assists native plant populations to compete with exotic species. • Increases natural aesthetics sought by many lake users. • Decreases sediment and nutrient loads entering the lake from developed properties. • Reduces bottom sediment re-suspension and shoreland erosion. • Lower cost when compared to rip-rap and seawalls. • Restoration projects can be completed in phases to spread out costs. • Once native plants are established, they require less water, maintenance, no fertilizer; provide wildlife food and habitat, and natural aesthetics compared to ornamental (non-native) varieties. • Many educational and volunteer opportunities are available with each project.	• Property owners need to be educated on the benefits of native plant restoration before they are willing to participate. • 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.

Buffalo Lake Shoreland Zone Condition

Shoreland Development

Buffalo 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 shoreland 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 shorelands 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 shoreland 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 shoreland that was restored would likely be included here, also.

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

3.3-1. Shoreland assessment category descriptions.

On Buffalo Lake, the development stage of the entire shoreland was surveyed during fall of 2015 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. The results of the shoreland development survey can be found on Maps 4.1-4.4.

Buffalo Lake has stretches of shoreland that fit all of the five shoreland assessment categories. In total, 17.2 miles (65%) of the shoreline was delineated as natural/undeveloped and developed-natural, the two shoreline categories that are the most ecologically beneficial for the lake. The majority of the natural/undeveloped shorelines along Buffalo Lake represent the edge of adjacent wetlands, areas that are protected by law and cannot be developed. Approximately 5.0 miles (19%) of Buffalo Lake's shoreline were delineated as developed-semi-natural, a category given to shorelines with a combination of human development and natural shoreland habitat. This is the category typically given to restored shoreland areas, and represents a shoreline that accommodates both human use and provides ecological benefits to the lake.

Approximately 4.2 miles (16%) of Buffalo Lake's shoreline was delineated as developed-unnatural and urbanized, areas which provide little benefit to and likely degrade Buffalo Lake's ecology. These areas should be the primary focus for shoreland restoration efforts. The 2015 shoreland development survey on Buffalo Lake also revealed that approximately 18% (4.7 miles) of the lake's shoreline contains some type of seawall comprised of masonry, metal, rip-rap, or wood (Table 3.3-1).

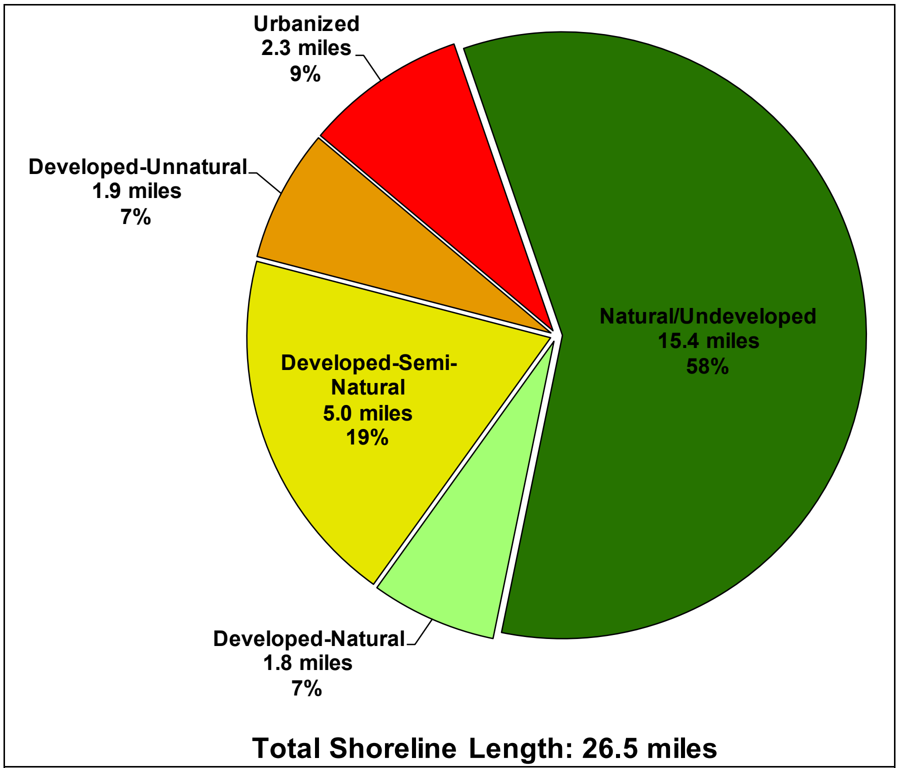


Figure 3.3-2. Buffalo Lake shoreland development categories and total lengths. Based upon a fall 2015 survey. Locations of these categorized shorelands can be found on Maps 4.1-4.4.

Table 3.3-1. Buffalo Lake shoreland seawall categories and total lengths. Created using data from fall 2015 shoreland development survey. Locations of these seawalls can be found on Maps 4.1-4.4.

Seawall Type	Length (miles)	%Shoreline
Masonry	0.22	0.8%
Metal	0.04	0.1%
Rip-Rap	4.08	15.4%
Wood	0.36	1.3%
Total	**4.69**	**17.7%**

While producing a completely natural shoreland is ideal for a lake ecosystem, it is not always practical from a riparian property owner'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

Buffalo Lake was surveyed in 2015 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 three size categories (2-8 inches in diameter, >8 inches in diameter, and cluster of pieces) 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, a total of 621 pieces of coarse woody habitat were observed along 26.5 miles of shoreline, yielding a coarse woody habitat to shoreline mile ratio of 23:1 in Buffalo Lake (Figure 3.3-3). This ratio is relatively high when compared to other lakes surveyed by Onterra; however, some 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). It must be noted that this survey also quantified submersed coarse woody habitat, while the 2015 survey on Buffalo Lake only quantified coarse woody

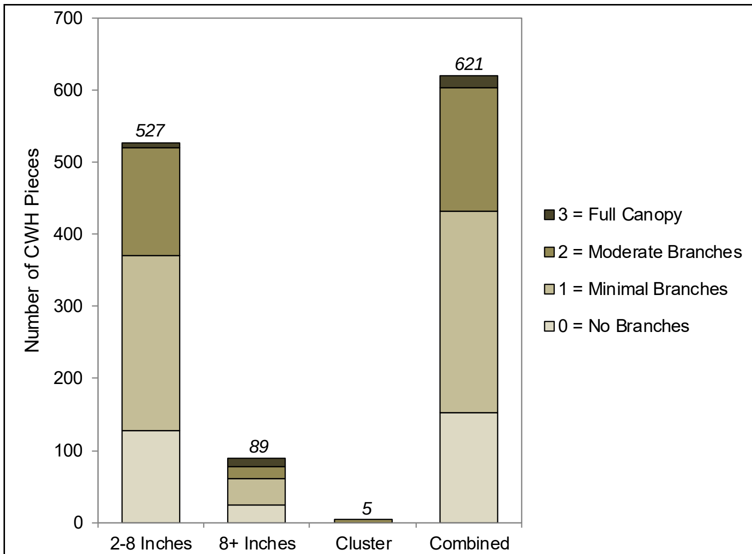


Figure 3.3-3. Buffalo Lake coarse woody habitat (CWH) survey results. Based upon a Fall 2015 survey. Locations of Buffalo Lake coarse woody habitat can be found on Map 5.

habitat that extended from shore and into the water. Trees falling into the lake are natural and are an important component of lake ecology, providing valuable structural habitat for fish and other wildlife. Fallen trees should be left in place unless they impact access to the lake or recreational safety. Locations of coarse woody habitat in Buffalo Lake are displayed on Map 5.

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.

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 watermilfoil (*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 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 Buffalo 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 Buffalo 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 management 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

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 watermilfoil 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

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

Cost

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

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

Herbicide Treatment

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

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)
Contact		Endothall	Inhibits respiration & protein synthesis	Submersed species, largely for curly-leaf pondweed; Eurasian water milfoil control when mixed with auxin herbicides
Contact		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
Systemic	Auxin Mimics	Triclopyr	auxin mimic, plant growth regulator	Submersed species, largely for Eurasian water milfoil
Systemic	In Water Use Only	Fluridone	Inhibits plant specific enzyme, new growth bleached	Submersed species, largely for Eurasian water milfoil
Systemic	Enzyme Specific (ALS)	Penoxsulam	Inhibits plant-specific enzyme (ALS), new growth stunted	New to WI, potential for submergent and floating-leaf species
Systemic	Enzyme Specific (ALS)	Imazamox	Inhibits plant-specific enzyme (ALS), new growth stunted	New to WI, potential for submergent and floating-leaf species
Systemic	Enzyme Specific (foliar use only)	Glyphosate	Inhibits plant-specific enzyme (ALS)	Emergent species, including purple loosestrife
Systemic	Enzyme Specific (foliar use only)	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 watermilfoil. • 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 watermilfoil 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 watermilfoil stands in Wisconsin, Washington, Vermont, and other states. Research is currently being conducted to discover the best situations for the use of the insect in battling Eurasian watermilfoil. Currently the milfoil weevil is not a WDNR grant-eligible method of controlling Eurasian watermilfoil.

Cost

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

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

Species Diversity and Richness

Species diversity is probably the most misused value in ecology because it is often confused with species richness. Species richness is simply the number of species found within a system or community. Although these values are related, they are far from the same because diversity also takes into account how evenly the species occur within the system. A lake with 25 species may not be more diverse than a lake with 10 if the first lake is highly dominated by one or two species and the second lake has a more even distribution.

A lake with high species diversity is much more stable than a lake with a low diversity. This is analogous to a diverse financial portfolio in that a diverse lake plant community can withstand environmental fluctuations much like a diverse portfolio can handle economic fluctuations. For example, a lake with a diverse plant community is much better suited to compete against exotic infestation than a lake with a lower diversity.

Simpson's diversity index is used to determine this diversity in a lake ecosystem. Simpson's diversity (1-D) is calculated as:

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

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

A box plot or box-and-whisker diagram graphically shows data through five-number summaries: minimum, lower quartile, median, upper quartile, and maximum. Just as the median divides the data into upper and lower halves, quartiles further divide the data by calculating the median of each half of the dataset.

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. Between 2005 and 2009, WDNR Science Services conducted point-intercept surveys on 252 lakes within the state. In the absence of comparative data from Nichols (1999), the Simpson's Diversity Index values of the lakes within the WDNR Science Services dataset will be compared to Buffalo Lake. Comparisons will be displayed using boxplots that showing median values and upper/lower quartiles of lakes in the same ecoregion (Water Quality section, Figure 3.1-1) and in the state. Please note for this parameter, the Northern Lakes and Forests Ecoregion data includes both natural and flowage lakes.

As previously stated, species diversity is not the same as species richness. One factor that influences species richness is the "development factor" of the shoreland. This is not the degree of human development or disturbance, but rather it is a value that attempts to describe the nature of the habitat a particular shoreland may hold. This value is referred to as the shoreland complexity. It specifically analyzes the characteristics of the shoreland and describes to what degree the lake shape deviates from a perfect circle. It is calculated as the ratio of lake perimeter to the circumference of a circle of area equal to that of the lake. A shoreland complexity value of

1.0 would indicate that the lake is a perfect circle. The further away the value gets from 1.0, the more the lake deviates from a perfect circle. As shoreland complexity increases, species richness increases, mainly because there are more habitat types, bays and back water areas sheltered from wind.

Floristic Quality Assessment

Floristic Quality Assessment (FQA) is used to evaluate the closeness of a lake's aquatic plant community to that of an undisturbed, or pristine, lake. The higher the floristic quality, the closer a lake is to an undisturbed system. FQA is an excellent tool for comparing individual lakes and the same lake over time. In this section, the floristic quality of Buffalo Lake will be compared to lakes in the same ecoregion and in the state. Ecoregional and state-wide medians were calculated from whole-lake point-intercept surveys conducted on 392 lakes throughout Wisconsin by Onterra and WDNR ecologists.

> 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.

The floristic quality of a lake is calculated using its species richness and average species conservatism. As mentioned above, species richness is simply the number of species that occur in the lake, for this analysis, only native species are utilized. Average species conservatism utilizes the coefficient of conservatism values for each of those species in its calculation. A species coefficient of conservatism value indicates that species likelihood of being found in an undisturbed (pristine) system. The values range from one to ten. Species that are normally found in disturbed systems have lower coefficients, while species frequently found in pristine systems have higher values. For example, cattail, an invasive native species, has a value of 1, while common hard and softstem bulrush have values of 5, and Oakes pondweed, a sensitive and rare species, has a value of 10. 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 survey and does not include incidental species or those encountered during other aquatic plan surveys.

Community Mapping

A key component of the aquatic plant survey is the creation of an aquatic plant community map. The map represents a snapshot of the important plant communities in the lake as they existed during the survey and is valuable in the development of the management plan and in comparisons with surveys completed in the future. A mapped community can consist of submergent, floating-leaf, or emergent plants, or a combination of these life-forms. Examples of submergent plants include wild celery and pondweeds; while emergents include cattails, bulrushes, and arrowheads, and floating-leaf species include white and yellow pond lilies. Emergents and floating-leaf communities lend themselves well to mapping because there are distinct boundaries between communities. Submergent species are often mixed throughout large areas of the lake and are seldom visible from the surface; therefore, mapping of submergent communities is more difficult and often impossible.

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, curly-leaf pondweed and Eurasian watermilfoil are the primary targets of this extra attention.

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

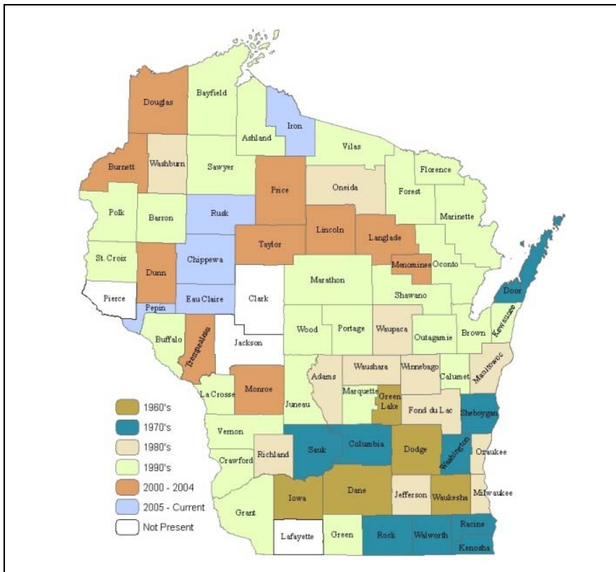


Figure 3.4-1. Spread of Eurasian watermilfoil within WI counties. WDNR Data 2011 mapped by Onterra.

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 Eurasian watermilfoil, curly-leaf pondweed 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 curly-leaf pondweed occurrence within the lake. Although Eurasian watermilfoil 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

One of the primary goals of this management plan update for Buffalo Lake was to assess how Buffalo Lake's aquatic plant community had changed following the water level drawdown that took place between the fall of 2012 and the spring of 2014 and to develop management strategies for reducing aquatic invasive species. To attribute changes in Buffalo Lake's aquatic plant community to the water level drawdown, ideally surveys would have been conducted the year immediately prior to and the year immediately following the drawdown. It must be noted that the pre-drawdown data being used in the following analyses were collected in 2004, eight years prior to the water level drawdown and post-drawdown data were collected in 2015, one year following the lake's refilling. While the changes in aquatic plant community between these two surveys are likely largely a result of the water level drawdown, it cannot be said with scientific certainty that there were not additional factors (i.e. climate, etc.) that contributed to these changes.

A number of aquatic plant surveys were completed by Onterra ecologists on Buffalo Lake in 2015. During these surveys, a total of 39 aquatic plant species were located, seven of which are considered to be non-native (exotic) species: Eurasian watermilfoil, hybrid watermilfoil, curly-leaf pondweed, curly-leaf/white-stem pondweed hybrid, brittle naiad, purple loosestrife, and pale-yellow iris (Table 3.4-1). Because of their ecological, sociological, and economical significance, these non-native aquatic plant populations in Buffalo Lake are discussed in detail in the *Non-Native Aquatic Plants* section. Table 3.4-1 also contains the aquatic plant species located during the surveys completed by Onterra in 2004, and shows that 13 native aquatic plant species were located in Buffalo Lake in 2015 that were not located in 2004. These differences between the pre- and post-drawdown plant surveys are discussed in further detail later in this section.

Lakes in Wisconsin vary in their morphometry, water chemistry, and substrate composition, and all of these factors influence aquatic plant community composition. During the whole-lake point-intercept survey completed on Buffalo Lake by Onterra on July 21 and 22, 2015, substrate data were also recorded at each sampling location in one of three general categories: rock, sand, and soft sediments. These data indicate that the majority (96%) of sampling locations contained soft sediments, 4% contained sand, and 0% were found to contain rock (Figure 3.4-2 and Map 6).

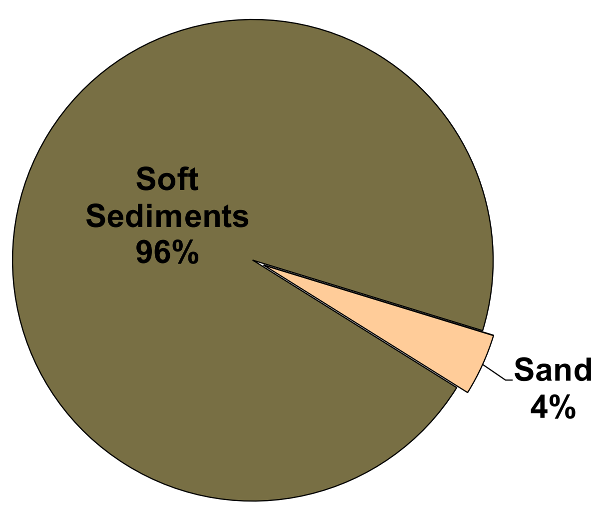


Figure 3.4-2. Buffalo Lake proportion of substrate types. Created from data collected during 2015 whole-lake point-intercept survey (N = 675). Spatial distribution of sediment types in Buffalo Lake are displayed in Map 6.

Like terrestrial plants, aquatic plants vary in their preference for a particular substrate type; some species are usually only found growing in soft sediments, others only course substrates like sand, while some are more generalists and can be found growing in either. Lakes with varying types of substrates generally support a higher number of aquatic plant species because of the different habitat types that are available. The majority of the aquatic plants located in Buffalo Lake in 2015 are typically found growing in soft substrates; however, some species, like muskgrasses and slender naiad, were more frequently located in areas of sand.

Table 3.4-1. Aquatic plant species located in Buffalo Lake during 2004 and 2015 aquatic plant surveys.

Growth Form	Scientific Name	Common Name	Coefficient of Conservatism (C)	2004	2015
Emergent	*Bolboschoenus fluviatilis*	River bulrush	5		I
	Carex comosa	Bristly sedge	5		I
	Iris pseudacorus	Pale-yellow iris	Exotic		I
	Iris versicolor	Northern blue flag	5	I	I
	Juncus effusus	Soft rush	4		I
	Lythrum salicaria	Purple loosestrife	Exotic		I
	Phragmites australis subsp. americanus	Common reed	5		I
	Sagittaria latifolia	Common arrowhead	3	I	I
	Schoenoplectus acutus	Hardstem bulrush	5		X
	Schoenoplectus tabernaemontani	Softstem bulrush	4	I	I
	Sparganium eurycarpum	Common bur-reed	5		I
	Typha spp.	Cattail spp.	1	I	X
	Zizania spp.	Wild rice sp.	8	I	X
FL	*Nuphar variegata*	Spatterdock	6	I	
	Nymphaea odorata	White water lily	6	X	X
	Persicaria amphibia	Water smartweed	5	I	
FL/E	*Nelumbo lutea*	American lotus	8	X	X
Submergent	*Chara* spp.	Muskgrasses	7		X
	Ceratophyllum demersum	Coontail	3	X	X
	Elodea canadensis	Common waterweed	3	X	X
	Heteranthera dubia	Water stargrass	6	I	X
	Myriophyllum sibiricum	Northern watermilfoil	7		X
	Myriophyllum sibiricum X spicatum	Hybrid watermilfoil	Exotic		I
	Myriophyllum spicatum	Eurasian watermilfoil	Exotic	X	X
	Najas flexilis	Slender naiad	6		X
	Najas guadalupensis	Southern naiad	7		X
	Najas minor	Brittle naiad	Exotic		I
	Potamogeton crispus	Curly-leaf pondweed	Exotic	X	X
	Potamogeton nodosus	Long-leaf pondweed	5	X	X
	Potamogeton praelongus	White-stem pondweed	8		X
	Potamogeton pusillus	Small pondweed	7		X
	Potamogeton richardsonii	Clasping-leaf pondweed	5		I
	Potamogeton X undulatus	Curly-leaf X White-stem pondweed	Exotic		I
	Potamogeton zosteriformis	Flat-stem pondweed	6	X	X
	Ranunculus aquatilis	White water crowfoot	8		X
	Stuckenia pectinata	Sago pondweed	3	I	X
	Vallisneria americana	Wild celery	6	X	X
FF	*Lemna trisulca*	Forked duckweed	6		X
	Lemna minor	Lesser duckweed	5	X	X
	Spirodela polyrhiza	Greater duckweed	5	X	X
	Wolffia spp.	Watermeal spp.	N/A	X	X

FL = Floating Leaf; FL/E = Floating Leaf and Emergent; FF = Free Floating
X = Located on rake during point-intercept survey; I = Incidental Species

During the 2015 point-intercept survey, aquatic plants were found growing out to a maximum depth of 7.0 feet, indicating that the entire area of Buffalo is comprised of littoral zone, or the entire lake supports aquatic plant growth (Map 7). However, only 1.2% of the sampling locations that contained aquatic plant growth were located in 6 to 7 feet of water, and the majority of vegetation in Buffalo Lake occurs between 3 and 4 feet (Figure 3.4-3). While average water clarity reaches a maximum of around 5 feet in Buffalo Lake during the mid- to late-summer, water clarity in the spring is usually low at around 3.5 feet. While clarity during the summer is sufficient to support aquatic plant growth in the deepest areas of Buffalo Lake, the lower water clarity in the spring likely prevents their initial establishment within these deeper areas.

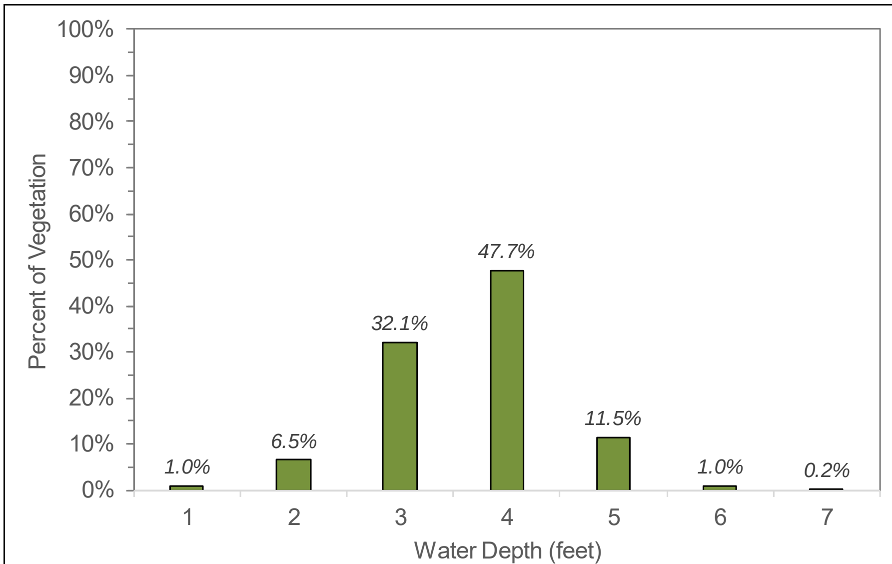


Figure 3.4-3. Buffalo Lake relative frequency of vegetation across water depth. Created from data collected during 2015 whole-lake point-intercept survey (N = 521 locations that contained vegetation). Spatial distribution of vegetation in Buffalo Lake are displayed in Maps 7 and 8.

Of the 907 sampling locations that comprised the whole-lake point-intercept survey on Buffalo Lake, 675 were able to be sampled; the remaining 232 locations were inaccessible due to plant growth or obstacles such as piers. Of the 675 point-intercept sampling locations sampled in 2015, 77% (521) contained aquatic vegetation (Map 7). Aquatic plant rake fullness data collected in 2015 indicates that 32% of the 675 sampling locations contained vegetation with a total rake fullness rating of 1, 21% had a total rake fullness rating of 2, and 24% had a total rake fullness of 3 (Figure 3.4-4).

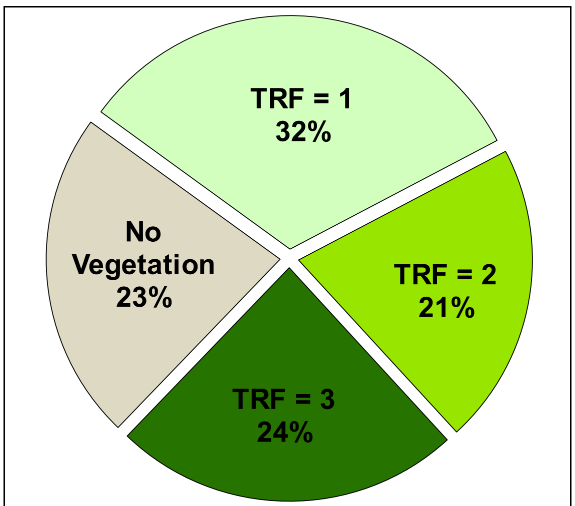


Photo 3.4-4. Buffalo Lake 2015 aquatic vegetation total rake fullness ratings. Created from data collected during the 2015 whole-lake point-intercept survey (N = 675).

Of the 40 aquatic plant species located in Buffalo Lake in 2015, 24 were physically encountered on the rake during the whole-lake point-intercept survey (Figure 3.4-5). The remaining 16 plants were located 'incidentally', meaning they were observed and collected while on the lake but they were not recorded on the sampling rake at any of the 675 sampling locations during the point-intercept survey. Of the 24 species encountered on the rake during the point-intercept survey, coontail, common waterweed, small pondweed, and wild celery were the four-most frequently encountered (Figure 3.4-5).

Coontail, arguably the most abundant aquatic plant in Wisconsin, was the most frequently encountered species in Buffalo Lake with a littoral frequency of occurrence of approximately 63% (Figure 3.4-5). Coontail, as its name suggests, possess closely-spaced whorls of stiff leaves that give the plant a raccoon tail-like appearance. 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. 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 dominate in high-nutrient, eutrophic lakes. Coontail has the capacity to form dense beds which mat on the surface and can hinder recreation, and this was observed in some areas of Buffalo Lake in 2015.

While coontail can grow to nuisance levels, it provides many benefits to the aquatic community. Its dense whorls for leaves provide excellent structural habitat for aquatic invertebrates and fish, especially in winter as this plant remains green under the ice. In addition, it competes for nutrients that would otherwise be available for free-floating algae and helps maintain Buffalo Lake's clear-water state.

