Beaver Dam Lake

Dodge County, Wisconsin

Comprehensive Management Plan

September 2015

Sponsored by:

Beaver Dam Lake Improvement Association, Inc.

WDNR Grant Program

LPL-1555-14

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Onterra LLC
Lake Management Planning

Beaver Dam Lake

Dodge County, Wisconsin

Comprehensive Management Plan

September 2015

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Beaver Dam Lake Planning Committee

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Laura Stremick-Thompson

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1.0 INTRODUCTION

Beaver Dam Lake, Dodge County, is a 6,841-acre impoundment of the Beaver Dam River with a maximum depth of 9.0 feet and a mean depth of 5.6 feet. This shallow, hypereutrophic lake is currently in a turbid, phytoplankton-dominated state and suffers from nuisance algal blooms spurred by excessive levels of nutrients. These nutrients originate both externally from the lake's agriculturally-dominated watershed and internally from the lake's common carp population, wind-induced sediment resuspension, and nutrient release from sediments under anoxic and/or elevated pH conditions. Currently, the lake is listed as impaired under the Clean Water Act for total phosphorus and chlorophyll-*a* concentrations that exceed thresholds for recreational use and fish and aquatic life. Aquatic macrophyte cover is sparse, and of the 15 native species recorded in 2014, sago pondweed (*Stuckenia pectinata*) was the most abundant. Populations of the invasive plants curly-leaf pondweed and Eurasian water milfoil are also present.

Field Survey Notes

Submersed aquatic plants are sparse, and most of the plants that are present are tolerant of turbid conditions. Much algae and other suspended material observed within the water. However, Rakes Bay (pictured) contained the highest-quality habitat in terms of aquatic plants with large colonies of white water lily observed. The state-endangered black tern was observed nesting within these white water lily colonies. Overall, water quality appears poor and the lake is lacking aquatic plant habitat.

Photograph 1.0-1. Beaver Dam Lake, Dodge County.

Lake at a Glance - Beaver Dam Lake

Morphology	
Surface Area (acres)	6,841
Maximum Depth (ft)	9.0
Mean Depth (ft)	5.6
Shoreline Complexity	18.7
Watershed to Lake Area Ratio	13:1
Vegetation	
Comprehensive Aquatic Plant Survey Date	July 14, 15, & 17, 2014
Number of Native Species	15
Exotic Plant Species	Curly-leaf pondweed; Eurasian water milfoil; Reed Canary Grass
Simpson's Diversity	0.69
Average Conservatism	4.4
Water Quality	
Trophic State	Hypereutrophic
Limiting Nutrient	Transitional between phosphorus & nitrogen
Water pH	8.0 – 9.0
Sensitivity to Acid Rain	Not Sensitive

The Beaver Dam Lake Improvement Association, Inc. (BDLIA), originally founded in 1962 as the Beaver Dam Property Owners Association, has worked diligently with local municipalities, the Wisconsin Department of Natural Resources (WDNR), and private contractors to manage the lake's water quality and fisheries. Understanding that Beaver Dam Lake is a highly sought resource in Central Wisconsin and that the lake is facing complicated challenges, the BDLIA successfully applied for WDNR grant funds to complete a comprehensive lake management plan for the lake. However, the 2012 planning project was suspended when the planning firm contracted to assist the BDLIA create the plan when out of business. With the 2012 planning project suspended, the BDLIA contracted with Onterra, and with their assistance, successfully applied for a WDNR Lake Management Planning Grant in 2014 to aid in funding the completion of the planning project that was initiated in 2012.

The BDLIA was interested in creating a lake management to gain a better understanding of the Beaver Dam Lake ecosystem and the actions that can be taken to enhance and protect it. Numerous studies were completed in 2014 which assessed Beaver Dam Lake's water quality, watershed, immediate shoreland areas, and aquatic plant community. This report discusses the results of these studies, and the information obtained from these studies will help guide future BDLIA plans and programs. Also included is the Implementation Plan which included goals and actions specific to Beaver Dam Lake's current and future management that were developed by both members of the Beaver Dam Lake Planning Committee, Onterra ecologists, and WDNR staff.

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 August 23, 2014, a project kick-off meeting was held at the Beaver Dam Conservationists Club to introduce the project to the general public. The meeting was announced through a mailing and personal contact by Beaver Dam Lake Improvement Association, Inc. board members. The approximately 60 attendees observed a presentation given by Tim Hoyman, an aquatic ecologist with Onterra. Tim'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 March 11, 2015, Tim Hoyman and Brenton Butterfield of Onterra met with ten members of the Beaver Dam Lake Planning Committee and Susan Graham of the Wisconsin Department of Natural Resources for over three hours. In advance of the meeting, attendees were provided an early draft of the study report sections to facilitate better discussion. The primary focus of this meeting was the delivery of the study results and conclusions to the committee. All study components including water quality analysis, watershed modeling, and aquatic plant inventories were presented and discussed. The majority of the meeting focused on the causes of Beaver Dam Lake's poor water quality and lack of aquatic macrophytes.

Planning Committee Meeting II

On April 14, 2015, Tim Hoyman and Brenton Butterfield met with the ten members of the Planning Committee and Susan Graham and Laura Stremick-Thompson of the WDNR. The meeting started with a presentation by Laura Stremick-Thompson on current fisheries management in Beaver Dam Lake. Her presentation included management of gamefish, removal of common carp, and the results of the common carp population study that had been conducted in 2014. Following Laura's presentation, Onterra ecologists led the group through a discussion of the primary challenges that Beaver Dam Lake is facing and what Onterra ecologists felt were appropriate steps to take to meet these challenges. Given the challenges the lake is facing are large and complex, another planning meeting was scheduled to put together the framework of the Implementation Plan.

Planning Committee Meeting III

On May 5, 2015, Tim Hoyman and Brenton Butterfield met with the ten members of the Planning Committee and Susan Graham WDNR to develop the framework for the Implementation Plan. The first part of the meeting involved Tim and Brenton discussing the challenges Beaver Dam Lake is facing that were already brought forward at the previous meetings. A management goal was developed to meet each of these challenges and proposed management actions were discussed and approved to meet these goals. The meeting was concluded with a brainstorming session where the planning committee listed additional challenges that the lake was facing that had not been addressed. Following this brainstorming session, a management goal and associated actions were developed for each of the challenges presented. This meeting resulted in the framework from which the Implementation Plan was created.

Project Wrap-up Meeting

On August 22, 2015, Tim Hoyman met with the general membership of the BDLIA to hold the project's Wrap-up Meeting. During this meeting, highlights of the study were presented and discussed by Mr. Hoyman, with emphasis placed upon nutrient levels within the lake, the lake's aquatic plant community, and aquatic invasive species. The presentation concluded with a discussion of the management goals and actions as they are presented within the Implementation Plan. A question and answer session followed the presentation.

Management Plan Review and Adoption Process

Prior to the first planning meeting, the Planning Committee received copies of the results section of this report (Section 3.0). Their comments were addressed at this meeting and appropriate changes were incorporated within the management plan. The first draft of the Implementation Plan was sent to the Planning Committee in early June 2015, and the first official draft of the plan was provided to the Planning Committee and the BDLIA Board of Directors in mid-July 2015. This draft was also sent to the WDNR for review. The WDNR provided comments on the plan in August 2015, and Onterra staff discussed and then addressed the WDNR comments in September 2015. The plan was ultimately approved in September of 2015.

3.0 RESULTS & DISCUSSION

3.1 Lake Water Quality

Primer on Water Quality Data Analysis and Interpretation

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

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

As mentioned above, chemistry is a large part of water quality analysis. In most cases, listing the values of specific parameters really does not lead to an understanding of a lake's water quality, especially in the minds of non-professionals. A better way of relating the information is to compare it to lakes with similar physical characteristics and lakes within the same regional area. In this document, a portion of the water quality information collected on Beaver Dam 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 Beaver Dam Lake's water quality analysis:

Phosphorus is the nutrient that controls the growth of plants in the vast majority of Wisconsin lakes. It is important to remember that in lakes, the term "plants" includes both algae and macrophytes. Monitoring and evaluating concentrations of phosphorus within the lake helps to create a better understanding of the current and potential growth rates of the plants within the lake.

Chlorophyll-*a* is the green pigment in plants used during photosynthesis. Chlorophyll-*a* concentrations are directly related to the abundance of free-floating algae in the lake. Chlorophyll-*a* values increase during algal blooms.

Secchi disk transparency is a measurement of water clarity. Of all limnological parameters, it is the most used and the easiest for non-professionals to understand. Furthermore, measuring Secchi disk transparency over long periods of time is one of the best methods of monitoring the health of a lake. The measurement is conducted by lowering a weighted, 20-cm diameter disk with alternating black and white quadrates (a Secchi disk) into the water and recording the depth just before it disappears from sight.

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

Trophic State

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

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

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

Limiting Nutrient

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

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

Temperature and Dissolved Oxygen Profiles

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

Lake stratification occurs when temperature gradients are developed with depth in a lake. During stratification the lake can be broken into three layers: The epiliminion 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 strong stratification, 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 the spring and fall turnover events, these high concentrations of phosphorus are mixed within the lake and utilized by algae and some macrophytes. 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 screen non-candidate and candidate lakes following the general guidelines below:

Non-Candidate Lakes

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

Candidate Lakes

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

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

Comparisons with Other Datasets

The WDNR document *Wisconsin 2014 Consolidated Assessment and Listing Methodology* (WDNR 2013A) is an excellent source of data for comparing water quality from a given lake to lakes with similar features and lakes within specific regions of Wisconsin. Water quality among lakes, even among lakes that are located in close proximity to one another, can vary due to natural factors such as depth, surface area, the size of its watershed and the composition of the watershed's land cover. For this reason, the water quality of Beaver Dam Lake will be compared to lakes in the state with similar physical characteristics. The WDNR groups Wisconsin's lakes into ten natural communities (Figure 3.1-1).

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

> **Seepage Lakes** have no surface water inflow or outflow in the form of rivers and/or streams.
>
> **Drainage Lakes** have surface water inflow and/or outflow in the form of rivers and/or streams.
>
> > Headwater drainage lakes have a watershed of less than four square miles.
> >
> > Lowland drainage lakes have a watershed of greater than four square miles.

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

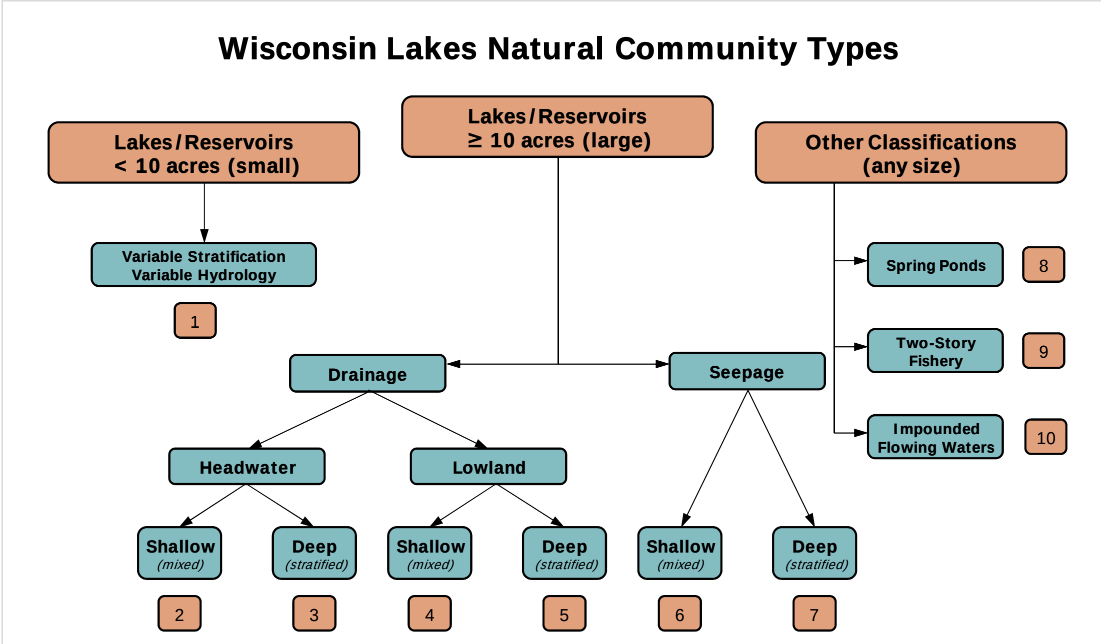


Figure 3.1-1. Wisconsin Lake Natural Communities. Adapted from WDNR 2013A.

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

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.

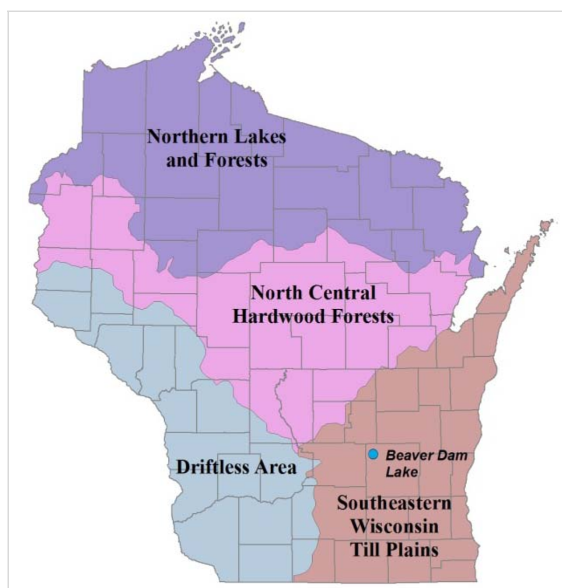


Figure 3.1-2. Location of Beaver Dam Lake within the ecoregions of Wisconsin. After Nichols 1999.

These data along with data corresponding to statewide natural lake means, historic, current, and average data from Beaver Dam Lake is displayed in Figures 3.1-3 - 3.1-9. Please note that the data in these graphs represent concentrations and depths taken only during the growing season (April-October) or summer months (June-August). Furthermore, the phosphorus and chlorophyll-*a* data represent only surface samples. Surface samples are used because they represent the depths at which algae grow and depths at which phosphorus levels are not greatly influenced by phosphorus being released from bottom sediments.

Beaver Dam Lake Water Quality Results

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 or lake thereof, 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.

Beaver Dam Lake contains 15 monitoring stations, six located in open water and nine located near or on shore (Map 2). The nine near-shore monitoring stations do not contain data pertaining to water quality, and thus are not discussed within this report. However, historical and current water quality data are available from all six of the open water locations, though some locations contain more historical data than others (Table 3.1-1).

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

Site Name	Site #	Location	Years with Water Quality Data	Type of Data
At Dam	10037070	Open Water	2004-2006, 2008-2009, 2011	Secchi
Breezy Point	143311	Open Water	2004-2014	Secchi, TP, Chl-α
Deep Hole (Denning Park)	143122	Open Water	1973-1974, 1980, 1995-1999, 2004-2014	Secchi, TP, Chl-α
North End	143034	Open Water	1991-1996, 2014	Secchi, TP, Chl-α
South End	143035	Open Water	1991-1996, 2014	Secchi, TP, Chl-α
Sunset Point	143310	Open Water	2004-2006, 2008-2009, 2011	Secchi
Beaver Creek	10007664	Near-Shore	N/A	N/A
Derge County Park	10017522	Near-Shore	N/A	N/A
Edgewater Park	10017520	Near-Shore	N/A	N/A
Fish Camp Boat Launch	10017519	Near-Shore	N/A	N/A
Mill Road	10019663	Near-Shore	N/A	N/A
Spring Road	10017825	Near-Shore	N/A	N/A
Tahoe Park	10017827	Near-Shore	N/A	N/A
Unamed Tributary	10012228	Near-Shore	N/A	N/A
Waterworks Park	10017826	Near-Shore	N/A	N/A

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

Volunteers have been actively collecting water quality on Beaver Dam Lake almost annually since 1996 through the Citizens Lake Monitoring Network (CLMN) Program. Through this WDNR-sponsored program, volunteers are trained to collect water quality data samples from the lake during the spring and three times during the summer. Samples are analyzed through the State Lab of Hygiene in Madison, WI and data are entered into the Surface Water Integrated Monitoring System (SWIMS), an online database which allows for quick access to all current and historical water quality data collected in Wisconsin through WDNR programs. This process allows stakeholders to become directly engaged in protecting their lake, while producing reliable and comparable data that managers may recall through a streamlined website. Additional historical baseline water quality data collected by the WDNR are available intermittently back to 1973.

As previously mentioned, the three primary water quality parameters that are studied in lakes include total phosphorus, chlorophyll-*a*, and Secchi disk clarity. The long-term trends and 2014 data regarding each of these parameters will be discussed in the following sub-sections. The Deep Hole and Breezy Point monitoring locations contain the most historical water quality data, and the available water quality data collected at these two locations will be discussed. In addition, within each sub-section, the weighted average value for the respective parameter from all six open water sampling locations will be presented. The current CLMN volunteer indicated that data recorded as being collected at the Deep Hole sampling location was actually collected from the South End sampling location. The South End sampling location is located within the deepest location of Beaver Dam Lake, and it is not clear why the Deep Hole sampling locations is named as such.

Beaver Dam Lake Long-Term Trends

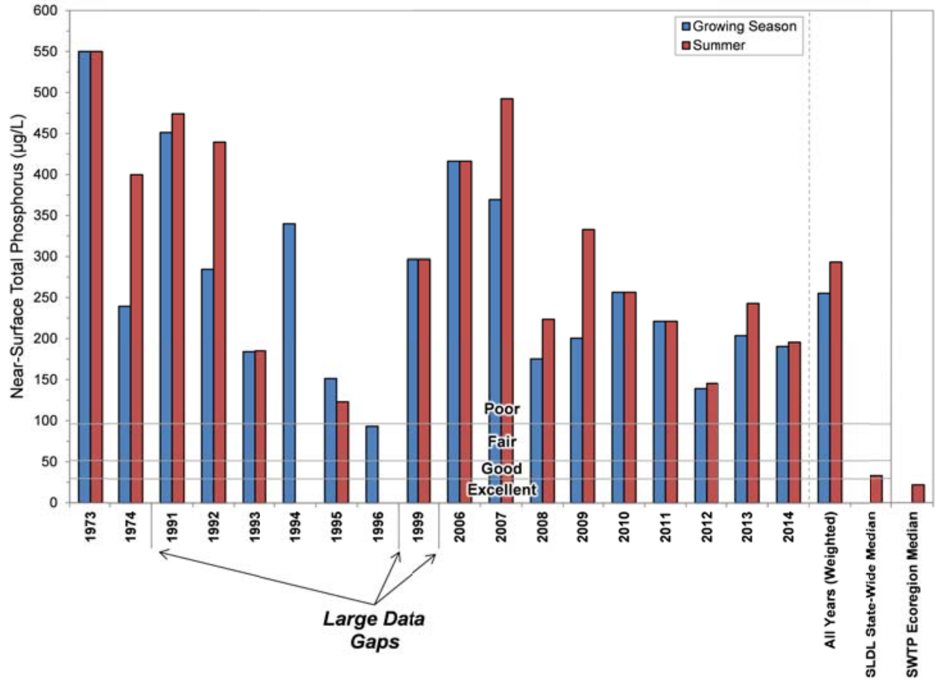
Total Phosphorus

Near-surface total phosphorus concentrations are available from the South End sampling location from 1973-1974, 1991-1996, 1999, and 2006-2014 (Figure 3.1-3a). Annual average growing season near-surface total phosphorus concentrations range from 550 µg/L in 1973 to 93 µg/L in 1996. The average growing season near-surface total phosphorus concentration appears to have declined starting in 2008. The average near-surface growing season total phosphorus concentration from 2008-2014 is 198 µg/L compared to approximately 300 µg/L prior to 2008. The possible reasons for this observed decline in total phosphorus concentration starting in 2008 is discussed within the Drivers of Beaver Dam Lake's Water Quality Section.

At the Breezy Point sampling location, near-surface total phosphorus data are available annually from 2006-2014 (Figure 3.1-3b). Like at the South End sampling location, growing season total phosphorus concentrations were higher in 2006 and 2007 compared to 2008-2014, with average concentrations of 391 µg/L and 214 µg/L, respectively. While the Breezy Point sampling location is approximately 4.5 miles upstream from the Deep Hole sampling location, growing season and summer total phosphorus concentrations from 2006-2014 were not statistically different between these locations (one-way analysis of variance [ANOVA] $\alpha = 0.05$).

Weighted averages of summer total phosphorus concentration data are used to compare Beaver Dam Lake's total phosphorus concentrations to median values for other shallow lowland drainage lakes throughout the state and to median values of all lake types within the SWTP ecoregion. The weighted average summer total phosphorus concentrations from all years that data are available from the South End and Breezy Point sampling locations is 294 µg/L and 286 µg/L, respectively (Figure 3.1-3a and 3.1-3b). Both of these values fall into the *poor* category for shallow lowland drainage lakes in Wisconsin. While phosphorus concentrations have declined since 2007 at both locations, summer concentrations are still nearly 10 times higher than the median concentration for shallow lowland drainage lakes in Wisconsin and approximately 13 times higher than the median value for all lakes within the SWTP ecoregion (Figure 3.1-3a and 3.1-3b).

a) South End Sampling Location



b) Breezy Point Sampling Location

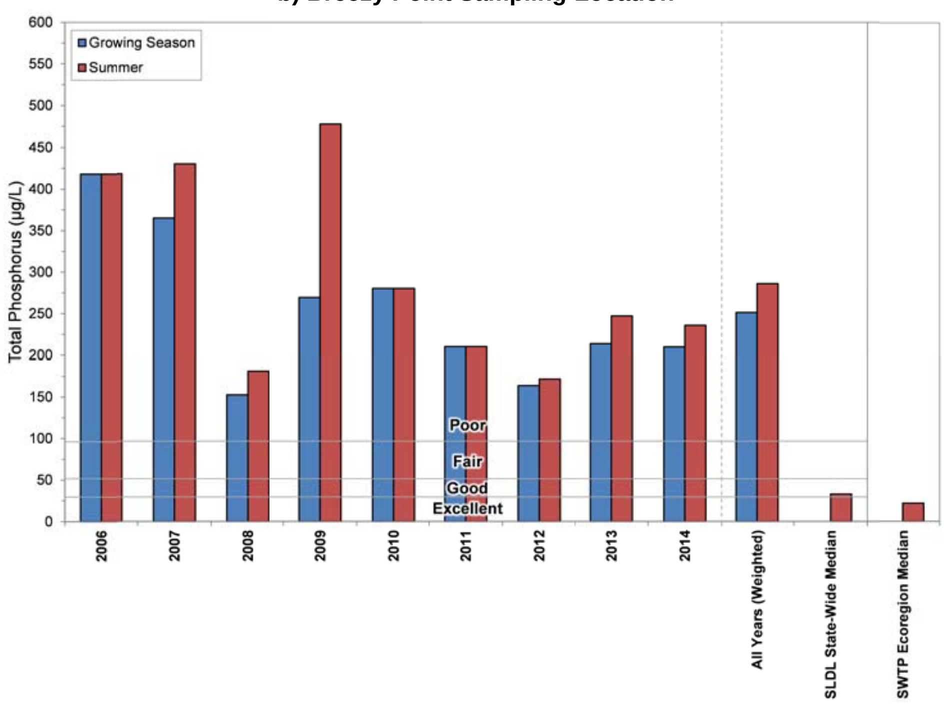


Figure 3.1-3. Beaver Dam Lake average annual near-surface total phosphorus concentrations measured from the South End sampling location (a) and the Breezy Point sampling location (b). Also displayed are the median near-surface total phosphorus concentrations for state-wide shallow lowland drainage lakes (SLDL) and Southeastern Wisconsin Till Plain (SWTP) ecoregion lakes. Water Quality Index values adapted from WDNR PUB WT-913.