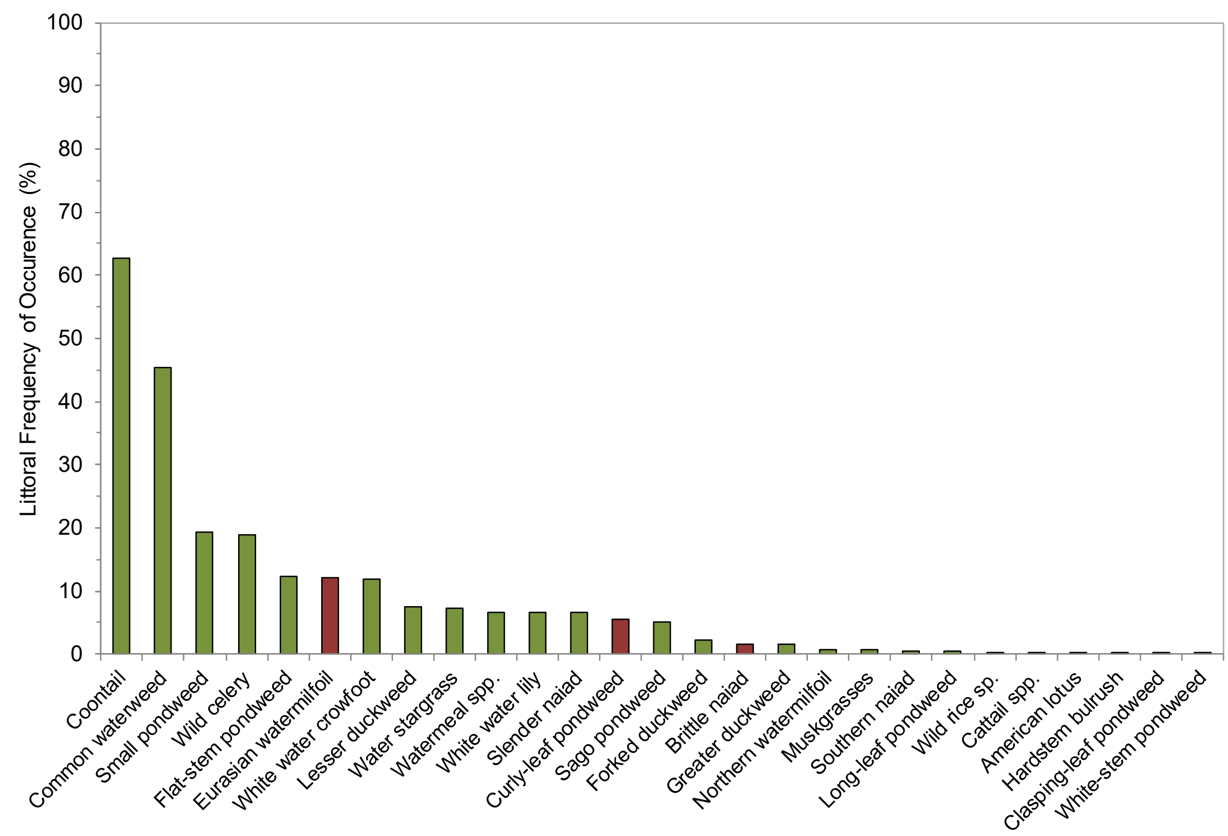


Figure 3.4-5. Buffalo Lake 2015 littoral frequency of occurrence of aquatic plant species. Non-native species indicated with red. Eurasian watermilfoil also includes hybrid watermilfoil. Created using data from 2015 whole-lake point-intercept survey.

Common waterweed was the second-most frequently encountered aquatic plant species in Buffalo Lake during the 2015 whole-lake point-intercept survey with a littoral frequency of approximately 46% (Figure 3.4-5). Like coontail, common waterweed is found in waterbodies across Wisconsin and is tolerant of low-light conditions, often making it one of the more abundant plants in eutrophic lakes. It prefers growing in soft sediments, and can often grow in dense beds that mat at the surface. However, like coontail, common waterweeds dense network of stems and leaves provide excellent habitat for aquatic wildlife, and its abundance in Buffalo Lake helps to maintain the clear-water state.

The third-most frequently encountered aquatic plant during the 2015 whole-lake point-intercept survey in Buffalo Lake with a littoral frequency of occurrence of approximately 19% was small pondweed (Figure 3.4-5). Small pondweed is one of several narrow-leaf pondweed species that can be found in Wisconsin, and possesses slender leaves which alternate on a long stem. Like other pondweeds, small pondweed produces fruit that feed wildlife, and it is often found growing in larger clumps which provide valuable structural habitat. Of the narrow-leaf pondweed species in Wisconsin, small pondweed is the most tolerant of eutrophic conditions. It is rarely observed growing to nuisance levels, and it was not observed growing excessively in Buffalo Lake.

Wild celery, or tape grass, was the fourth-most frequently encountered aquatic plant during the 2015 whole-lake point-intercept survey on Buffalo Lake with a littoral frequency of occurrence of 19% (Figure 3.4-5). This plant possesses long, ribbon-like leaves which emerge from a basil rosette, and it produces a deep network of roots and rhizomes which stabilize bottom sediments. Later in the summer, wild celery produces numerous seeds in a banana-shaped seed pod which float at the surface. These seeds have been shown to be an essential component of the diet of certain migratory waterfowl (Borman et al. 2014). Wild celery prefers to grow on firmer substrates, and like the other plants discussed, is tolerant of eutrophic conditions.

While non-native aquatic plant species in Buffalo Lake are discussed in greater detail in subsequent sections, Eurasian watermilfoil was the most frequently encountered non-native species in Buffalo Lake in 2015 with a relatively low littoral frequency of occurrence of 12% (Figure 3.4-5). Curly-leaf pondweed and brittle naiad also had lower littoral frequencies of occurrence in 2015 at 6% and 2%, respectively (Figure 3.4-5).

Comparison of 2004 and 2015 Aquatic Plant Community Data

To facilitate the reconstruction of the Montello Dam as well as public access locations to Buffalo Lake, an approximate 5.93-foot water level drawdown was initiated in the fall of 2012 and maintained through the spring of 2014. While the primary goal of this water level drawdown was dam maintenance, water level management in impoundments has also been used as a management tool for the restoration of the aquatic plant community. Following the 1.5-year water level drawdown in Buffalo Lake, anecdotal reports indicated that there was a marked change in the lake's aquatic plant community, most notably that the presence of non-native species (EWM and CLP) had declined and emergent and floating-leaf species had increased. One of the primary objectives of the studies completed in 2015 on Buffalo Lake was to quantify the changes to the lake's aquatic plant community since 2004 as well as to determine if periodic water level drawdowns are a viable management option for controlling non-native aquatic plants while promoting valuable native species.

The response of the aquatic plant community to a water level drawdown depends on the extent of the drawdown (i.e. how much lakebed becomes exposed), the time of year (summer versus winter), and the duration of the drawdown. The extent, timing, and duration of a water level drawdown depend on the management objective, aquatic plant restoration or control. Aquatic plants have evolved and adapted to natural, seasonal fluctuations in water level and many depend on these seasonal fluctuations for reproduction. In Wisconsin, under natural conditions water levels are typically highest in the spring and decline to a minimum in late-summer. As water levels decline in early summer, both emergent and submergent aquatic plant species become established. However, dams have altered these natural water level fluctuations by stabilizing and maintaining high water levels during the summer, and this has led to alterations and even losses of aquatic plants in shallow lakes (Wang et al. 2016).

In instances where aquatic plant abundance and diversity has declined, water levels have been manipulated to mimic more natural conditions in an effort to reestablish aquatic plants. This involves the lowering of water levels in early summer and maintaining a lower water level until the fall. This type of water level drawdown was conducted on Pool 8 in the Mississippi River during the summers of 2001 and 2002. The water level was reduced by 1.5 feet from mid-June through mid-September of each year, and researchers found that these drawdowns significantly increased emergent and submergent aquatic plant abundance and diversity for at least five years following these drawdowns (Kenow and Lyon 2009).

In contrast, water level drawdowns have been conducted in the winter with a goal of reducing nuisance aquatic plant abundance, primarily for non-native aquatic plants such as Eurasian watermilfoil. Unlike most native aquatic plant species which overwinter via turions (asexual reproductive structures), seeds, or tubers, Eurasian watermilfoil generally overwinters as an entire plant with above-ground biomass making it vulnerable to freezing and/or desiccation. Greenhouse studies conducted by Stanley (1976) found that the biomass of dewatered Eurasian watermilfoil shoots and roots decreased by 99% when exposed to temperatures just below freezing for 96 hours. In addition, Eurasian watermilfoil plants that were left submersed (10 cm of water) and exposed to subfreezing temperatures for 96 hours saw a 35% decrease in biomass (Stanley 1976).

The aquatic plant community of Lac Sault Dore, a 561-acre impoundment along the Elk River in Price County, Wisconsin, was dominated by Eurasian watermilfoil in 2010 with a littoral frequency of occurrence of 37%. Given the size of this impoundment, the control of Eurasian watermilfoil through mechanical or chemical means was not a feasible option. Like Buffalo Lake, the dam on Lac Sault Dore required maintenance and a 4.0-foot water level drawdown was to be initiated over the winter of 2010-2011. Because it was believed that this drawdown could also be used as a tool to control the lake's Eurasian watermilfoil population, the water level drawdown was extended to 6.0 feet as a survey in 2010 indicated the majority of the Eurasian watermilfoil population was between 2.0 and 6.0 feet of water. Water levels in Lac Sault Dore were drawn down beginning in September of 2010 and the lake was refilled in April of 2011.

Post-drawdown whole-lake point-intercept surveys conducted on Lac Sault Dore indicate that the occurrence of Eurasian watermilfoil was reduced by 99%, and its littoral frequency of occurrence has remained below 4% in the five years since the winter water level drawdown (Onterra 2013). Certain native aquatic plant species like coontail, fern-leaf pondweed, and common waterweed that maintain above-ground biomass over the winter also saw declines following the drawdown; however, their declines were not as substantial as Eurasian watermilfoil. Overall, no native aquatic plant species were lost following the winter water level drawdown in Lac Sault Dore. With the data that has been collected surrounding the drawdown on Lac Sault Dore, the lake group is now positioned to utilize winter water level drawdowns as a management tool in the future to control the lake's Eurasian watermilfoil population.

A 6.0-foot winter water level drawdown was conducted on another impoundment along the Elk River, Musser Lake (533 acres), in 2013-2014 also to facilitate the maintenance of the dam. Musser Lake contains a population of curly-leaf pondweed, which has a different life cycle when compared to Eurasian watermilfoil. Curly-leaf pondweed deposits turions in mid-summer, some of which sprout in the fall and overwinter as small plants under the ice while others lie dormant and sprout at a later time. Little information exists on the response of curly-leaf pondweed to winter water level drawdowns, and Onterra and WDNR ecologists wanted to take the opportunity on Musser Lake to determine the effects of a winter water level drawdown on the lake's curly-leaf pondweed population and determine if this could be employed as a control technique as was done on Lac Sault Dore for Eurasian watermilfoil.

Post-drawdown surveys completed on Musser Lake in the two years since the drawdown show that the occurrence of curly-leaf pondweed was reduced by approximately 90% (Onterra 2015). And like in Lac Sault Dore, coontail and common waterweed exhibited declines in their occurrence following the winter water level drawdown. Surveys are scheduled to be completed again on Musser Lake in 2016 to gain a better understanding on the longer-term effects of winter water level drawdowns on curly-leaf pondweed and the native aquatic plant community.

The water level drawdown in Buffalo Lake occurred for approximately 1.5 years, and spanned over two winters. Given what is known about water level drawdowns and their effects on the aquatic plant community, it was hypothesized that this drawdown would have resulted in a reduction in the lake's Eurasian watermilfoil and curly-leaf pondweed populations, and likely a reduction in the occurrence of all vegetation within the lake. Unfortunately, whole-lake point-intercept surveys were not completed the year immediately preceding and the year immediately following the water level drawdown in Buffalo Lake. However, whole-lake point-intercept data collected in 2004 (pre-drawdown) can be compared against the whole-lake point-intercept data collected in 2015 (post-drawdown) to determine the changes that have occurred over this time period. It must be noted that not all of the changes found between the surveys can be attributed to the drawdown due to the span of time between the surveys.

Figure 3.4-6 displays the littoral frequency of occurrence of aquatic plant species in Buffalo Lake as determined from the 2004 and 2015 whole-lake point-intercept surveys. It should be noted that only those species with a littoral frequency of occurrence of at least 5% in one of the two surveys are applicable for analysis (Chi-square $\alpha = 0.05$). As illustrated, Eurasian watermilfoil exhibited a statistically valid reduction in occurrence of 83%, declining from a littoral frequency of occurrence of approximately 70% in 2004 to 12% in 2015.

The littoral occurrence of curly-leaf pondweed in 2004 of approximately 8% was not statistically different from the occurrence of approximately 6% recorded in 2015. Because curly-leaf pondweed naturally begins to senesce (die-back) in early July, ideally a survey should be completed in June to gain an accurate representation of a lake's curly-leaf pondweed population when it is at or near its peak growth. The 2004 and 2015 whole-lake point-intercept surveys were completed in August and July, respectively, to coincide with the peak growth of native plants, and because of this, they do not capture the full extent of the curly-leaf pondweed population in Buffalo Lake.

Five native aquatic plant species exhibited statistically valid reductions in their littoral occurrence between the 2004 and 2015 surveys and include: coontail (26% reduction), lesser duckweed (89% reduction), watermeal spp. (90% reduction), white water lily (72% reduction), and flat-stem pondweed (43% reduction) (Figure 3.4-6). As discussed previously, coontail also overwinters with above-ground biomass, and was likely impacted by freezing/desiccation. However, emerging research is also showing that the occurrence of coontail often increases with the presence of Eurasian watermilfoil (Allison Mikulyuk personal comm. 2015). It is hypothesized that coontail can find ideal habitat growing near the surface entangled amongst the dense stems of Eurasian watermilfoil. When Eurasian watermilfoil declines, this habitat for coontail is also eliminated.

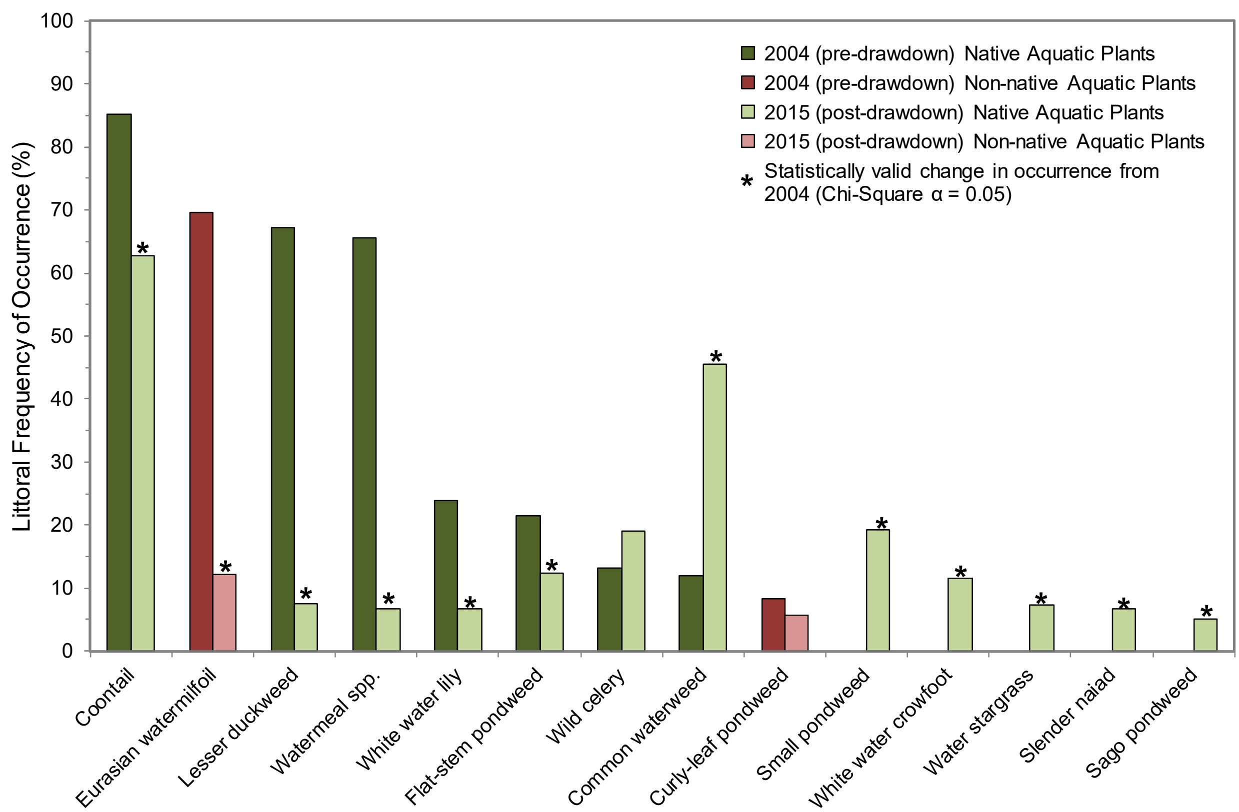


Figure 3.4-6. Buffalo Lake littoral frequency of occurrence of aquatic plant species from 2004 (pre-drawdown) and 2015 (post-drawdown). Created using data from 2004 (N = 168) and 2015 (N = 675) whole-lake point-intercept surveys. Species with a littoral frequency of occurrence of at least 5% in one of the two surveys are displayed. Statistical significance determined using Chi-square analysis (α = 0.05). Eurasian watermilfoil also includes hybrid watermilfoil.

Lesser duckweed and watermeal spp. are small, free-floating aquatic plants which float at the water's surface and derive all of their nutrients from the water. Their decline in Buffalo Lake is likely an indication of a reduction in surface-matted vegetation like Eurasian watermilfoil. Lesser duckweed and watermeal spp. grow in areas of still water, and in 2004 they were mainly found growing amongst surface-matted Eurasian watermilfoil. Like coontail, the decline of lesser duckweed and watermeal spp. is likely largely a result of the reduction of Eurasian watermilfoil and loss of their preferred habitat.

White water lily overwinters via large rhizomes, and it is likely that some of these froze or where desiccated during the drawdown. In Lac Sault Dore, white water lily was found to have declined in occurrence one year immediately following the drawdown, but increased to pre-drawdown levels by two years post-drawdown. Like curly-leaf pondweed, flat-stem pondweed mainly overwinters via turions. A reduction in the occurrence of flat-stem pondweed was also observed in Lac Sault Dore, and its occurrence has not yet recovered to pre-drawdown levels five years after the drawdown. It is not known why flat-stem pondweed has been observed to decline following winter water level drawdowns, but its turions may be more susceptible to freezing and/or desiccation.

The native plant common waterweed increased from a littoral occurrence of 12% in 2004 to an occurrence of 46% in 2015, a statistically valid increase in occurrence of 282% (Figure 3.4-6). Two years following the drawdown in Lac Sault Dore, common waterweed exhibited a similar increase in occurrence after an initial decline in the first year following the drawdown. Long-term trends data pertaining to aquatic plants by the WDNR collected from a number of lakes state-wide show that common waterweed populations have the capacity to fluctuate widely on an interannual basis under natural conditions. It is not known if the increase in common waterweed in 2015 represents effects from the drawdown or some other environmental factor.

Five aquatic plant species recorded in 2015 that were not recorded in 2004 all exhibited statistically valid increases in their littoral occurrence. These include: small pondweed, white water crowfoot, water stargrass, slender naiad, and sago pondweed. Overall, 13 additional native aquatic plant species were located in 2015 compared to 2004 (Table 3.4-1). Only two native plants located in 2004, spatterdock and water smartweed, we not relocated in 2015. Overall, 89% of the sampling locations in 2004 contained aquatic vegetation compared to 76% in 2015.

As discussed in the primer section, the calculations used to create 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 incidentally located species. The native species encountered on the rake during the 2004 and 2015 point-intercept surveys and their conservatism values were used to calculate the FQI of Buffalo Lake's aquatic plant community (equation shown below).

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

Figure 3.4-7 compares the 2004 and 2015 FQI components of Buffalo Lake to median values of lakes within the Southeast Wisconsin Till Plains (SWTP) ecoregion and lakes throughout Wisconsin. The number of native aquatic plant species recorded on the rake during the point-intercept surveys, or the native species richness, increased from 11 in 2004 prior to the water level drawdown to 24 in 2015 following the water level drawdown. The native species richness recorded in 2015 exceeds the upper quartile value for lakes in the SWTP ecoregion and the median value for lakes statewide.

The average conservatism of Buffalo Lake's aquatic plant community also increased from 5.5 in 2004 to 5.8 in 2015 (Figure 3.4-7). Buffalo Lake's 2015 average conservatism exceeds the upper quartile value for lakes in the SWTP ecoregion but falls below the median value for lakes statewide. In other words, Buffalo Lake contains a higher number of environmentally-sensitive aquatic plant species when compared to other lakes within the ecoregion, but contains a lower number of environmentally-sensitive plant species when compared to other lakes throughout Wisconsin. Using Buffalo Lake's native species richness and average conservatism to calculate the FQI (equation above) indicates that the lake's FQI increased from 18.2 in 2004 to 28.5 in 2015 (Figure 3.4-7). Overall, this analysis indicates that the quality of Buffalo Lake's aquatic plant community has increased between the 2004 and 2015 surveys, and is currently of higher quality than the majority of lakes within the SWTP ecoregion.

As explained earlier, lakes with diverse aquatic plant communities have higher resilience to environmental disturbances and greater resistance to invasion by non-native plants. In addition, a plant community with a mosaic of species with differing morphological attributes provides zooplankton, macroinvertebrates, fish, and other wildlife with diverse structural habitat and various sources of food. Because Buffalo Lake contains a high number of native aquatic plant species, one may assume the aquatic plant community has high species diversity. However, species diversity is also influenced by how evenly the plant species are distributed within the community.

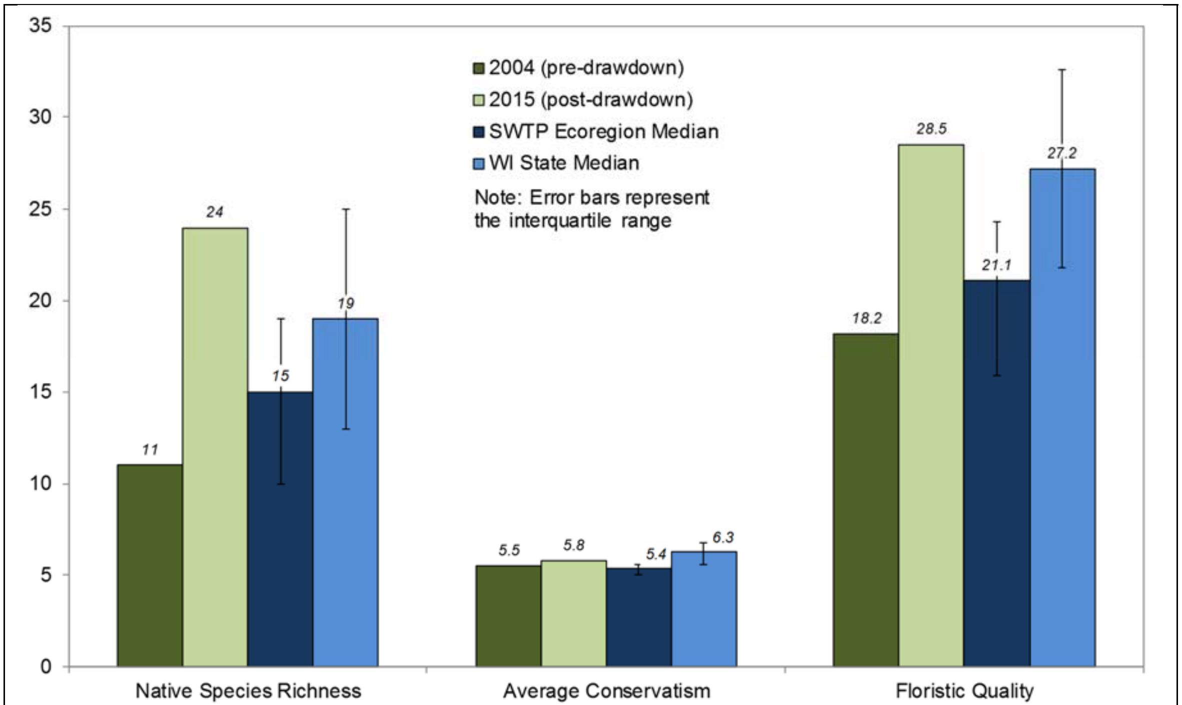


Figure 3.4-7. Buffalo Lake 2004 and 2015 Floristic Quality Assessment. Created using data from WDNR 2010 and Onterra 2014 point-intercept surveys. Analysis follows Nichols (1999).

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 Buffalo Lake's diversity value ranks. In addition, this analysis allows for a comparison of aquatic plant diversity in Buffalo Lake from pre- and post-drawdown. Using data collected by Onterra and WDNR Science Services, quartiles were calculated for 77 lakes within the SWTP Ecoregion (Figure 3.4-8). Using the data collected from the 2004 and 2015 point-intercept surveys shows that aquatic plant diversity increased from 0.84 in 2004 to 0.87 in 2015. In other words, if two individual aquatic plants were randomly samples from Buffalo Lake in 2015, there would be an 87% probability that they would be different species. Buffalo Lake's 2015 species diversity value exceeds the median value for both lakes within the SWTP ecoregion and lakes throughout Wisconsin.

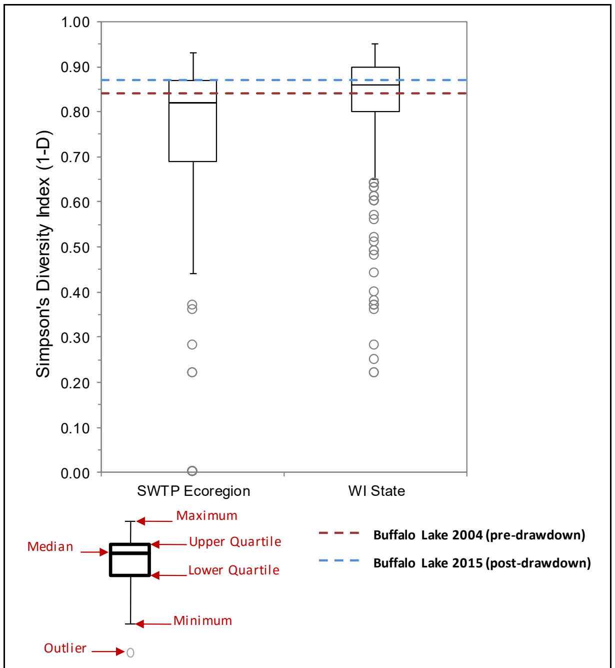


Photo 3.4-8. Buffalo Lake 2004 and 2015 aquatic plant community Simpson's Diversity Index. SWTP = Southeast Wisconsin Till Plains. Created using data from Onterra 2001 and 2015 whole-lake point-intercept surveys.