Figure 3.1-4 compares the weighted average growing season and summer near-surface total phosphorus concentrations from three of the five open-water sampling locations from which total phosphorus data are available. Total phosphorus concentrations were not statistically different between any of the locations (one-way ANOVA), and concentrations from all locations fall within the *poor* category for shallow lowland drainage lakes. The sources of the elevated phosphorus concentrations in Beaver Dam Lake will be discussed following the Watershed Section.

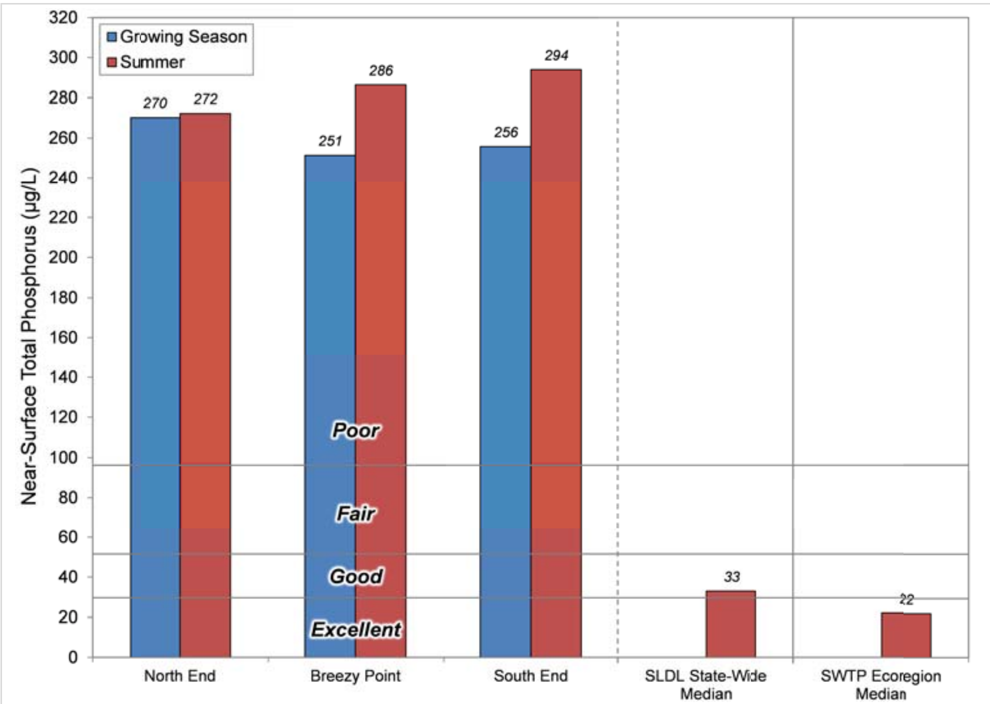


Figure 3.1-4. Beaver Dam Lake weighted average near-surface total phosphorus concentrations from the North End, Breezy Point, and South End sampling locations and median near-surface total phosphorus concentrations for state-wide shallow lowland drainage lakes (SLDL) and Southeastern Wisconsin Till Plain (SWTP) ecoregion lakes. Please see Table 3.1-1 for a list of years of available phosphorus data for each location.

Often, near-surface water samples of phosphorus are analyzed because they are easy to collect and are representative of what is occurring in the littoral zone (sunlit, plant and algae growing area) of a lake. Figures 3.1-3 and 3.1-4 include only data collected from the near-surface of Beaver Dam Lake. However, comparing surface and bottom phosphorus samples can be advantageous to understanding other nutrient dynamics in lakes, such as internal nutrient loading from anoxic bottom sediments as discussed previously. Figure 3.1-5 displays data depicting surface and bottom phosphorus concentrations collected in 2014 by Onterra from the South End sampling location.

During times in which a lake is mixed, we can expect phosphorus concentrations to be similar near the surface and the bottom of the lake. During times that the lake is stratified however, the bottom phosphorus concentration may be two to three times or more than what was observed in the surface waters. Under anoxic conditions, phosphorus may be released from the sediments which accounts for the higher concentrations. During the 2014 growing season sampling events, Beaver Dam Lake was always found to be uniformly mixed and not stratified, and phosphorus concentrations were similar at the surface and near the bottom (Figure 3.1-5). However, as will be discussed following the Watershed Section, it is believed some processes of internal nutrient loading contribute significant sources of nutrients to the lake.

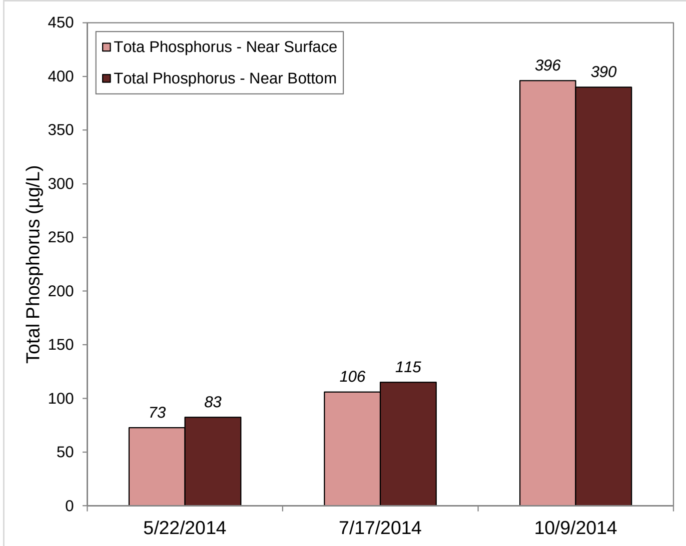


Figure 3.1-5. Beaver Dam Lake 2014 near-surface and near-bottom total phosphorus concentrations collected at the South End sampling location.

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. Chlorophyll-*a* concentrations in Beaver Dam Lake are available from the South End sampling location from 1980, 1991-1996, 1999, and 2006-2014 (Figure 3.1-6a). Average annual growing season chlorophyll-*a* concentrations range from 227 µg/L in 1992 to 5.7 µg/L in 1996; however, this low value in 1996 represents only one sampling event in early May when algal biomass is usually low. While total phosphorus concentrations from 2006-2014 were highest in 2006 and 2007, these years saw lower chlorophyll-*a* concentrations when compared to concentrations from 2008-2014. The average chlorophyll-*a* concentration in 2006 and 2007 was 70.7 µg/L, while the average from 2008-2014 was 123 µg/L. The relationship between total phosphorus and chlorophyll-*a* is logarithmic, and the decline in total phosphorus since 2007 is not enough to cause a marked decline in chlorophyll-*a* concentrations.

Chlorophyll-*a* concentrations are available from the Breezy Point sampling location from 2006-2014 (Figure 3.1-6b). Unlike at the South End sampling location, chlorophyll-*a* concentrations at the Breezy Point sampling location were not significantly lower in 2006 and 2007 when compared to concentrations from 2008-2014. Chlorophyll-*a* concentrations are more variable between the South End and Breezy Point sampling locations than total phosphorus concentrations; however, statistical analysis indicates that growing season and summer concentrations from 2006-2014 between these two locations are not statistically different (one-way ANOVA).

Weighted averages of summer chlorophyll-*a* concentration data are used to compare Beaver Dam Lake's chlorophyll-*a* concentrations to median values for other shallow lowland drainage lakes throughout the state and to median values of all lake types within the SWTP ecoregion. The weighted average summer chlorophyll-*a* concentrations from all years that data are available from the South End and Breezy Point sampling locations is 108 µg/L and 126 µg/L, respectively (Figure 3.1-6a and 3.1-6b). Both of these values fall into the *poor* category for shallow lowland drainage lakes in Wisconsin. These values are between 11 and 13 times higher than the median concentration for shallow lowland drainage lakes in Wisconsin and approximately 20 times higher than the median value for all lakes within the SWTP ecoregion (Figure 3.1-6a and 3.1-

6b). Perceptible algae blooms occur in reservoirs when chlorophyll-*a* concentrations reach approximately 30 µg/L, and Beaver Dam Lake's average concentrations are approximately four times greater than this threshold.

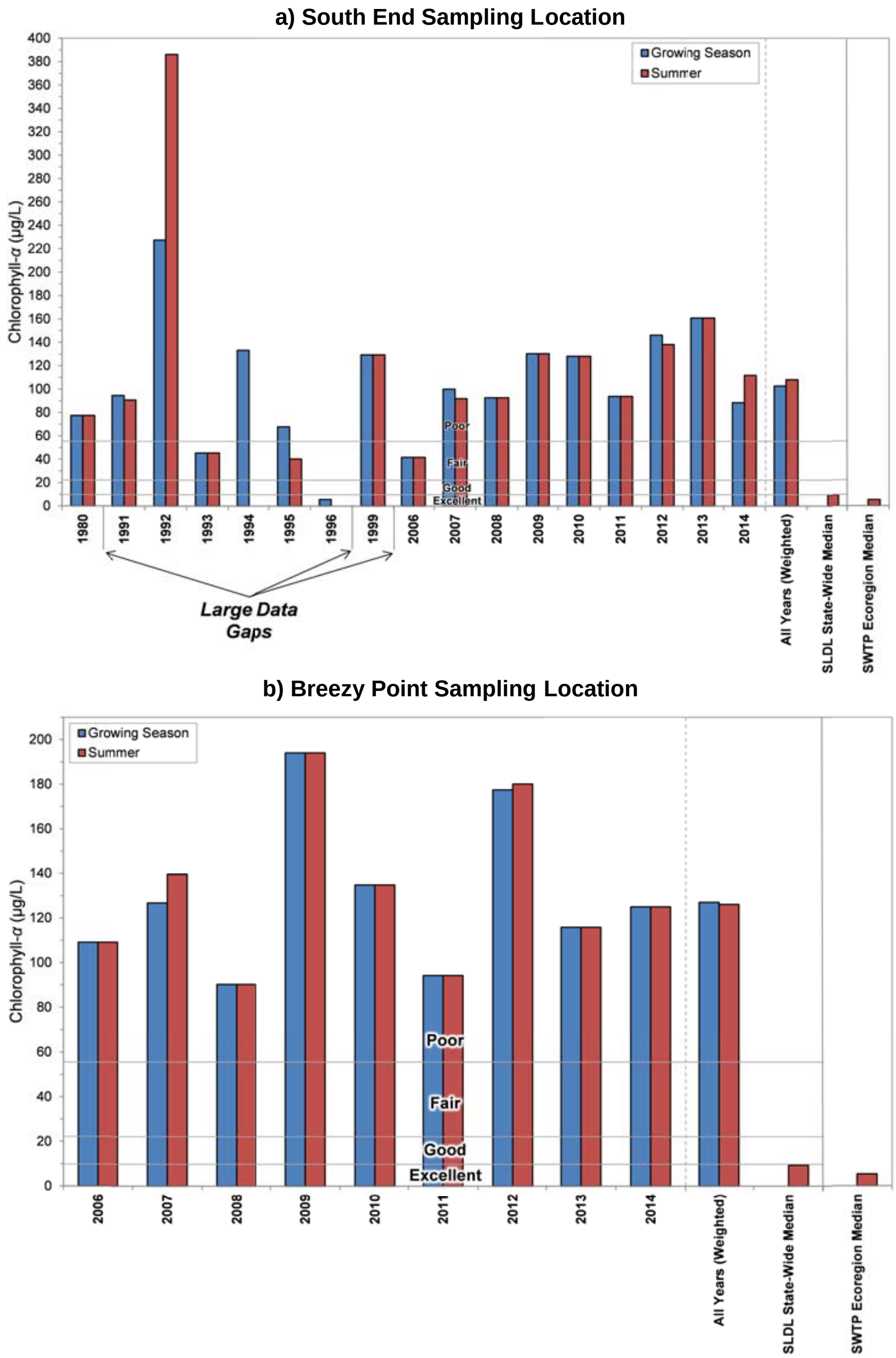


Figure 3.1-6. Beaver Dam Lake average annual chlorophyll-α concentrations measured from the South End sampling location (a) and the Breezy Point sampling location (b). Also displayed are the median chlorophyll-α concentrations for state-wide shallow lowland drainage lakes (SLDL) and Southeastern Wisconsin Till Plain (SWTP) ecoregion lakes. Water Quality Index values adapted from WDNR PUB WT-913.

Figure 3.1-7 compares the weighted average growing season and summer chlorophyll-*a* concentrations from three of the five open-water sampling locations from which data are available. Chlorophyll-*a* concentrations were not statistically different between any of the locations (one-way ANOVA), and concentrations from all locations fall within the *poor* category for shallow lowland drainage lakes. The high algal biomass found in Beaver Dam Lake will be discussed in more detail later in this section.

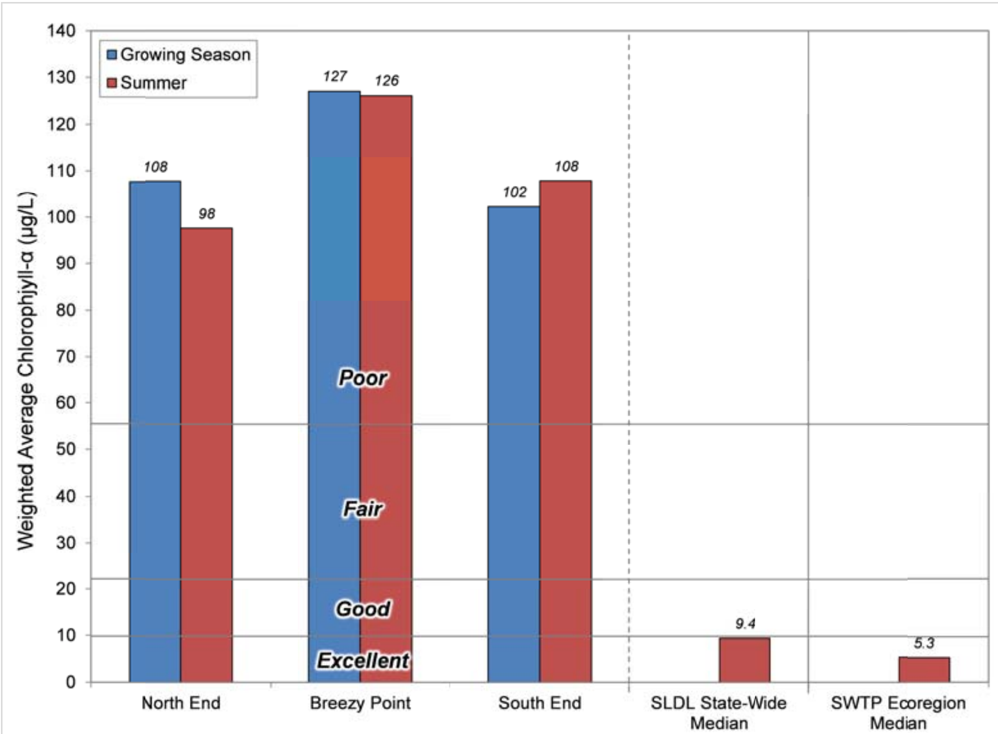


Figure 3.1-7. Beaver Dam Lake weighted average chlorophyll-α concentrations from the North End, Breezy Point, and South End sampling locations and median chlorophyll-α concentrations for state-wide shallow lowland drainage lakes (SLDL) and Southeastern Wisconsin Till Plain (SWTP) ecoregion lakes. Please see Table 3.1-1 for a list of years of available chlorophyll-α data for each location.

Secchi Disk Transparency

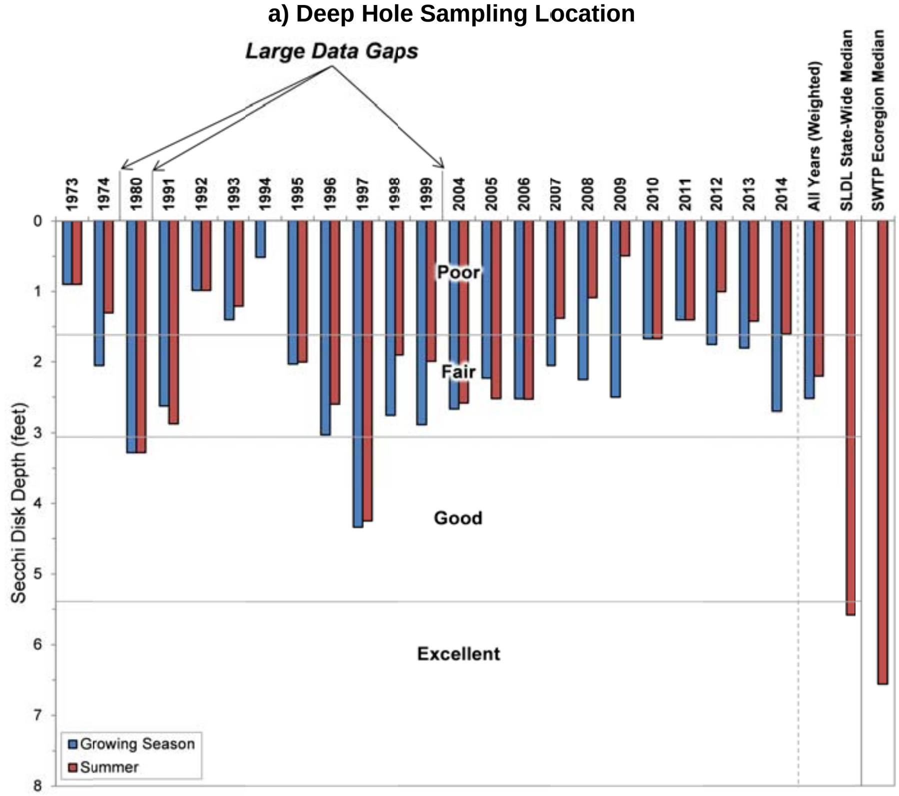
Secchi disk transparency is a measure of water clarity. In Beaver Dam Lake, Secchi disk transparency data are available from the South End sampling location from 1973-1974, 1980, 1991-1999, and 2004-2014 (Figure 3.1-8a). Average growing season Secchi disk transparency ranges from 4.3 feet in 1997 to 0.5 feet in 1994. From 2004-2014 there is a slight decreasing trend in growing season water clarity; however, this trend was not statistically valid (Mann-Kendall Test). Secchi disk transparency at the South End sampling location in 2014 was the highest recorded since 2009.

Secchi disk transparency data are available from the Breezy Point sampling location from 2004-2014 (Figure 3.1-8b). Like at the South End sampling location, there is a slight decreasing trend in water clarity from 2004-2014; however, this trend was not statistically valid (Mann-Kendall Test). And like at the South End sampling location, water clarity in 2014 was the highest recorded since 2009. Water clarity from 2004-2014 was not statistically different between these two sampling locations (one-way ANOVA).

Weighted averages of summer Secchi disk transparency data are used to compare Beaver Dam Lake's Secchi disk transparency values to median values for other shallow lowland drainage lakes throughout the state and to median values of all lake types within the SWTP ecoregion. The weighted average summer Secchi disk transparency from all years that data are available from the South End and Breezy Point sampling locations is 2.2 feet and 1.8 feet, respectively (Figure 3.1-8a and 3.1-8b). Both of these values fall into the *fair* category for shallow lowland drainage lakes in Wisconsin. These values are approximately three to four times lower than the median concentration for shallow lowland drainage lakes in Wisconsin and the median value for all lakes within the SWTP ecoregion (Figure 3.1-8a and 3.1-8b).

Figure 3.1-9 compares the weighted average growing season and summer Secchi disk transparency values from all five open-water sampling locations from which data are available. Secchi disk transparency values were not statistically different between any of the locations (one-way ANOVA), and Secchi disk transparency values from all six locations fall within the *fair* category for shallow lowland drainage lakes.

a) Deep Hole Sampling Location



b) Breezy Point Sampling Location

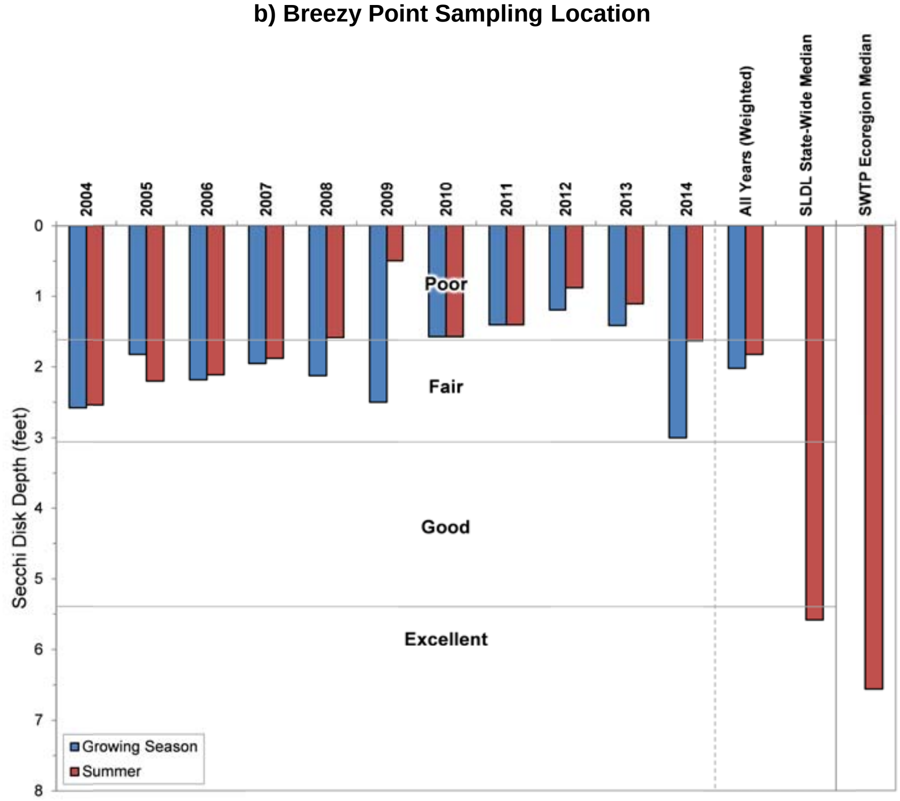


Figure 3.1-8. Beaver Dam Lake average annual Secchi disk transparency measured from the South End sampling location (a) and the Breezy Point sampling location (b). Also displayed are median Secchi disk transparency values for state-wide shallow lowland drainage lakes (SLDL) and Southeastern Wisconsin Till Plain (SWTP) ecoregion lakes. Water Quality Index values adapted from WDNR PUB WT-913.

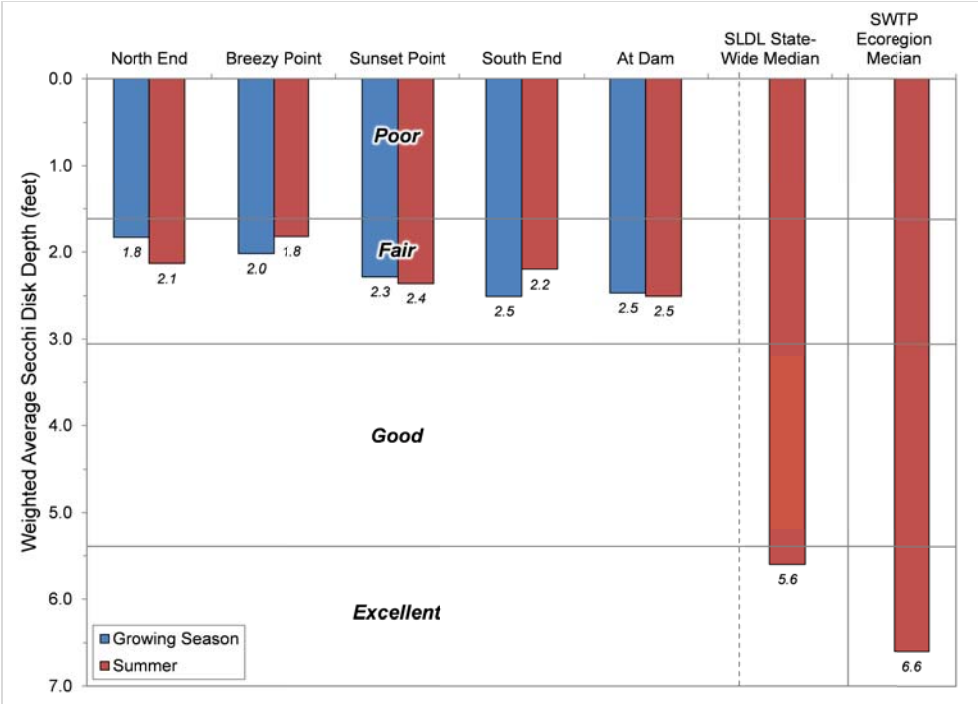


Figure 3.1-9. Beaver Dam Lake weighted average Secchi disk transparency data from the North End, Breezy Point, Sunset Point, South End, and At Dam sampling locations and median Secchi disk transparency values for state-wide shallow lowland drainage lakes (SLDL) and Southeastern Wisconsin Till Plain (SWTP) ecoregion lakes. Please see Table 3.1-1 for a list of years of available Secchi disk data for each location.

Limiting Plant Nutrient of Beaver Dam Lake

Using mid-July and late-August nitrogen and phosphorus concentrations from Beaver Dam Lake, nitrogen:phosphorus ratios of 15:1 and 10:1 were calculated, respectively. This finding indicates that Beaver Dam Lake likely transitions between phosphorus and nitrogen limitation. As will be discussed following the Watershed Section, nutrient concentrations in Beaver Dam Lake increase over the course of the growing season. Early in the growing season the lake is phosphorus-limited; however, phosphorus concentrations increase at a higher rate than nitrogen throughout the summer, and eventually, nitrogen likely becomes the limiting nutrient.

Beaver Dam Lake Trophic State

Figure 3.1-10 contains the weighted average Trophic State Index (TSI) values from each open-water sampling location in Beaver Dam Lake for which total phosphorus, chlorophyll-*a*, or Secchi disk transparency data are available. The TSI values are calculated with annual average summer month Secchi disk, chlorophyll-*a*, and total phosphorus values. In general, the best values to use in judging a lake's trophic state are chlorophyll-*a* and total phosphorus, as water clarity can be influenced by other factors such as dissolved organic compounds and abiotic suspended materials. The weighted average TSI values for chlorophyll-*a* and total phosphorus indicate Beaver Dam Lake is *hypereutrophic*. Hypereutrophic lakes are characterized by having excessive levels of nutrients and algae with poor water clarity. Lakes which have total phosphorus concentrations of greater than 100 µg/L fall into the hypereutrophic category.

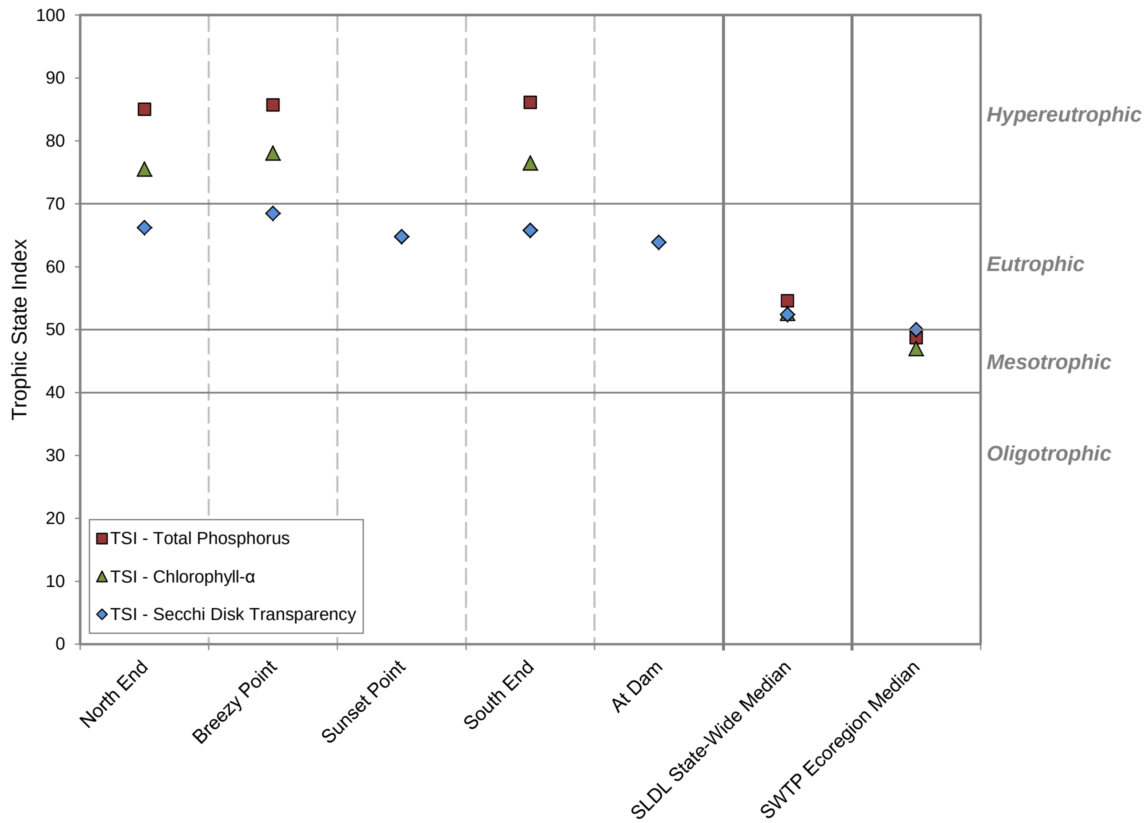


Figure 3.1-10. Beaver Dam Lake, state-wide shallow lowland drainage lakes (SLDL), and Southeastern Wisconsin Till Plains (SWTP) ecoregion Trophic State Index values. Values calculated with summer month surface sample data using WDNR PUB-WT-193.

Dissolved Oxygen and Temperature in Beaver Dam Lake

Dissolved oxygen and temperature were measured during water quality sampling visits to Beaver Dam Lake by Onterra staff and during the summer months by the CLMN volunteer. Profiles depicting these data are displayed in Figure 3.1-11. These data indicate that Beaver Dam Lake likely remains mixed throughout the growing season and does not undergo strong stratification. This mixing behavior is to be expected given the lake's relatively shallow depth and large surface area. In productive lakes like Beaver Dam Lake, dissolved oxygen can often become depleted during the winter resulting in fish kills. While this has occurred in the past on Beaver Dam Lake, a profile collected in February of 2015 indicated sufficient levels of oxygen were present throughout the water column. While aerators were installed to provide open areas of water during the winter, the lack of thick snow cover likely also allowed sufficient light to penetrate through the ice and sustain a higher level of oxygen-producing algae.

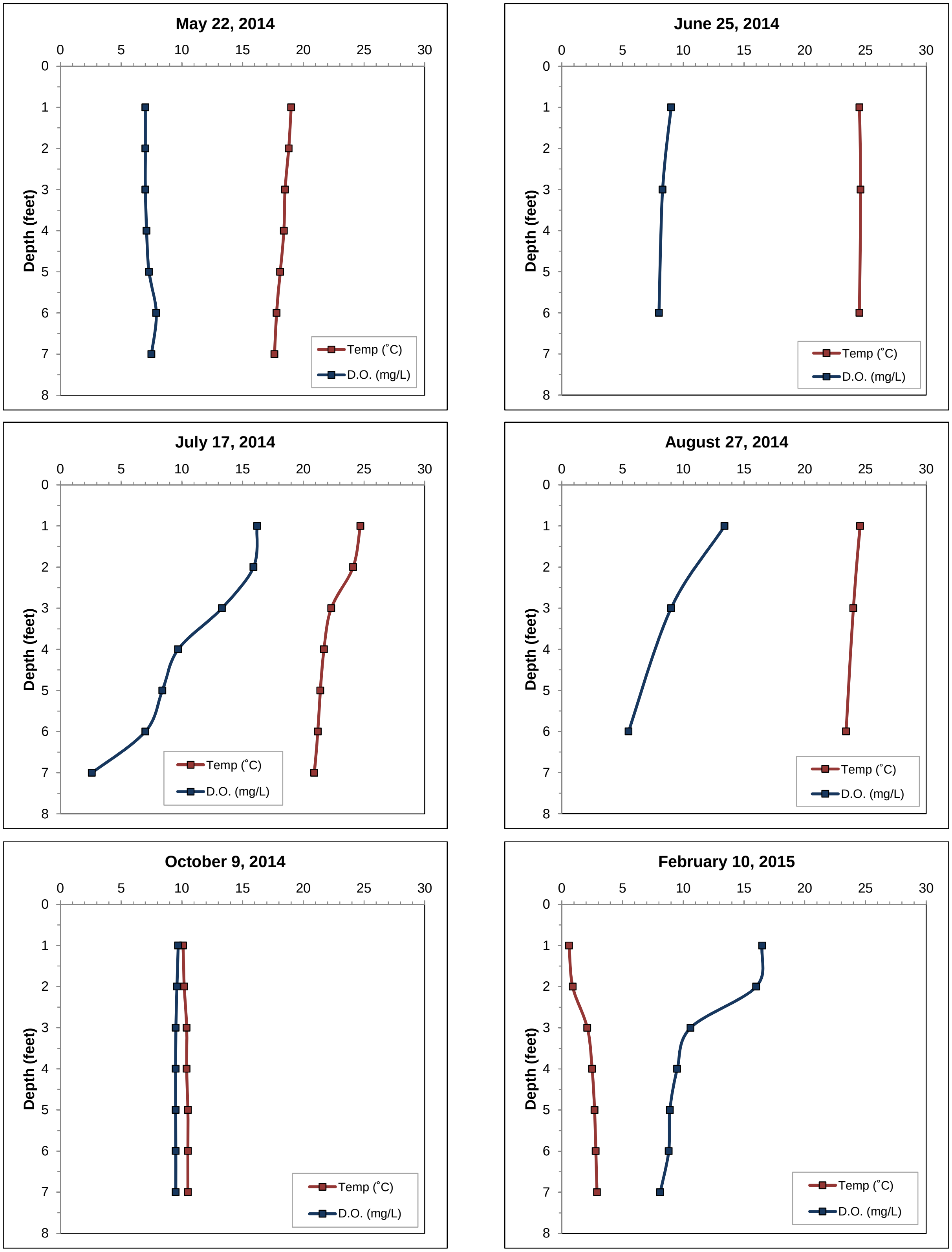


Figure 3.1-11. Beaver Dam Lake 2014-2015 temperature and dissolved oxygen profiles.

Additional Water Quality Data Collected at Beaver Dam 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 Beaver Dam Lake's water quality and are recommended as a part of the WDNR long-term lake trends monitoring protocol. These parameters include pH, alkalinity, and total suspended solids.

The pH scale ranges from 0 to 14 and indicates the concentration of hydrogen ions (H^+) within the lake's water and is an index of the lake's acidity. Water with a pH value of 7 has equal amounts of hydrogen ions and hydroxide ions (OH^-), and is considered to be neutral. Water with a pH of less than 7 has higher concentrations of hydrogen ions and is considered to be acidic, while values greater than 7 have lower hydrogen ion concentrations and are considered basic or alkaline. The pH scale is logarithmic; meaning that for every 1.0 pH unit the hydrogen ion concentration changes tenfold. The normal range for lake water pH in Wisconsin is about 5.2 to 8.4, though values lower than 5.2 can be observed in some acid bog lakes and higher than 8.4 in some marl lakes. In lakes with a pH of 6.5 and lower, the spawning of certain fish species such as walleye becomes inhibited (Shaw and Nimphius 1985). The pH of the water in Beaver Dam Lake was found to be alkaline with values ranging from 8.0 to 9.0 in 2014.

Alkalinity is a lake's capacity to resist fluctuations in pH by neutralizing or buffering against inputs such as acid rain. The main compounds that contribute to a lake's alkalinity in Wisconsin are bicarbonate (HCO_3^-) and carbonate (CO_3^-), which neutralize hydrogen ions from acidic inputs. These compounds are present in a lake if the groundwater entering it comes into contact with minerals such as calcite ($CaCO_3$) and/or dolomite ($CaMgCO_3$). A lake's pH is primarily determined by the amount of alkalinity. Rainwater in northern Wisconsin is slightly acidic naturally due to dissolved carbon dioxide from the atmosphere with a pH of around 5.0. Consequently, lakes with low alkalinity have lower pH due to their inability to buffer against acid inputs. The average near-surface alkalinity in Beaver Dam Lake was measured at 185 (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.

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 Beaver Dam Lake near the surface and near the bottom in spring and fall of 2014. While regional and state-wide values for total suspended solids in Wisconsin's lakes have not been developed, total suspended solids measured from the lake in May 2014 were low, with a value of 4.2 mg/L. However, in early-October 2014, total suspended solids had increased to 29 mg/L, which is one of the highest values Onterra ecologists have seen. Total suspended solids will be discussed in more detail following the Watershed Section.

Beaver Dam Lake Water Levels

Beaver Dam Lake is a flowage, and water levels are maintained and controlled by the Upper Beaver Dam which is owned by the City of Beaver Dam. The dam is continually monitored to prevent excessive fluctuation in water level and according to the Dam Order, water levels are to be maintained as close as possible to the normal operating level of 88.30 feet. Water levels in the lake are lowered beginning March 1 of every year to reach a level of 87.70 by March 15 to mitigate against potential flooding from spring runoff. This lower water level is maintained until April 1 or until the lake is completely free of ice; however, the lake level cannot exceed 88.00 until April 15. A minimum discharge of 3.0 cubic feet per second must be passing through the dam at all times, and the lake level may be lowered to allow for this flow rate.

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.

Beaver Dam Lake Watershed

The surface water drainage basin, or watershed, for Beaver Dam Lake encompasses approximately 98,647 acres (154 square miles) across Fond du Lac, Green Lake, Columbia, and Dodge Counties, yielding a watershed to lake area ratio of 13:1 (Map 3). In other words, approximately 13 acres of land drain to every one acre of Beaver Dam Lake. Using water flow data recorded at the Upper Beaver Dam by the City of Beaver Dam, Beaver Dam Lake's water residence time is approximately 0.3 years, or the water within the lake is completely replaced (flushing rate) three times per year.

The watershed can be divided into three sub-basins: Beaver Dam Lake's direct watershed, or the area of land which drains directly to Beaver Dam Lake, Fox Lake's watershed, and Lost Lake's watershed. Approximately 60% of the watershed is Beaver Dam Lake's direct watershed, 39% is Fox Lake's watershed, and 1% is Lost Lake's watershed (Figure 3.2-1). The majority of Beaver Dam Lake's direct watershed is comprised of row crop agriculture (57%), followed by areas of pasture/grass (14%), the lake's surface itself (12%), wetlands (9%), rural residential areas (4%), forests (3%), and urban areas of medium and high density (1%) (Figure 3.2-1). Approximately 80% of Fox Lake's watershed and 67% of Lost Lake's watershed are comprised of row crop agriculture and areas of pasture/grass.

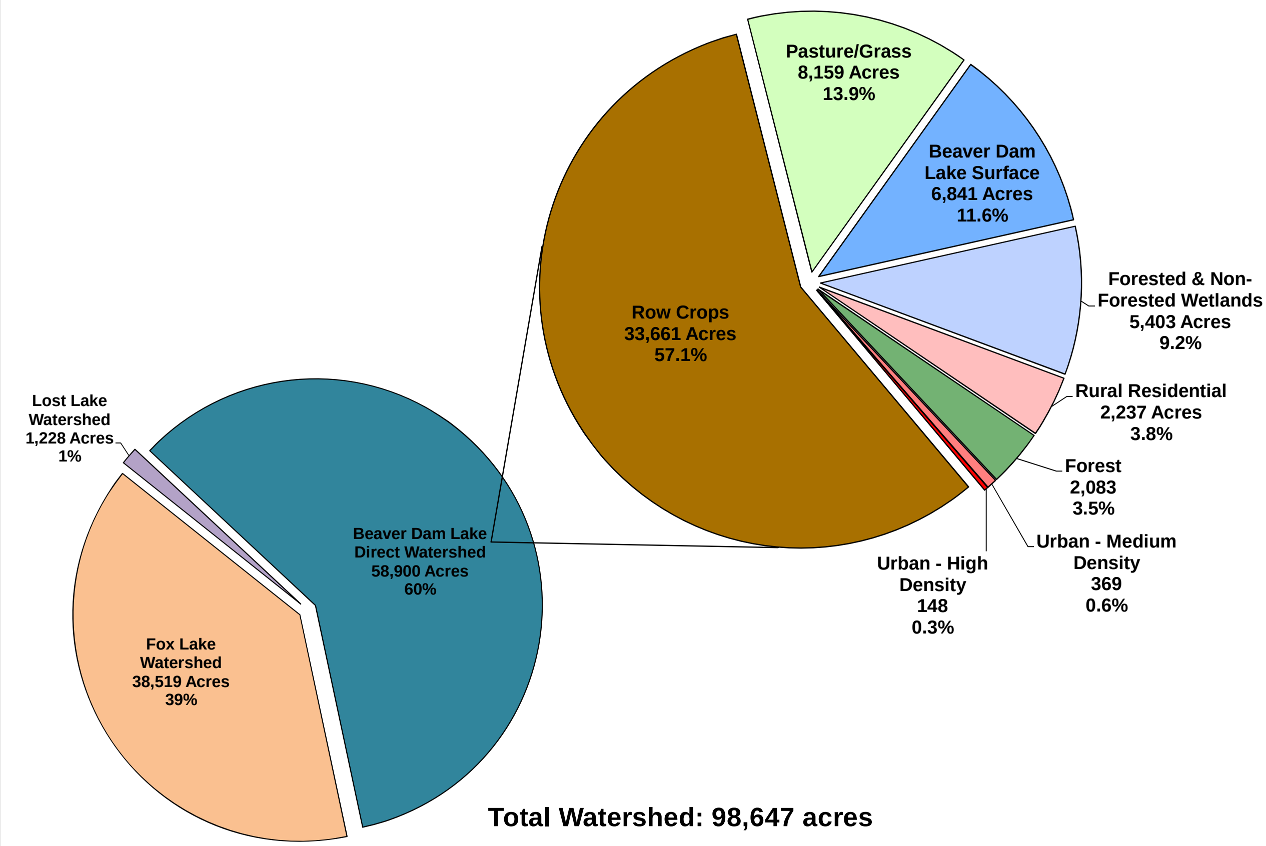


Figure 3.2-1. Beaver Dam Lake watershed land cover types in acres. Based upon National Land Cover Database (NLCD – Fry et. al 2011).

3.3 Drivers of Beaver Dam Lake's Water Quality

The previous Water Quality and Watershed Sections presented the historical and current water quality conditions present within Beaver Dam Lake along with the current composition of the lake's watershed. While the Water Quality Section indicated that the current water quality within Beaver Dam Lake is poor with elevated levels of nutrients fueling excessive algae growth and reducing water clarity, the sources of these nutrients in Beaver Dam Lake were not discussed. This section will discuss the sources, both external and internal, of these nutrients to Beaver Dam Lake.

Given their general nature of being relatively shallow and having relatively large watersheds, flowages like Beaver Dam Lake tend to be more productive than natural lakes even when their watersheds are comprised mainly of natural land cover types (e.g. forests). However, the concentrations of phosphorus measured in Beaver Dam Lake are orders of magnitude higher than the median values for other shallow lowland drainage lakes throughout the state. The water quality within a lake is largely a reflection of the state of the land that drains to the lake, or its watershed. When water quality within a lake is poor or is beginning to degrade, the first area lake managers usually look to is the status of the lake's watershed. As discussed in the Watershed Section, the majority of Beaver Dam Lake's watershed is comprised of row crop agriculture and areas of pasture/grass, land cover types which export the greatest amount phosphorus to lakes.

Using the Wisconsin Lakes Modeling Suite (WiLMS), the acreages of land cover types within Beaver Dam Lake's direct watershed and total phosphorus data from Fox and Lost Lakes were used to determine the annual potential phosphorus load to Beaver Dam Lake from its watershed. This modeling indicates that Beaver Dam Lake potentially receives an estimated 46,000 pounds (23 tons) of phosphorus from its watershed on an annual basis. Using this annual potential phosphorus load, WiLMS predicted an in-lake growing season mean total phosphorus concentration of 62 µg/L. While this predicted concentration is high for phosphorus standards, it is four times lower than actual growing season mean total phosphorus concentration of 256 µg/L calculated from available data from the South End sampling location. The 46,000 pounds of phosphorus being delivered annually to Beaver Dam Lake was similar to the estimated 59,000 pounds predicted within the Rock River TMDL Report (The Cadmus Group 2011).

The fact that WiLMS underestimated the growing season mean total phosphorus concentration within Beaver Dam Lake based upon the composition and size of its watershed indicates that there are sources of phosphorus to Beaver Dam Lake that are not being accounted for in the model. WiLMS was used to gain an understanding of how much additional phosphorus needs to be added to the lake on an annual basis to achieve a growing season mean of 256 µg/L. This modeling indicates that to achieve a growing season mean of 256 µg/L, Beaver Dam Lake needs to receive an additional 485,000 pounds (243 tons) of phosphorus annually, bringing the total estimated annual phosphorus load to 531,000 pounds (266 tons).

Previous studies have indicated that Beaver Dam Lake's poor water quality is a result of the high level of agricultural development within its watershed. While WiLMS indicates agriculture is a significant contributor of phosphorus to Beaver Dam Lake, its underestimation of phosphorus concentration within the lake is an indication that there are additional contributors of phosphorus. While WiLMS is a general assessment model and phosphorus export from agricultural lands can vary, it is not believed that the additional sources of phosphorus are originating externally from the lake's watershed, but rather evidence indicates that there are internally-derived sources of phosphorus in Beaver Dam Lake (Figure 3.3-1).