As explained earlier, 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 63% of the littoral sampling locations in Buffalo Lake in 2015, its relative frequency of occurrence is 27% (Figure 3.4-9). Explained another way, if 100 plants were randomly sampled from Buffalo Lake, 27 would be coontail, 19 would be common waterweed, 8 would be wild celery, etc.

Figure 3.4-9 displays the relative frequency of occurrence of aquatic plant species in Buffalo Lake from 2004 and 2015. As illustrated, approximately 78% of Buffalo Lake's plant community was comprised of just four plant species in 2004, 19% of which was Eurasian watermilfoil. In 2015 not only are there more species present, but their distribution within the community is more even compared to 2004.

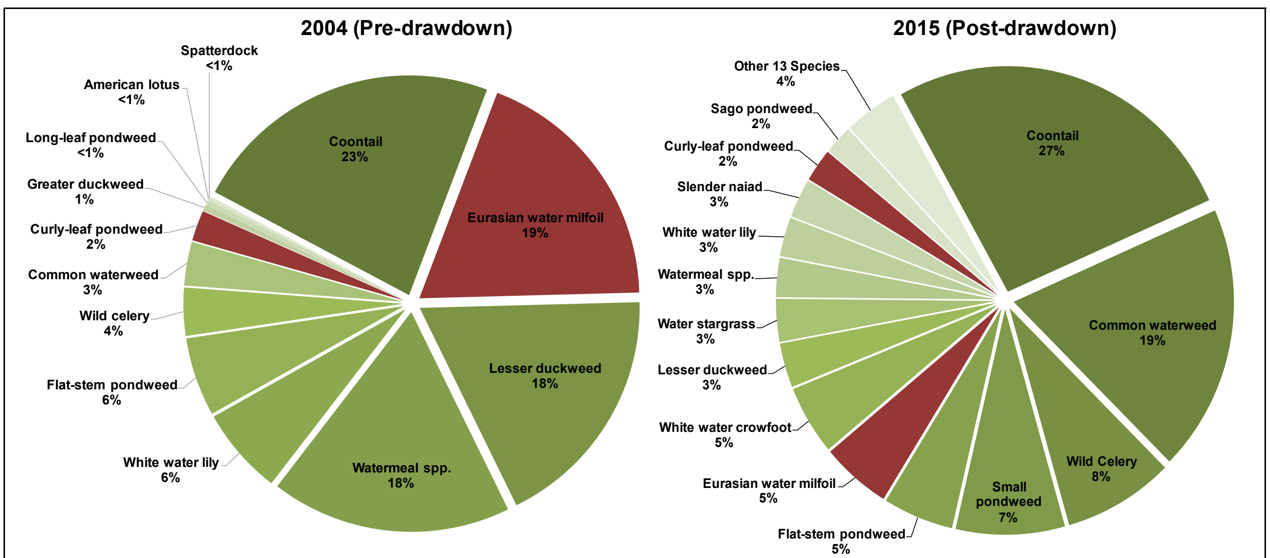


Figure 3.4-9. Buffalo Lake 2004 and 2015 relative frequency of occurrence of aquatic plant species. Non-native species indicated with red. Created using data from Onterra 2004 and 2015 whole-lake point-intercept surveys.

Emergent & Floating-leaf Aquatic Plant Communities

The 2015 community mapping survey indicated that approximately 923 acres, or 41% of Buffalo Lake's 2,227 acres contains emergent and floating-leaf aquatic plant communities (Table 3.4-2 and Maps 8.1-8.3). These communities were comprised of 15 aquatic plant species, six more than were located during the surveys in 2004 (Table 3.4-1). These communities typically respond positively to water level drawdowns and initially increase in area. However, these communities tend to decrease in subsequent years with stable water levels. Unfortunately, a community mapping survey using the methodology employed in 2015 was not conducted in 2004, and a comparison of emergent and floating-leaf community acreage between these two years cannot be made. However, anecdotal reports indicate that these communities, in particular those comprised of cattail, expanded following the 2012-2014 water level drawdown.

Table 3.4-2. Buffalo Lake 2015 acres of emergent and floating-leaf aquatic plant communities. Created using data from 2015 aquatic plant community mapping survey. Locations of these communities are displayed in Maps 8.1-8.3.

Aquatic Plant Community	Acres
Emergent	373.0
Floating-leaf	505.6
Mixed Emergent & Floating-leaf	43.8
Total	**922.5**

Emergent and floating-leaf aquatic plant communities are an important component of the lake ecosystem as the provide valuable structural habitat, reduce sediment resuspension, and reduce shoreline erosion. Continuing the analogy that 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 Buffalo 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 shorelines when compared to undeveloped shorelines 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 shorelines.

Realizing the importance of these communities, the BLPRD has taken a proactive approach and initiated actions to restore these communities in areas of Buffalo Lake. In 2013, the BLPRD successfully applied for a WDNR Small-Scale Lake Planning Grant to aid in funding protection and restoration of American lotus (*Nelumbo lutea*) communities in Buffalo Lake (Photo 3.4-1). Not only does American lotus provide valuable wildlife habitat, stabilize bottom sediments, and reduce non-native plant colonization, its large and showy flowers act as a source of eco-tourism

Photo 3.4-1. American lotus community in Buffalo Lake. Photo credit Onterra 2015.

and provide aesthetic beauty to Buffalo Lake.

The ongoing BLPRD project includes the mapping of lotus beds annually from 2013-2017 by district volunteers, the installation of informational signs at boat launches, the deployment of buoys around lotus beds to prevent damage from watercraft, and re-seeding to establish new colonies. Studies have shown that in many waterbodies within its range, American lotus colonies are expanding (Turner et al. 2010). American lotus is relatively tolerant of eutrophic and turbid conditions, and it is believed that its expansion is a result of these waterbodies becoming more eutrophic from human activities. The 2015 community mapping survey indicates that Buffalo Lake currently contains approximately 6.1 acres of American lotus-dominated communities (Figure 3.4-10). The majority of these communities are located in the downstream area of Buffalo Lake, and includes the 1.0-acre bed that is marked with buoys. The ongoing mapping of lotus beds by the BLPRD will provide insight into the dynamics of the lotus population in Buffalo Lake.

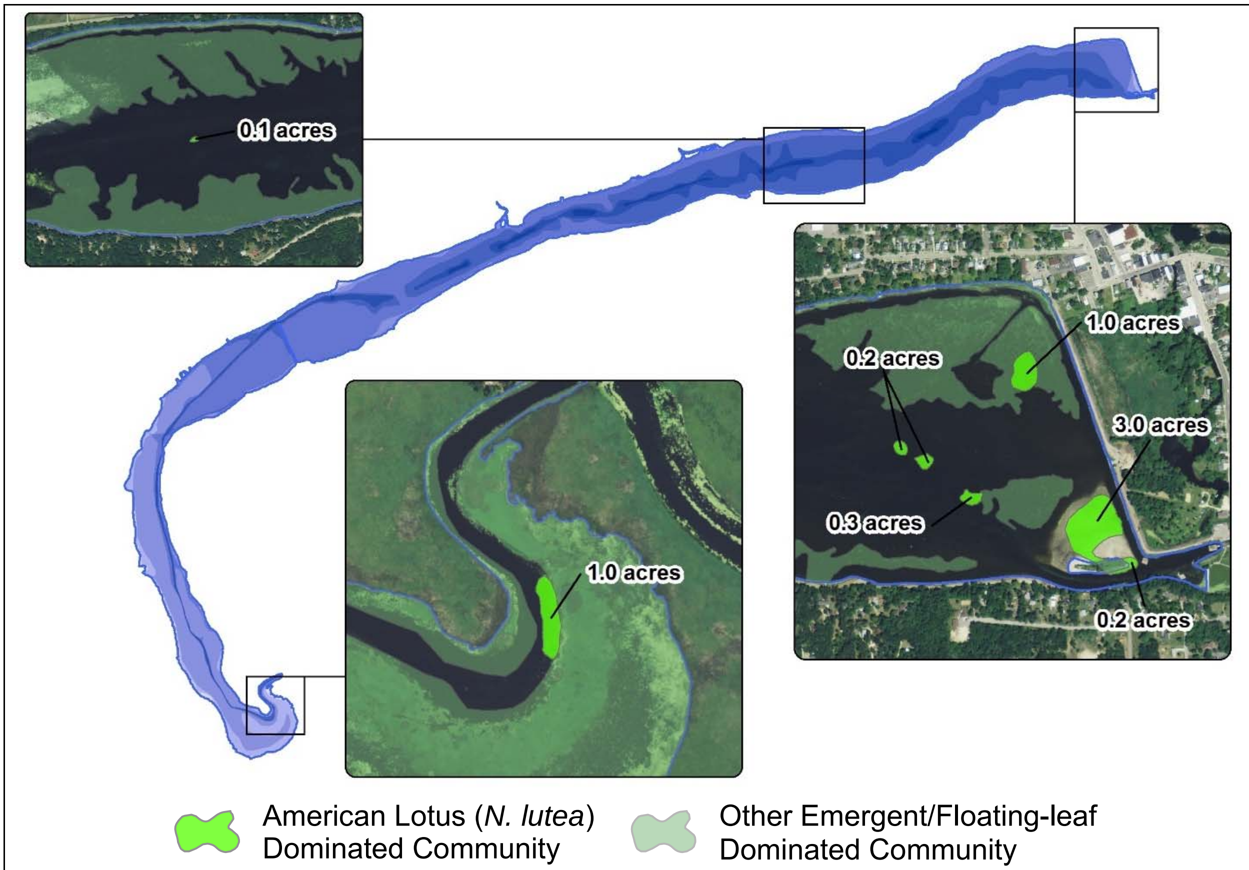


Figure 3.4-10. Buffalo Lake 2015 American lotus (*N. lutea*) locations. Created using data collected during 2015 community mapping survey.

Non-native Aquatic Plants in Buffalo Lake

Eurasian & Hybrid watermilfoil

Photo 3.4-2. Eurasian watermilfoil, a non-native, invasive aquatic plant.

Eurasian watermilfoil (*Myriophyllum spicatum*; EWM) was first documented in Buffalo Lake in 1991 (Photo 3.4-2). During the surveys completed in 2015, Onterra ecologists noted two morphologically-distinct populations of EWM in Buffalo Lake; one looked like EWM while the other had morphological attributes of the indigenous northern watermilfoil (*M. sibiricum*). Specimens from both populations were collected and sent to the Annis Water Resources Institute at Grand Valley State University in Michigan to undergo DNA analysis. The results indicated that Buffalo Lake contains populations of both pure-strain EWM and hybrid watermilfoil (HWM), a genetic cross between EWM and northern watermilfoil. Buffalo Lake contains a population of northern watermilfoil, but it is not known if the hybrid originated within Buffalo Lake or was introduced from another waterbody. Knowing whether a milfoil population is pure-strain EWM or HWM is important when considering herbicide application as a method for control as ongoing research is showing that certain strains of HWM are more tolerant to herbicides.

As discussed earlier, the littoral occurrence of EWM (and HWM) in Buffalo Lake declined by 83% between the 2004 and 2015 point-intercept surveys, and this decline is likely a result of the water level drawdown. The 2004 survey data indicated that EWM was widespread throughout Buffalo Lake. The 2015 surveys indicate that EWM is still widespread throughout the lake, but at a significantly lower density. The 2015 EWM Peak-Biomass Survey indicated that Buffalo Lake contained approximately 1,168 acres of colonized EWM in 2015. However, the vast majority (87%) of this acreage is comprised of *highly scattered* EWM (Figure 3.4-11 and Map 10). While these areas of highly scattered EWM are illustrated with polygons, it should be noted that a designation of highly scattered is given to areas that are just over the threshold of having too many EWM plants that can each be marked with an individual waypoint. While EWM is widespread in Buffalo Lake, only 10 acres were found to have areas considered to be *dominant* or *highly dominant*.

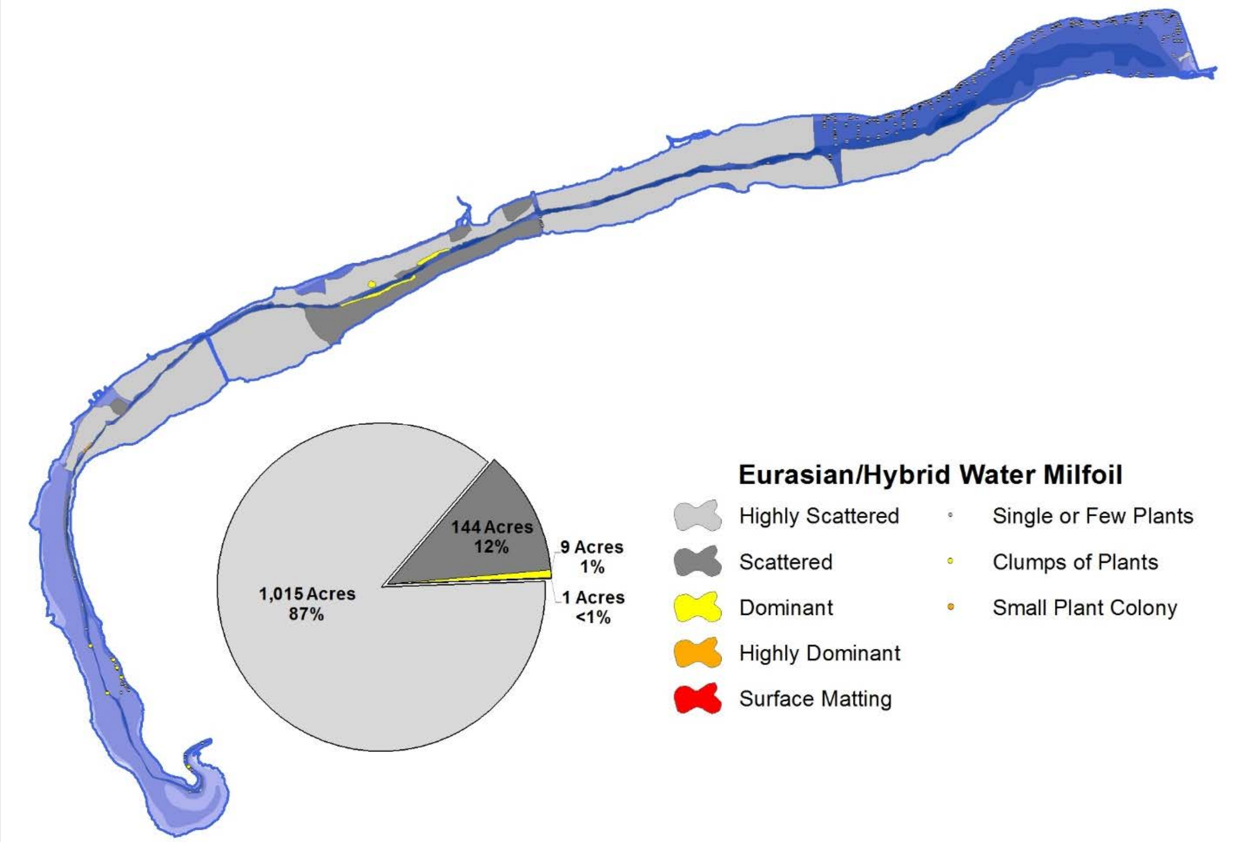


Figure 3.4-11. Buffalo Lake 2015 Eurasian/hybrid watermilfoil locations. Created using data collected during late-summer peak-biomass survey.

Curly-leaf pondweed & curly-leaf X white-stem pondweed hybrid

The earliest record of curly-leaf pondweed (*Potamogeton crispus*; CLP) in Buffalo Lake was in 1982 during a US Army Corps of Engineers study (Photo 3.4-3). As discussed earlier, the 2004 and 2015 point-intercept surveys were conducted later in the summer to coincide with the peak biomass of native aquatic plants. Given that CLP naturally senesces in early summer, its littoral occurrence is likely lower than it would be had these surveys been conducted in June when CLP is near or at its peak growth. The littoral occurrence of CLP in 2015 (6%) was not statistically different from its occurrence in 2004 (8%). Mapping of CLP when it was at or near its peak growth in late-May of 2015 shows that CLP is more widespread and of higher density than the EWM population (Figure 3.4-12 and Map 11).

During the surveys completed on Buffalo Lake in 2015, a few occurrences of a presumed hybrid between curly-leaf pondweed and the indigenous white-stem pondweed (*P. praelongus*) were located (Photo 3.4-3). This hybrid has been described as *P.* X *undulatus*, and genetic analysis is needed to positively identify this plant as such in Buffalo Lake. It is not known how widespread this plant is within Wisconsin, but populations have also been found in downstream Lake Puckaway and some lakes in the Madison area. *P.* X *undulatus* was only found growing in a few locations in Buffalo Lake in 2015, and it was not observed growing in any large colonies. This plant has not been observed to grow to nuisance conditions in Wisconsin and is currently not a concern in Buffalo Lake.

Photo 3.4-3. Curly-leaf pondweed (*Potamogeton crispus*; left) and presumed curly-leaf X white-stem pondweed hybrid (*P. X undulates*; right) collected from Buffalo Lake in 2015.

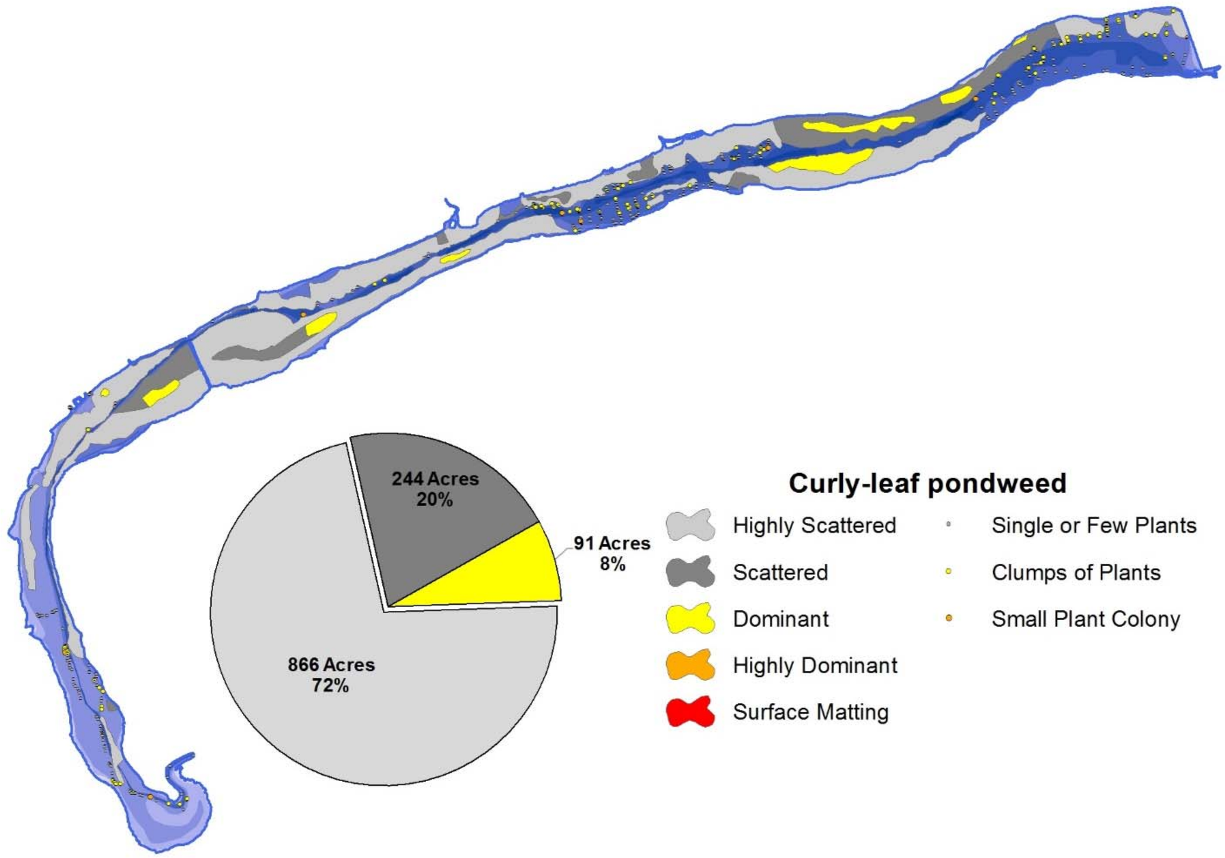


Figure 3.4-12. Buffalo Lake 2015 curly-leaf pondweed locations. Created using data collected during a late-May Early-Season AIS Survey.

Brittle naiad

Photo 3.4-4. Brittle naiad (*Najas minor*), a non-native, invasive aquatic plant. Photo taken by Alabama Department of Conservation and Natural Resources.

Brittle naiad (*Najas minor*; Photo 3.4-4) was first discovered in Buffalo Lake in 2014 and a population is also present in downstream Lake Puckaway. In 2015, brittle naiad had a low littoral occurrence of 1.6%, indicating a small population in Buffalo Lake. Brittle naiad is similar in appearance to the two native naiads found in Buffalo Lake, slender and southern naiads. Brittle naiad grows relatively short and it was not always visible from the surface in Buffalo Lake making mapping of this species difficult. However, using data collected during the 2015 point-intercept survey and during the Late-Summer EWM Peak-Biomass Survey, an idea of the general distribution of brittle naiad in Buffalo Lake could be made (Figure 3.4-13 and Map 12). The majority was located just downstream of the County D Causeway, while occurrences were also located upstream of the causeway as well as in the downstream area of the lake. While brittle naiad has been known to reach high densities, its low occurrence in Buffalo Lake does not warrant control at this time.

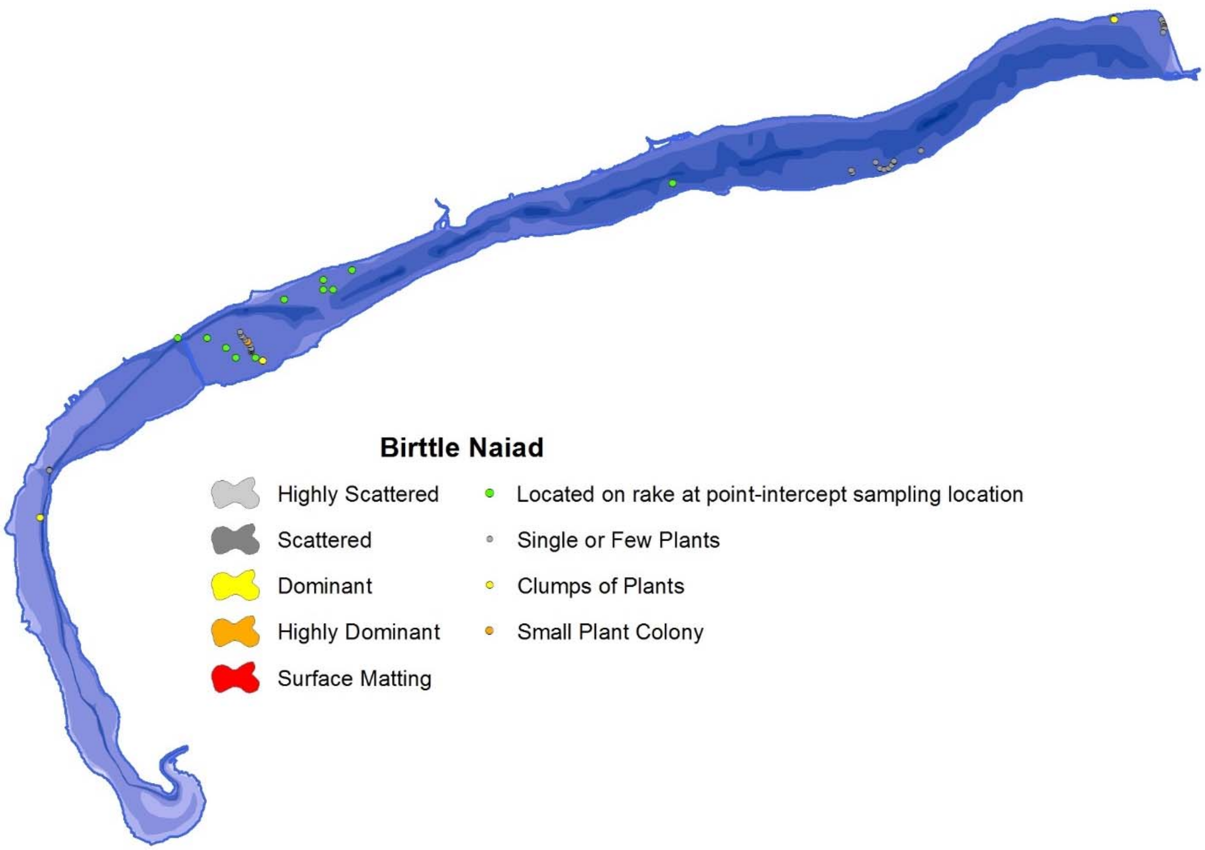


Figure 3.4-13. Buffalo Lake 2015 brittle naiad locations. Created using data collected during 2015 aquatic plant surveys.

Purple loosestrife

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

In Buffalo Lake, purple loosestrife was located in seven locations along shore or in wetland areas adjacent to the lake from the extreme upstream end of the lake to about mid-way downstream (Maps 8.2 & 8.3). There are a number of effective control strategies for combating this aggressive plant, including herbicide application, biological control by native beetles, and manual hand removal. At this time, hand removal by volunteers is likely the best option as it would decrease costs significantly. Additional purple loosestrife monitoring would be required to ensure the eradication of the plant from the shorelines and wetland areas around Buffalo Lake.

Pale-yellow iris

Pale yellow iris (*Iris pseudacorus*) is a large, showy iris with bright yellow flowers. Native to Europe and Asia, this species was sold commercially in the United States for ornamental use and has since escaped into Wisconsin's wetland areas forming large monotypic colonies and displacing valuable native wetland species. One occurrence of pale-yellow iris was located along the shore in the upstream portion of Buffalo Lake (Map 8.3). The optimal time to locate pale-yellow iris is in May and June when the plants are in flower. Hand-pulling or cutting of these plants to below the water line appears to be the most effective method of control for this species at this time.

Aquatic Plant Control in Buffalo Lake

Aquatic Plant Mechanical Harvesting in Buffalo Lake

Mechanical harvesting of aquatic plants in Buffalo Lake has occurred annually for decades to alleviate nuisance aquatic plant growth and maintain areas of open water for watercraft navigation and recreation. Currently, the BLPRD operates three harvesters which are permitted to harvest approximately 350 acres of the lake where they are used to create navigational lanes along shore and out to the main channel of the lake (Map 9). As was discussed within the 2006 lake management plan, mechanical harvesting is not a feasible means of reducing aquatic plant growth at a lake-wide level within a waterbody, but its intent is to create access to open water areas via navigational lanes. Buffalo Lake's shallow depth, high water clarity, and nutrient-rich water and sediments are ideal conditions for supporting abundant aquatic plant growth. Given these conditions, mechanical harvesting of aquatic plants will be an ongoing management tool for the BLPRD to employ to maintain navigation in Buffalo Lake.

Dredging

A number of comments within the 2015 stakeholder survey indicated that Buffalo Lake should be dredged to deepen the lake and control aquatic plant growth. Dredging is not an applicable method of plant control on Buffalo Lake for a number of reasons. First, as discussed previously, the aquatic plants in Buffalo Lake maintain the lake's current clear-water state and provide valuable habitat the lake's fishery, the most sought-after resource in Buffalo Lake as indicated by BLPRD members. Second, dredging represents a large disturbance to the aquatic environment. Dredging resuspends bottom sediments and nutrients and also opens up new areas for colonization by pioneering invasive plants, like EWM.

Third, dredging the lake deep enough so the area is no longer within the photic zone to support aquatic plant growth would be very cost-prohibitive. Aquatic plants generally grow to depths of two to three times the average Secchi disk transparency, or 9.0 to 12.0 feet in Buffalo Lake. For example, if 1% of Buffalo Lake was to be removed from the photic zone, approximately 22 acres would need to be deepened to a depth of at least 9.0 feet. Using Buffalo Lake's mean depth of 3.7 feet, approximately 5.3 feet of sediment (9.0-3.7 = 5.3) would need to be removed from 22 acres of the lake bottom which equates to 117 acre-feet of sediment. Hydraulic dredging is costly due to labor, permitting, and disposal. Dredging expenses cost anywhere from approximately $10-$15 per cubic yard of sediment removed. Using $10 per cubic yard of sediment, removing approximately 117 acre-feet of sediment in Buffalo Lake to remove approximately 1% of the lake from the photic zone would cost approximately $1.8 million. And given Buffalo Lake's large drainage basin, it is like the dredged areas would begin to fill in relatively quickly.

Herbicide Application

Herbicides that target submersed plant species are directly applied to the water, either as a liquid or an encapsulated granular formulation. Factors such as water depth, water flow, treatment area size, and plant density work to dilute herbicide concentration within aquatic systems. Understanding concentration-exposure times is an important consideration 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.

A Cooperative Research and Development Agreement between the Wisconsin Department of Natural Resources and U.S. Army Corps of Engineers Research and Development Center in conjunction with significant participation by private lake management consultants have coupled quantitative aquatic plant monitoring with field-collected herbicide concentration data to evaluate efficacy, selectivity, and longevity of chemical control strategies implemented on a subset of Wisconsin waterbodies. Based on the preliminary findings from this research, 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 effects outside of that area. Herbicide application rates for spot treatment are formulated volumetrically, typically targeting EWM with 2,4-D at 3.0-4.0 ppm acid equivalent (ae). This means that sufficient 2,4-D is applied within the *Application Area* such that if it mixed evenly with the *Treatment Volume*, it would equal 3-4.0 ppm ae. This standard method for determining spot treatment use rates is not without flaw, as no physical barrier keeps the herbicide within the *Treatment Volume* and herbicide dissipates horizontally out of the area before reaching equilibrium (Figure 3.4-14). While lake managers may propose that a particular volumetric dose be used, such as 3.0-4.0 ppm ae, it is understood that actually achieving 3.0-4.0 ppm ae within the water column is not likely due to dissipation and other factors.

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

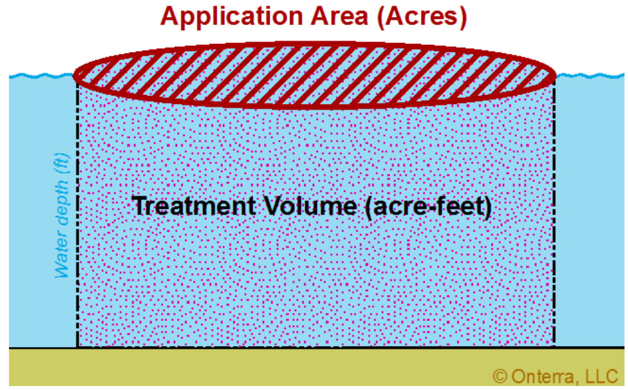


Figure 3.4-14. Herbicide Spot Treatment diagram.

Whole-lake treatments are those where the herbicide is applied to specific sites, but when the herbicide reaches equilibrium within the entire volume of water (of the lake, lake basin, or within the epilimnion of the lake or lake basin); it is at a concentration that is sufficient to cause mortality to the target plant within that entire lake or basin. The application rate of whole-lake treatments is dictated by the volume of water in which the herbicide will reach equilibrium with. The target herbicide concentration for whole-lake EWM treatments is typically between 0.250 and 0.400 parts per million (ppm) acid equivalent (ae) when exposed to the target plants for 7-14 days or longer. However, these same rates have been shown to impact some native plant species, particularly dicot species, some thin-leaved pondweeds, and naiad species. It is also important to note that US EPA registration of aquatic herbicides typically requires organismal toxicity studies to be conducted using concentrations and exposure times consistent with spot-treatment use patterns (high concentrations, short exposure times). Therefore, only limited organismal toxicity data is available for concentrations and exposure times consistent with whole-lake treatment use patterns (low concentrations, long exposure times).

Given Buffalo Lake's large size, targeting EWM and/or CLP at the lake-wide level with herbicides would cost upwards of $500 thousand to $1 million dollars. While whole-lake herbicide control strategies exist, the effective use of this control strategy is dependent on long herbicide exposure times. With a high flushing rate of approximately 14 days, the use of herbicides in this manner is likely not appropriate for Buffalo Lake. Smaller-scale spot treatments targeting isolated dense colonies of EWM and/or CLP may also have decreased efficacy given the high rate of water movement through this system.

Water Level Drawdown

As discussed previously, periodic winter water level drawdowns in impoundments in Wisconsin have been shown to be effective management tools for reducing the occurrence of both EWM and CLP at the lake-wide level. The data collected in 2015 on Buffalo Lake indicates that the large reduction observed in EWM since 2004 and other changes including a healthier native aquatic plant community were likely the result of the 1.5-year water level drawdown conducted from 2012-2014. If the BLRPD moves forward with utilizing periodic winter water level drawdowns in the future as a management tool for the control of non-native plants and enhancement of the lake native plant community, the duration of these drawdowns would be approximately seven months from September to April.

Determining the frequency and magnitude of winter water level drawdowns would require studies be completed prior to and after the drawdown. Strictly as an example, to gain an understanding of how rapidly EWM is increasing within the lake since the previous drawdown, whole-lake point-intercept surveys could be completed once every three years. If the EWM littoral occurrence reached or exceeded 30%, this would trigger the process of implementing another winter water level drawdown. Post-drawdown surveys would also be completed to assess the effects of the drawdown on both non-native and native aquatic plant species. Knowing when EWM occurrence reaches 30% will allow lake managers to gain an understanding of how often winter water level drawdowns may need to take place. The lakes fisheries will also aid in deciding the how often winter water level drawdowns would be able to take place on Buffalo Lake. The costs associated with conducting a winter water level drawdown on Buffalo Lake would be studies implemented before and after the drawdown to assess its efficacy as well as the economic costs (ice fishing, snowmobiling, etc.).

3.5 Fisheries Data Integration

Fishery management is an important aspect in the comprehensive management of a lake ecosystem; therefore, a brief 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 numerous fisheries biologists overseeing Buffalo Lake. The goal of this section is to provide an overview of some of the data that exists. Although current fish data were not collected, the following information was compiled based upon data available from the WDNR (WDNR 2015).

Buffalo Lake Fishery

Buffalo Lake Fishing Activity

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 Buffalo 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 3.5-1.

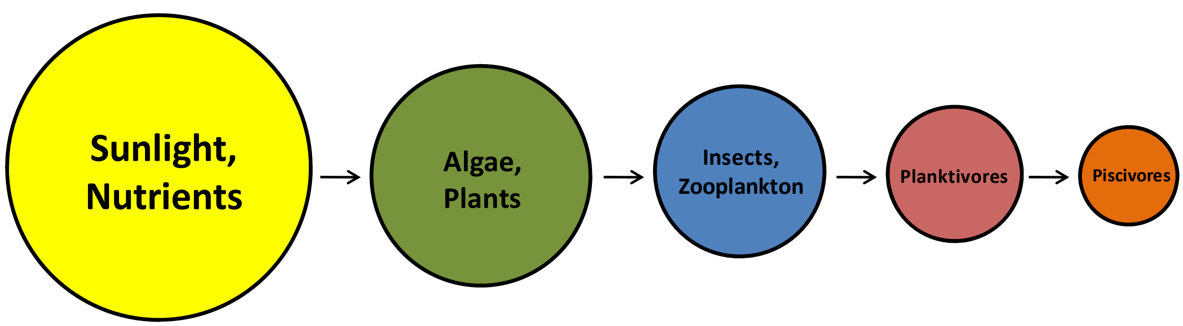


Figure 3.5-1. Aquatic food chain. Adapted from Carpenter et. al 1985.

As discussed in the Water Quality section, Buffalo Lake is a eutrophic system, meaning it has high nutrient content and thus relatively high primary productivity. Simply put, this means Buffalo Lake should be able to support sizable populations of predatory fish (piscivores) because the supporting food chain is relatively robust. Table 3.5-1 shows the popular game fish that are present in the system.

Table 3.5-1. Gamefish present in Buffalo Lake with corresponding biological information (Becker, 1983)**.**

Common Name	Scientific Name	Max Age (yrs)	Spawning Period	Spawning Habitat Requirements	Food Source
Black Crappie	*Pomoxis nigromaculatus*	7	May - June	Near *Chara* or other vegetation, over sand or fine gravel	Fish, cladocera, insect larvae, other invertebrates
Bluegill	*Lepomis macrochirus*	11	Late May - Early August	Shallow water with sand or gravel bottom	Fish, crayfish, aquatic insects and other invertebrates
Bowfin	*Amia calva*	30	Late April – Early June	Vegetated areas from 2 - 5 ft with soft rootlets, sand or gravel	Fish, crayfish, small rodents, snakes, frogs, turtles
Channel Catfish	*Ictalurus punctatus*	15	May - July	Dark cavities or crevices, rock ledges, beneath tree roots	Fish, insects, other invertebrates, seeds, plant materials
Common Carp	*Cyprinus carpio*	47	April – August	Shallow, weedy areas from 3 - 6 ft	Insect larvae, crustaceans, mollusks, some fish and fish eggs
Largemouth Bass	*Micropterus salmoides*	13	Late April - Early July	Shallow, quiet bays with emergent vegetation	Fish, amphipods, algae, crayfish and other invertebrates
Muskellunge	*Esox masquinongy*	30	Mid April – Mid May	Shallow bays over muck bottom with dead vegetation, 6 - 30 in.	Fish including other muskies, small mammals, shore birds, frogs
Northern Pike	*Esox lucius*	25	Late March - Early April	Shallow, flooded marshes with emergent vegetation with fine leaves	Fish including other pike, crayfish, small mammals, water fowl, frogs
Pumpkinseed	*Lepomis gibbosus*	12	Early May - August	Shallow warm bays 0.3 - 0.8 m, with sand or gravel bottom	Crustaceans, rotifers, mollusks, flatworms, insect larvae (terrestrial and aquatic)
Rock Bass	*Ambloplites rupestris*	13	Late May - Early June	Bottom of course sand or gravel, 1 cm - 1 m deep	Crustaceans, insect larvae, and other invertebrates
Smallmouth Bass	*Micropterus dolomieu*	13	Mid May - June	Nests more common on north and west shorelines over gravel	Small fish including other bass, crayfish, insects (aquatic and terrestrial)
Walleye	*Sander vitreus*	18	Mid April - Early May	Rocky, wavewashed shallows, inlet streams on gravel bottoms	Fish, fly and other insect larvae, crayfish
Yellow Perch	*Perca flavescens*	13	April - Early May	Sheltered areas, emergent and submergent veg	Small fish, aquatic invertebrates

Buffalo Lake Fish Stocking

To assist in meeting fisheries management goals, the WDNR may stock fish in a waterbody that were raised in nearby permitted hatcheries. Stocking of a lake is sometimes done to assist the population of a species due to a lack of natural reproduction in the system, or to otherwise enhance angling opportunities. Table 3.5-2 displays recent (1972-present) stocking efforts in Buffalo Lake.

Table 3.5-2. Stocking data available for Buffalo Lake (1972-2015).

Year	Species	Strain (Stock)	Age Class	# Fish Stocked	Avg Fish Length (in)
2014	Black Crappie	Unspecified	Fingerling	4,000	
2015	Black Crappie	Unspecified	Fingerling	514	4-7
2014	Bluegill	Unspecified	Fingerling	6,000	
2015	Bluegill	Unspecified	Fingerling	800	4.5
1972	Largemouth Bass	Unspecified	Fingerling	3,150	3
2014	Largemouth Bass	Unspecified	Fingerling	200	
2015	Largemouth Bass	Unspecified	Fingerling	2,990	6-14
1991	Muskellunge	Unspecified	Fingerling	640	9
1992	Muskellunge	Unspecified	Fingerling	2,550	10
1993	Muskellunge	Unspecified	Fingerling	2,500	10.5
1972	Northern Pike	Unspecified	Fry	15,835,225	1
1974	Northern Pike	Unspecified	Fry	2,940,000	
1975	Northern Pike	Unspecified	Fry	4,000,000	
1976	Northern Pike	Unspecified	Fry	750,000	
1977	Northern Pike	Unspecified	Fry	126,000	
1978	Northern Pike	Unspecified	Fry	4,304,000	
1985	Northern Pike	Unspecified	Fry	600,000	1
1987	Northern Pike	Unspecified	Fry	120,000	3
1988	Northern Pike	Unspecified	Fry	800,000	1
1987	Northern Pike X Muskellunge	Unspecified	Fingerling	1,161	10
1988	Northern Pike X Muskellunge	Unspecified	Fingerling	1,100	9
1989	Northern Pike X Muskellunge	Unspecified	Fingerling	1,331	8
1990	Northern Pike X Muskellunge	Unspecified	Fingerling	1,000	9
2014	Perch	Unspecified	Fingerling	4,000	
1972	Walleye	Unspecified	Fry	8,111,110	1
1973	Walleye	Unspecified	Fry	1,000,000	
1992	Walleye	Unspecified	Fingerling	280	4.7

Buffalo Lake Substrate and Near Shore Habitat

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

According to the point-intercept survey conducted by Onterra, 96% of the substrate sampled in the littoral zone on Buffalo Lake was soft sediments, with the remaining 4% composed of sandy substrate (Map 10). Substrate and habitat are critical to fish species that do not provide parental care to their eggs, in other words, the eggs are left after spawning and not tended to by the parent fish. 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 is 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 in muck as well.

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.

Buffalo Lake Regulations and Management

Because Buffalo Lake is a popular sportfishing destination, special fisheries regulations may occur, specifically in terms of walleye and other popular gamefish. For specific fishing regulations 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 would contain this information.

Viral Hemmorrhagic Septicemia (VHS)

Viral Hemmorrhagic Septicemia or VHS, is an infectious disease in fish caused by the *Viral hemorrhagic septicemia* virus. Originally identified in European freshwater trout, the virus was discovered in the Pacific northwest of the United States in the late 1980's and subsequently in the Great Lakes region in 2005. A strain of the VHS virus was discovered in the Lake Winnebago system in 2006, which includes the Fox River system and Buffalo Lake. The VHS virus is a threat to many fish species in Wisconsin and has caused large scale fish kills since its discovery. The VHS virus has never been associated with human illness and diseased fish caught by anglers may be consumed.

It is important to make efforts to prevent the spread of the VHS virus to other waters in Wisconsin. Specific laws aiming to prevent the spread of VHS in Wisconsin are in place and can be reviewed on the WDNR website at: http://dnr.wi.gov/topic/fishing/vhs/vhs_prevent.html.

Fish Consumption Advisories

As is discussed in the *Water Quality* section of this report, Buffalo Lake is listed as an impaired waterbody due to contamination of fish tissue by mercury and polychlorinated biphenyls (PCB's). Review Table 3.1-2 for the specific fish consumption advisories in place for Buffalo Lake.

4.0 SUMMARY AND CONCLUSIONS

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

1) Increase the general understanding of the Buffalo Lake ecosystem through comprehensive studies designed to assess the lake's water quality, watershed, immediate shoreland zone, aquatic plant community.

2) Document the present state of the native and non-native aquatic plant populations and develop strategies to prevent non-native aquatic plants from attaining levels observed prior to the 2012 water level reduction.

3) In collaboration with the Buffalo Lake Protection and Rehabilitation District (BLPRD), gather sociological information regarding stakeholder use of the lake, stakeholder perceptions pertaining to the past and current condition of the lake, and how the stakeholders would like to move forward with Buffalo Lake's management.

These three objectives were fulfilled during this project and have led to an increased understanding of the Buffalo Lake ecosystem, the people who care about the lake, and the management actions that are most appropriate for future protection and enhancement. The water quality data collected as a part of this project along with available historical data indicate that Buffalo Lake is currently in a eutrophic state with near-surface total phosphorus concentrations exceeding 100 µg/L. However, despite these high phosphorus concentrations, phytoplankton production is relatively low and water clarity is relatively high. While phosphorus regulates phytoplankton production in Buffalo Lake in spring, by early summer large reductions in nitrogen concentrations cause the lake to become nitrogen-limited. As is discussed in the Water Quality Section, the reduction in nitrogen over the course of the growing season is believed to be due to a process known as denitrification. While there is an ample supply of phosphorus in Buffalo Lake in summer, nitrogen is lacking, and thus limits the production of phytoplankton.

In nitrogen-limited systems, blue-green algae (cyanobacteria) often become dominant as they are able to utilize access atmospheric nitrogen when nitrogen in the water is limiting. However, it is believed that the abundant aquatic plant growth prevents blue-green algae blooms from forming in Buffalo Lake. The aquatic plants in Buffalo Lake compete for nutrients, release chemicals which can inhibit the growth of phytoplankton, and provide phytoplankton-grazing zooplankton refuge from predators. The aquatic plants in Buffalo Lake are essential for maintaining its current water quality, and disturbances which lead to losses in aquatic plants could result in Buffalo Lake transitioning into a turbid, phytoplankton-dominated state.

A lake's water quality is often driven by the condition of the lake's watershed, or drainage basin. Buffalo Lake's watershed is large and modeling indicated that approximately 77% of the phosphorus delivered to the lake annually originates from areas of row crop agriculture within the lake's direct watershed. Currently, the WDNR is developing a Total Maximum Daily Load (TMDL) for waterbodies within the Upper Fox River Watershed (including Buffalo Lake). This process will identify the largest sources of phosphorus and sediments to Buffalo Lake and develop management actions that can be taken to reduce the load of these pollutants to the lake.

The aquatic plant studies completed in 2015 indicated that Buffalo Lake's aquatic plant community saw significant positive changes following the 2012-2014 water level reduction. The occurrence of Eurasian watermilfoil declined by over 80%, while native aquatic plant species richness and diversity increased. Although Eurasian watermilfoil and curly-leaf pondweed are still widespread throughout Buffalo Lake, they are currently in relatively low abundance.

During the planning process, the Planning Committee received detailed information regarding the current condition of Buffalo Lake, including how the lake's aquatic plant community has changed following the 2012 water level reduction. Much of that information focused upon shallow lake ecology and the tendency of shallow lakes to exist in either an aquatic plant-dominated, clear state or a phytoplankton-dominated, turbid state. The Planning Committee understands that Buffalo Lake is currently in a clear state and maintenance of a healthy aquatic plant community is necessary to prevent the lake from transitioning to a turbid state.

The data collected in 2015 indicate that water level management in Buffalo Lake can be an effective management tool for controlling non-native aquatic plants while enhancing the native aquatic plant community. The BLPRD Planning Committee recognizes dredging, herbicides, and mechanical harvesting of aquatic plants in Buffalo Lake are not realistic management strategies for long-term control of non-native aquatic plants and that periodic, winter water level management is the most realistic strategy for maintaining a healthy Buffalo Lake. While the BLPRD Planning Committee understands the importance of implementing periodic water level management in Buffalo Lake, the stakeholder survey indicated that the majority of survey respondents are not in favor of utilizing water level management as a tool in Buffalo Lake. The following Implementation Plan discusses in detail the actions that the BLPRD will take to inform their membership and other Buffalo Lake stakeholders on the effectiveness of the 2012-2014 water level reduction and how future water level management in Buffalo Lake can be used to maintain a healthy plant community and fishery.

Through the process of this lake management planning effort, the BLPRD has learned much about their lake, both in terms of its positive and negative attributes. It is now the BLPRD's responsibility to maximize the lake's positive attributes while minimizing the negative attributes to the greatest extent possible. The Implementation Plan that follows this section was developed through discussions between Onterra ecologists, the BLPRD Planning Committee, and WDNR staff, and outlines the goals and action steps that the BLPRD will take to enhance and protect Buffalo Lake.

5.0 IMPLEMENTATION PLAN

The Implementation Plan presented below was created through the collaborative efforts of the Buffalo Lake Protection & Rehabilitation District (BLPRD) Planning Committee, Onterra ecologists, and WDNR staff. It represents the path the BDLIA will follow in order to meet their lake management goals. The goals detailed within the plan are realistic and based upon the findings of the studies completed in conjunction with this planning project and the needs of the Buffalo Lake stakeholders as portrayed by the members of the Planning Committee and the 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: Maintain current water quality conditions

Management Action:	Initiate volunteer-based annual water quality monitoring of Buffalo Lake through the WDNR Citizen Lake Monitoring Network.
Timeframe:	Initiate in 2017
Facilitator:	BLPRD Board of Directors (suggested)
Description:	As is discussed within the Water Quality Section, Buffalo Lake is currently in an aquatic plant-dominated, clear water state. Monitoring water quality is an important aspect of every lake management planning activity. Collection of water quality data at regular intervals aids in the management of the lake by building a database that can be used for long-term trend analysis. Early discovery of negative trends may lead to the reason as of why the trend is developing. Or conversely, the detection of positive trends may indicate that remediation actions are working. The Citizen Lake Monitoring Network (CLMN) is a WDNR program in which volunteers are trained to collect water quality information on their lake. The BLPRD recognizes the importance of collecting water quality data on a regular basis to understand trends in water quality within Buffalo Lake over time or to determine if any changes occur following activities such as water level management. It is the responsibility of the BLPRD Board of Directors to recruit and coordinate a volunteer(s) to regularly collect these data. According to the stakeholder survey sent to district members in 2015, nearly 90 individuals indicated they would be willing to participate in water quality monitoring if called upon by the district. 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 deepest location in Buffalo Lake four times during the growing season (May, June, July,

and August). A couple 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 BLPRD Board of Directors recruits a volunteer(s) to collect water quality data four times per year on Buffalo 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 BLPRD Board of Directors recruits new CLMN volunteers as needed.

Management Goal 2: Inform BLPRD District Membership on Benefits to Buffalo Lake Realized from 2012-2014 Water Level Reduction & Gain Support of BLPRD Membership to Implement Future, Periodic Seasonal Water Level Management in Buffalo Lake

<u>Management Action:</u> Utilize the Buffalo Lake Comprehensive Management Planning Update Project Wrap-Up Meeting to inform the BLPRD membership on the ecological benefits gained from the 2012-2014 water level reduction and why the implementation of future, periodic seasonal water level management is necessary for maintaining Buffalo Lake's ecological integrity.

Timeframe: Meeting to occur in October of 2017

Facilitator: BLPRD Planning Committee/Board of Directors (suggested)

Description: As is discussed in the study results sections, the quality of Buffalo Lake's aquatic plant community increased markedly following the water level reduction from 2012-2014 required for dam reconstruction. The non-native Eurasian watermilfoil decreased in its occurrence by over 80%, while native aquatic plant species richness and diversity increased. The reduction in non-native plants and reestablishment of a more diverse native aquatic plant community has led to improved fisheries habitat and a reduction in areas of dense plant growth which hinder navigation.

With no management actions taken, non-native plant populations in Buffalo Lake will likely increase to levels observed prior to the 2012-2014 water level reduction. However, it is not known how quickly these populations will rebound. Given the size of Buffalo Lake and the rate of water flow through the system, herbicide applications are not viable and cost-effective method for maintaining lower non-native plant populations in the long-term. Periodic, seasonal water level reductions, specifically those conducted over the winter, would be the most cost-effective method for controlling non-native plants in Buffalo Lake and preventing their populations from returning to pre-2012 levels.

During the Buffalo Lake Management Plan development in in 2004-2006, winter water level management was proposed as a possible management tool for reducing non-native plants and enhancing the native aquatic plant community. However, despite substantial efforts to gain support from the district membership, the district voted against the implementation of winter water level management. However, data are now available that show the positive effects that water level management on Buffalo Lake can have. These data were presented to the BLPRD membership at the project Wrap-Up Meeting in the fall of 2017 to highlight the benefits of water management and why they are likely the most realistic means of maintaining the ecological integrity of Buffalo Lake into the future.

This meeting included a presentation from Onterra lake ecologist Brenton Butterfield. The purpose of this meeting was to present the changes documented to Buffalo Lake following the 2012-2014 water level reduction, discuss why periodic winter water level management is important for future management, how they will differ from the 2012-2014 water level reduction, and to address concerns of the BLPRD members. The overall goal of this meeting was to resolve any misunderstandings the BLPRD members may have regarding water level management, and to gain their support for periodic water level management in the future.

Action Steps:

1. BLPRD Board of Directors to schedule a public meeting for the fall of 2016 on a Saturday morning to maximize BLPRD membership attendance.
2. BLPRD Board of Directors creates pamphlet to be mailed to district members to announce the meeting and highlight the topics to be discussed.
3. BLPRD Board of Directors creates and distributes fliers to local businesses to advertise the meeting and the topics that will be discussed.
4. BLPRD Board of Directors will also include an announcement for the meeting on the district's website and Facebook page.