The evidence for internal sources of phosphorus comes from the dynamics of water quality parameters within a single growing season. In all years for which data are available, total phosphorus concentrations increase markedly over the course of the growing season, being lowest in the spring and highest in the fall. This increase in concentration over the course of growing season is an indication of internal nutrient loading. If external sources from the watershed alone were responsible for the phosphorus concentrations measured in Beaver Dam Lake, it would be expected that concentrations would likely be highest in the spring following the snowmelt and following large precipitation events. However, as mentioned, this is not what has been observed as phosphorus concentrations are lowest in the spring and reach a maximum in the fall.

In addition to phosphorus, total nitrogen and total suspended solids also increase over the course of the growing season. In response to higher levels of nutrients, chlorophyll-*a* concentrations also increase, while Secchi disk transparency declines (Figure 3.3-2). This internal nutrient loading, or in-lake nutrient cycling, is believed to a result of a combination of three interrelated processes: wind-induced resuspension of bottom sediments, common carp-induced resuspension of bottom sediments and excretion, and sediment release during periods of brief anoxia and/or high pH. Phosphorus-laden sediment in Beaver Dam Lake originates from its highly disturbed watershed and has accumulated over time since the lake's creation.

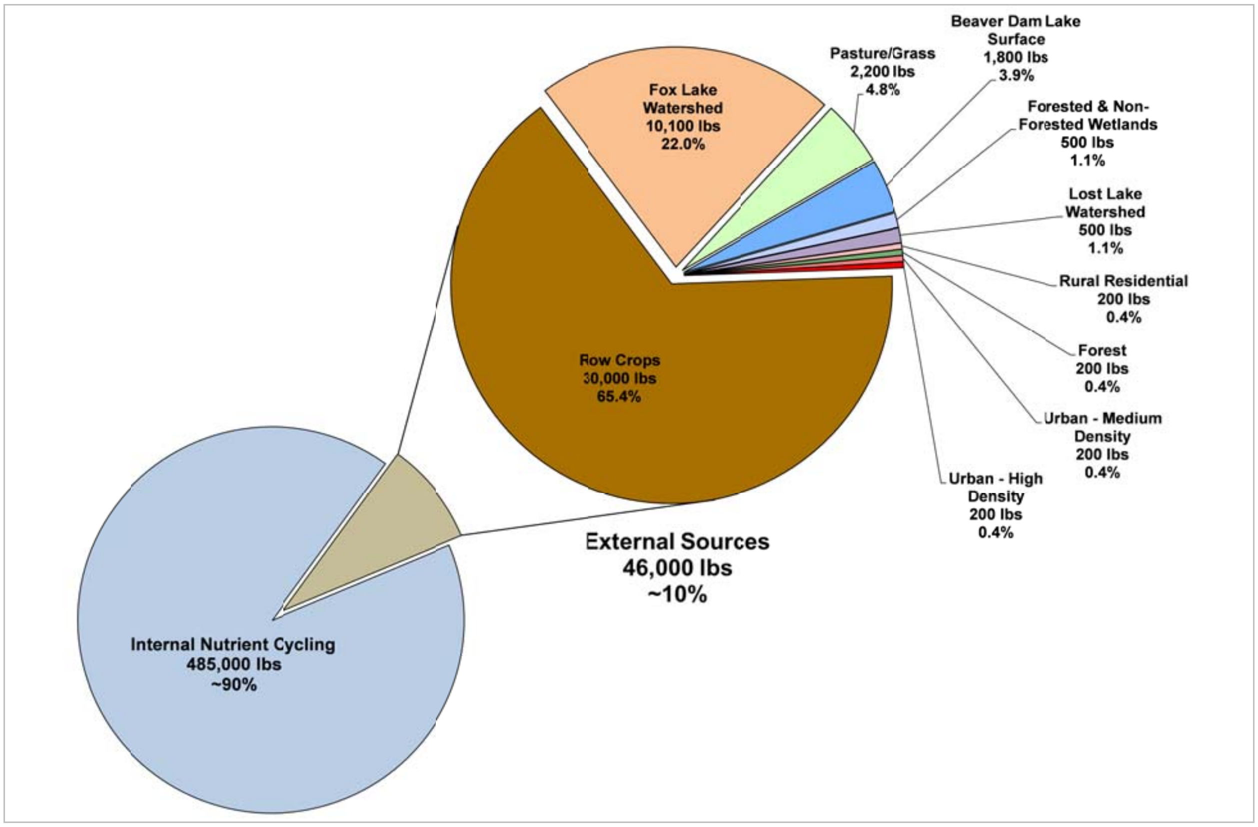


Figure 3.3-1. Beaver Dam Lake watershed estimated annual phosphorus loading from external and internal sources. Based upon Wisconsin Lake Modeling Suite (WiLMS) estimates and 2014 water quality data.

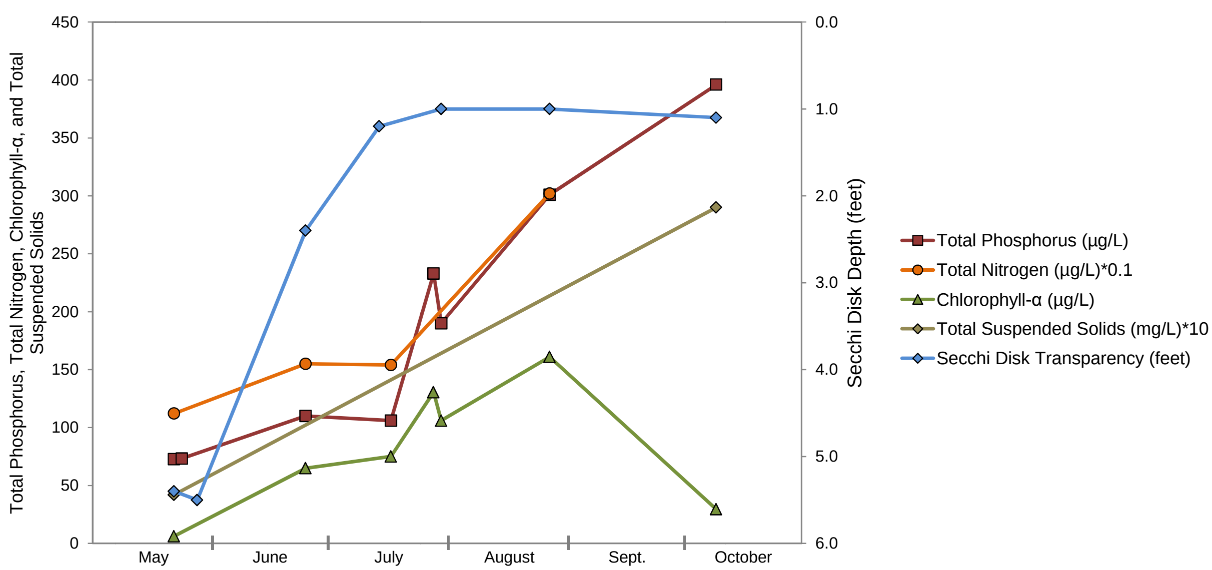


Figure 3.3-2. Beaver Dam Lake 2014 near-surface total phosphorus, total nitrogen, chlorophyll-α, total suspended solids, and Secchi disk transparency recorded at the South End sampling location. Please note that total nitrogen concentrations were multiplied by 0.1 and total suspended solids concentrations were multiplied by 10.

Causes of In-Lake Nutrient Cycling in Beaver Dam Lake

Wind-Induced Sediment Resuspension

Maximum fetch length is defined as the largest unbroken stretch of open water across a lake (Wetzel 2001).

Physical resuspension of bottom sediments in Beaver Dam Lake is believed to occur via wind-induced resuspension. With a mean depth of only 5.7 feet, a surface area of 6,841 acres, a *maximum fetch length* of approximately six miles, and lack of submersed vegetation, Beaver Dam Lake is prone to sediment resuspension from wind. In shallow lakes, wind-induced sediment resuspension often leads to increased total phosphorus concentrations and total suspended solids (Søndergaard et al. 2007).

Common Carp

Common carp (*Cyprinus carpio*; Photo 3.3-1), an invasive species which originates from Eurasia, were intentionally introduced to Beaver Dam Lake sometime shortly after they were imported to Wisconsin in 1877 as a food source (Kordus 2002). Since their introduction to waterbodies in the United States and other countries around the world, numerous studies have documented the deleterious effects these fish have on lake ecosystems. Common carp can survive in a wide range of waterbody conditions, but they reach their greatest densities in shallow, eutrophic systems like Beaver Dam Lake (Weber et al. 2011). Because of their ability to reach extreme densities, they are considered to be one of the most detrimental invasive species to waterbodies they inhabit (Weber and Brown 2011).

Photo 3.3-1. Common carp (*Cyprinus carpio*) are an invasive species that degrade aquatic ecosystems.

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

Common carp population data collected during a WDNR 2014 study estimated that there are approximately 330 pounds of carp per acre in Beaver Dam Lake. LaMarra (1975) estimated that 1 pound of carp produces 0.11 pounds of phosphorus per year. Using these data, it is estimated that the common carp population in Beaver Dam Lake produce approximately 256,000 pounds of phosphorus each year, or approximately 53% of the total annual phosphorus load to the lake. However, this estimation is likely exaggerated and given the seasonal increases in nutrients within the lake, it is likely that wind-induced sediment resuspension and phosphorus release from bottom sediments (discussed next) are the primary contributors of internally-derived phosphorus. While the estimated phosphorus loading from common carp is likely overestimated, this analysis clearly indicates that the common carp population, at its current density, is a significant contributor of phosphorus to Beaver Dam Lake.

Recognizing the effects common carp have on Beaver Dam Lake, commercial seining of common carp and bigmouth buffalo (*Ictobus cyprinellus*) has been conducted on the lake since the 1920s (Kordus 2002). Annual pounds of common carp and bigmouth buffalo removed from Beaver Dam Lake are available since 1996, and indicate that over 9.8 million pounds of common carp and over 900 thousand pounds of bigmouth buffalo have been removed from 1996-2014 (Figure 3.3-3).

As discussed within the Water Quality Section, a marked decrease in total phosphorus concentration occurred in 2008 and concentrations have remained lower through present. While total phosphorus concentrations are still extremely high, this decrease may be a result of a reduction in the common carp population due to commercial removal. Looking solely at the total number of pounds of carp and buffalo removed does not indicate any relationship between total pounds removed and phosphorus concentration. However, looking at the catch per unit effort (CPUE), or the pounds of fish caught per day from 1996-2014, reveals that the average CPUE from 1996-2007 was 55,585 pounds per day compared to 24,710 pounds per day from 2008-2014 (Figure 3.3-4). This reduction in CPUE may be an indication of a reduction in the carp population and a corresponding reduction in total phosphorus over this time period.

The reduction in total phosphorus concentration in 2008 is likely also due in part to the implementation of best management practices within the watershed during the priority watershed project. According to the Dodge County Land Conservation Plan (2012), transect surveys indicate that county-wide soil erosion rates are lower from post-2007, declining by over 300 tons per year.

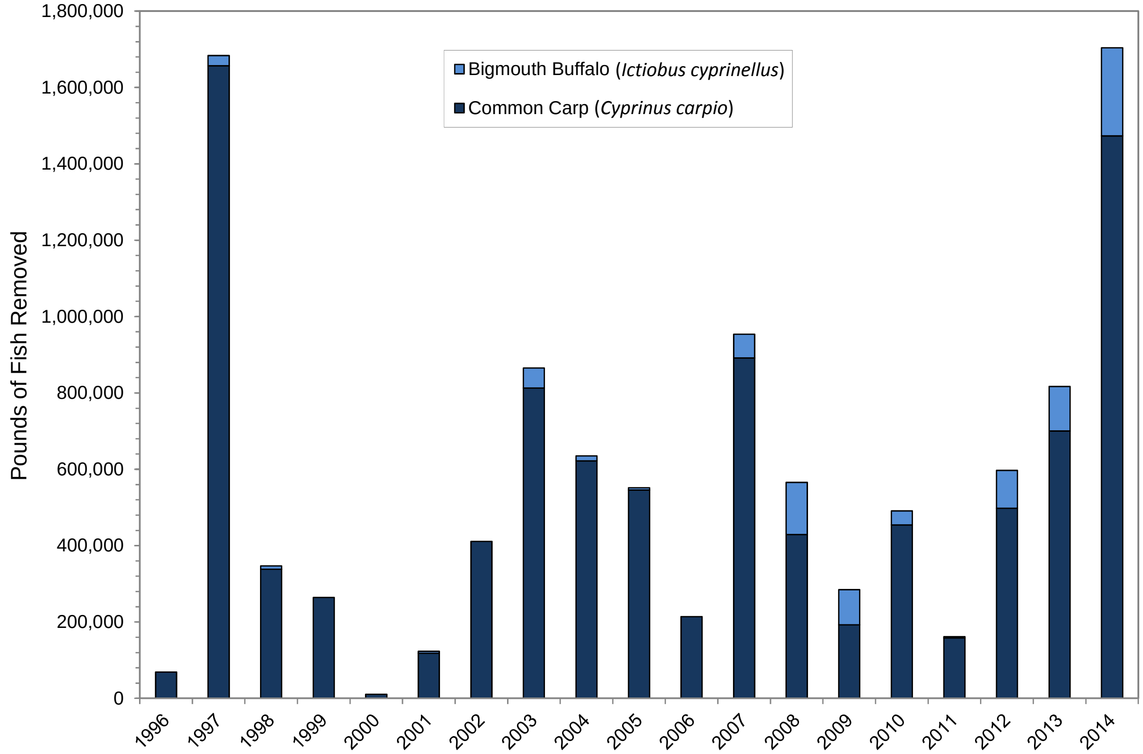


Figure 3.3-3. Beaver Dam Lake annual pounds of common carp and bigmouth buffalo removed via commercial seining from 1996-2014. Created using data provided by WDNR fisheries staff.

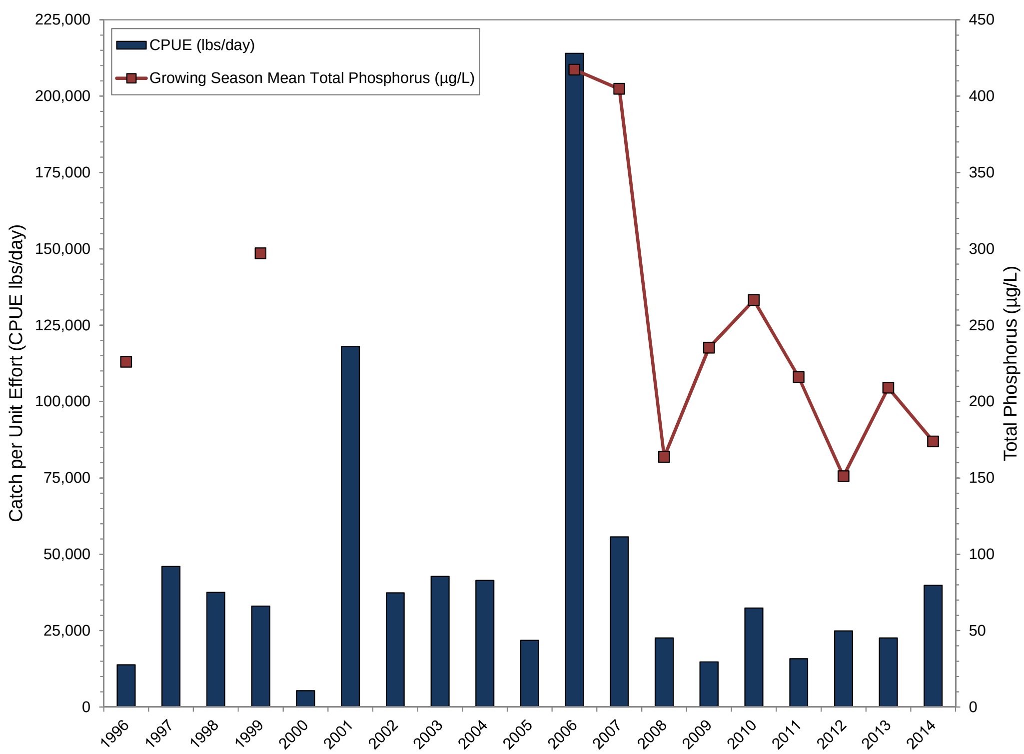


Figure 3.3-4. Beaver Dam Lake catch per unit effort (CPUE) of common carp from 1996-2014 and growing season mean near-surface total phosphorus.

Phosphorus Release from Bottom Sediments

As discussed in the previous two sub-sections, the physical resuspension of bottom sediments is believed to be a significant contributor of phosphorus to Beaver Dam Lake. Phosphorus is often found attached to sediment particles, and while some algae are able to utilize this particulate phosphorus, others are only able to use the phosphorus once it is released from the sediment particle. This is known as bio-available phosphorus. Typically, phosphorus release from bottom sediments is observed when the overlying water becomes anoxic, or devoid of oxygen, and is usually seen in lakes that become stratified forming distinct layers of water based on differences in temperature and density. In more productive lakes, the bottom, cold layer of water (hypolimnion) can become depleted of oxygen as bacteria utilize it for decomposition. With the warmer, less dense layer of water (epilimnion) floating on top of hypolimnion, the hypolimnion becomes cut-off from the atmosphere and oxygen is not replenished.

As discussed earlier, Beaver Dam Lake is shallow with a large surface area and was not found to be stratified during any of the summer sampling events in 2014. However, it is likely that the lake does periodically stratify during periods of calm weather. During these periods, oxygen is likely depleted relatively rapidly near the bottom given Beaver Dam Lake's high productivity. In addition, oxygen may be quickly depleted at night as the high levels of algae are respiring and taking in oxygen. As waters near the sediment layer become anoxic, phosphorus is likely released from the sediment into the water column. While phosphorus can be released from bottom sediments during periods of anoxia in Beaver Dam Lake, conditions are also likely present to facilitate the release of phosphorus even when oxygen is present.

Carbon dioxide reacts with water to form carbonic acid, which increases the water's acidity and lowers the pH. However, during the day, algae consume carbon dioxide during photosynthesis and can raise the pH of the water. When algae become highly abundant, like in Beaver Dam Lake, the pH can increase to 9.0 or greater. This increase in pH is known to reduce the capacity of phosphorus' ability to remain bound to the sediment, and phosphorus can be released from the sediment under these conditions (Solim and Wanganeo 2009). Increases in water temperature accelerate photosynthetic activity, and this phenomena is likely to occur in Beaver Dam Lake in mid- to late-summer when water temperatures are highest. pH measurements from Beaver Dam Lake in 2014 indicate values can reach at least 9.0 in the summer, and during these periods, phosphorus is likely being released from bottom and suspended sediments.

Internal-Nutrient Cycling Summary

The modeling of Beaver Dam Lake's watershed indicates that while phosphorus loading from the agriculturally-dominated watershed is substantial, these external sources alone do not account for the concentrations of phosphorus measured within the lake. In fact, modeling indicates that external sources from Beaver Dam Lake's watershed account for only approximately 10% of the annual phosphorus load to the lake, and that the remaining 90% is likely due to internal nutrient cycling.

Since Beaver Dam Lake's creation in 1843, its highly disturbed watershed has been delivering phosphorus-laden sediment to the lake which has accumulated over time. However, much of this phosphorus does not remain in the sediments and is believed to be delivered into the water via multiple interrelated mechanisms. Beaver Dam Lake's shallow nature and large size make it prone to wind-induced sediment resuspension. Amplifying this effect, the common carp population not only physically resuspend sediment through their foraging and spawning behavior, but they also make bottom sediments more flocculent and remove aquatic vegetation increasing the sediment's susceptibility to wind-induced resuspension. Given the high density of common carp within the lake, their excretion is also likely a significant contributor of phosphorus to the lake.

In addition, phosphorus is likely also being released from bottom sediments during brief periods of stratification which form during periods of calm weather. Depletion of oxygen, even if just near the sediment water interface, is enough to cause significant release of phosphorus into the water column. Similarly, photosynthesis of the abundant algae population increases the pH of the lake during the day as they consume carbon dioxide. Under these elevated pH conditions, phosphorus also can be released from the sediment.

A study conducted on a hypereutrophic lake in New York found that under oxygenated conditions, with a water pH of 7.5, phosphorus was released at rates of 3.4, 7.0, and 4.8 $mg/m^2/day$ in May, June, and August, respectively (Penn et al. 2000). Applying these phosphorus release rates to the sediment of Beaver Dam Lake (6,841 acres) indicates that potentially over 40,000 pounds of phosphorus could be released from May through August. It must be noted that pH in Beaver Dam Lake was measured around 9.0, and phosphorus release rates may be higher given the higher pH. This estimate was calculated assuming that the lake remains oxygenated throughout the summer; however, as discussed previously, it is likely that Beaver Dam Lake experiences periods of anoxia during calm periods. During periods of anoxia, researchers found that phosphorus release rates from bottom sediments increased markedly to rates of nearly 40 $mg/m^2/day$ in the lake in New York. Using this anoxic phosphorus release rate, if Beaver Dam Lake experienced anoxia for just 12 hours at depths of 6 feet and greater, approximately 600 pounds of phosphorus would be released.

The estimates of phosphorus loading from bottom sediments from May through August align with phosphorus concentrations that have been measured within the lake. In May of 2014, phosphorus concentrations were measured at 73 µg/L. Using Beaver Dam Lake's water volume, it can be estimated that there was approximately 7,600 pounds of phosphorus within the water of the lake at that time. By October 2014, phosphorus concentrations had increased to 396 µg/L indicating that there was approximately 41,200 pounds of phosphorus within the water. This represents an increase of approximately 33,600 pounds of phosphorus from May to October. The previous analysis indicated that even if Beaver Dam Lake remains oxygenated, sediment release from bottom sediments can account for the measured increase in phosphorus concentration within the lake. It must be noted that this analysis did not include the phosphorus loading predicted from common carp, and that these values are estimates. However, while these estimates are not precise, they are indicators of the magnitude that phosphorus release from bottom sediments is likely having in the lake.

The water quality and watershed analyses of Beaver Dam Lake indicate complex processes are occurring within the lake, and the lake's poor water quality cannot solely be attributed to phosphorus loading from its highly developed watershed. WiLMS can also be used to estimate how a lake's water quality can change with modifications in land use within the watershed. As an extreme example, a model was created where 100% of the agricultural land within Beaver Dam Lake's watershed was converted to forest. The results of this model indicated a significant decline in the amount of phosphorus delivered to the lake, and excluding in-lake phosphorus cycling, predicted a growing season mean total phosphorus concentration of 22 µg/L. However, studies have shown that even if external sources of phosphorus are minimized, in-lake nutrient cycling can continue for decades (Jeppesen et al. 1990). When the estimated amount of phosphorus delivered via in-lake nutrient cycling was added to this model, predicted phosphorus concentrations only declined by a negligible 9 µg/L, from 250 µg/L to 241 µg/L. This model highlights the significance of these internal processes on Beaver Dam Lake's nutrient concentrations and overall water quality.

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. Beaver Dam Lake was first placed on the 303(d) list and listed as impaired in 2010. In the last listing cycle in 2014, Beaver Dam Lake was listed as impaired because total phosphorus concentrations exceed the 40 µg/L threshold for shallow lowland drainage lakes and the Trophic State Index value for chlorophyll-*a* exceeds 71. Both the total phosphorus and chlorophyll-*a* concentrations exceed thresholds for fish and aquatic life and for recreation.