Management Goal 3: Control Existing Aquatic Invasive Species, Prevent New Introductions to and Spread from Buffalo Lake, and Protect Native Aquatic Plants

Management Action:	Implement winter water level management to control non-native aquatic plants and enhance native aquatic plant community in Buffalo Lake.
Timeframe:	Initiate in 2018
Facilitator:	BLPRD Board of Directors (suggested)
Possible Funding:	WDNR AIS-Education, Planning and Prevention Grant <$10,000 sub-category (Deadline: December 10 of each year)
Description:	As is discussed within the Aquatic Plant Section, the littoral frequency of occurrence of Eurasian watermilfoil (EWM) was reduced from approximately 70% in 2004 to 12% in 2015, a reduction of 83% following the 2012-2014 water level reduction. The occurrence of curly-leaf pondweed (CLP) was also believed to be reduced; however, the point-intercept surveys conducted pre- and post-water level reduction were conducted in mid-summer following the natural senescence (die-back) of CLP and did not capture this population at its full potential. Periodic, winter water level reductions are believed to be the most cost-effective method for controlling these non-native aquatic plants in Buffalo Lake and preventing them from rebounding to occurrences that were observed prior to 2012. In addition, the native aquatic plant community was also shown to be enhanced in terms of species richness and diversity following the 2012-2014 water level reduction. Water level management has been shown to be an effective tool to reduce the occurrence of non-native plants in Buffalo Lake, and the goal of future water level management is to maintain low levels of non-native aquatic invasive plants and prevent them from reaching levels observed prior to 2012. Continued monitoring of the lake's plant community will be required to determine when water level management should be implemented again. Unlike the water level reduction that took place over the course of one summer and two winters from 2012-2014, the proposed water level management strategy would involve maintaining water levels 3-4 feet below full pool for approximately seven months beginning in early fall through the following spring. Water levels would be gradually lowered likely soon after Labor Day, maintained 3-4 feet below full pool through the winter, and gradually raised to full pool the following April. Eurasian watermilfoil does not completely die back in winter, and the goal is to desiccate/freeze as much of the population as possible. It would also be the hope that a portion of the overwintering structures (turions) of curly-leaf pondweed would also desiccate/freeze. The previous water level reduction proved effective; however, the

effectiveness of future water level management will likely be dependent upon winter temperatures and snow cover.

The level at which EWM will begin to negatively impact a lake varies from lake to lake, and in Buffalo Lake it is believed that when EWM approaches a littoral occurrence of around 30% that it begins to interfere with navigation and alter habitat structure. Because of this, it was agreed during the planning meetings with the BLPRD Planning Committee that when EWM reaches a littoral occurrence of around 30%, the steps for pursuing a winter water level management strategy would be initiated. While CLP is also present in Buffalo Lake, it is believed the level of EWM would be a more appropriate threshold for initiating water level management in Buffalo Lake because the majority of CLP naturally dies back by early July. In addition, to quantify the level of both species in Buffalo Lake would require two separate surveys at different times of the growing season. Using the level of just EWM is a cost-saving measure as only one survey would need to be completed. To monitor Buffalo Lake's aquatic plant community and determine if winter water level management is warranted, the following series of steps are proposed:

1. A whole-lake point-intercept survey is completed during the summer of 2019.

    a. If EWM littoral occurrence is <25% in 2019, the process for initiating winter water level management in 2020 would not be pursued and another whole-lake point-intercept survey would be conducted in 2022 to determine the level of EWM within the lake.

    b. If EWM littoral occurrence is found to be ≥25% in 2019, the process for pursuing winter water level management in 2020 would be initiated and the following steps would be conducted.

2. A whole-lake point-intercept survey would be conducted during the summer of 2020 to serve as a pre-water level management dataset for the season immediately prior to water level management. Surveys would also be conducted to map the CLP population (Early-Season AIS Survey), EWM population (Late-Summer EWM Peak-Biomass Survey), and emergent and floating-leaf communities (Community Mapping Survey).

3. Winter water level management begins in Fall of 2020 (likely immediately after Labor Day). Depending on EWM survey results, water level gradually reduced to 3-4 feet below full pool and maintained through the winter. Water levels are

gradually raised to full pool in April 2021.

4. The surveys discussed in Step 3 are completed again during the summer of 2021 to serve as a post-water level management dataset of the aquatic plant community.

5. A whole-lake point-intercept survey is completed in 2026 to again reassess Buffalo Lake's aquatic plant community and determine if water level management is again warranted using the thresholds discussed above.

Action Steps:

1. Retain qualified professional assistance to develop specific monitoring designs and to implement surveys described above.
2. BLPRD Board of Directors works with qualified professional in 2018 to seek WDNR AIS-EPP Grant (<$10,000 sub-category) to aid in funding of surveys in 2019.
3. Qualified professional conducts whole-lake point-intercept survey in 2019.
4. Depending on level of EWM in 2019, follow steps as outlined above.

Management Action: Initiate Clean Boats Clean Waters (CBCW) watercraft inspections at Buffalo Lake public access locations.

Timeframe: Initiate 2018

Facilitator: BLPRD Board of Directors (suggested)

Possible Funding: WDNR Clean Boats Clean Waters Project Funding Grant

Description: Buffalo Lake is a popular destination for anglers and other recreationalists making the lake vulnerable to new introductions of non-native species as well as increasing the risk of spread of non-native species already present in Buffalo Lake to other waterbodies. The intent of watercraft inspections would not only be to prevent additional non-native species from entering the lake through public access points, but also to prevent the potential infestation of other waterbodies with non-native species that originated from Buffalo Lake. The goal would be to monitor the busiest public access locations for a total of 200 hours per year during the busiest times (e.g. holiday weekends) in order to maximized contact with lake users, spreading the word about the negative impacts that non-native species have and educating lake users how they are the primary vector of their spread.

A commitment of monitoring of 200 hours per year is required to qualify for WDNR AIS-Education Planning and Prevention funds. The CBCW funding grant will provide a maximum of $4,000 for 200 hours for one landing or a combination of two landings. Often, it is difficult for lake groups to recruit and maintain a volunteer base to oversee CBCW inspections throughout the summer months.

Recruitment outside of the BLPRD may be necessary in order to have sufficient coverage of Buffalo Lake public access locations. Volunteer monitors will need to be trained on CBCW protocols in order to participate in public boat landing inspections. Fully understanding the importance of CBCW inspections, paid watercraft inspectors may be sought to ensure monitoring occurs at the public boat landing. These paid inspectors may be purchased alone or in conjunction with volunteers through the BLPRD or in the community.

Action Steps:

1. BLPRD Board of Directors recruits volunteer watercraft inspectors.
2. BLPRD applies for CBCW funding during December 10, 2018 grant cycle.
3. Volunteers periodically attend CBCW training sessions through the WDNR (Erin McFarlane – 715.346.4978) to update their skills to current standards.
4. Training of additional volunteers completed by those previously trained.
5. Report results to WDNR and BLPRD
6. Promote enlistment and training of new volunteers to keep program fresh.

Management Action: Continue monitoring and control of the shoreline/wetland invasive plant purple loosestrife and pale-yellow iris on Buffalo Lake.

Timeframe: Continuation of current effort

Facilitator: BLPRD Board of Directors (suggested)

Description: During the 2015 aquatic plant surveys on Buffalo Lake, Onterra ecologists located a number of purple loosestrife occurrences and one occurrence of pale-yellow iris along the lake's shoreline (Maps 8.1-8.3). The BLPRD has been working with AIS specialists from the Golden Sands RC&D to control these invasive wetland plants in Buffalo Lake. For purple loosestrife, *Galerucella* beetles are raised and placed on the purple loosestrife plants annually in attempt to control these plants. Given the low abundance of pale-yellow iris, the best method of control at this time is likely hand-removal.

Action Steps:

1. BLPRD to continue working with Krista Kampke (608.296.2815), the Golden Sands RC&D regional aquatic invasive species coordinator for Marquette and Green Lake counties, to coordinate annual monitoring and development of control strategies for purple loosestrife and pale-yellow iris in Buffalo Lake.

Management Action: Continue American lotus restoration and monitoring project in Buffalo Lake.

Timeframe: Continuation of current effort

Facilitator: Richard Brefeld (suggested)

Description: In 2013, the BLPRD was awarded a WDNR Small-Scale Lake Planning Grant to aid in funding the protection and restoration of American lotus (*Nelumbo lutea*) communities in Buffalo Lake. American lotus provides valuable wildlife habitat, stabilizes bottom sediments, and helps to reduce non-native plant establishment. In addition, its large, fragrant flowers are a source of ecotourism and provide aesthetic beauty to Buffalo Lake.

The ongoing project includes the mapping of lotus communities on an annual basis from 2013-2017 by district volunteers, the installation of informational signs at boat launches, the deployment of buoys around lotus communities to prevent damage from watercraft, and re-seeding areas of the lake in an attempt to establish new colonies. In 2015, Onterra ecologists mapped approximately 6.1 acres of lotus-dominated communities in Buffalo Lake. The ongoing protection and monitoring of lotus in Buffalo Lake will provide insight into the dynamics of these populations over time.

Action Steps:

1. Richard Brefeld continues coordination of American lotus protection and monitoring in Buffalo Lake through 2017.

Management Goal 4: Enhance the Fishery of Buffalo Lake

Management Action: Continue to work with fisheries managers to enhance the overall fishery in Buffalo Lake.

Timeframe: Continuation of current effort

Facilitator: BLPRD Fisheries Committee (suggested)

Description: The BLPRD would like to continue its relationship with the WDNR fisheries biologist to protect and enhance the overall fishery of Buffalo Lake. The BLPRD has ongoing concerns regarding the effects of the 2012-2014 water level reduction on the lake's fishery as well as the potential effects of future, periodic water level management on the fishery.

The BLPRD has formed a fisheries committee which oversees periodic stocking of sportfish, panfish, and baitfish in Buffalo Lake. Buffalo Lake is currently overseen by WDNR fisheries biologist David Bartz. In order to keep informed of surveys/studies that are completed on Buffalo Lake, the BLPRD fisheries committee should contact David Bartz at least one a year (perhaps during the winter months when field work is not occurring) for a brief summary of activities. Additionally, the BLPRD may discuss options for improving the fishery in Buffalo Lake, which may include habitat enhancements.

Action Steps:

1. See description above.

Management Goal 5: Assure and Enhance the Communication and Outreach of the Buffalo Lake Protection and Rehabilitation District with Buffalo Lake Stakeholders

Management Action: Support an Education and Communication Committee to promote stakeholder involvement, inform stakeholders on various lake issues, as well as the quality of life on Buffalo Lake.

Timeframe: Initiate 2017

Facilitator: BLPRD Board of Directors (suggested)

Description: Education represents an effective tool to address lake issues like shoreline development, invasive species, water quality, lawn fertilizers, as well as other concerns such as community involvement and boating safety. An Education and Communication Committee will be created to promote lake preservation and enhancement through a variety of educational efforts.

Currently, the BLPRD regularly publishes and distributes a yearly newsletter and maintains a district website and Facebook page that provide district-related information including current district projects and updates, meeting times, and educational topics. Both of these mediums are an excellent source for communication and education to both district and non-district members.

Approximately 40% of the stakeholder survey respondents indicated that the BLPRD keeps them *fairly well informed* or *highly well informed*; however, approximately 40% of respondents indicated that they were *not too informed* or *not at all informed* (Appendix B, Question #28). The remaining 20% were *unsure*. The BLPRD would like to increase its capacity to reach out to and educate district and non-district members regarding Buffalo Lake and its preservation. In addition to creating a yearly newsletter, a variety of educational efforts will be initiated by the Education and Communication Committee. These may include educational materials such as a tri-fold brochure and/or a new membership informational packet containing information about the BLPRD (projects, finances, etc.) as well as facts about Buffalo Lake and steps lake residents can take to maintain and enhance the quality of the lake, as well as quality of life for those who live and recreate on it. The Education and Communication Committee will also organize workshops and speakers surrounding lake-related topics.

Education of lake stakeholders on all matters is important, and a list of potential educational topics can be found below. These topics can be included within the district's newsletter and/or website or distributed as separate educational materials. In addition, the BLPRD can invite professionals who work within these topics to come and speak at the district's annual meeting or hold workshops if available.

Example Educational Topics

- Shoreline restoration and protection
- Importance of maintaining course woody habitat
- Effect lawn fertilizers/herbicides have on the lake
- Fishing rules and regulations
- Catch-and-release fishing
- Importance of periodic water level management in Buffalo Lake (discussed in previous management action)
- Boating regulations and safety
- Pier regulations and responsible placement to minimize habitat disturbance
- Importance of maintaining a healthy native aquatic plant community
- Respect to and maintaining a safe distance from wildlife (e.g. nesting terns) within the lake
- Aquatic invasive species (AIS) prevention and updates for AIS in Buffalo Lake
- Water quality monitoring updates from Buffalo Lake
- Littering on the ice and year-round

Action Steps:

1. See description above.

Management Action: Enhance the BLPRD's involvement with other entities that manage aspects of Buffalo Lake.

Timeframe: Continuation of current effort

Facilitator: BLPRD Board of Directors (suggested)

Description: The waters of Wisconsin belong to everyone and, therefore, this goal of protecting and enhancing these share resources is also held by other agencies and entities. It is important that the BLPRD actively engage with all management entities to enhance the district's understanding of the common management goals and to participate in the development of these goals. This also helps all management entities understand the actions that others are taking to reduce the duplication of efforts.

While not an inclusive list, the primary management units regarding Buffalo Lake are the WDNR (fisheries, AIS, and lake management personnel), the Montello Area Chamber of Commerce, the City of

Montello, the Marquette County Land and Water Conservation Department, Marquette County Lakes Association, and Wisconsin Lakes. Each entity is specifically addressed in the table below.

Action Steps:

1. See the following table guidelines below.

Partner	Contact Person	Role	Contact Frequency	Contact Basis
Montello Area Chamber of Commerce	General staff (info@montellowi.com)	Provides information and networking related to the advancement of the Montello Community.	Once a year, or more as needed. May check website (http://www.montellowi.com/) for updates.	The Chamber of Commerce serves a valuable role in promoting local businesses, tourism, and community within the Buffalo Lake area.
Marquette County Lakes Association	Al Rosenthal (608.589.5036)	Protects Marquette County waters through facilitating discussion and education.	Twice a year or as needed. May check website (https:// http://marquettecla.blogspot.com/) for updates	Become aware of training or education opportunities, partnering in special projects, or networking on other topics pertaining to Marquette County waterways.
Marquette County AIS Coordinator	AIS Coordinator (Krista Kampke – 608.296.2815)	Oversees AIS monitoring and prevention activities locally.	Twice a year or more as issues arise.	Spring: AIS training and ID, AIS monitoring techniques Summer: Report activities to Krista
Marquette County Land and Water Conservation Department	County Conservationist (Pat Kilbey – 608.296.2815)	Oversees conservation efforts for land and water projects.	Twice a year or more as needed.	
Wisconsin Department of Natural Resources	Fisheries Biologist (David Bartz– 920.787.3016)	Manages the fishery of Buffalo Lake.	Once a year, or more as issues arise.	Scheduled surveys, survey results, and volunteer opportunities for improving fishery.
	Lakes Coordinator (Ted Johnson– 920.424.2104)	Oversees management plans, grants, all lake	Once a year, or more as issues arise.	Information on updating a lake management plan (every 5

		activities.		years) or to seek advice on other lake issues.
	Conservation Warden (Ben Nadolski – 920.960.6700)	Oversees regulations handed down by the state.	As needed. May call the WDNR violation tip hotline for anonymous reporting (1-800-847-9367, 24 hours a day).	Contact regarding suspected violations pertaining to recreational activity on Buffalo Lake, including fishing, boating safety, ordinance violations, etc.
	Citizens Lake Monitoring Network contact (Paul Skawinski – 715.346.4853)	Provides training and assistance on CLMN monitoring, methods, and data entry.	Twice a year or more as needed.	Late winter: arrange for training as needed, in addition to planning out monitoring for the open water season. Late fall: report monitoring activities.
Wisconsin Lakes	General staff (800.542.5253)	Facilitates education, networking and assistance on all matters involving WI lakes.	As needed. May check website (www.wisconsinlakes.org) often for updates.	SLA members may attend WL's annual conference to keep up-to-date on lake issues. WL reps can assist on grant issues, AIS training, habitat enhancement techniques, etc.

Management Goal 6: Lessen the Impact of Shoreline Development on Buffalo Lake

Management Action:	Investigate restoring high developed shoreland areas on Buffalo Lake
Timeframe:	Continuation of current effort
Facilitator:	BLPRD Board of Directors (suggested)
Description:	The 2015 shoreland condition assessment found that approximately 16% (4.2 miles) of Buffalo Lake's shoreland zone is in a highly-developed state. When shorelands are developed, the resulting impacts on a lake range from a loss of biological diversity to impaired water quality. Because of its proximity to the waters of the lake, even small disturbances to a natural shoreland area can produce ill effects.

Fortunately, restoration of the shoreland zone can be less expensive, less time-consuming and much easier to accomplish than restoration efforts in other parts of the watershed. Cost-sharing grants and Marquette County staff devoted to these types of projects give private property owners partial funding and informational resources to restore quality shoreland habitat to their lakeside residence. The BLPRD is currently working with Marquette County partners to potentially restore shoreland areas on properties of four Buffalo Lake riparians. The BLPRD can continue to acquire information from and work with appropriate entities such as the Marquette County Land and Water Conservation Department to research grant programs, shoreland restoration techniques, and other pertinent information that will help the BLPRD.

Because property owners may have little experience with or be uncertain about restoring a shoreland to its natural state, properties with restoration on their shorelands could serve as demonstration sites. Other lakeside property owners could have the opportunity to view a shoreland that has been restored to a more natural state, and learn about the maintenance, labor, and cost-sharing opportunities associated with these projects.
The WDNR's Healthy Lakes Implementation Plan allows partial cost coverage for native plantings in transition areas. This reimbursable grant program is intended for relatively straightforward and simple projects. More advanced projects that require advanced engineering design may seek alternative funding opportunities, potentially through the county and the WDNR Lake Protection Grant Program.

- 75% state share grant with maximum award of $25,000; up to 10% state share for technical assistance
- Maximum of $1,000 per 350 ft^2 of native plantings (best practice cap)

- Implemented according to approved technical requirements (WDNR, County, Municipal, etc.) and complies with local shoreland zoning ordinances
- Must be at least 350 ft^2 of contiguous lakeshore; 10 feet wide by 35 feet deep
- Landowner must sign Conservation Commitment pledge to leave project in place and provide continued maintenance for 10 years
- Additional funding opportunities for water diversion projects and rain gardens (maximum of $1,000 per practice) also available

However, for a larger project that may include a number of properties, it may be more appropriate to seek funding through a WDNR Lake Protection Grant. While more funding can be provided through a Lake Protection Grant and there are no limits to where that funding utilized (e.g. technical, installation, etc.), the grant does require that the restored shorelines remain undeveloped in perpetuity.

Action Steps:

1. See description above.

<u>Management Action:</u> Preserve natural shoreland areas on Buffalo Lake.

Timeframe: Initiate 2017

Facilitator: BLPRD Board of Directors (suggested)

Description: Approximately 65% (17.2 miles) of Buffalo Lake's shoreline is currently contains little or no development. It is very important that owners of these properties become educated on the benefits their shoreland is providing to Buffalo Lake, and that these shorelands remain in a natural state.

The shoreland areas delineated as Natural and Developed-Natural should be prioritized for education initiatives and physical preservation. The BLPRD board of directors will work with appropriate entities to research grant programs and other pertinent information that will aid BLPRD in preserving Buffalo Lake's shoreland. This would be accomplished through education of property owners, or direct preservation of land through implementation of conservation easements or land trusts that the property owner would approve of.

Valuable resources for this type of conservation work include the WDNR, UW-Extension, and Marquette Land and Water Conservation Department. Several websites of interest include:

- Wisconsin Lakes website:

www.wisconsinlakes.org/shorelands)
- Northeast Wisconsin Land Trust: (newlt.org)
- UW-Extension Shoreland Restoration: http://www.uwex.edu/ces/shoreland/Why1/whyres.htm)
- WDNR Shoreland Zoning website: (http://dnr.wi.gov/topic/ShorelandZoning/)

Action Steps:

1. See description above.

Management Goal 7: Maintain and Enhance Recreational Opportunities on Buffalo Lake

Management Action:	Continue mechanical harvesting of aquatic plants to maintain reasonable navigation in Buffalo Lake.
Timeframe:	Continuation of current effort
Facilitator:	BLPRD Harvesting Committee (suggested)
Description:	During the development of the Buffalo Lake Comprehensive Management Plan in 2006, the BLPRD formed a Harvesting Committee which would oversee the annual harvesting budget, keep record of harvesting funds, and collect and report harvesting data to the district and WDNR. As part of this project, the mechanical harvesting plan was updated for Buffalo Lake (Map 9). The updated mechanical harvesting plan includes 100 x 200-foot areas being harvested in front of each culvert on either side of the Hwy D causeway. This will increase flow through the culverts as well as enhance fishing opportunities from the causeway in this area. A 100-foot lane was also included in the northeastern portion of the lake near the Montello City pier. In addition, there are approximately 226 acres of 50-foot wide main-channel harvest lanes and approximately 26 acres of 30-foot wide lateral lanes. In total, the mechanical harvesting plan permits harvesting of approximately 261 acres.

Action Steps:

1. District works with Ted Johnson (WDNR) to modify existing mechanical harvesting permit to mechanical harvesting plan outlined on Map 9.
   District reapplies for a multiyear harvesting permit in 2021 (5 year).
2. District harvests in areas shown on Map 9 while following the plan listed above and restrictions indicated on the WDNR permit.
3. Harvest summary report is provided to the WDNR annually after each harvesting season.

6.0 METHODS

Lake Water Quality

Baseline water quality conditions were studied to assist in identifying potential water quality problems in Buffalo Lake (e.g., elevated phosphorus levels, anaerobic conditions, etc.). Water quality was monitored at the deepest point on the lake that would most accurately depict the conditions of the lake (Map 2). Water quality was monitored at the deepest point in Buffalo Lake by Onterra staff. Samples were be collected only at subsurface (S) depths and occurred once in spring, winter and fall, and three times during the summer. All samples requiring laboratory analysis were processed through the Wisconsin State Laboratory of Hygiene. The parameters measured and sample collection timing are in the following table.

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

● indicates samples collected by consultant under proposed project.

Watershed Analysis

The watershed analysis began with an accurate delineation of Buffalo 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

Comprehensive Macrophyte Surveys

Comprehensive surveys of aquatic macrophytes were conducted on Buffalo Lake to characterize the existing communities within the lake and include inventories of emergent, submergent, and floating-leaved aquatic plants within them. The point-intercept method as described in the Wisconsin Department of Natural Resource document, Recommended Baseline Monitoring of Aquatic Plants in Wisconsin: Sampling Design, Field and Laboratory Procedures, Data Entry, and Analysis, and Applications (WDNR PUB-SS-1068 2010) was used to complete this study on July 21 and 22, 2015. A point spacing of 100 meters was used resulting in 907 points.

Community Mapping

During the species inventory work, the aquatic vegetation community types within Buffalo 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.

7.0 LITERATURE CITED

Bajer, P.G. and P.W. Sorensen. 2015. Effects of common carp on phosphorus concentrations, water clarity, and vegetation density: a whole system experiment in a thermally stratified lake. Hydrobiologia. Vol. 746. 30 –311.

Becker, G.C. 1983. Fishes of Wisconsin. The University of Wisconsin Press. London, England.

Borman, S., R. Korth., J. Temte. Through the looking glass. PUB-FH-207-97.

Canter, L.W., D.I. Nelson, and J.W. Everett. 1994. Public Perception of Water Quality Risks – Influencing Factors and Enhancement Opportunities. Journal of Environmental Systems. 22(2).

Carpenter, S.R., J.F. Kitchell, and J.R. Hodgson. 1985. Cascading Trophic Interactions and Lake Productivity. BioScience, Vol. 35 (10) pp. 634-639.

Carlson, R.E. 1977 A trophic state index for lakes. Limnology and Oceanography 22: 361-369.

Dinius, S.H. 2007. Public Perceptions in Water Quality Evaluation. Journal of the American Water Resource Association. 17(1): 116-121.

Elias, J.E. and M.W. Meyer. 2003. Comparisons of Undeveloped and Developed Shorelands, Northern Wisconsin, and Recommendations of Restoration. Wetlands 23(4):800-816. 2003.

Fischer J.R. and R.M. Krogman. 2013. Influences of native and non-native benthivorous fishes on aquatic ecosystem degradation. Hydrobiologia. Vol. 711. 187–199.

Fry, J., G. Xian, S. Jin, J. Dewitz, C. Homer, L. Yang, C. Barnes, N. Herold, and. 2011. Completion of the 2006 National Land Cover Database for the Conterminous United States, *PE&RS*, Vol. 77(9):858-864.

Garn, H.S. 2002. Effects of Lawn Fertilizer on Nutrient Concentration in Runoff from Two Lakeshore Lawns, Lauderdale Lakes, Wisconsin. USGS Water-Resources Investigations Report 02-4130.

Garrison, P., M. Jennings, A. Mikulyuk, J. Lyons, P. Rasmussen, J. Hauxwell, D. Wong, J. Brandt, and G. Hatzenbeler. 2008. Implementation and Interpretation of Lakes Assessment Data for the Upper Midwest. Wisconsin Department of Natural Resources Bureau of Science Services. PUB-SS-1044.

Graczyk, D.J., Hunt, R.J., Greb, S.R., Buchwald, C.A. and J.T. Krohelski. 2003. Hydrology, Nutrient Concentrations, and Nutrient Yields in Nearshore Areas of Four Lakes in Northern Wisconsin, 1999-2001. USGS Water-Resources Investigations Report 03-4144.

Hanchin, P.A., Willis, D.W. and T.R. St. Stauver. 2003. Influence of introduced spawning habitat on yellow perch reproduction, Lake Madison South Dakota. Journal of Freshwater Ecology 18.

Jennings, M. J., E. E. Emmons, G. R. Hatzenbeler, C. Edwards and M. A. Bozek. 2003. Is littoral habitat affected by residential development and landuse in watersheds of Wisconsin lakes? Lake and Reservoir Management. 19(3):272-279.

Jeppesen, E., J.P. Jensen, P. Kristensen, M. Søndergaard, E. Mortensen, O. Sortkjaer, and K. Olrik. 1990. Fish manipulation as a lake restoration tool in shallow, eutrophic, temperate lakes 2: threshold levels, long-term stability and conclusions. Hydrobiologia. Vol. 200/201. 219–227.

Lathrop, R.D., and R.A. Lillie. 1980. Thermal Stratification of Wisconsin Lakes. Wisconsin Academy of Sciences, Arts and Letters. Vol. 68.

Lin Y. and C.H. Wu. 2013. Response of bottom sediment stability after carp removal in a small lake. Ann. Limnol. – Int. J. Lim. Vol. 49. 157–168.

Lillie, R.A., S. Graham, P.W. Rasmussem. 1993. Trophic state index equations and regional predictive equations of Wisconsin lakes. Bureau of Research, Wisconsin Depeartment of Natural Resources.

Lindsay, A., Gillum, S., and M. Meyer 2002. Influence of lakeshore development on breeding bird communities in a mixed northern forest. Biological Conservation 107. (2002) 1-11.

Newbrey, M.G., Bozek, M.A., Jennings, M.J. and J.A. Cook. 2005. Branching complexity and morphological characteristics of coarse woody structure as lacustrine fish habitat. Canadian Journal of Fisheries and Aquatic Sciences. 62: 2110-2123.