3.4 Shoreland Condition

The Importance of a Lake's Shoreland Zone

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

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

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

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

Shoreland Zone Regulations

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

Wisconsin-NR 115: Wisconsin's Shoreland Protection Program

Wisconsin's shoreland zoning rule, NR 115, sets the minimum standards for shoreland development. First adopted in 1966, the code set a deadline for county adoption of January 1, 1968. By 1971, all counties in Wisconsin had adopted the code and were administering the shoreland ordinances it specified. Interestingly, in 2007 it was noted that many (27) counties had recognized inadequacies within the 1968 ordinance and had actually adopted more strict shoreland ordinances. Passed in February of 2010, 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:

- <u>Vegetation Removal</u>: For the first 35 feet of property (shoreland zone), no vegetation removal is permitted except for: sound forestry practices on larger pieces of land, access and viewing corridors (may not exceed 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).

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

- <u>Nonconforming structures</u>: Nonconforming structures are structures that were lawfully placed when constructed but do not comply with distance of water setback. Originally, structures within 75 ft of the shoreline had limitations on structural repair and expansion. 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

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

Shoreland Research

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

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

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

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 3.4-1. Example of a biolog restoration site.

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

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

Cost

The cost of native, aquatic, and shoreland plant restorations is highly variable and depends on the size of the restoration area, the depth of buffer zone required to be restored, the existing plant density, the planting density required, the species planted, and the type of planting (e.g. seeds, bare-roots, plugs, live-stakes) being conducted. Other sites may require erosion control stabilization measures, which could be as simple as using erosion control blankets and plants and/or seeds or more extensive techniques such as geotextile bags (vegetated retaining walls), geogrids (vegetated soil lifts), or bio-logs (see above picture). Some of these erosion control techniques may reduce the need for rip-rap or seawalls which are sterile environments that do nott allow for plant growth or natural shorelines. Questions about rip-rap or seawalls should be directed to the local Wisconsin DNR Water Resources Management Specialist. Other measures possibly required include protective measures used to guard newly planted area from wildlife predation, wave-action, and erosion, such as fencing, erosion control matting, and animal deterrent sprays. One of the most important aspects of planting is maintaining moisture levels. This is done by watering regularly for the first two years until plants establish themselves, using soil amendments (i.e., peat, compost) while planting, and using mulch to help retain moisture.

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

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

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

- A native seed mix is used in bare areas of the upland buffer zone.
- An aquatic zone with shallow-water 2 - 5’ x 35’ areas.
- Plant spacing for the aquatic zone would be 3 feet.
- Each site would need 70’ of erosion control fabric to protect plants and sediment near the shoreland (the remainder of the site would be mulched).
- Soil amendment (peat, compost) would be needed during planting.
- There is no hard-armor (rip-rap or seawall) that would need to be removed.
- The property owner would maintain the site for weed control and watering.

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

Beaver Dam Lake Shoreland Zone Condition

Shoreland Development

Beaver Dam 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 3.4-1 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.

3.4-1. Shoreland assessment category descriptions.

On Beaver Dam Lake, the development stage of the entire shoreland was surveyed during fall of 2014, 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 3.4-2.

Beaver Dam Lake has stretches of shoreland that fit all of the five shoreland assessment categories. In all, 25.5 miles (50%) of the shoreline was comprised of natural/undeveloped and developed-natural shoreline categories (Figure 3.2-2). These shoreland types provide the most benefit to the lake and should be left in their natural state if at all possible. During the survey, 19.3 miles (38%) of urbanized and developed–unnatural shoreland were observed. If restoration of the Beaver Dam Lake shoreland is to occur, primary focus should be placed on these shoreland areas as they currently provide little benefit to, and actually may harm, the lake ecosystem. Map 4 displays the location of these shoreland lengths around the entire lake.

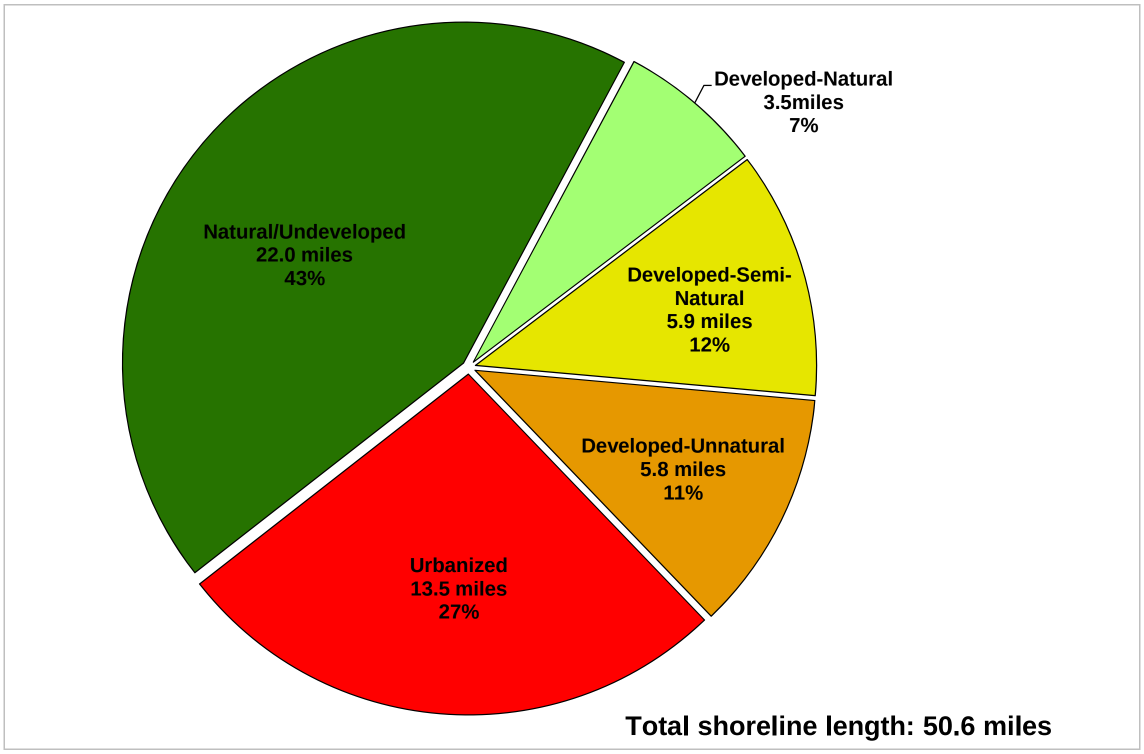


Figure 3.4-2. Beaver Dam Lake shoreland categories and total lengths. Based upon a fall 2014 survey. Locations of these categorized shorelands can be found on Map 4.

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

Coarse Woody Habitat

Beaver Dam Lake was surveyed in 2014 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 diameter, >8 inches 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 944 pieces of coarse woody habitat were observed along 50.6 miles of shoreline, which gives Beaver Dam Lake a coarse woody habitat to shoreline mile ratio of 19:1. To put this into perspective, Wisconsin researchers have found that in completely undeveloped lakes, an average of 345 coarse woody habitat structures may be found per mile (Christensen et al. 1996). 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 are displayed on Map 5.

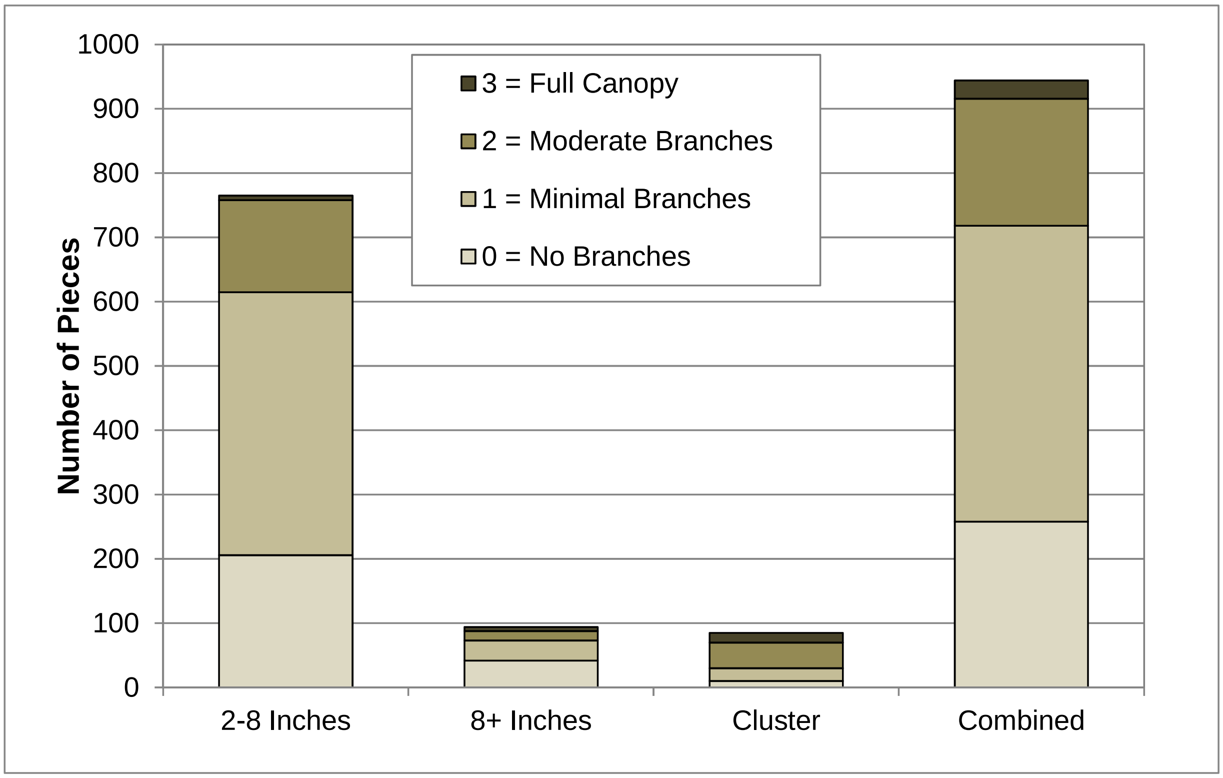


Figure 3.4-3. Beaver Dam Lake coarse woody habitat survey results. Based upon a Fall 2014 survey. Locations of Beaver Dam Lake coarse woody habitat can be found on Map 5.

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 water-milfoil (*Myriophyllum spicatum*) and curly-leaf pondweed (*Potamogeton crispus*) can also upset the delicate balance of a lake ecosystem by out competing native plants and reducing species diversity. These 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

Important Note:
Even though most of these techniques are not applicable to Beaver Dam 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 Beaver Dam Lake are discussed in Summary and Conclusions section and the Implementation Plan found near the end of this document.

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.

Permits

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

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

Manual Removal

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

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

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

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

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

Bottom Screens

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

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

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

Water Level Drawdown

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

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

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

Mechanical Harvesting

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

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

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

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

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

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

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

Biological Controls

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

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

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

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

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

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

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

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

Analysis of Current Aquatic Plant Data

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

As described in more detail in the methods section, multiple aquatic plant surveys were completed on Beaver Dam 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 Beaver Dam 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 Beaver Dam 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 Beaver Dam 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 water milfoil are the primary targets of this extra attention.

Eurasian water-milfoil is an invasive species, native to Europe, Asia and North Africa, that has spread to most Wisconsin counties (Figure 3.5-1). Eurasian water-milfoil is unique in that its primary mode of propagation is not by seed. It actually spreads by shoot fragmentation, which has supported its transport between lakes via boats and other equipment. In addition to its propagation method, Eurasian water-milfoil has two other competitive advantages over native aquatic plants, 1) it starts growing very early in the spring when water temperatures are too cold for most native plants to grow, and 2) once its stems reach the water surface, it does not stop growing like most native plants, instead it continues to grow along the surface creating a canopy that blocks light from reaching native plants. Eurasian water-milfoil can 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.

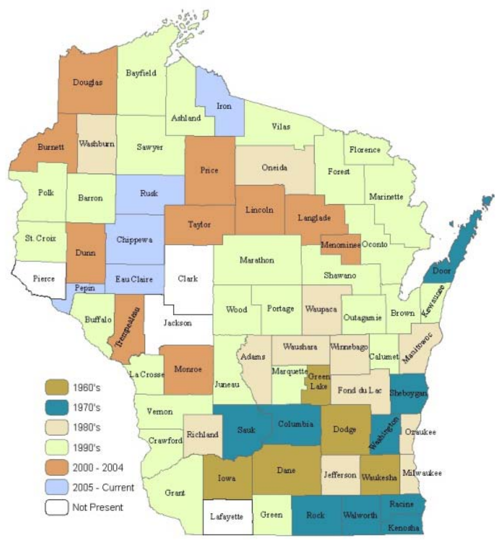


Figure 3.5-1. Spread of Eurasian water milfoil within WI counties. WDNR Data 2011 mapped by Onterra.

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 water-milfoil, 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 water milfoil starts to grow earlier than our native plants, it is at peak biomass during most of the summer, so it is inventoried during the comprehensive aquatic plant survey completed in mid to late summer.

Aquatic Plant Survey Results

As mentioned previously, a number of plant surveys were completed as a part of this project. Onterra ecologists completed the whole-lake aquatic point-intercept survey and emergent and floating-leaf plant community mapping survey on July 14, 16, and 17, 2014. During these surveys, 17 aquatic plant species were located, three of which are considered to be non-native, invasive species: curly-leaf pondweed, Eurasian water milfoil, and reed canary grass (Table 3.5-1). Because of their significance, these non-native plants in Beaver Dam Lake are discussed in the Non-Native Aquatic Plant Section.

Table 3.5-1. Aquatic plant species located in Beaver Dam Lake during 2014 surveys.

Growth Form	Scientific Name	Common Name	Coefficient of Conservatism (C)	2014 (Onterra)
Emergent	*Bolboschoenus fluviatilis*	River bulrush	5	I
	Phalaris arundinacea	Reed canary grass	Exotic	I
	Phragmites australis subsp. *americanus*	Giant reed	5	I
	Sagittaria latifolia	Common arrowhead	3	I
	Schoenoplectus tabernaemontani	Softstem bulrush	4	I
	Sparganium eurycarpum	Common bur-reed	5	I
FL	*Nymphaea odorata*	White water lily	6	X
Submergent	*Ceratophyllum demersum*	Coontail	3	X
	Elodea canadensis	Common waterweed	3	X
	Heteranthera dubia	Water stargrass	6	I
	Myriophyllum spicatum	Eurasian water milfoil	Exotic	I
	Potamogeton crispus	Curly-leaf pondweed	Exotic	X
	Potamogeton foliosus	Leafy pondweed	6	X
	Potamogeton strictifolius	Stiff pondweed	8	I
	Stuckenia pectinata	Sago pondweed	3	X
FF	*Lemna minor*	Lesser duckweed	5	X
	Spirodela polyrhiza	Greater duckweed	5	X

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

During the 2014 whole-lake point-intercept survey, information regarding substrate type was collected at locations sampled with a pole-mounted rake. These data indicate that the majority (95%) of point-intercept locations contained soft sediments, 3% contained sand, and 2% contained rock (Figure 3.5-2). Map 6 displays the distribution of substrate types in Beaver Dam Lake as determined from the 2014 point-intercept survey. Like terrestrial plants, different aquatic plant species are adapted to grow in certain substrate types; some species are only found growing in soft substrates, others only in sandy areas, and some can be found growing in either. Lakes that have varying substrate types generally support a higher number of plant species because of the different habitat types that are available. Beaver Dam Lake's substrate is relatively homogenous throughout, and areas of rock and sand were found in some areas near shore and around islands (Map 6).

The 2014 whole-lake point-intercept survey revealed that aquatic vegetation in Beaver Dam Lake is very sparse, with only 99 (14%) of the 703 point-intercept sampling locations that fell at or below the maximum depth of plant growth containing aquatic vegetation. Of the 99 sampling locations that contained aquatic vegetation, 83% fell within 2.0-4.0 feet of water. Map 7 displays the point-intercept locations that contained aquatic vegetation in Beaver Dam Lake in 2014 along with their respective total rake fullness rating. Submersed aquatic vegetation was most abundant in Rakes Bay, near the mouth of Beaver Creek, Weiss Bay, and Starkweather Bay. Most of the point-intercept locations containing aquatic vegetation had a total rake fullness rating of 1, indicating the density of vegetation was relatively low in areas where it was present (Figure 3.5-3).

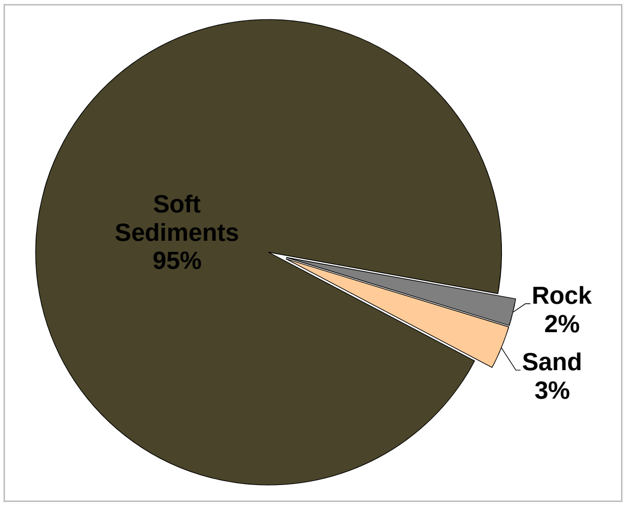


Figure 3.5-2. Beaver Dam Lake 2014 proportion of substrate types. Created using data from Onterra 2014 whole-lake point-intercept survey.

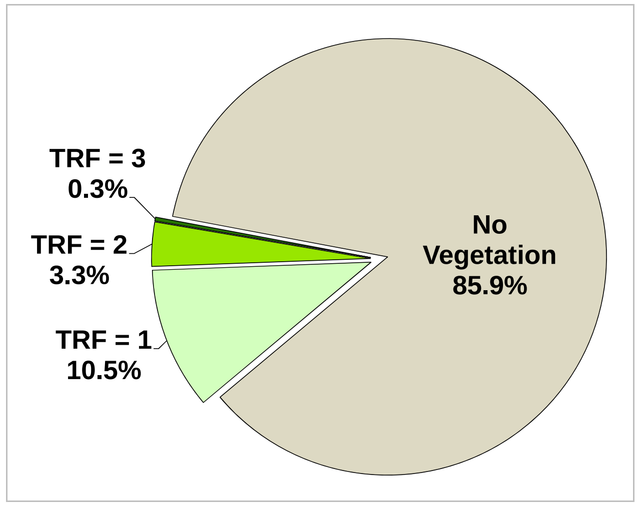


Figure 3.5-3. Beaver Dam Lake 2014 aquatic vegetation total rake fullness (TRF) ratings. Created using data from Onterra 2014 whole-lake point-intercept survey.

Of the 16 aquatic plant species located in Beaver Dam Lake in 2014, eight were physically encountered on the rake during the whole-lake point-intercept survey (Figure 3.5-4). Of these eight species, sago pondweed, curly-leaf pondweed, and coontail were the most frequently encountered. Sago pondweed, the most frequently encountered aquatic plant in Beaver Dam Lake with a littoral frequency of occurrence of approximately 10%, is a common rooted plant found in a variety of waterbodies throughout Wisconsin (Photo 3.5-1). It is highly tolerant of low-light conditions, and is often the last rooted plant able to survive in waterbodies with extremely turbid water (Borman et al. 2007). To survive in these conditions, it produces numerous needle-like leaves that spread out near or at the water's surface in a fan-shape to gather light. Sago pondweed has been found to be one of the most valuable food

Photo 3.5-1. Sago pondweed (*Stuckenia pectinata*), the dominant aquatic plant in Beaver Dam Lake, is highly tolerant of turbid conditions.

resources for waterfowl, producing numerous seeds and tubers.

The non-native curly-leaf pondweed was the second-most frequently encountered aquatic plant in Beaver Dam Lake in 2014; however, this species will be discussed in more detail in Non-Native Aquatic Plants Section. Coontail, a free-floating submersed species, was the third-most frequently encountered aquatic plant in 2014 with a littoral frequency of occurrence of 2% (Figure 3.5-4). Like sago pondweed, coontail is relatively tolerant of turbid conditions, and often one of the few aquatic plant species found in highly eutrophic lakes.

All of the remaining plants in Beaver Dam Lake, with the exception of stiff pondweed, are tolerant of the eutrophic, turbid conditions present within the lake. Stiff pondweed, one of the narrow-leaf pondweeds, is a species that is relatively sensitive and can only persist in relatively clear water (Hellquist and Pike 2003). In Beaver Dam Lake, a small population of stiff pondweed was located in the northwest portion of Rakes Bay near the mouth of an unnamed stream where water was noticeably clearer compared to the rest of the bay. The turbid conditions found throughout most of Beaver Dam Lake are not suitable for this species.

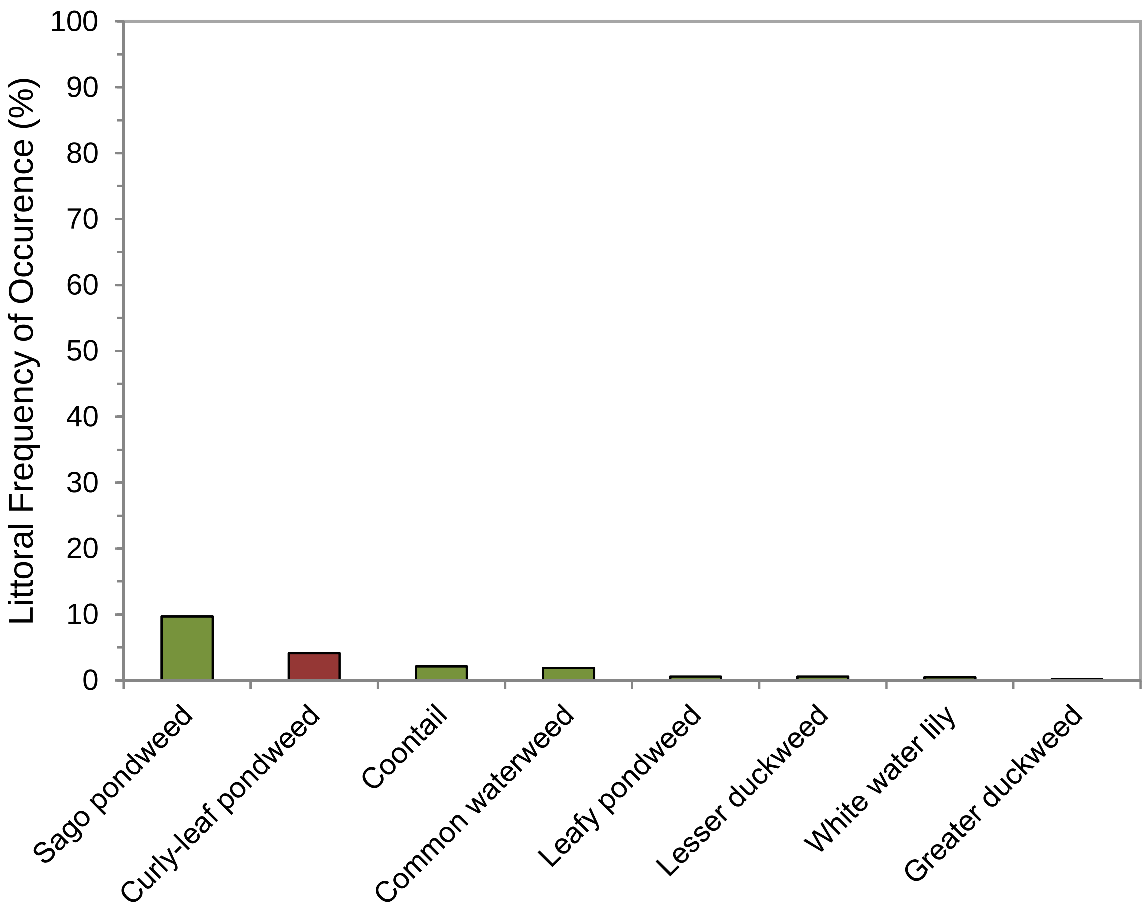


Figure 3.5-4. Beaver Dam Lake 2014 aquatic plant species littoral frequency of occurrence. Exotic species indicated with red. Created using data from 2014 whole-lake point-intercept survey.