Nichols, S.A. 1999. Floristic quality assessment of Wisconsin lake plant communities with example applications. Journal of Lake and Reservoir Management 15(2): 133-141

Radomski P. and T.J. Goeman. 2001. Consequences of Human Lakeshore Development on Emergent and Floating-leaf Vegetation Abundance. North American Journal of Fisheries Management. 21:46–61.

Reed, J. 2001. Influence of Shoreline Development on Nest Site Selection by Largemouth Bass and Black Crappie. North American Lake Management Conference Poster. Madison, WI.

Sass, G.G. 2009. Coarse Woody Debris in Lakes and Streams. In: Gene E. Likens, (Editor) Encyclopedia of Inland Waters. Vol. 1, pp. 60-69 Oxford: Elsevier.

Scheuerell M.D. and D.E. Schindler. 2004. Changes in the Spatial Distribution of Fishes in Lakes Along a Residential Development Gradient. Ecosystems (2004) 7: 98–106.

Shaw, B.H. and N. Nimphius. 1985. Acid Rain in Wisconsin: Understanding Measurements in Acid Rain Research (#2). UW-Extension, Madison. 4 pp.

Smith D.G., A.M. Cragg, and G.F. Croker.1991. Water Clarity Criteria for Bathing Waters Based on User Perception. Journal of Environmental Management.33(3): 285-299.

Solim, S.U. and A. Wanganeo. 2009. Factors influencing release of phosphorus from sediments in a high productive polymictic lake system. Water Science and Technology. Vol. 60.4. 1013–1023.

Søndergaard, M., E. Jeppesen, T.L. Lauridsen, C. Skov, E.H. Van Nes, R. Roijackers, E. Lammens, and R. Portielje. 2007. Lake restoration: successes, failures and long-term effects. Journal of Applied Ecology. Vol. 44(6). 1095–1105.

United States Environmental Protection Agency. 2009. National Lakes Assessment: A Collaborative Survey of the Nation's Lakes. EPA 841-R-09-001. U.S. Environmental

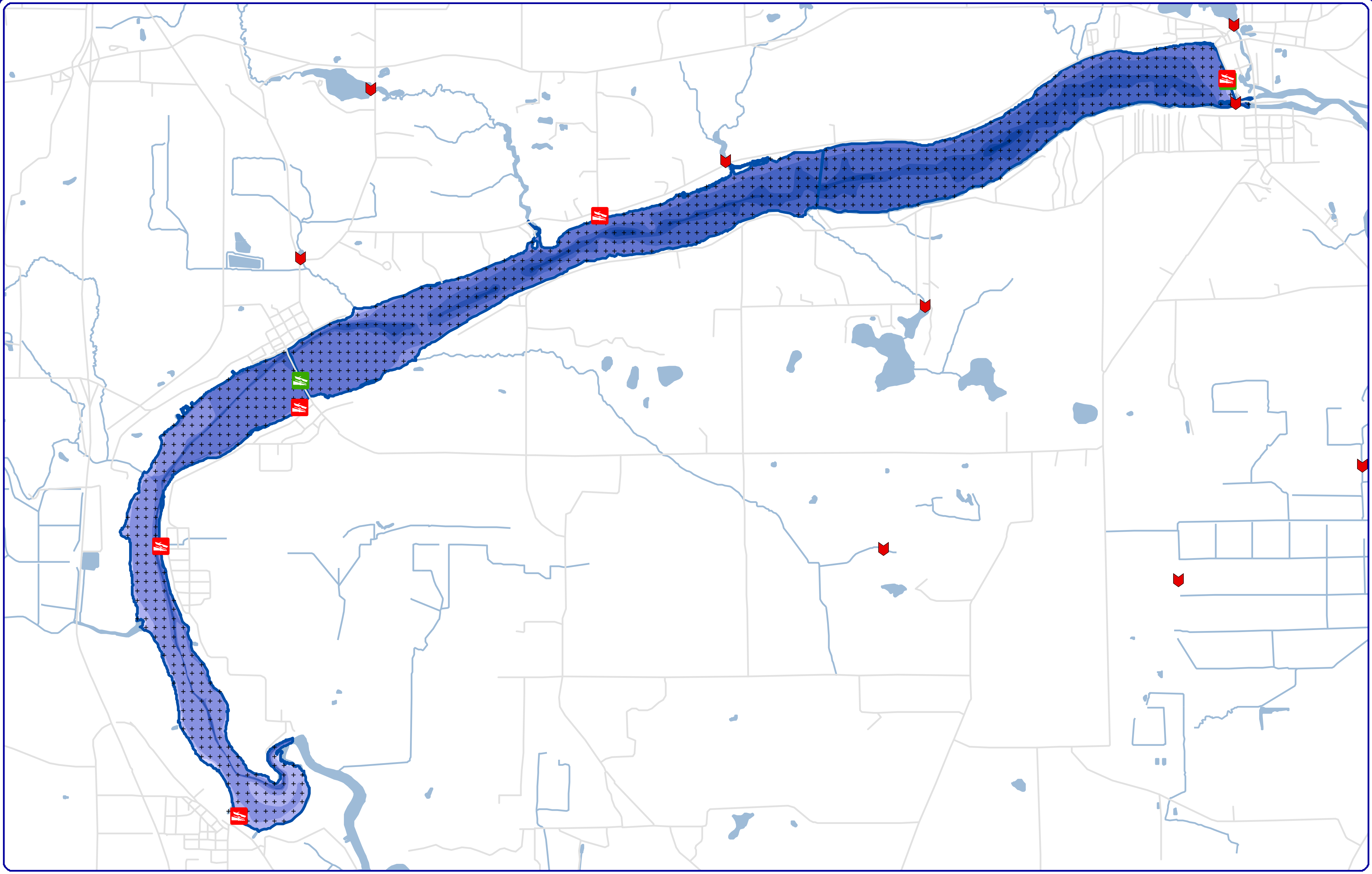
Protection Agency, Office of Water and Office of Research and Development, Washington, D.C.

Weber, M.J., M.J. Hennen, and M.L. Brown. 2011. Simulated population responses of common carp to commercial exploitation. North American Journal of Fisheries Management. Vol. 31. 269–279.

Wisconsin Department of Natural Resources – Bureau of Fisheries Management. 2011. Fish data summarized by the Bureau of Fisheries Management. Available at: http://infotrek.er.usgs.gov/wdnr_public. Last accessed March 2015.

Wisconsin Department of Natural Resources – Water Division. 2009. Wisconsin 2014 Consolidated Assessment and Listing Methodology (WisCALM).

Woodford, J.E. and M.W. Meyer. 2003. Impact of Lakeshore Development on Green Frog Abundance. Biological Conservation. 110, pp. 277-284.



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Feet

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www.onterra-eco.com

Sources:
Roads, Hydro, Monitoring Stations: WDNR
Bathymetry: Onterra, 2015
Map Date: April 5, 2016
Filename: Map1_Buffalo_Location.mxd

Project Location in Wisconsin

Legend

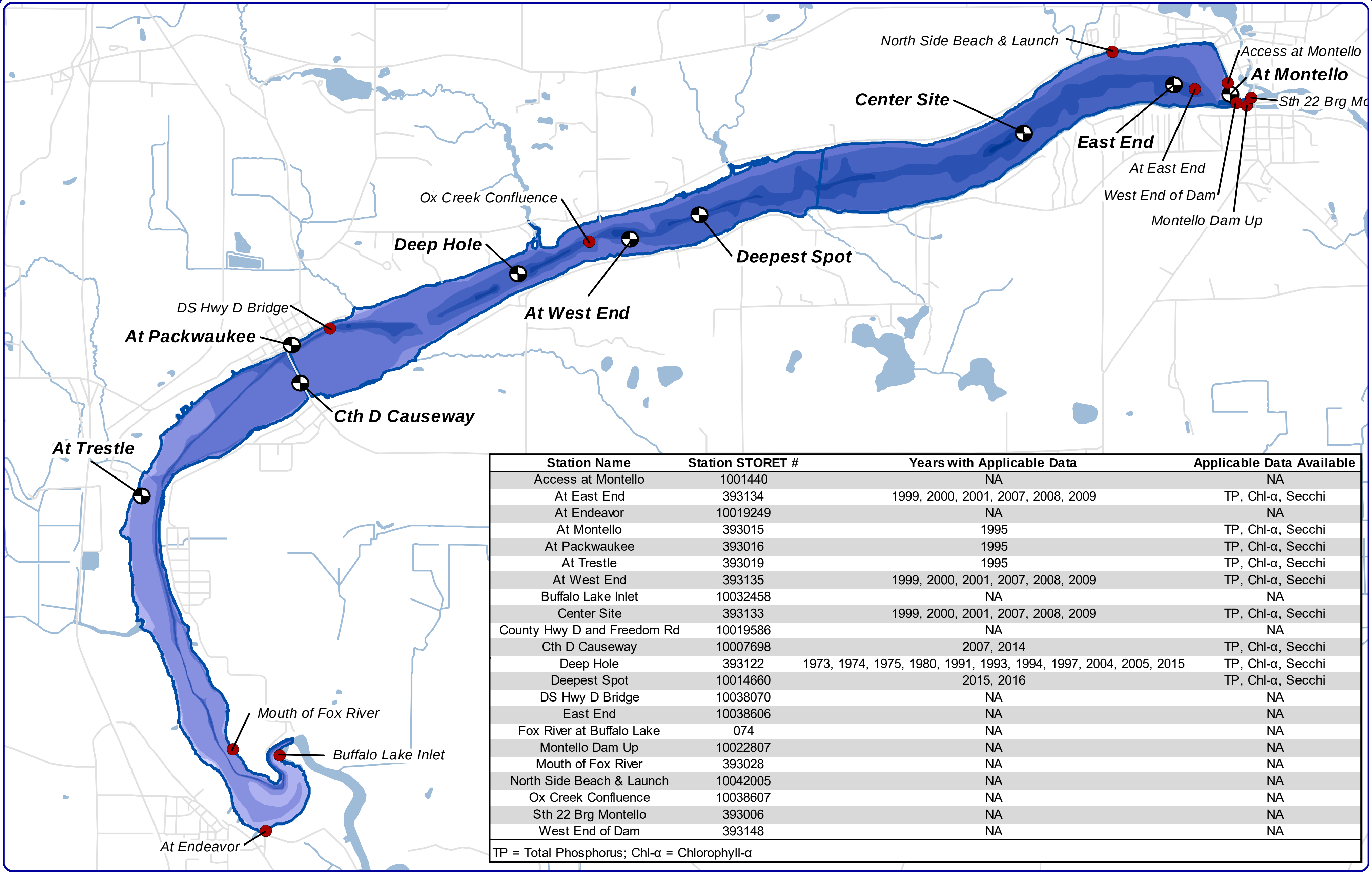
- Buffalo Lake ~ 2,227 acres
- Point-Intercept Survey Location
  100 meter spacing, 907 total points
- Public Access
- Carry-In Public Access
- Dam Location

Map 1

Buffalo Lake

Marquette County, Wisconsin

Project Location & Lake Boundaries



Station Name	Station STORET #	Years with Applicable Data	Applicable Data Available
Access at Montello	1001440	NA	NA
At East End	393134	1999, 2000, 2001, 2007, 2008, 2009	TP, Chl-α, Secchi
At Endeavor	10019249	NA	NA
At Montello	393015	1995	TP, Chl-α, Secchi
At Packwaukee	393016	1995	TP, Chl-α, Secchi
At Trestle	393019	1995	TP, Chl-α, Secchi
At West End	393135	1999, 2000, 2001, 2007, 2008, 2009	TP, Chl-α, Secchi
Buffalo Lake Inlet	10032458	NA	NA
Center Site	393133	1999, 2000, 2001, 2007, 2008, 2009	TP, Chl-α, Secchi
County Hwy D and Freedom Rd	10019586	NA	NA
Cth D Causeway	10007698	2007, 2014	TP, Chl-α, Secchi
Deep Hole	393122	1973, 1974, 1975, 1980, 1991, 1993, 1994, 1997, 2004, 2005, 2015	TP, Chl-α, Secchi
Deepest Spot	10014660	2015, 2016	TP, Chl-α, Secchi
DS Hwy D Bridge	10038070	NA	NA
East End	10038606	NA	NA
Fox River at Buffalo Lake	074	NA	NA
Montello Dam Up	10022807	NA	NA
Mouth of Fox River	393028	NA	NA
North Side Beach & Launch	10042005	NA	NA
Ox Creek Confluence	10038607	NA	NA
Sth 22 Brg Montello	393006	NA	NA
West End of Dam	393148	NA	NA

TP = Total Phosphorus; Chl-α = Chlorophyll-α

N W E S

4,600

Feet

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

Sources:
Roads, Hydro, Monitoring Stations: WDNR
Bathymetry: Onterra, 2015
Map Date: April 5, 2016
Filename: Map2_Buffalo_WQ_Locations.mxd

Project Location in Wisconsin

Legend

Monitoring Stations (WDNR Surface Water Data Viewer)

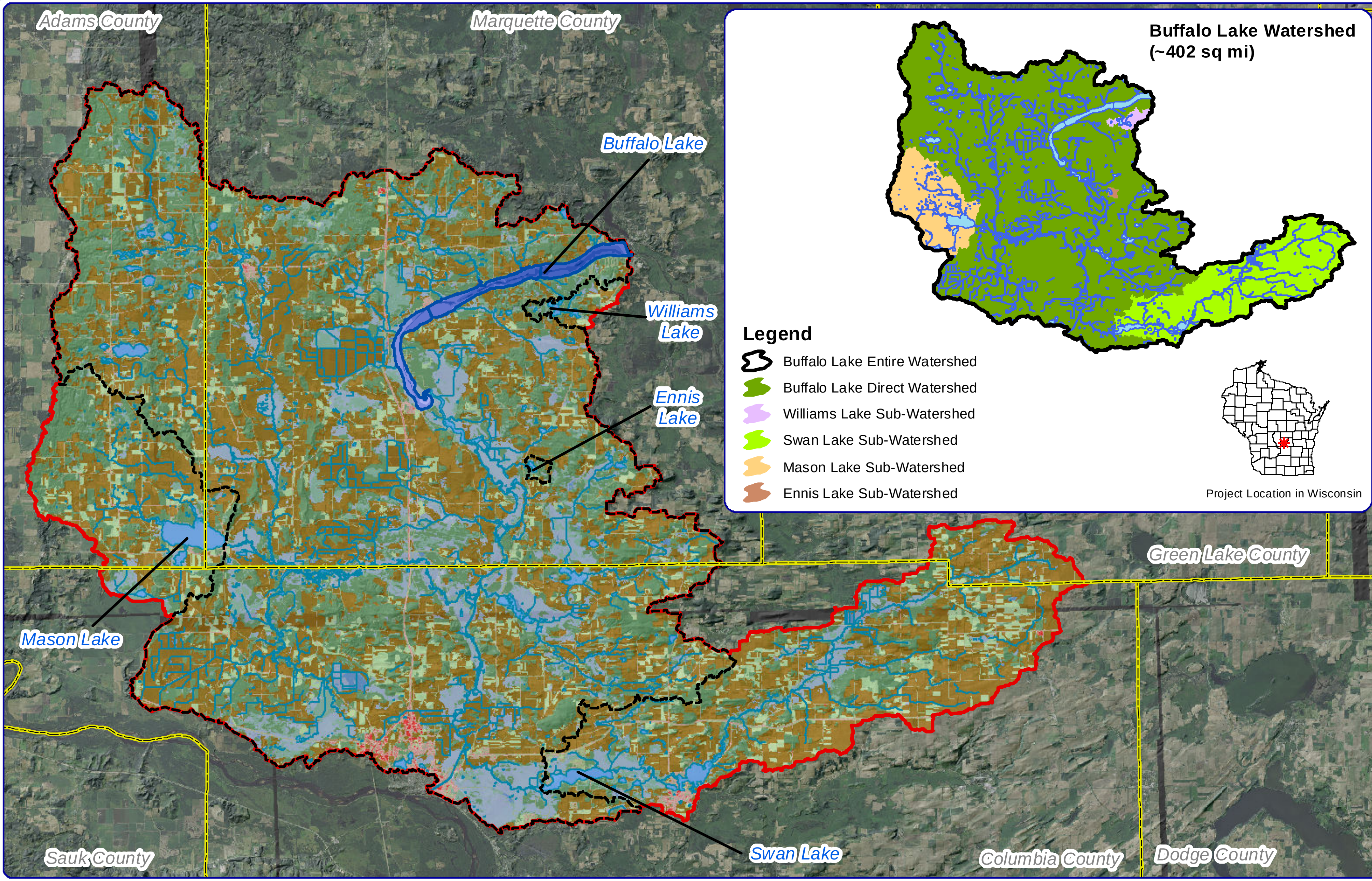
- Applicable Water Quality Data Available
- Applicable Water Quality Data Not Available

Map 2

Buffalo Lake

Marquette County, Wisconsin

Water Quality Monitoring Station Locations



N W E S

4

Miles

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

Sources:
Hydro: WDNR
Bathymetry: Onterra, 2015
Orthophotography: NAIP 2010/13
Watershed Boundaries: Onterra, 2016

Map Date: March 29, 2016

Filename: Map3_Buffalo_WS.mxd

Legend

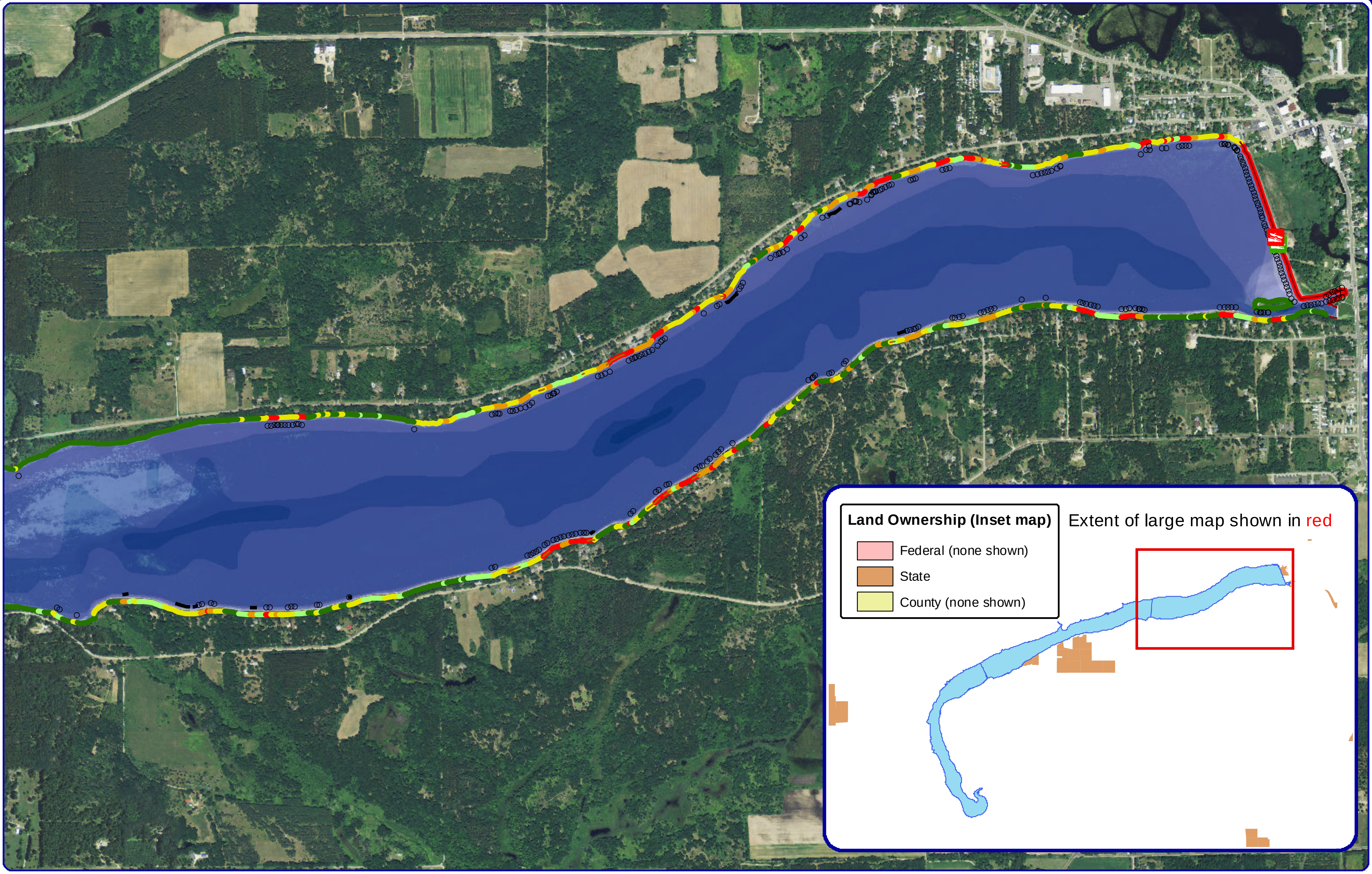
- Buffalo Lake Entire Watershed
- Buffalo Lake Direct Watershed
- Buffalo Lake
- Forest
- Forested Wetlands
- Non-Forested Wetlands
- Open Water
- River/Stream
- Rural Open Space
- Pasture/Grass
- Row Crops
- Rural Residential
- Urban - Medium Density
- Urban - High Density

Map 3

Buffalo Lake

Marquette County, Wisconsin

Watershed Boundaries & Land Cover Types



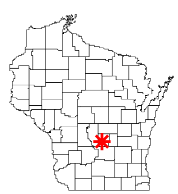
N
W
E
S

1,600

Feet

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

Sources:
Hydro: WDNR
Orthophotography: NAIP, 2013
Shoreline Assessment: Onterra, 2015
Map Date: December 1, 2015
Filename: Map4.1_Buffalo_SA_2015.mxd



Project Location in Wisconsin

Legend

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

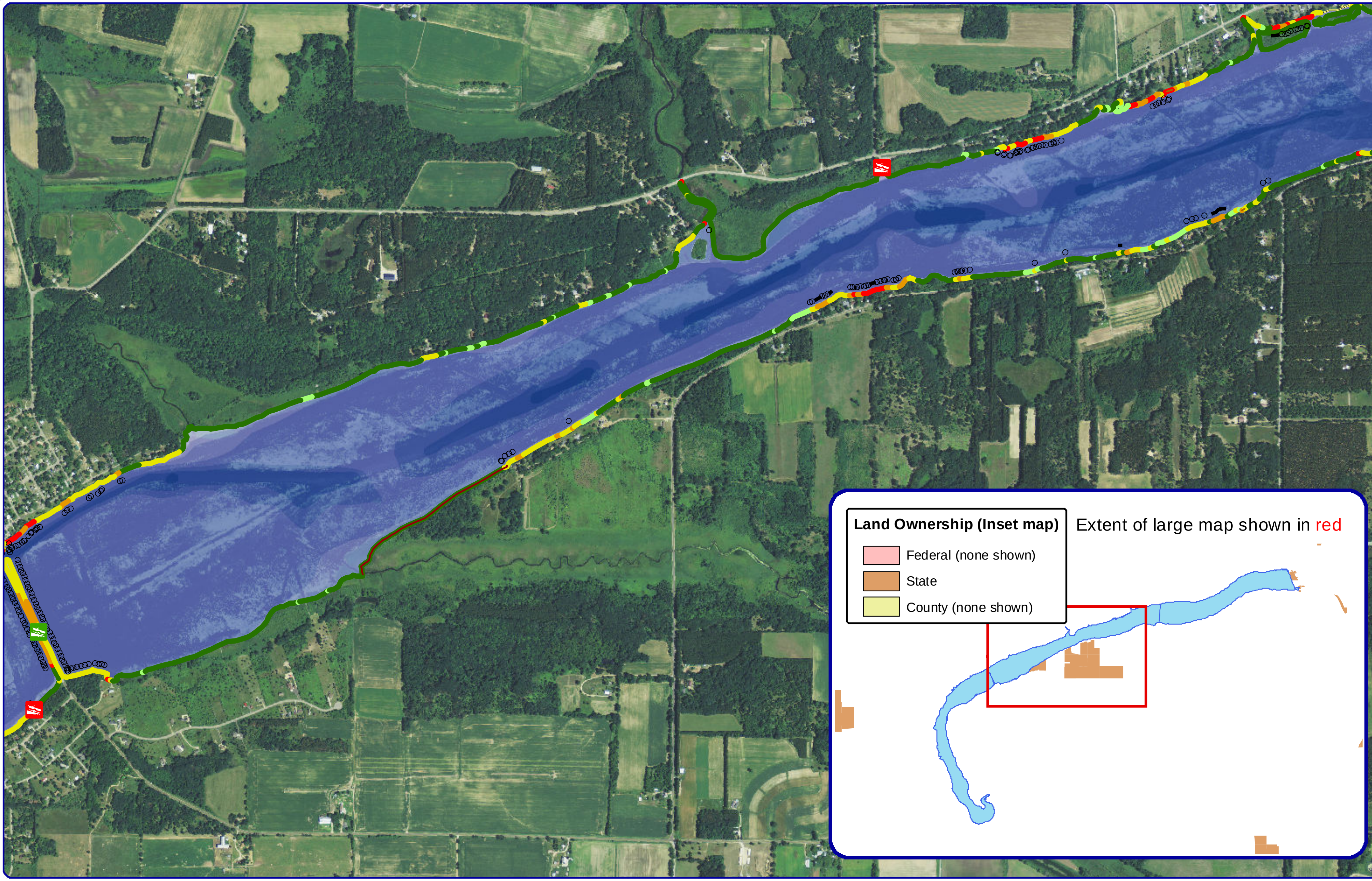
Seawall
Rip-Rap
Wood/Masonary/Metal

Map 4.1

Buffalo Lake

Marquette County, Wisconsin

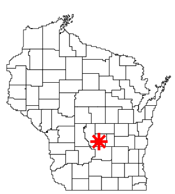
2015 Shoreland Condition



N
W E
S
1,600
Feet

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

Sources:
Hydro: WDNR
Orthophotography: NAIP, 2013
Shoreline Assessment: Onterra, 2015
Map Date: December 1, 2015
Filename:Map4.2_Buffalo_SA_2015.mxd



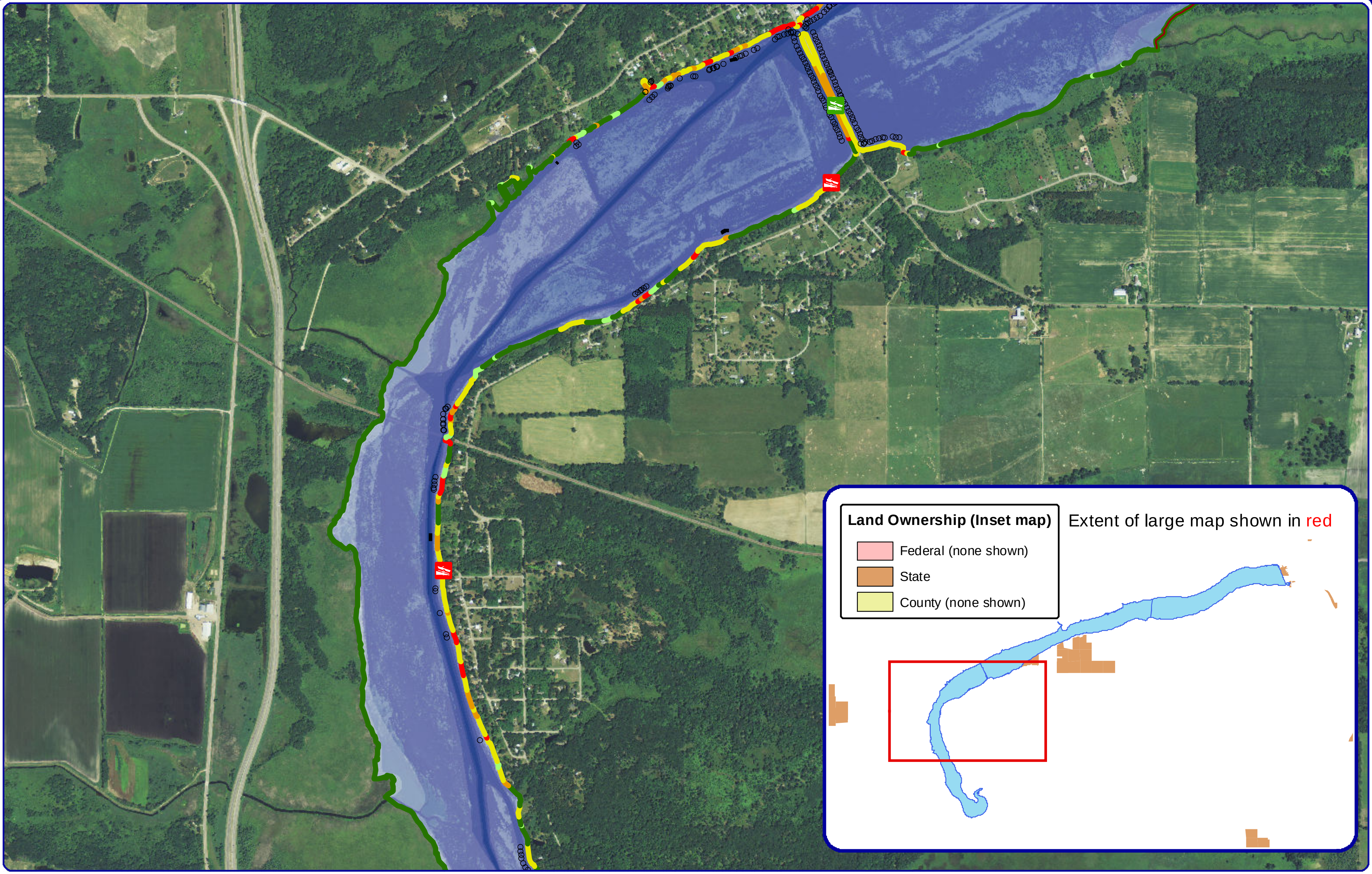
Project Location in Wisconsin

Legend

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

Seawall
- Rip-Rap
- Wood/Masonary/Metal

Map 4.2
Buffalo Lake
Marquette County, Wisconsin
2015 Shoreland Condition



N
W E
S
1,600
Feet

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

Sources:
Hydro: WDNR
Orthophotography: NAIP, 2013
Shoreline Assessment: Onterra, 2015
Map Date: December 1, 2015
Filename: Map4.3_Buffalo_SA_2015.mxd

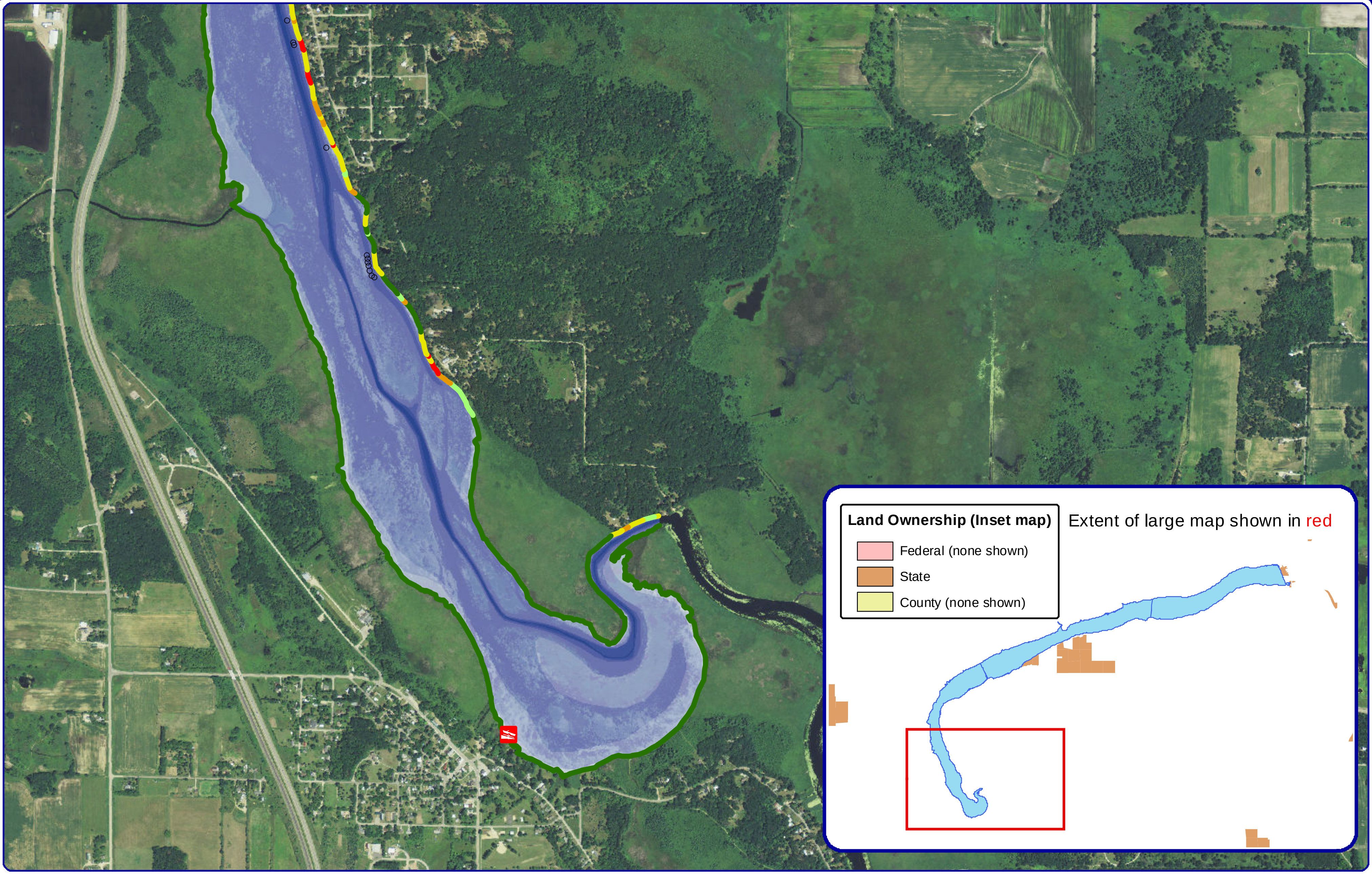
Project Location in Wisconsin

Legend

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

Seawall
Rip-Rap
Wood/Masonary/Metal

Map 4.3
Buffalo Lake
Marquette County, Wisconsin
2015 Shoreland Condition

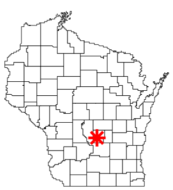


N
W E
S

1,600
Feet

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

Sources:
Hydro: WDNR
Orthophotography: NAIP, 2013
Shoreline Assessment: Onterra, 2015
Map Date: December 1, 2015
Filename: Map4.4_Buffalo_SA_2015.mxd



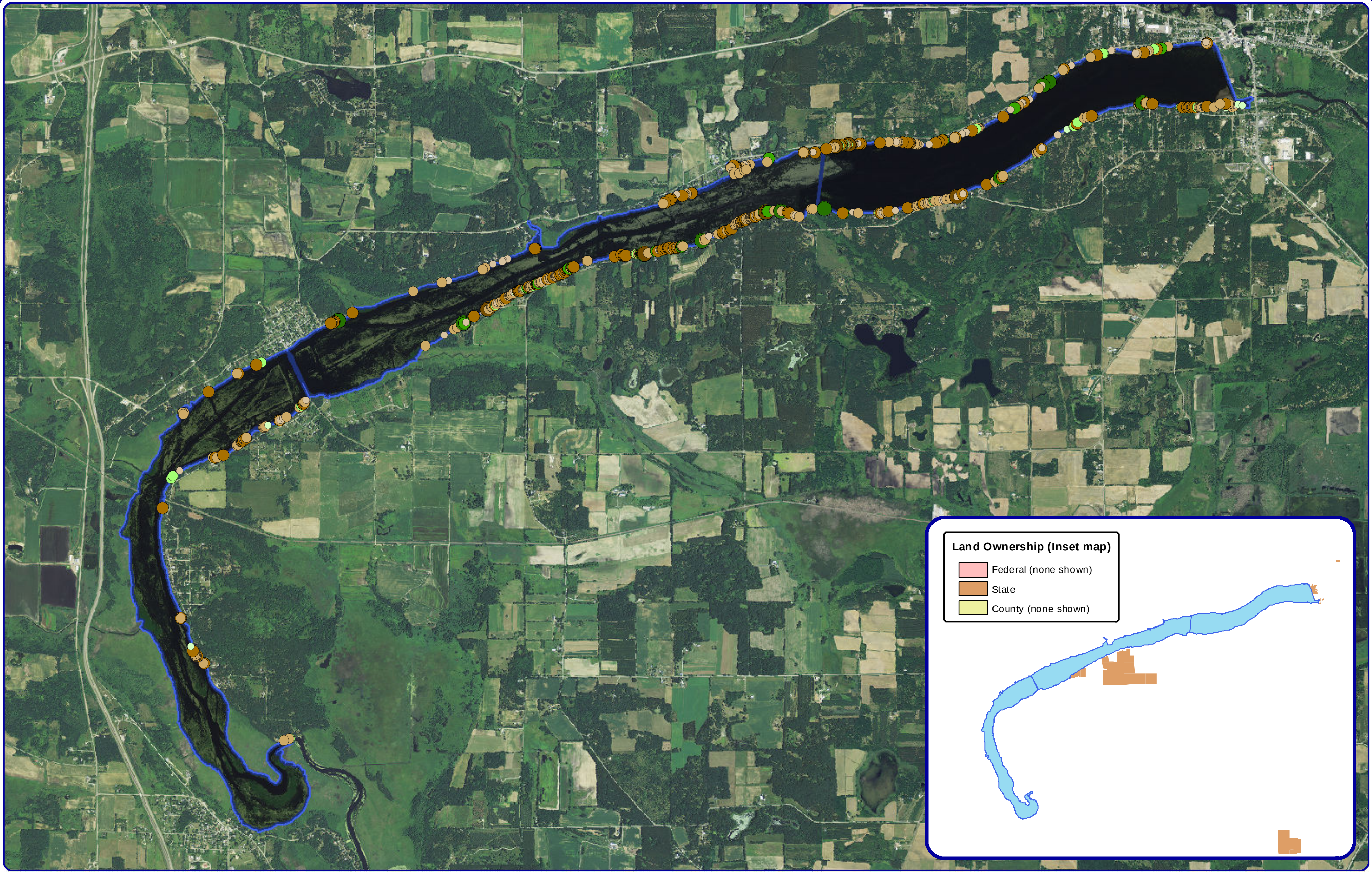
Project Location in Wisconsin

Legend

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

Seawall
Rip-Rap
Wood/Masonary/Metal

Map 4.4
Buffalo Lake
Marquette County, Wisconsin
2015 Shoreland Condition



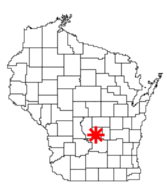
N
W E
S

4,600

Feet

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

Sources:
Hydro: WDNR
Orthophotography: NAIP, 2013
Shoreline Assessment: Onterra, 2015
Map Date: December 1, 2015
<ITA>Filename:Map5_Buffalo_CWH_2015.mxd

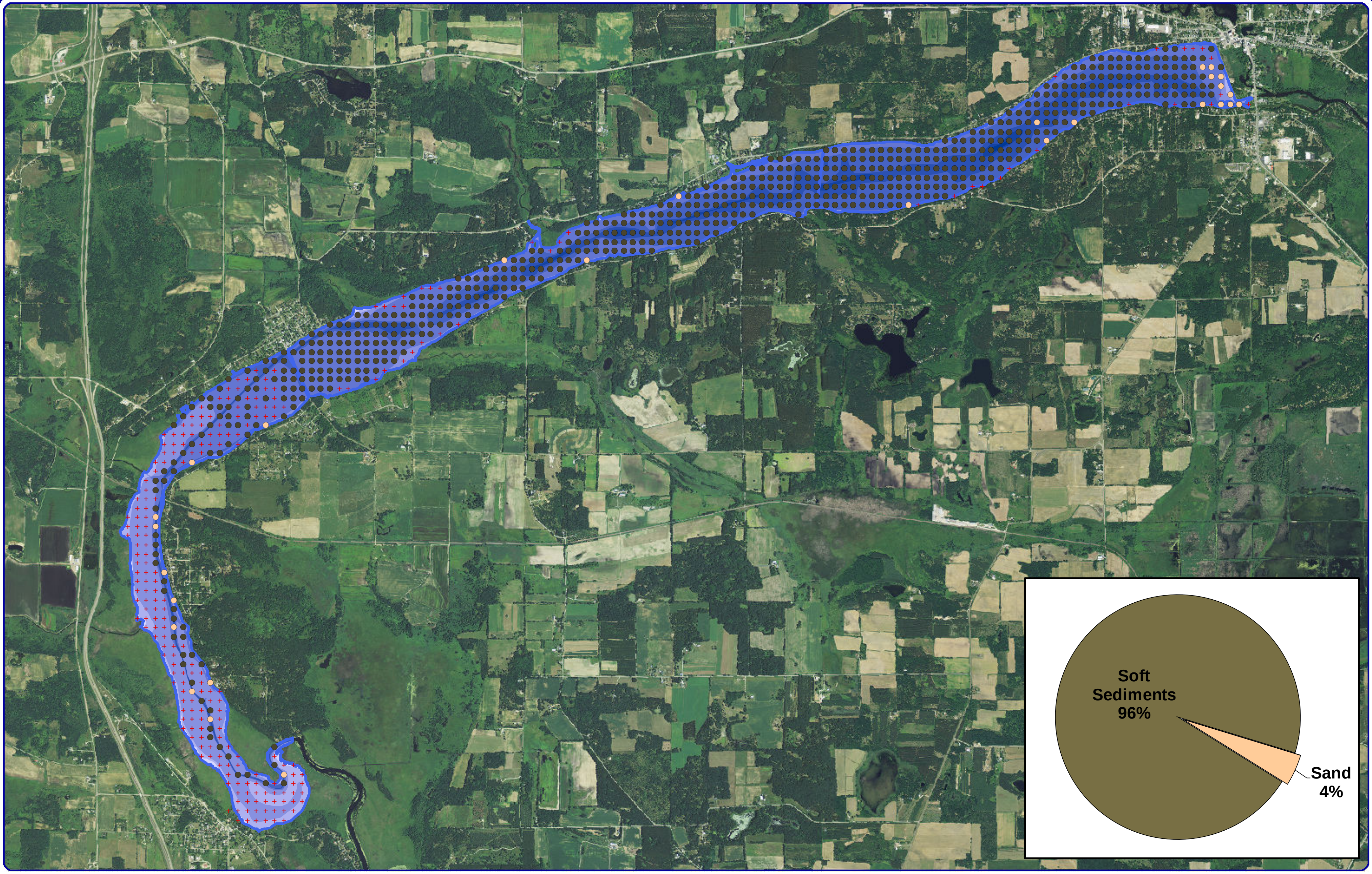


Project Location in Wisconsin

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
Full Canopy (none)	Full Canopy (none)	Full Canopy (none)

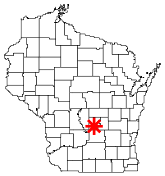
Map 5
Buffalo Lake
Marquette County, Wisconsin
2015 Coarse Woody Habitat



N
W E
S

1,900,000

Feet



Project Location in Wisconsin

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

Sources:
Roads and Hydro: WDNR
Plant Survey: Onterra, 2015
Map Date: December 21, 2015
Filename: *Map5_Buffalo_SedimentPI.mxd*

Legend

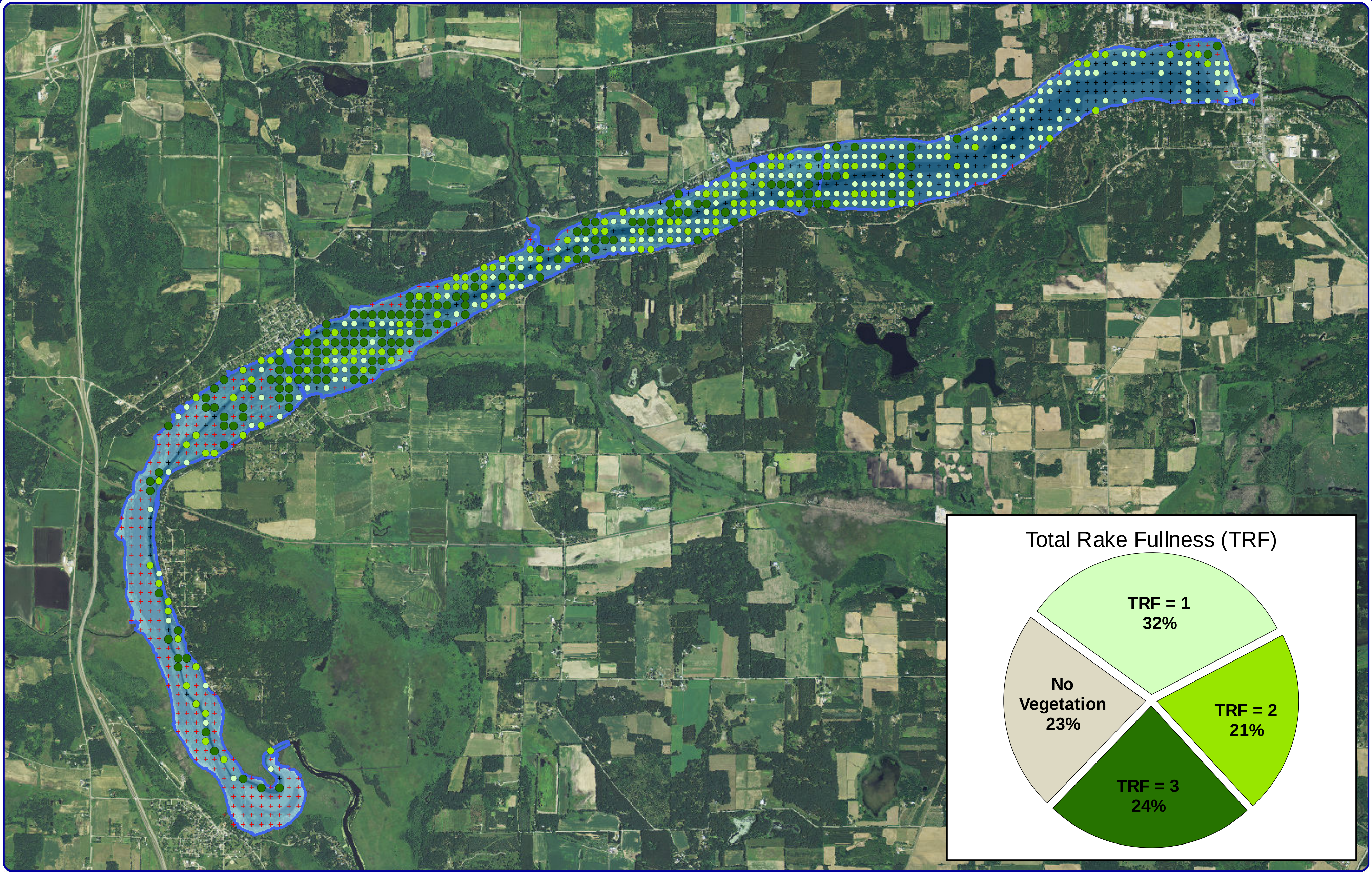
- Soft Sediments
- Rock
- Sand
- Non-Navigable

Map 6

Buffalo Lake

Marquette County, Wisconsin

2015 PI Survey: Substrate Types



N
W E
S

4,600

Feet

Onterra LLC
Lake Management Planning
815 Prosper Rd
De Pere, WI 54115
920.338.8860
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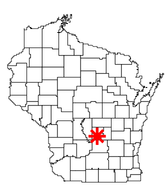
Sources:
Roads and Hydro: WDNR
Plant Survey: Onterra, 2015
Map Date: December 21, 2015
Filename: Map7_Buffalo_TRFPI.mxd



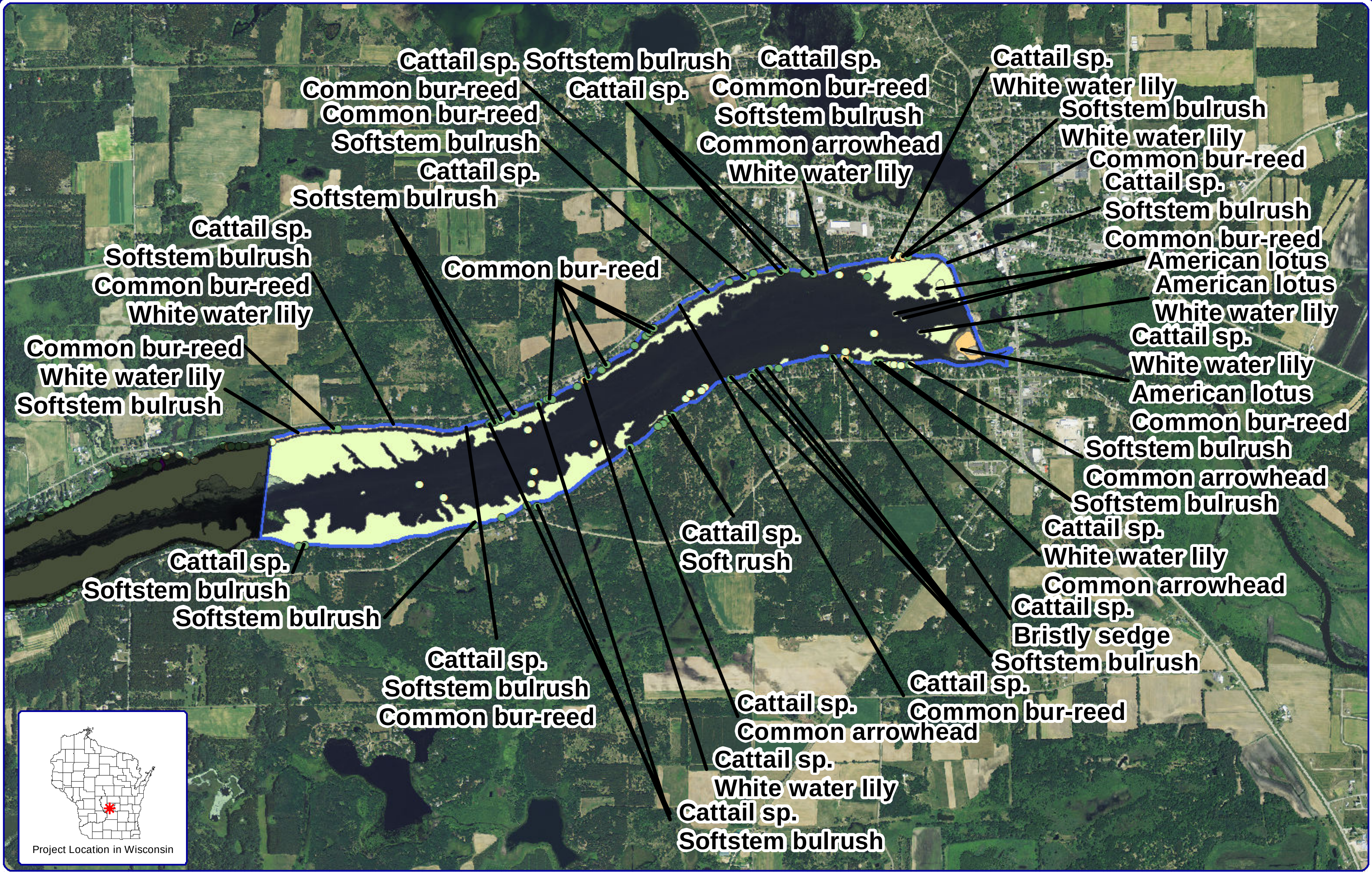
Project Location in Wisconsin

Legend

- Total Rake Fullness = 1
- Total Rake Fullness = 2
- Total Rake Fullness = 3
- No Vegetation
- Non-Navigable

Map 7
Buffalo Lake
Marquette County, Wisconsin

2015 PI Survey: Aquatic Vegetation Distribution



N
W E
S

2,300
Feet

Onterra LLC
Lake Management Planning

815 Prosper Road
De Pere, WI 54115
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www.onterra-eco.com

Sources:
Hydro and Roads: WDNR
Bathymetry: WDNR, digitized by Onterra
Aquatic Plant Survey: Onterra, 2015
Map Date: October 30, 2015
Filename: *Map8.1_Buffalo_Comm_2015.mxd*

Small Plant Communities

- Emergent *(Cattail unless otherwise noted)*
- Floating-leaf *(White water lily unless otherwise noted)*
- Mixed Floating-leaf & Emergent

Large Plant Communities

- Emergent *(Cattail unless otherwise noted)*
- Floating-leaf *(White water lily unless otherwise noted)*
- Mixed Floating-leaf & Emergent