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 native aquatic plant species that were encountered on the rake during the point-intercept survey and does not include incidentally located species. The seven native species encountered on the rake during the 2014 point-intercept survey and their conservatism values were used to calculate the FQI of Beaver Dam Lake's aquatic plant community (equation shown below).

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

Figure 3.5-5 compares Beaver Dam Lake's FQI components to median values of lakes within the Southeast Wisconsin Till Plains (SWTP) ecoregion and lakes throughout Wisconsin. The number of native aquatic plant species encountered in 2014 (7) is significantly lower than the median number for lakes in the SWTP ecoregion and the state. In fact, Beaver Dam Lake's species richness value falls in the bottom 25% for lakes in the ecoregion and the state. Beaver Dam Lake's average conservatism value of 4.4 also falls in bottom 25% for lakes within the SWTP ecoregion and lakes throughout Wisconsin. Using the native species richness and average conservatism value to calculate the FQI yields an exceptionally low value of 11.7 for Beaver Dam Lake. This value falls well below the median values for lakes within the ecoregion and lakes state-wide. Overall, this analysis indicates that Beaver Dam Lake's aquatic plant community is highly degraded and is an indicator of the poor conditions present within the lake.

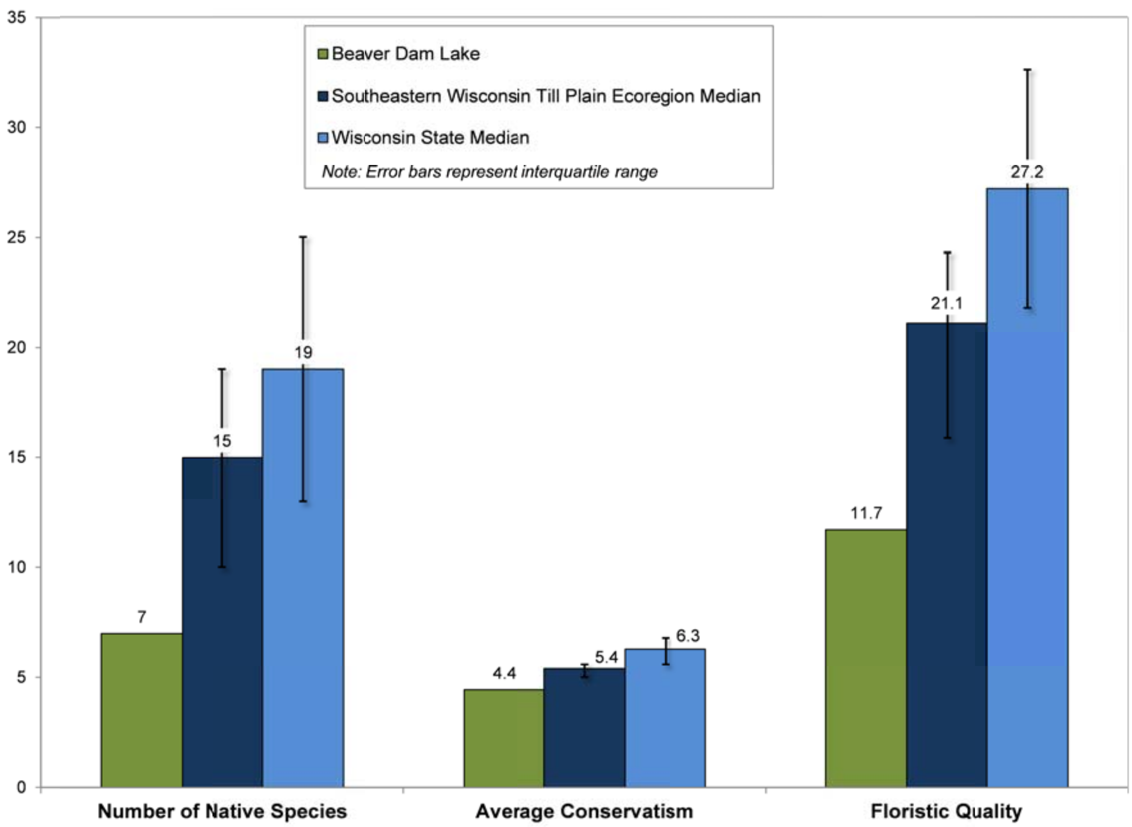


Figure 3.5-5. Beaver Dam Lake Floristic Quality Assessment. Created using data from 2014 whole-lake point-intercept survey. Regional and state medians calculated with Onterra and WDNR data.

As explained earlier, lakes with diverse aquatic plant communities are believed to 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. Unlike species richness, species diversity is also influenced by how evenly the plant species are distributed within the community.

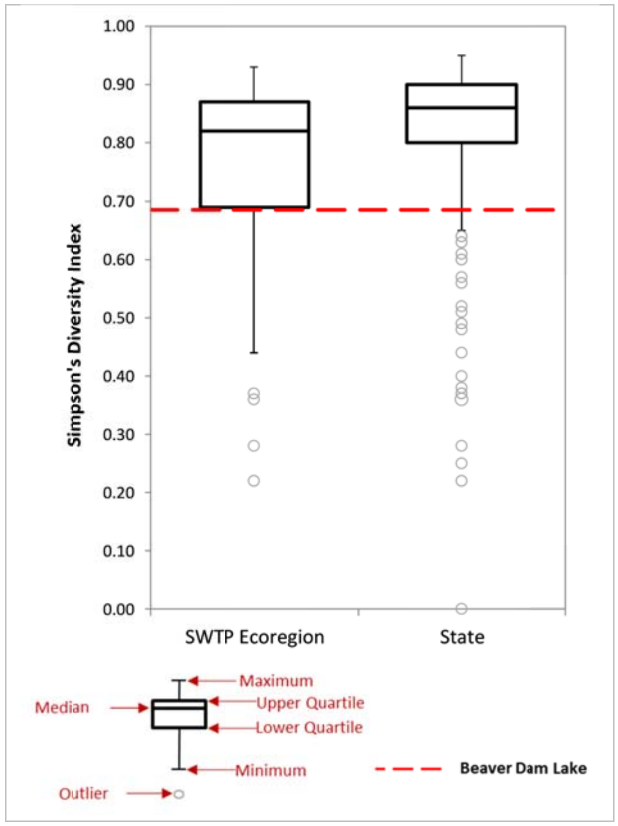


Figure 3.5-6. Beaver Dam Lake Simpson's Diversity Index. Created using data from WDNR 2006 and Onterra 2010, 2011, and 2014 whole-lake point-intercept surveys. Regional and state medians calculated with Onterra and WDNR data.

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 Beaver Dam Lake's diversity value ranks. Using data collected by Onterra and WDNR Science Services, quartiles were calculated for 77 lakes within the SWTP Ecoregion (Figure 3.5-6). Using the data collected from the 2014 point-intercept survey, Beaver Dam Lake's aquatic plant community was shown to have low species diversity with a Simpson's diversity value of 0.69. This value falls in the bottom 25% for lakes within the ecoregion and lakes throughout Wisconsin. In other words, if two individual aquatic plants were randomly sampled from Beaver Dam Lake in 2014, there would be a 69% probability that they would be different species.

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 sago pondweed was found at 10% of the littoral sampling locations in Beaver Dam Lake in 2014, its relative frequency of occurrence was 50%. Explained another way, if 100 plants were randomly sampled from Beaver Dam Lake in 2014, 50 of them would be sago pondweed. Figure 3.5-7 displays the relative occurrence of aquatic plant species from Beaver Dam Lake in 2014, and illustrates that the aquatic plant community is dominated by sago pondweed. The dominance of just a few species results in low species diversity.

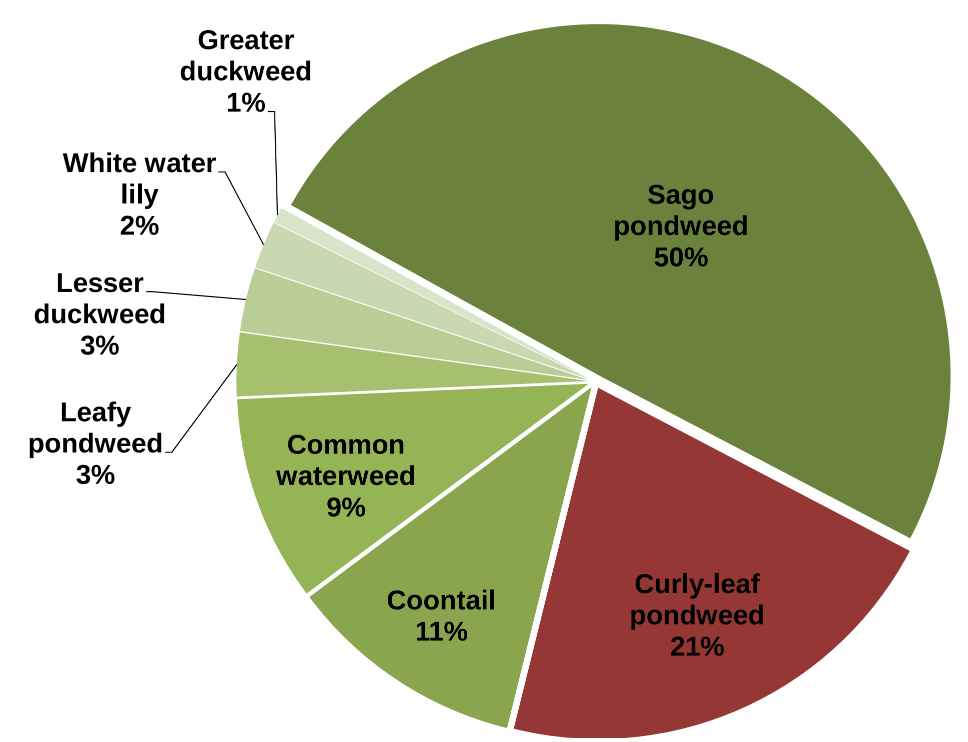


Figure 3.5-7. Relative frequency of occurrence of aquatic plant species in Beaver Dam Lake in 2014. Created using data from 2014 whole-lake point-intercept survey. Exotic species indicated with red.

As mentioned, Onterra ecologists also conducted an aquatic plant community mapping survey in 2014 aimed at mapping communities of emergent and floating-leaf vegetation. During this survey, approximately 34.0 acres, or 0.5% of the 6,841-acre lake, were found to contain emergent and floating-leaf aquatic plant communities (Table 3.5-2 Map 8-10). Six emergent and one floating-leaf species were located during the survey (Table 3.5-1). The majority of emergent communities in Beaver Dam Lake are dominated by cattails, while floating-leaf communities are comprised solely of white water lily. Giant reed was located in two locations during the 2014 survey. While an invasive subspecies of giant reed exists in Wisconsin, the UW-Stevens Point Herbarium identified the specimens from Beaver Dam Lake as the native subspecies.

Table 3.5-2. Acres of emergent and floating-leaf aquatic plant communities on Beaver Dam Lake in 2014. Created using data from 2014 aquatic plant community mapping survey.

Plant Community	Acres
Emergent	16.9
Floating-Leaf	15.2
Mixed Emergent & Floating-Leaf	1.9
Total	**34.0**

Over half of the emergent and floating-leaf aquatic plant community acreage was located in Rakes Bay where there is little shoreline development (Map 8). The majority of these communities were comprised of white water lily (Photo 3.5-2). 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 Beaver Dam 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.

Photo 3.5-2. Community of white water lily (*Nymphaea odorata*) in Rakes Bay.

In Rakes Bay, the state-endangered black tern (*Chlidonias niger*) was observed nesting within communities of white water lily (Photo 3.5-2). The black tern was listed as endangered in Wisconsin in 2014 after studies showed a 78% decline in their population since the early 1980s (WDNR 2014). According to the WDNR, this bird typically breeds in areas containing a mixed habitat of emergent vegetation and open water, and the largest threat to this species is habitat loss. The nearby Horicon Marsh is one of the primary conservation sites for this species in Wisconsin.

Non-native Aquatic Plants in Beaver Dam Lake

Curly-leaf pondweed

A date for the first verification of curly-leaf pondweed (*Potamogeton crispus*; CLP) in Beaver Dam Lake is not available; however, it was first documented in upstream Fox Lake in 1989, and it has likely been present in Beaver Dam Lake for some time. During the mid-July 2014 whole-lake point-intercept survey, curly-leaf pondweed had a littoral frequency of occurrence of 4% and was most abundant within the southwestern portion of the lake (Map 11). Unlike most of Wisconsin's aquatic plant species, curly-leaf pondweed reaches its peak growth in late-spring/early-summer before naturally senescing (dying back), and surveys aimed at quantifying CLP populations need to be conducted at that time. While CLP was observed and detected during the mid-July whole-lake point-intercept survey, it is likely that this occurrence is underestimated given that many plants likely had already senesced. To capture the full extent of CLP within Beaver Dam Lake, an Early-Season AIS Survey would need to be conducted sometime in June.

Eurasian water milfoil

Eurasian water milfoil (*Myriophyllum spicatum*; EWM) was first discovered in Beaver Dam Lake in 1990. In 2014, EWM was only located within the northern part of the lake, and occurrences were comprised of *single or few plants* and a *small plant colony* (Map 12). Eurasian water milfoil was not detected at any of the sampling locations during the 2014 whole-lake point-intercept survey, indicating it exists at a very low level within Beaver Dam Lake.

Reed canary grass

Reed canary grass (*Phalaris arundinacea*) is a large, coarse perennial grass that can reach three to six feet in height. Reed canary grass was found growing in areas along shoreline in the northern part of Beaver Dam Lake in 2014 (Map 9). Often difficult to distinguish from native grasses, this species forms dense, highly productive stands that vigorously outcompete native species. Unlike native grasses, few wildlife species utilize the grass as a food source, and the stems grow too densely to provide cover for small mammals and waterfowl. It grows best in moist soils such as wetlands, marshes, stream banks and exposed lake shorelands.

Reed canary grass is difficult to eradicate; at the time of this writing there is no efficient control method. Small, discrete patches have been covered by black plastic to reduce growth for an entire season. However, the species must be monitored because rhizomes may spread out beyond the plastic.

Beaver Dam Lake Aquatic Plant Community Summary

Standard analysis of the aquatic plant data collected during the 2014 whole-lake point-intercept survey and emergent/floating-leaf community mapping survey indicate that Beaver Dam Lake's aquatic plant community is highly degraded and indicative of a highly disturbed system. The majority of the lake is devoid of submersed vegetation, and areas that do contain vegetation are comprised of species that are highly tolerant to turbid, eutrophic conditions. As discussed within the Water Quality and Watershed Sections, the lake's poor water quality is driven by both external and internal processes. While aquatic plant species like sago pondweed are more tolerant of the turbid conditions present within Beaver Dam Lake, they are unable to withstand physical uprooting by common carp. The lack of vegetation within Beaver Dam Lake is due to a combination of limited light availability due to the high productivity of the lake driven by excessive nutrients and physical uprooting by common carp.

3.6 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 Beaver Dam 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).

Beaver Dam Lake Fishery

Beaver Dam 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 Beaver Dam Lake are supported by an underlying food chain. At the bottom of this food chain are the elements that fuel algae and plant growth – nutrients such as phosphorus and nitrogen, and sunlight. The next tier in the food chain belongs to zooplankton, which are tiny crustaceans that feed upon algae and plants, and insects. Smaller fish called planktivores feed upon zooplankton and insects, and in turn become food for larger fish species. The species at the top of the food chain are called piscivores, and are the larger gamefish that are often sought after by anglers, such as bass and walleye.

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

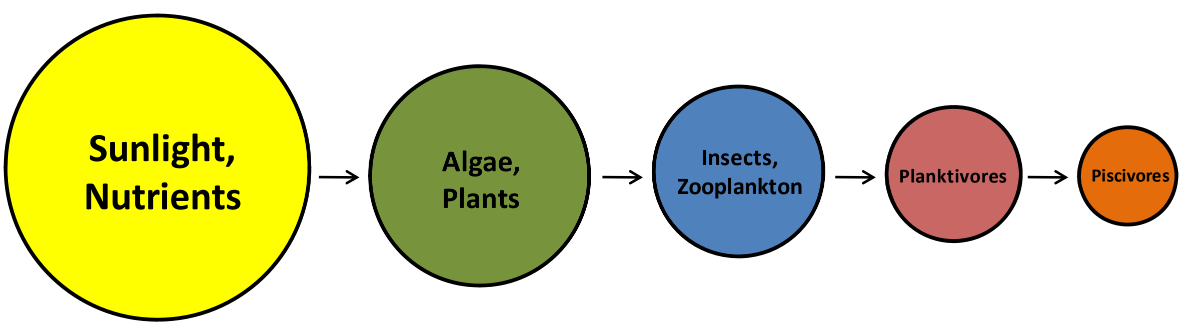


Figure 3.6-1. Aquatic food chain. Adapted from Carpenter et. al 1985.

As discussed in the Water Quality section, Beaver Dam Lake is a eutrophic system, meaning it has high nutrient content and thus relatively high primary productivity. Simply put, this means Beaver Dam Lake should be able to support sizable populations of predatory fish (piscivores) because the supporting food chain is relatively robust. Table 3.6-1 shows the popular game fish that are present in the system.

Table 3.6-1. Gamefish present in Beaver Dam 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
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
Warmouth	*Lepomis gulosus*	13	Mid May - Early July	Shallow water 0.6 - 0.8 m, with rubble slightly covered with silt	Crayfish, small fish, odonata, and other invertebrates
Yellow Perch	*Perca flavescens*	13	April - Early May	Sheltered areas, emergent and submergent veg	Small fish, aquatic invertebrates

Beaver Dam 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. The BDLIA and BDLDC have also contributed funds towards private stocking in years past. Table 3.6-2 displays recent (2003-present) stocking efforts in Beaver Dam Lake.

Table 3.6-2. Stocking data available for Beaver Dam Lake (2003-present).

Year	Species	Strain (Stock)	Age Class	# Fish Stocked	Avg Fish Length (in)	Stocked By
2007	Bass	-	-	200	-	BDLIA & BDLDC
2014	Bass	-	-	4,000	-	BDLIA & BDLDC
2005	Bluegill	-	-	8,300	-	BDLIA & BDLDC
2006	Bluegill	-	-	2,000	-	BDLIA & BDLDC
2007	Bluegill	-	-	4,500	-	BDLIA & BDLDC
2013	Bluegill	-	-	4,100	-	BDLIA & BDLDC
2014	Bluegill	-	-	14,000	-	BDLIA & BDLDC
2003	Northern Pike	Puckaway	Fry	300,000	0.4	WDNR
2003	Northern Pike	-	-	1,050	-	BDLIA & BDLDC
2004	Northern Pike	-	-	865	-	BDLIA & BDLDC
2005	Northern Pike	Puckaway	Fry	200,000	0.5	WDNR
2005	Northern Pike	-	-	1,000	-	BDLIA & BDLDC
2006	Northern Pike	Puckaway	Fry	200,000	0.5	WDNR
2006	Northern Pike	-	-	1,000	-	BDLIA & BDLDC
2007	Northern Pike	-	-	1,874	-	BDLIA & BDLDC
2009	Northern Pike	-	-	525	-	BDLIA & BDLDC
2010	Northern Pike	Mud Lake - Madison Chain of Lakes	Small fingerling	17,798	3.0	WDNR
2010	Northern Pike	-	-	875	-	BDLIA & BDLDC
2011	Northern Pike	Mud Lake - Madison Chain of Lakes	Small fingerling	19,089	2.6	WDNR
2012	Northern Pike	Mud Lake - Madison Chain of Lakes	Small fingerling	42,600	3.2	WDNR
2012	Northern Pike	-	Fry	250,000	-	BDLIA & BDLDC
2013	Northern Pike	Mud Lake - Madison Chain of Lakes	Small fingerling	15,056	3.6	WDNR
2013	Northern Pike	-	-	750	-	BDLIA & BDLDC
2014	Northern Pike	Mud Lake - Madison Chain of Lakes	Small fingerling	46,026	2.2	WDNR
2014	Northern Pike	-	-	200	-	BDLIA & BDLDC
2003	Walleye	Lake Michigan	Fry	940,000	0.5	WDNR
2003	Walleye	Rock-Fox	Fry	2,060,000	0.5	WDNR
2005	Walleye	Rock-Fox	Fry	1,870,000	0.5	WDNR
2006	Walleye	Rock-Fox	Fry	1,000,000	0.5	WDNR
2007	Walleye	Rock-Fox	Fry	2,540,000	0.2	WDNR
2008	Walleye	Rock-Fox	Small fingerling	111,124	1.6	WDNR
2008	Walleye	-	Large fingerling	32,000	-	BDLIA & BDLDC
2010	Walleye	Rock-Fox	Fry	2,300,000	0.1	WDNR
2010	Walleye	Rock-Fox	Small fingerling	114,889	1.7	WDNR
2011	Walleye	Rock-Fox	Small fingerling	111,214	1.5	WDNR
2012	Walleye	Rock-Fox	Small fingerling	104,259	2.1	WDNR
2013	Walleye	Rock-Fox	Small fingerling	111,326	1.4	WDNR
2013	Walleye	-	Large fingerling	1,325	-	BDLIA & BDLDC
2014	Walleye	Rock-Fox	Small fingerling	235,382	1.5	WDNR
2005	Yellow Perch	-	-	7,200	-	BDLIA & BDLDC
2006	Yellow Perch	-	-	15,625	-	BDLIA & BDLDC
2007	Yellow Perch	-	-	31,250	-	BDLIA & BDLDC
2009	Yellow Perch	-	-	40,000	-	BDLIA & BDLDC
2010	Yellow Perch	-	-	25,500	-	BDLIA & BDLDC
2011	Yellow Perch	-	-	19,000	-	BDLIA & BDLDC
2013	Yellow Perch	-	-	6,500	-	BDLIA & BDLDC
2014	Yellow Perch	-	-	14,000	-	BDLIA & BDLDC

Beaver Dam 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, 95% of the substrate sampled in the littoral zone on Beaver Dam Lake was soft sediments, with the remaining 5% being split between rock (2%) and sand (3%) (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.

Beaver Dam Lake Regulations and Management

Because Beaver Dam Lake is a popular sportfishing destination, special fisheries regulations may occur, specifically in terms of walleye and other popular gamefish. For 2015-2016, the daily bag limit is set at 3 for the lake. There is currently a minimum length limit of 18" for walleye. Table 3.5-3 displays the 2015-2016 regulations for species that may be found in Beaver Dam Lake. This table is intended to be for reference purposes, 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.

Table 3.6-3. WDNR fishing regulations for Beaver Dam Lake, 2015-2016.

Species	Season	Regulation
Catfish	Open All Year	No minimum length limit and the daily bag limit is 10.
Panfish	Open All Year	No minimum length limit and the daily bag limit is 25.
Largemouth and smallmouth bass	May 2, 2015 to March 6, 2016	The minimum length limit is 14” and the daily bag limit is 5.
Muskellunge and hybrids	May 2, 2015 to December 31, 2016	The minimum length limit is 40" and the daily bag limit is 1.
Northern pike	May 2, 2015 to March 6, 2016	The minimum length limit is 26” and the daily bag limit is 2.
Walleye, sauger, and hybrids	May 2, 2015 to March 6, 2015	The minimum length limit is 18" and the daily bag limit is 3.
Bullheads and rough fish	Open All Year	No minimum length limit and the daily bag limit is unlimited.
Rock, yellow, and white bass	Open All Year	No minimum length limit and the daily bag limit is unlimited.

4.0 SUMMARY AND CONCLUSIONS

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

1) Increase the general understanding of the Beaver Dam Lake ecosystem through studies designed to assess the lake's water quality, watershed, immediate shoreland zone, aquatic plant community, and fisheries.
2) In collaboration with Beaver Dam Lake Improvement Association, Inc. and other Beaver Dam Lake stakeholders, gather sociological information regarding their use of the lake, their thoughts pertaining to the past and current condition of the lake, and how they would like to move forward with the lake's management.

These two objectives were fulfilled during the project and have led to a better understanding of the Beaver Dam Lake ecosystem, the people who care about the lake, and what management actions need to be taken to protect and enhance it. Through the studies that were conducted on Beaver Dam Lake, it is clear that the lake is highly degraded in terms of its water quality and wildlife habitat. As discussed within the Water Quality Section, all parameters assessed indicate that the lake is hypereutrophic, suffering from excessive loading of nutrients (phosphorus and nitrogen), high algal production, and low water clarity. Presently, the lake is in a turbid, phytoplankton-dominated state.

The state of a lake's water quality is often a reflection of the state of the lake's watershed, or drainage basin. Beaver Dam Lake's watershed is highly disturbed, being mainly comprised of row crop agriculture which when compared to other land cover types exports the highest amounts of phosphorus. Modeling of Beaver Dam Lake's watershed estimated that approximately 23 tons of phosphorus is delivered to the lake from its watershed on an annual basis. The watershed is considered the primary *external* source of phosphorus. While this is a substantial amount of phosphorus, it is still not enough to account for the growing season mean total phosphorus concentration of 256 µg/L measured within the lake. An estimated additional 242 tons of phosphorus needs to be loaded to the lake annually to achieve the growing season mean total phosphorus concentration of 256 µg/L. This additional phosphorus is believed to be originating from *internal* sources of phosphorus. These internal sources include sediment resuspension by wind-induced wave action and common carp, excretion from common carp, and phosphorus release from bottom sediments during periods of anoxia and/or elevated pH.

Given the turbid conditions and presence of common carp in Beaver Dam Lake, the lake is sparsely vegetated and supports a low number of native aquatic plant species. Most of the native species that are present, such as sago pondweed and coontail, are tolerant of the turbid conditions. The Floristic Quality Assessment indicates that Beaver Dam Lake's plant community is of lower quality when compared to other lakes within the Southeast Wisconsin Till Plains ecoregion and lakes throughout Wisconsin. While the lake overall is lacking submersed, floating-leaf, and emergent vegetation, there are localized areas which contain more robust plant communities. Rakes Bay in the northwest portion of the lake contained larger expanses of sago pondweed, white water lily, and cattails. A number of water birds, including the state-endangered black tern, where observed in this area.

Small populations of the non-native, invasive submersed plants curly-leaf pondweed and Eurasian water milfoil were also observed during the 2014 surveys in Beaver Dam Lake. While a survey aimed specifically at curly-leaf pondweed was not conducted as part of this project, anecdotal reports from Beaver Dam Lake riparians in 2014 and 2015 indicate that there may be dense colonies of CLP throughout the lake in early summer. Within the Implementation Plan that follows, management actions are outlined to assess the lake's curly-leaf pondweed population. The non-native, invasive wetland plant reed canary grass was also observed along portions of the lake's shoreline.

During the planning process, the Planning Committee received detailed information regarding the condition of the lake, both in terms of its water quality and depauperate aquatic plant community. Much of that information focused upon shallow lake ecology and the tendency of shallow lakes, especially those with high nutrient levels like Beaver Dam Lake, to exist in either an algae dominated turbid-state, or a macrophyte-dominated clear state. Beaver Dam Lake is solidly in a turbid state and will likely remain that way until major actions are taken to attempt to convert it to a clear-state by enhancing aquatic plant growth. Decades of research has shown that maintaining static water levels reduces aquatic plant life in lakes. Research has also shown the periodic water level drawdowns during the growing season can initiate aquatic plant growth. Based upon that research and addition case-studies from Wisconsin, Onterra ecologists recommended a water level management plan be developed for Beaver Dam Lake aimed at increasing beneficial aquatic plant growth. During the second planning meeting a water level management plan was proposed that included drawing the lake down 2 feet during June and July in two consecutive years. Recent studies on some Mississippi Pools indicated that consecutive growing season drawdowns spurred on annual and perennial plant growth that sustained for up to 7 years.

Drawdowns are a very controversial topic around Beaver Dam Lake, as they are around many lakes in Wisconsin, especially flowages. During the second planning meeting, after discussion, the Planning Committee elected to not include any type of a water level management plan within Beaver Dam Lake's management plan.

Through the process of this lake management planning effort, the BDLIA has learned much about their lake, both in terms of its positive and negative attributes. Overall, the lake is in an unhealthy condition, but there are actions that can be taken to improve the ecosystem and recreational quality of the Beaver Dam Lake resource. It is now the BLDIA'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 BDLIA Planning Committee, and WDNR staff, and outlines the goals and action steps that the BDLIA will take to enhance and protect Beaver Dam Lake.

5.0 IMPLEMENTATION PLAN

The Implementation Plan presented below was created through the collaborative efforts of the Beaver Dam Lake Improvement Association, Inc. (BDLIA) 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 Beaver Dam 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: Improve Beaver Dam Lake's Water Quality

Management Action:	Continue monitoring of Beaver Dam Lake's water quality through WDNR Citizens Lake Monitoring Network.
Timeframe:	Continuation of current effort
Facilitator:	Bob Roell (Current CLMN Volunteer)
Description:	Monitoring water quality is an import aspect of every lake management planning activity. Collection of water quality data at regular intervals aids in the management of the lake by building a database that can be used for long-term trend analysis. 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. Volunteers from the BDLIA have been collecting water quality data on Beaver Dam Lake from two locations almost annually since 1995. The BDLIA realizes the importance of continuing this effort, which will supply them with valuable data about their lake. Moving forward, it is the responsibility of Bob Roell, current CLMN volunteer, to coordinate new volunteers as needed. When a change in the collection volunteer occurs, Rachel Sabre or the appropriate WDNR/UW-Extension staff will need to be contacted to ensure the proper training occurs and the necessary sampling materials are received by the new volunteer. 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.	Bob Roell, current CLMN volunteer, recruits new volunteer(s) as needed.

2. Volunteer contacts Rachel Sabre (262.574.2133) as needed.
3. Coordinator reports results to WDNR and BDLIA members during annual meeting.

Management Action: Continue annual harvesting of common carp from Beaver Dam Lake.

Timeframe: Continuation of current effort

Facilitator: Beaver Dam Lake Improvement Association, Inc. Board of Directors

Description: As discussed within the study results sections, non-native common carp impose negative impacts on lake ecosystems by increasing nutrients and turbidity, decreasing aquatic macrophyte abundance, and altering native fish communities. A WDNR study of the common carp population in Beaver Dam Lake in 2014 revealed that the density of common carp is approximately 330 pounds per acre, nearly twice the density that Lamarra (1976) indicated would cause detectable negative ecosystem impacts. It is believed that the common carp population in Beaver Dam Lake is a significant factor contributing to the current turbid state of the lake.

Commercial harvesting of common carp in Beaver Dam Lake has been occurring annually since the 1990s. While the commercial harvesters contract with the WDNR to harvest common carp on Beaver Dam Lake to sell to fish markets around the world, the removal of common carp also benefits the health of the lake. Understanding this, the BDLIA has subsidized the fishermen in the past to ensure harvesting in years when common carp prices fell below what was profitable.

Weber et al. (2011) found that common carp abundance substantially declined with commercial exploitation of up to 40% of the population. Beyond 40% exploitation, effects on carp abundance were limited; however, with exploitation from 40-60%, carp abundance and recruitment were reduced. They concluded that to maximize reductions to the common carp population, commercial harvesting should target 40-60% of population annually.

Based on the common carp population study conducted in Beaver Dam Lake in 2014, to achieve 40-60% exploitation of the carp population would include harvesting approximately 903 thousand to 1.3 million pounds of common carp annually. The average pounds of common carp (and buffalo) removed annually from 1996-2014 has been approximately 565 thousand pounds, or 25% of the 2014 population level. However, achieving the 40-60% exploitation level is not unrealistic as up to 1.7 million pounds of carp, or 75% of 2014 population level, have been harvested from the lake in one year (2014).

If the WDNR recommends that removing additional poundage of common carp from Beaver Dam Lake annually, the BDLIA would consider initiating an incentive program for the commercial harvester, such as offering a bonus to achieve the desired exploitation. However, the BDLIA needs to work with Laura Stremick-Thompson, or the current WDNR fisheries biologist, to determine the legalities of offering incentives to commercial fishermen. The BDLIA will also need to consult with Laura to determine if the current lottery system for commercial harvesters or contracted commercial harvesting would be the best method moving forward. In an effort to harvest more carp (and buffalo) from the lake, the BDLIA will also work with Laura to determine if the minimum size of fish caught can be lowered in the future.

Action Steps:

1. The BDLIA will work closely with Laura Stremick-Thompson (920.387.7876), or the current WDNR fisheries biologist, on the continued aggressive, annual harvesting of common carp by commercial fishermen in Beaver Dam Lake.
2. If warranted by the WDNR, the BDLIA will work with Laura-Stremick-Thompson, or current WDNR fisheries biologist to determine if avenues are available for the BDLIA to offer an incentive to the commercial harvester to achieve the recommended exploitation level.

<u>Management Action:</u> Reassess common carp population in Beaver Dam Lake in 2020.

Timeframe: Initiate 2018

Facilitator: Beaver Dam Lake Improvement Association, Inc. Board of Directors

Description: To determine if the annual commercial harvesting of common carp is successful at maintaining/lowering Beaver Dam Lake's population, the assessment of the carp population that was conducted in 2014 should be repeated in 2020. Based on the findings of this assessment, the commercial harvesting strategy can be "fine-tuned" as necessary. Like the assessment conducted in 2014, the BDLIA will need to begin preparations for the assessment with Beaver Dam Lake's WDNR fisheries biologist ahead of the 2020 study. The BDLIA should begin preparations for the 2020 carp population assessment in 2018.

Action Steps:

1. BDLIA Board of Directors contacts Laura Stremick-Thompson, or current WDNR fisheries biologist for Beaver Dam Lake, in 2018 to begin preparations for the 2020 carp population study.
2. Based on findings from the 2020 carp population study and guidance from WDNR fisheries biologist, the BDLIA Board of Directors modifies commercial harvesting strategy if necessary.

Management Action: Further investigate feasibility of limiting lake fetch to reduce wind-induced sediment resuspension.

Timeframe: Initiate 2016

Facilitator: Beaver Dam Lake Improvement Association, Inc. Board of Directors

Funding Source: WDNR Lake Protection Grant

Description: As discussed within the project results sections, shallow lakes like Beaver Dam Lake with a large surface area, sparse vegetation, and soft sediments are prone to experience the resuspension of bottom sediments due to wind-driven water movement. The resuspension of bottom sediments decreases water clarity suppressing aquatic plant growth and increases organic matter and nutrients within the water column.

Beaver Dam Lake's large surface area, shallow depth, and maximum fetch length of six miles makes the lake highly susceptible to wind-induced sediment resuspension. During the planning meetings, the possibility of reducing the fetch length of Beaver Dam Lake through the construction of barriers (islands, etc.) was discussed. Onterra ecologists conducted a literature review on fetch reduction and found that while it had been implemented on a number of shallow lakes, particularly in western Europe, the improvements to water quality in the lakes as a result were not readily apparent. However, because modeling of Beaver Dam Lake's watershed and water quality indicated that internal sources of phosphorus including wind-induced sediment resuspension are at present the most significant source of phosphorus to Beaver Dam Lake, the feasibility of limiting fetch length within the lake to reduce wind-induced sediment resuspension should be investigated further.

The first step in the feasibility study would include modeling of various wind speeds and directions across Beaver Dam Lake to determine the areas that are most susceptible to sediment resuspension. This same modeling can then be used to determine if the installation of barriers to limit the fetch within the areas would significantly reduce wind-induced sediment resuspension.

Action Steps:

1. Consultant solidifies study design with assistance of WDNR and other agencies as applicable.
2. Create preliminary project cost estimate.
3. BDLIA to apply to WDNR Lake Protection Grant for the February 2017 grant cycle to aid in funding for costs of fetch-limitation feasibility study.

Management Action:	Investigate feasibility of dredging specific areas of the lake to create barriers to reduce wind-induced sediment resuspension and/or improve navigation on Beaver Dam Lake.
Timeframe:	Initiate 2016
Facilitator:	Beaver Dam Lake Improvement Association Board of Directors
Description:	Sedimentation is a natural process that occurs as a lake ages. However, the high sedimentation rates in Beaver Dam Lake are likely driven mainly by the dominance of agriculture within the lake's watershed. During the planning meetings, the Planning Committee discussed the possibility of investigating areas of Beaver Dam Lake that could potentially be dredged to create barriers to reduce wind-induced sediment resuspension and/or improve navigation in certain areas of the lake. Completing a dredging project is not only costly to implement, but the extensive permitting process is extremely taxing. All forms of dredging require a permit. As a part of the permitting process, the BDLIA may be required to conduct an analysis of the sediments to be extracted if upon pre-application screening the department determines there is a reason to believe some level of contamination may exist. If contaminants are not perceived to exist within the system, the department may waive the sediment sampling requirements under NR 347.06 (3)(a) Adm. Code. More information regarding dredging in lakes and the permits that are or are not required may be found at the WDNR's waterway and wetland permits dredging website: http://dnr.wi.gov/topic/waterways/construction/dredging.html.
Action Steps:	
1.	BDLIA contacts Travis Schroeder (262.574.2172), regional WDNR Water Regulations and Zoning Specialist, to investigate feasibility of dredging on Beaver Dam Lake.

Management Action:	Conduct nutrient budget analysis on Beaver Dam Lake.
Timeframe:	Initiate 2016
Facilitator:	Beaver Dam Lake Improvement Association, Inc. Board of Directors
Funding Source:	WDNR Lake Protection Grant
Description:	As discussed within the Water Quality and Watershed Sections, phosphorus in Beaver Dam Lake originates from two primary compartments: external and internal sources. While in-lake total phosphorus concentration data, lake volume, and flow rate data from the lake's dam allow for an accurate estimate of the total amount of phosphorus flowing into the lake on an annual basis, these data do not allow for an accurate breakdown of the amount of phosphorus

originating from external versus internal sources.

Modeling of Beaver Dam Lake’s watershed using the acreages of land cover types as well as water quality data from Fox and Lost Lakes was used to estimate the amount of phosphorus being loaded to the lake externally from the watershed. With this estimate, the additional phosphorus required to reach the measured in-lake concentration was attributed to internal sources. This modeling indicated that at present, approximately 90% of the phosphorus being loaded to Beaver Dam Lake annually originates from internal sources while 10% originates from external sources.

To obtain a more accurate estimate of the amount of phosphorus originating from external and internal sources, an in-depth tributary monitoring study or advanced watershed modeling analysis would need to take place. The goal of this study would be to gain a more accurate estimate of the phosphorus being loaded to Beaver Dam Lake externally via the watershed. This more accurate external estimate would then allow for a better estimate of the amount of phosphorus being loaded to the lake from internal sources. However, at this time there is not a feasible method for compartmentalizing the various internal sources (i.e. common carp, wind-induced sediment resuspension, etc.).

However, collecting bio-available phosphorus concentrations from within the lake and the tributaries may allow for a determination of what proportion of the total phosphorus within the lake is available for use by algae. This may also allow for a determination of where the most bio-available phosphorus is originating (i.e. internally from common carp or externally from the watershed). If the BDLIA decides to move forward with a tributary monitoring study, the collection of bio-available phosphorus data would need to be investigated further.

An advanced modeling assessment of Beaver Dam Lake’s watershed could include the utilization of the Soil and Water Assessment Tool (SWAT) model. While the SWAT model utilizes land cover types within the watershed like the WiLMS model utilized in this study, the SWAT model is much more in depth and utilizes a number of additional variables including basin slope, crop rotations, fertilizer application rates and timing, and others.

Another option for obtaining more accurate external phosphorus load estimates would be to conduct a tributary monitoring study. Beaver Dam Lake contains 15 perennial tributaries, and monitoring flow and water quality within all 15 is very likely unrealistic due to cost and time constraints. For this reason, the tributaries to be monitored would be selected based upon the amount of water and nutrients they contribute to Beaver Dam Lake. A combination of flow monitoring and land cover assessment within each tributary's watershed would be conducted to determine which tributaries likely contribute the most nutrients to the lake. These primary tributaries would be targeted for monitoring.

Phosphorus loading from these primary tributaries would be estimated using FLUX, a model developed by William Walker of the US Army Corps of Engineers Waterways Experimentation Station (Walker 1999). FLUX is an interactive program designed for use in estimating the loadings of nutrients or other water quality components passing a tributary sampling station over a given period of time. FLUX requires three sets of data for loading estimations: 1) continuous, daily flows spanning the time period of interest, 2) periodic grab samples analyzed for the parameter of concern and collected over a range of flows, and 3) instantaneous flows corresponding to the time the grab samples were collected.

Daily and instantaneous flows would be determined using flowmeters that would be installed within the primary tributaries of concern. Grab samples for total phosphorus and suspended solids would likely be collected by BDLIA volunteers at regular intervals throughout the growing season. To obtain the most accurate data, tributary monitoring would likely have to be conducted for at least two years. Because of the number of tributaries that would need to be monitored and the likely high cost of sample and data analysis, this project would be highly dependent on BDLIA volunteers to be able to collect the samples. In the end, the results of this study would allow for a determination of which tributaries require the most attention in terms of nutrient reductions, and it would yield a more accurate estimate of how much phosphorus originates from internal sources.

Action Steps:

1. BDLIA contacts consulting firm, such as Cadmus Group of Madison (608.250.1920) to discuss costs and limitations of using SWAT to model watershed inputs to Beaver Dam Lake. The names of additional consulting firms specializing in SWAT use may be obtainable from Mark Riedel (608.275.3471), WDNR TMDL Specialist.
2. If SWAT modeling is feasible, create Lake Protection Grant to fund modeling and subsequent analysis. If not feasible, move to Step 3.
3. Contact qualified consulting firm to conduct tributary monitoring and load modeling on a portion of the tributaries entering Beaver Dam Lake.

Management Action:	Collaborate with Dodge, Columbia, Green Lake, and Fond du Lac County land conservation departments to determine how the BDLIA can participate and assist with implementation of best management practices within Beaver Dam Lake's watershed.
Timeframe:	Initiate 2016
Facilitator:	William Foley
Description:	Beaver Dam Lake's watershed falls across four Wisconsin counties, with 72% of the watershed falling in Dodge County, 25% in Columbia County, 2% in Green Lake County, and 1% in Fond du Lac County. While many improvements were made to Beaver Dam Lake's watershed through the Beaver Dam River Priority Watershed Project that was completed in 2006, nonpoint source pollution from agricultural areas is still a significant contributor of phosphorus and sediments to the lake and its tributaries (Dodge County 2012). The BDLIA currently has a member, William Foley, on the Dodge County Land Conservation Committee and should continue to have association representation on this committee into the future. Through this representation, the BDLIA can bring Beaver Dam Lake's watershed concerns to the county and develop strategies for reducing phosphorus and sediment runoff into the lake and its tributaries. While the majority of Beaver Dam Lake's watershed falls within Dodge County, the BDLIA should also form relationships with the land conservations departments in Columbia, Green Lake, and Fond du Lac Counties which contain smaller portions of the lake's watershed. The contact information for each conservation department can be found in the table below. During the third planning meeting, concerns were raised about contaminated groundwater, specifically nitrates, around Beaver Dam Lake. The BDLIA should also work with these county land conservation departments to determine what actions can be taken to reduce groundwater contamination within the Beaver Dam Lake watershed.
Action Steps:	
1.	William Foley, as a member of the Dodge County Land Conservation Committee, works with the Dodge County Land Conservation Department to determine ways the BDLIA can assist the county in implementing best management practices within the portion of Beaver Dam Lake's watershed that falls within Dodge County.
2.	William Foley contacts conservation departments from Columbia, Green Lake, and Fond du Lac Counties (see table below) to determine how the BDLIA can work with these departments to implement best management practices within the respective portions of Beaver Dam Lake's watershed.

3. William Foley recruits new volunteer to be on Dodge County Land Conservation Committee as needed.

Partner	Contact
Dodge County Land Conservation Department	Marc Bethke (920.386.3660)
Columbia County Land & Water Conservation Department	General Contact (608.742.9670)
Green Lake County Land Conservation Department	General Contact (920.294.4051)
Fond du Lac County Land & Water Conservation Department	Paul Tollard (920.923.3033)

Management Action: Investigate procedure/cost to update Nine-Key Element Watershed Plan for Beaver Dam Lake.

Timeframe: Initiate 2016

Facilitator: Beaver Dam Lake Improvement Association, Inc. Board of Directors

Description: The completion of the Beaver Dam River Priority Watershed Project in 2006 also functioned as an Environmental Protection Agency (EPA)-approved Nine-Key Element (9KE) Watershed Plan. The EPA has identified nine key elements that are critical for realizing enhancements in water quality. Watershed plans that wish to seek funding for implementation projects through the Clean Water Act section 319 funds require that the following nine elements be addressed (adapted from USEPA 2008):

1. An identification of the causes of water quality impairment (e.g. excess phosphorus).
2. An estimate of the load reductions expected from management measures.
3. A description of nonpoint source management measures that need to be implemented to achieve load reductions.
4. An estimate of the amount of technical and financial assistance needed to implement the plan.
5. An information and education component to enhance public understanding of the project and encourage public participation.
6. Schedule for implementing the nonpoint source management measures identified in the plan.
7. Description of interim, measureable milestones to measure progress in implementing the management measures.
8. Criteria that can be used to determine whether loading reductions are being achieved over time.
9. A monitoring component to evaluate the effectiveness of the implementation efforts over time, measured against established criteria.