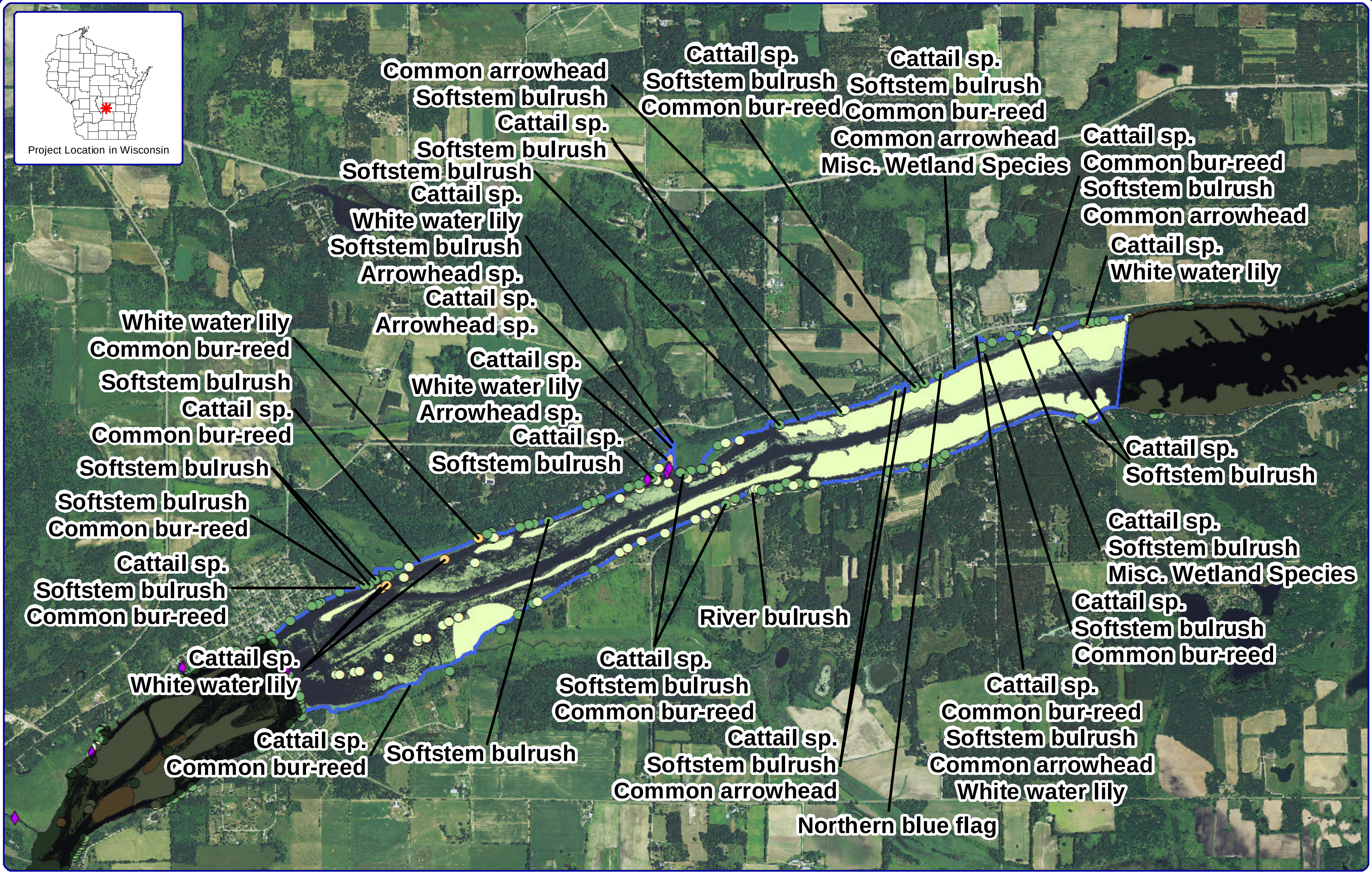
Exotic Plant Communities

- Purple loosestrife
- Pale-yellow iris

Map 8.1

Buffalo Lake
Marquette County, Wisconsin

2015 Emergent & Floating-leaf Aquatic Plant Communities



N W E S

2,500
Feet

Small Plant Communities

- Emergent *(Cattail unless otherwise noted)*
- Floating-leaf *(White water lily unless otherwise noted)*
- Mixed Floating-leaf & Emergent

Large Plant Communities

- Emergent *(Cattail unless otherwise noted)*
- Floating-leaf *(White water lily unless otherwise noted)*
- Mixed Floating-leaf & Emergent

Exotic Plant Communities

- Purple loosestrife
- Pale-yellow iris

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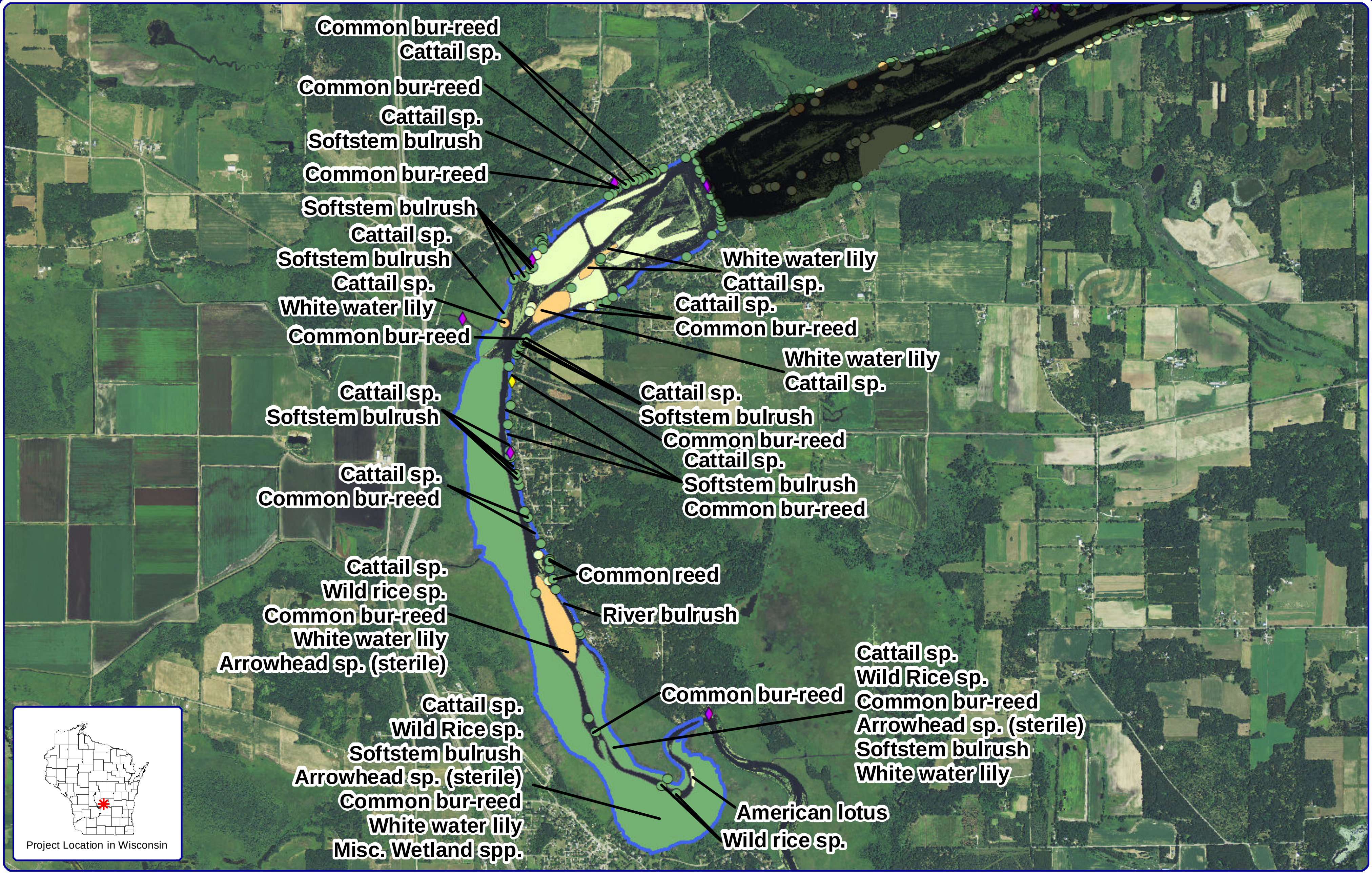
www.onterra-eco.com

Sources:
Hydro and Roads: WDNR
Bathymetry: WDNR, digitized by Onterra
Aquatic Plant Survey: Onterra, 2015
Map Date: October 30, 2015
Filename: Map8.2_Buffalo_Comm_2015.mxd

Map 8.2

Buffalo Lake
Marquette County, Wisconsin

2015 Emergent & Floating-leaf Aquatic Plant Communities



N
W E
S
2,750
Feet

Small Plant Communities

- Emergent (*Cattail unless otherwise noted*)
- Floating-leaf (*White water lily unless otherwise noted*)
- Mixed Floating-leaf & Emergent

Large Plant Communities

- Emergent (*Cattail unless otherwise noted*)
- Floating-leaf (*White water lily unless otherwise noted*)
- Mixed Floating-leaf & Emergent

Exotic Plant Communities

- Purple loosestrife
- Pale-yellow iris

Map 8.3

Buffalo Lake

Marquette County, Wisconsin

2015 Emergent & Floating-leaf Aquatic Plant Communities

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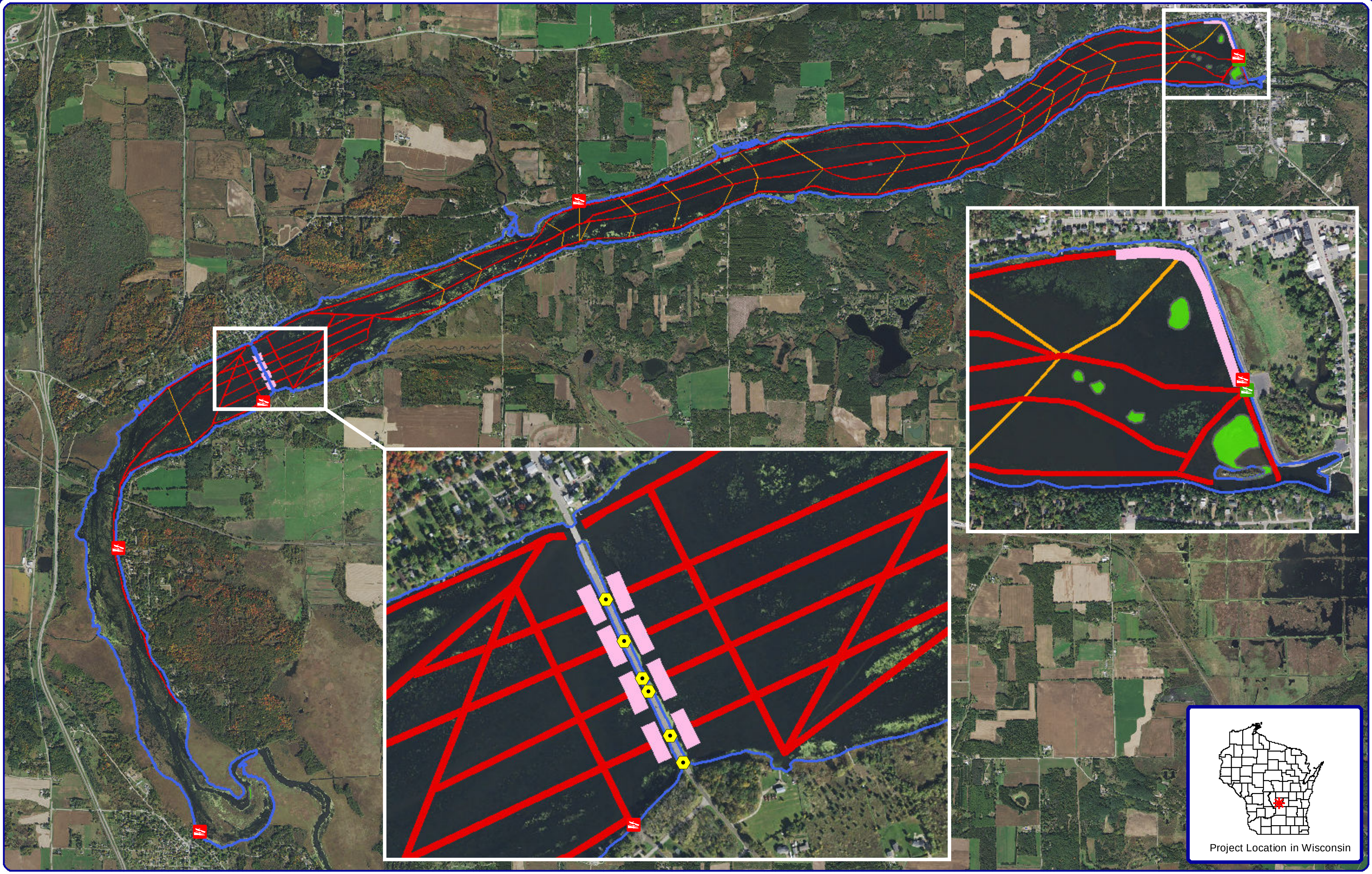
920.338.8860
www.onterra-eco.com

Sources:
Hydro and Roads: WDNR
Bathymetry: WDNR, digitized by Onterra
Aquatic Plant Survey: Onterra, 2015
Map Date: October 30, 2015
Filename: Map8.3_Buffalo_Comm_2015.mxd



4,400

Feet

Mechanical Harvest Areas (~261 acres)

- 100' Wide Causeway & Montello Pier Lanes (~9 acres)
- 50' Wide Main Channel Lane (~226 acres)
- 30' Wide Lateral Lane (~26 acres)

- Public Boat Ramp
- Public Carry-In Access
- Culvert Location
- American Lotus Population

Map 9

Buffalo Lake

Marquette County, Wisconsin

Aquatic Plant Mechanical Harvesting Areas

Onterra LLC
Lake Management Planning
815 Prosper Road
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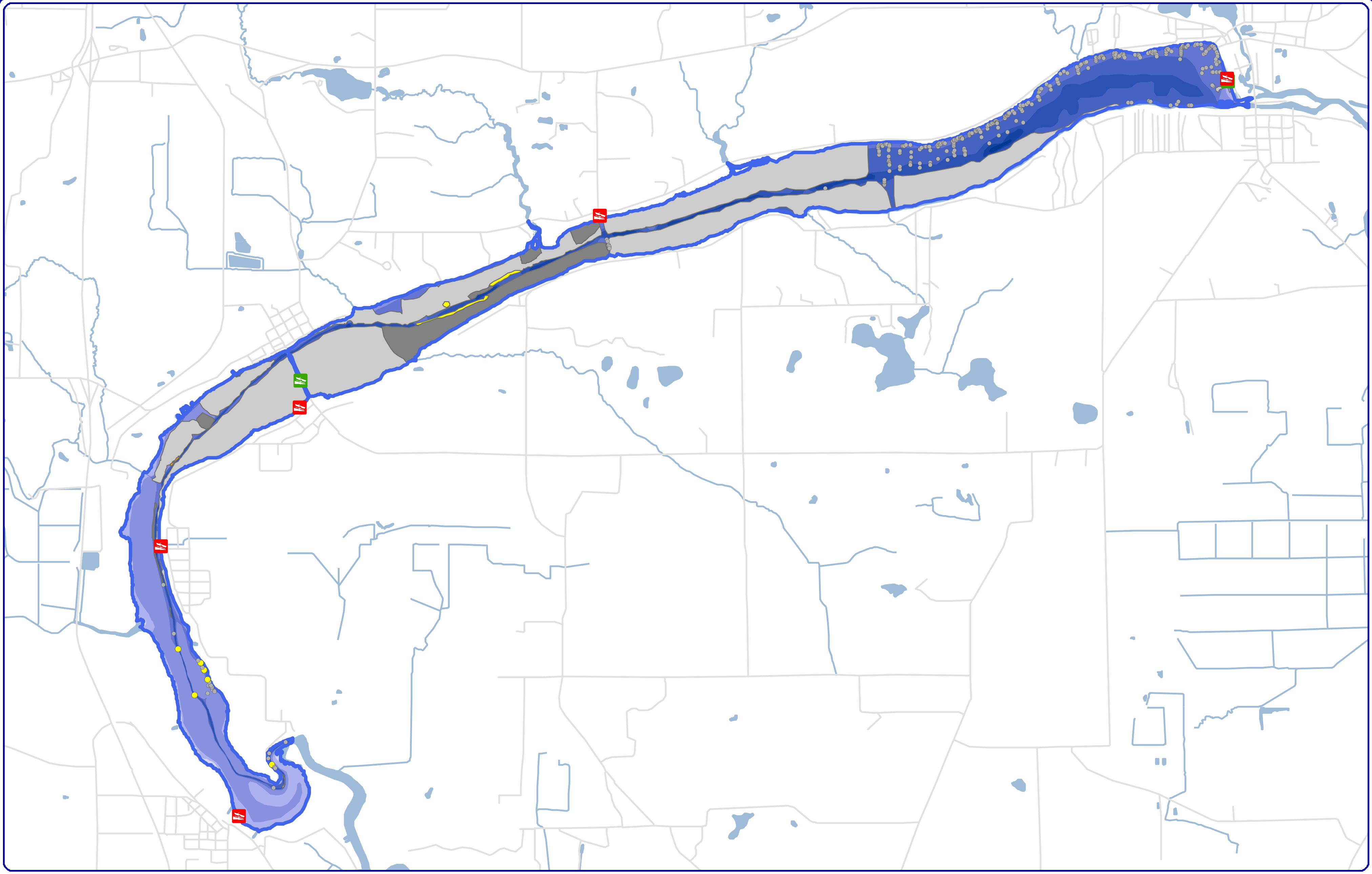
Sources:
Roads, Hydro, Monitoring Stations: WDNR
Bathymetry: Onterra, 2015
Map Date: January 19, 2018
Filename: Map9_Buffalo_HarvestLanes_Update2018.mxd



N
W E
S

4,600

Feet

Onterra LLC
Lake Management Planning
815 Prosper Road
De Pere, WI 54115
920.338.8860
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Sources:
Roads, Hydro, Monitoring Stations: WDNR
Bathymetry: Onterra, 2015
Map Date: April 5, 2016
Filename: Map10_Buffalo_EWM_Aug15.mxd

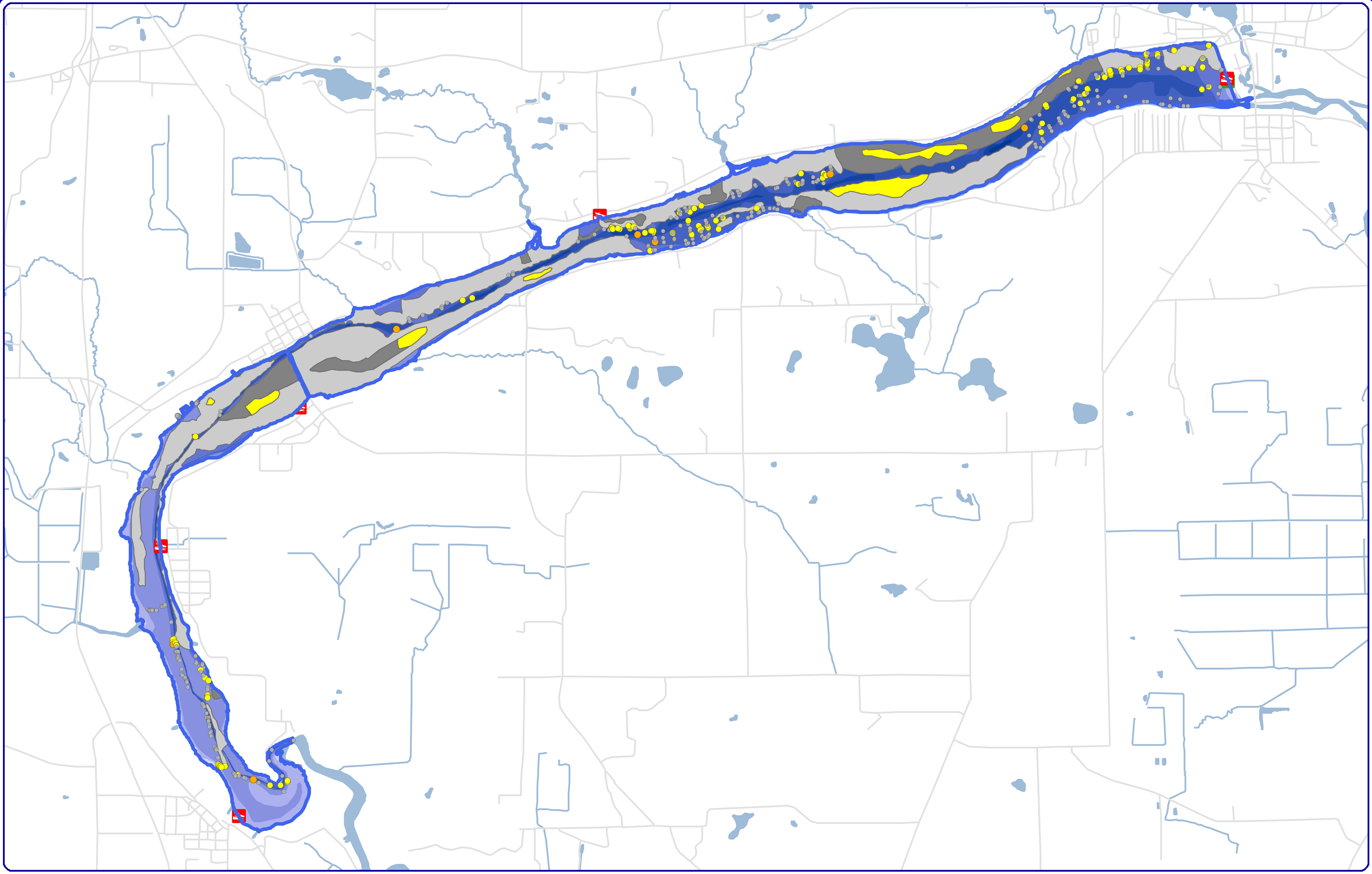
Project Location in Wisconsin

Eurasian/Hybrid Water Milfoil

- Highly Scattered
- Scattered
- Dominant
- Highly Dominant
- Surface Matting
- Single or Few Plants
- Clumps of Plants
- Small Plant Colony
- Public Access
- Carry-In Public Access

Map 10
Buffalo Lake
Marquette County, Wisconsin

August 2015
EWM Locations



N
W E
S

4,600

Feet

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

Sources:
Roads, Hydro, Monitoring Stations: WDNR
Bathymetry: Onterra, 2015
Map Date: April 5, 2016
Filename: Map11_Buffalo_CLP_May15.mxd

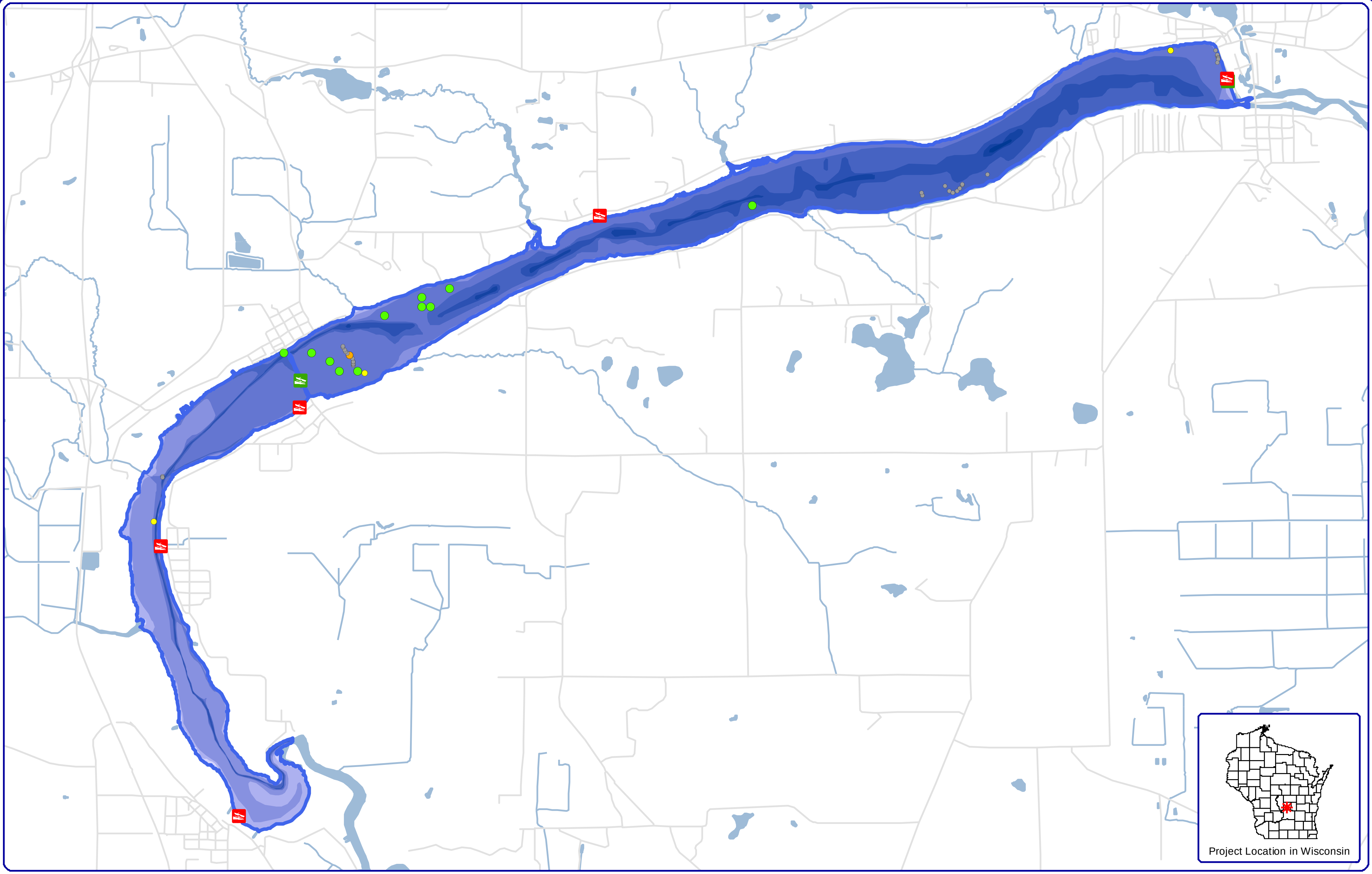
Project Location in Wisconsin

Curly-leaf Pondweed

- Highly Scattered
- Scattered
- Dominant
- Highly Dominant
- Surface Matting
- Single or Few Plants
- Clumps of Plants
- Small Plant Colony
- Public Access
- Carry-In Public Access

Map 11
Buffalo Lake
Marquette County, Wisconsin

May 2015
CLP Locations



N
W E
S

4,600

Feet

Brittle Naiad

- Highly Scattered
- Scattered
- Dominant
- Highly Dominant
- Surface Matting
- Located on rake at point-intercept sampling location
- Single or Few Plants
- Clumps of Plants
- Small Plant Colony
- Public Access
- Carry-In Public Access

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www.onterra-eco.com

Sources:
Roads, Hydro, Monitoring Stations: WDNR
Bathymetry: Onterra, 2015
Map Date: April 5, 2016
Filename: Map12_Buffalo_NAJMI_2015.mxd

Map 12

Buffalo Lake

Marquette County, Wisconsin

2015 Brittle Naiad Locations