The 9KE plan developed for Beaver Dam Lake in 2006 expires in

2019, meaning that the watershed will no longer be eligible for Section 319 funds. The BDLIA should investigate what steps need to be taken and what it will cost to update this 9KE watershed plan. An updated plan will make the watershed eligible for Section 319 funds to implement best management practices within the watershed beyond 2019.

Action Steps:

1. BDLIA Board of Directors contacts Andrew Craig, WDNR Nonpoint Source Planning Coordinator at 608.267.7695 do determine the feasibility of updating the 9 Nine-Key Element Watershed Plan.

Management Goal 2: Increase and Enhance Fish and Wildlife Habitat in and around Beaver Dam Lake

Management Action: Initiate aquatic plant community enhancement project on Rakes Bay, Trestle Bay, and Bayside Bay by restricting access to common carp.

Timeframe: Initiate 2016

Facilitator: Beaver Dam Lake Improvement Association, Inc. Board of Directors

Funding Source: WDNR Lake Protection Grant

Description: As discussed within the Aquatic Plant Section, Beaver Dam Lake lacks fish and wildlife habitat in terms of all forms of aquatic plants. The turbid, low-light conditions and physical uprooting/consumption by common carp suppress aquatic plant growth. While common carp will likely never be able to be eliminated from the system, the fact that Rakes Bay, Trestle Bay, and Bayside Bay all flow into Beaver Dam Lake Proper through narrow constrictions means that common carp may be restricted from these bays through the installation of barriers (Map 13). Restricting common carp in these areas may allow aquatic plant communities to expand, increasing fish and wildlife habitat, reducing sediment resuspension, and enhancing the quality of the water leaving these bays and into Beaver Dam Lake Proper. Carp were restricted from a bay on Big Green Lake (Green Lake County) and surveys documented large increases in aquatic plant growth and increases in water clarity within this bay following carp restriction.

The BDLIA will seek funding through a WDNR Lake Protection Grant in February of 2017 to fund the installation of carp barriers at the mouths of Rakes Bay, Trestle Bay, and Bayside Bay. The optimal time for barrier installation will likely the early spring or fall when most of the carp will be in deeper water in Beaver Dam Lake Proper. Because the barriers will be installed when most of the carp are absent from these bays, it is not believed that commercial harvesting of carp or chemical treatment of these bays will be necessary. The BDLIA will investigate which type of carp barrier (i.e. bar gates versus bubble gates) would be most appropriate at these locations.

To determine if the aquatic plant communities of Rakes Bay, Trestle Bay, and Bayside Bay improve following the restriction of carp, aquatic plant inventories would be completed pre-carp restriction in the summer of 2017 and post-carp restriction in the summers of 2018 and 2019. The whole-lake point-intercept survey method would be used in each bay each year to quantify the frequency of aquatic vegetation and the abundance of each species present. Statistical analysis (Chi-Square) would be used to determine if there are statistical differences in the occurrence of vegetation pre- and post-carp restriction. A community mapping survey to map areas of floating-leaf and emergent vegetation would also be conducted each year to determine if these communities expand following carp restriction.

While there is no established target that would determine a successful aquatic plant community restoration within these three bays, the restoration would be deemed successful if 1) the overall frequency of aquatic plant occurrences increases by a statistically valid margin each year post-carp restriction, 2) the Floristic Quality Index increases each year post-carp restriction, and 3) the acreage of floating-leaf and emergent aquatic plant communities increases by at least 20%.

Action Steps:

1. BDLIA selects qualified consultant to assist with project.
2. Consultant solidifies study design with assistance from WDNR and other agencies as applicable.
3. BDLIA works with WDNR fisheries biologist, Laura Stremick-Thompson, to determine cost of installing/repairing carp barriers at the mouths of Rakes Bay, Trestle Bay, and Bayside Bay.
4. Create preliminary project cost estimate.
5. BDLIA to apply for WDNR Lake Protection Grant for February 2017 grant cycle to aid in funding for costs of 2017, 2018, and 2019 analyses.

<u>Management Action:</u> Investigate restoring highly developed shoreland areas on Beaver Dam Lake.

Timeframe: Continuation of current effort

Facilitator: Beaver Dam Lake Improvement Association Board of Directors

Funding Source: WDNR Healthy Lakes Initiative Grant Program

Description: The 2014 Shoreland Assessment of Beaver Dam Lake found that approximately 38% (19.3 miles) of the lake's immediate shoreland zone is highly developed (urbanized and developed-unnatural) and in an unnatural 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 Dodge County staff devoted to these types of projects give private property owners the funds and informational resources to restore quality shoreland habitat to their lakeside residence. The BDLIA has already initiated five shoreland restoration projects on privately-owned shorelines through the WDNR's Healthy Lakes Initiative and is hosting a seminar on *Shoreline Landscape Solutions* in the fall of 2015.

To continue improvement of Beaver Dam Lake's shoreland zone, the shoreland areas on Beaver Dam Lake delineated as Urbanized and Developed-Unnatural should be prioritized for restoration. The BDLIA would acquire information from and work with appropriate entities such as Marc Bethke (920.386.3660) from the Dodge County Land Conservation Department to research grant programs, shoreland restoration techniques, and other pertinent information that will help the BDLIA.

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. Recruit facilitator(s) from BDLIA.
2. Facilitator contacts Marc Bethke (920.386.3660) from Dodge County Land Conservation Department to gather information on initiating and conducting shoreland restoration projects.
3. The BDLIA would encourage property owners that have restored their shorelines to serve as demonstration sites.

Management Action: Provide Beaver Dam Lake stakeholders with educational materials on the benefits of maintaining a natural shoreline and how to minimize impacts to the lake from lakeshore properties.

Timeframe: Initiate 2016

Facilitator: Beaver Dam Lake Improvement Association Board of Directors

Description: Education represents an effective tool to address lake issues such as best management practices of lakeshore properties. Currently, the BDLIA publishes an association newsletter and maintains a website. Both of these mediums are an excellent source for communication and education to both association and non-association members.

The BDLIA would like to provide Beaver Dam Lake property owners with information on how to maintain a lakeshore property that minimizes negative impacts to the lake. This information can be included within the association's newsletter and/or website or distributed as separate educational materials. Example educational topics pertaining to best management practices of lakeshore properties can be found below:

- Shoreline restoration and protection
- Importance of maintaining coarse woody habitat
- Effect lawn fertilizers/herbicides have on the lake
- Dodge County Shoreland Protection Ordinance (http://www.co.dodge.wi.us/modules/showdocument.aspx?docum docum=628)
- Reducing shoreline erosion

Action Steps: See description above.

Management Action: Preserve natural shoreland areas on Beaver Dam Lake.

Timeframe: Initiate 2016

Facilitator: Beaver Dam Lake Improvement Association Board of Directors

Description: The Shoreland Assessment conducted on Beaver Dam Lake in 2014 indicated that approximately 50% (25.5 miles) of the lake's shoreline are completely undeveloped or in a minimally developed state. While the majority of these natural shoreland areas are wetlands and undevelopable, many occur on potentially developable land. It is very important that owners of these properties become educated on the benefits their shoreland is providing to Beaver Dam 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. An appointed person(s) from the BDLIA will work with appropriate entities to research grant programs and other pertinent information that will aid the BDLIA in preserving Beaver Dam Lake's natural shorelands. 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 Dodge County Land Conservation Department. Several websites of interest include:

- Wisconsin Lakes website: www.wisconsinlakes.org/shorelands)
- Conservation easements or land trusts: (www.northwoodslandtrust.org)
- 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. Recruit facilitator(s) (potentially same facilitator as previous management action).
2. Facilitator(s) gathers appropriate information from sources described above.

Management Action:	Reevaluate Beaver Dam Lake's Dam Order.
Timeframe:	Initiate 2016
Facilitator:	Rob Davis and Beaver Dam Lake Improvement Association Board of Directors
Description:	As discussed within the Water Quality Section, water levels in Beaver Dam Lake are maintained and controlled by the Upper Beaver Dam which is owned by the City of Beaver Dam. The dam is continually monitored to prevent excessive fluctuation in water level and according to the Dam Order, water levels are to be maintained as close as possible to the normal operating level of 88.30 feet. Water levels in the lake are

lowered beginning March 1 of every year to reach a level of 87.70 by March 15 to mitigate against potential flooding from spring runoff. This lower water level is maintained until April 1 or until the lake is completely free of ice; however, the lake level cannot exceed 88.00 until April 15. A minimum discharge of 3.0 cubic feet per second must be passing through the dam at all times, and the lake level may be lowered to allow for this flow rate.

During the planning meetings, concerns were raised about the current dam order, specifically surrounding lowering of the water level while ice was still present on the lake. The Planning Committee indicated that when the water is lowered beneath the ice, the ice then scours the shoreline as well as damages property. Rob Davis and a representative from the BDLIA will investigate the lake's current dam order with the City of Beaver Dam. After this review, the BDLIA will work with the City to determine if the dam order can be modified to address the concerns of the Beaver Dam Lake stakeholders.

Action Steps:

1. Rob Davis and a representative(s) from the BDLIA will contact Don Quarford (920.887.4624), the City of Beaver Dam Utility Director to review Beaver Dam Lake's current dam order and determine if the order can be amended to address lake stakeholder concerns.

Management Goal 3: Enhance the Fishery of Beaver Dam Lake

Management Action: Work with WDNR and private landowners to expand coarse woody habitat in Beaver Dam Lake.

Timeframe: Initiate 2016

Facilitator: Beaver Dam Lake Improvement Association Board of Directors

Description: BDLIA stakeholders must realize the complexities and capabilities of the Beaver Dam Lake ecosystem with respect to the fishery it can produce. With this, an opportunity for education and habitat enhancement is present in order to help the ecosystem reach its maximum fishery potential. Often, property owners will remove downed trees, stumps, etc. from a shoreland area because these items may impede watercraft navigation shore-fishing or swimming. However, these naturally occurring woody pieces serve as crucial habitat for a variety of aquatic organisms, particularly fish.

The BDLIA will encourage its membership to implement coarse woody habitat projects along their shoreland properties. Habitat design and location placement would be determined in accordance with the WDNR fisheries biologist. The BDLIA's goal is to implement five course woody habitat implementation projects on Beaver Dam Lake through the WDNR's Fish Sticks Program (see below) in 2016.

The WDNR's Healthy Lakes Implementation Plan allows partial cost coverage for coarse woody habitat improvements (referred to as "fish sticks"). 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.

- 75% state share grant with maximum award of $25,000; up to 10% state share for technical assistance
- Maximum of $1,000 per cluster of 3-5 trees (best practice cap)
- Implemented according to approved technical requirements (WDNR Fisheries Biologist) and complies with local shoreland zoning ordinances
- Buffer area (350 ft^2) at base of coarse woody habitat cluster must comply with local shoreland zoning or :
  - The landowner would need to commit to leaving the area un-mowed
  - The landowner would need to implement a native planting (also cost share thought this grant program available)
- Coarse woody habitat improvement projects require a general permit from the WDNR
- Landowner must sign Conservation Commitment pledge to leave project in place and provide continued maintenance for 10 years

Action Steps:

1. Recruit facilitator(s) from BDLIA (potentially same facilitator as previous management actions).
2. Facilitator contacts Laura Stremick-Thompson (WDNR Fisheries Biologist – 920.387.7876) and Susan Graham (WDNR Lakes Coordinator – 608.275.3329) to gather information on initiating and conducting coarse woody habitat projects.
3. The BDLIA would encourage property owners that have enhanced coarse woody habitat to serve as demonstration sites.

<u>Management Action:</u> Work with fisheries managers to enhance the fishery of Beaver Dam Lake.

Timeframe: Continuation of current effort

Facilitator: Beaver Dam Lake Improvement Association Board of Directors

Description: Beaver Dam Lake is currently overseen by WDNR fisheries biologist Laura Stremick-Thompson. In order to keep informed of survey studies that are occurring on Beaver Dam Lake, a volunteer from the BDLIA should contact Ms. Stremick-Thompson at least once a year (perhaps during the winter months when field work is not occurring) for a brief summary of activities.

The BDLIA will work with Laura to investigate the following items relating to the lake's fisheries:

1) If natural recruitment of gamefish could be increased by enhancing spawning areas through substrate modification and habitat improvement.
2) Determine which gamefish species should be stocked, the amount that should be stocked, and when they should be stocked.
3) Effective methods of maintaining a walleye population that is deemed healthy by the WDNR.
4) The installation of a fish screen at the dam.

Action Steps:

1. See description above.

<u>Management Action:</u> Reevaluate winter aeration of Beaver Dam Lake to prevent winter fish kills.

Timeframe: Initiate 2016

Facilitator: Beaver Dam Lake Improvement Association Board of Directors

Description: Currently, the BDLIA deploys aerators in Beaver Dam Lake during the winter to maintain areas of open water and thus sufficient oxygen levels within the water to avoid winter fishkill. The aerators are deployed in three locations within the lake. However, the aerators are currently positioned linearly, and the BDLIA would like to continue to work on aerator guidelines for deployment and their placement. The BDLIA should work contact William/Reid LTD, LLC (262.255.5420), the firm that provided the BDLIA with the aerators, to reevaluate Beaver Dam Lake's aeration plan and find the most effective deployment arrangement. It may be appropriate to solicit guidance from other aeration contractors as well.

Action Steps:

1. Recruit facilitator(s) from BDLIA to contact William/Reid LTD, LLC (262.255.5420).
2. Facilitator works with William/Reid LTD, LLC to reevaluate Beaver Dam Lake's current aeration strategy and determine optimal deployment arrangement for aerators in the future.

Management Goal 4: Increase Recreational Enjoyment and Safety on Beaver Dam Lake

Management Action: Promote passive recreation (kayaking, canoeing, etc.) on Beaver Dam Lake.

Timeframe: Initiate 2016

Facilitator: Beaver Dam Lake Improvement Association Board of Directors

Description: During the third planning meeting, members of the Planning Committee indicated that they would like to increase passive recreation, such as kayaking, canoeing, wind surfing, sailboats, and ice boating on Beaver Dam Lake. The BDLIA should contact the Beaver Dam Chamber of Commerce (920.887.8879) and the Wisconsin Department of Tourism (608.266.7621) to determine methods of increasing and attracting passive recreationalists to Beaver Dam Lake.

The BDLIA will also work with the Beaver Dam Unified School District to get students interested in recreational activities on Beaver Dam Lake as well as provide them with education on the Beaver Dam Lake ecosystem. The BDLIA will continue to work with the City of Beaver Dam and the Dodge County Parks Department to improve public access points and signage and encourage the use of monofilament collectors at public access points.

Action Steps:

1. See description above.

Management Action: Reevaluate placement of slow-no-wake buoys on western side of Beaver Dam Lake.

Timeframe: Initiate 2016

Facilitator: Beaver Dam Lake Improvement Association Board of Directors

Description: The Beaver Dam Lake Citizen's Alliance first deployed 50 slow-no-wake buoys at the mouths of bays in the western portion of Beaver Dam Lake to reduced shoreline erosion from waves generated by fast-moving boats. However, the Planning Committee indicated that these buoys often are placed too far out and their placement should be reevaluated. The BDLIA should work with the Beaver Dam Lake Citizen's Alliance to reevaluate the placement of these slow-no-wake buoys so that they are used most effectively and determine questions of liability and maintenance for these buoys.

Action Steps:

1. See description above.

Management Action:	BDLIA to educate Beaver Dam Lake stakeholders on potential risks of blue-green algae.
Timeframe:	Initiate 2016
Facilitator:	Beaver Dam Lake Improvement Association Board of Directors
Description:	As discussed within the Water Quality Section, Beaver Dam Lake experiences blue-green algae blooms on an annual basis. Some species of blue-green algae can produce toxins which can be hazardous to human and animal health through ingestion or direct contact. Toxins are not always produced during these blooms and the conditions that lead to toxin production are not well understood. Therefore, because toxin production cannot be predicted, water use warnings are issued when there are high concentrations of blue-green algae present. The BDLIA will include information on blue-green algae blooms within their newsletter and on their website informing people to avoid contact with the water, including their pets, if it resembles "pea-soup." The BDLIA should encourage their membership to contact the WDNR Department of Health Services (608.266.1120) to report blue-green algae blooms so notices can be posted at public access points.
Action Steps:	
1.	See description above.

Management Goal 5: Monitor Existing Aquatic Invasive Species in Beaver Dam Lake

Management Action:	Initiate assessment of Beaver Dam Lake's curly-leaf pondweed and Eurasian water milfoil populations.
Timeframe:	Initiate 2015
Facilitator:	Beaver Dam Lake Improvement Association Board of Directors
Funding Source:	WDNR Education, Planning and Prevention Grant
Description:	As discussed within the Aquatic Plant Section, Beaver Dam Lake contains populations of both curly-leaf pondweed (CLP) and Eurasian water milfoil (EWM) which are non-native, invasive plants. Typically as part of a lake management planning project, an Early-Season Aquatic Invasive Species (ESAIS) Survey is conducted in June to locate and map occurrences of CLP which is at or near its peak growth at this time of year. The WDNR believed that Beaver Dam Lake did not contain a large CLP population, and therefore, the ESAIS Survey was removed and not conducted as part of the planning project. However, suspicions of a more significant CLP population within the lake began to surface after talking with Beaver Dam Lake riparians while out on the lake and during the project's planning meetings. These riparians had indicated that nuisance levels of aquatic plants are present within some of the bays in spring and early summer, but by July these nuisance levels tend to subside. Curly-leaf pondweed naturally senesces (dies back) in early summer, and this indication from riparians that aquatic plant biomass declines by July was an indication to Onterra ecologists that CLP may be causing the nuisance conditions within these bays. In May 2015, Bill Boettge sent images to Onterra ecologists of surface-matted aquatic plants in a bay near Derge County Park. These plants appeared to be a large colony of CLP (Photo 5.0-1). Based upon these photos and statements from Beaver Dam Lake riparians, it is believed that curly-leaf pondweed increased in 2015 compared to when the surveys were conducted in 2014. While conditions may have been ideal for curly-leaf pondweed growth in 2015, it is not clear if this growth will continue in 2016 or if it will be lower as in 2014. To monitor the CLP population, the BDLIA will seek a WDNR Education, Planning and Prevention grant in December of 2015 to aid in funding an assessment of the lake's CLP (and EWM) populations in 2016 and update the lake management plan as it pertains to the management of these plants.

Photo 5.0-1. Surface-matted colony of what is believed to be curly-leaf pondweed in Beaver Dam Lake near Derge County Park. Photo taken by Bill Boettge on May 22, 2015.

Eurasian water milfoil, which reaches its peak growth in mid- to late-summer, is present in Beaver Dam Lake at much lower levels than CLP. Onterra ecologists were able to map locations of EWM during the whole-lake point-intercept survey conducted in July of 2014, and they found only a few occurrences of EWM in the northern portion of the lake. However, it is recommended that the EWM population in Beaver Dam Lake continue to be monitored so that if it does increase, management strategies can be developed quickly.

In 2016, professional surveys would be conducted to map and locate occurrences of both CLP and EWM in Beaver Dam Lake. During the Early-Season AIS Survey, the entire littoral zone of Beaver Dam Lake would be visually searched for CLP and EWM, and their locations would be mapped using a GPS with sub-meter accuracy. Because EWM reaches its peak-growth later in the summer, Onterra ecologists would return to Beaver Dam Lake in late-summer of 2016 and only visit and refine areas where EWM was located during ESAIS Survey. Following these surveys, electronic maps would be created displaying the locations of CLP and EWM. Onterra ecologists would also hold a planning meeting with the BDLIA Planning Committee to present the AIS mapping results and determine possible control and monitoring strategies if warranted.

Action Steps:

1. BDLIA, with professional assistance, applies for a WDNR Education, Planning and Prevention Grant in December of 2015 to aid in funding a one-year invasive species assessment and management strategy development project in 2016.

Management Action:	Passively monitor Beaver Dam Lake's zebra mussel population.
Timeframe:	Continuation of current effort
Facilitator:	Beaver Dam Lake Improvement Association Board of Directors
Description:	The non-native, invasive Zebra mussel (*Dreissena polymorpha*) was first verified in Beaver Dam Lake in 2011. While there are currently no method of control of zebra mussels once they are introduced to a waterbody, the BDLIA would like to passively monitor the Beaver Dam Lake's population by making note of their locations and densities around the lake. The BDLIA will ask its membership to report the locations of zebra mussels observed on piers, rocks, and other hard substrates within the lake. Each year, the BDLIA will report to its membership the observed locations of zebra mussels and if their densities appear to be more or less than the previous year, and how they can prevent the spread of zebra mussels from Beaver Dam Lake to other waterbodies. The BDLIA will also stay informed with current research on zebra mussel control by visiting the WDNR's website on zebra mussels (http://dnr.wi.gov/topic/invasives/fact/zebra.html) and corresponding with Susan Graham, the regional WDNR Water Resources Management Specialist.
Action Steps:	
1.	See description above.

6.0 METHODS

Lake Water Quality

Baseline water quality conditions were studied to assist in identifying potential water quality problems in Beaver Dam 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). Samples were collected using WDNR Citizen Lake Monitoring Network (CLMN) protocols which occurred once in spring and three times during the summer. In addition to the samples collected by BDLIA members, professional water quality samples were collected at subsurface (S) and near bottom (B) depths once in spring, winter, and fall. Although BDLIA members collected a spring and mid-summer total phosphorus sample, professionals also collected a near bottom sample to coincide with the surface total phosphorus sample. Winter dissolved oxygen was determined with a calibrated probe and all samples were collected with a 3-liter Van Dorn bottle. Secchi disk transparency was also included during each visit.

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

Parameter	Spring		June	July		August	Fall		Winter	
	S	B	S	S	B	S	S	B	S	B
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 as a part of the Citizen Lake Monitoring Network.
● indicates samples collected by volunteers under proposed project.
■ indicates samples collected by consultant under proposed project.

Watershed Analysis

The watershed analysis began with an accurate delineation of Beaver Dam 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 Beaver Dam 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 14, 15, and 17, 2014. A point spacing of 160 meters was used resulting in 1,072 points.

Community Mapping

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

Dodge County Land Conservation Plan. 2012. Accessed from http://www.co.dodge.wi.us/index.aspx?page=60 in April 2015.

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.

Hellquist, C.B. and A.R. Pike. 2003. *Potamogeton strictifolius* A. Bennett Straight Leaved pondweed Conservation and Research Plan for New England. New England Wild Flower Society.

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.

Kordus, D. 2002. History of Beaver Dam Lake. University of Wisconsin-Extension.

Lamarra, V. 1975. Digestive activities of carp as a major contributor of the nutrient loading of lakes. Verh. Internat. Verein. Limnol. Vol. 19. 2461–2468.

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

Penn, M.R., M.T. Auer, S.M. Doerr, C.T. Driscoll, C.M. Brooks, and S.W. Effler. 2000. Seasonality in phosphorus release rates from the sediments of a hypereutrophic lake under a matrix of pH and redox conditions. Can. J. Fish. Aquat. Sci. Vol. 57. 1033–1041.

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.

The Cadmus Group, Inc. 2011. Total Maximum Daily Loads for Total Phosphorus and Total Suspended Solids in the Rock River Basin. Accessed from http://dnr.wi.gov/topic/tmdls/RockRiver/index.html.

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.

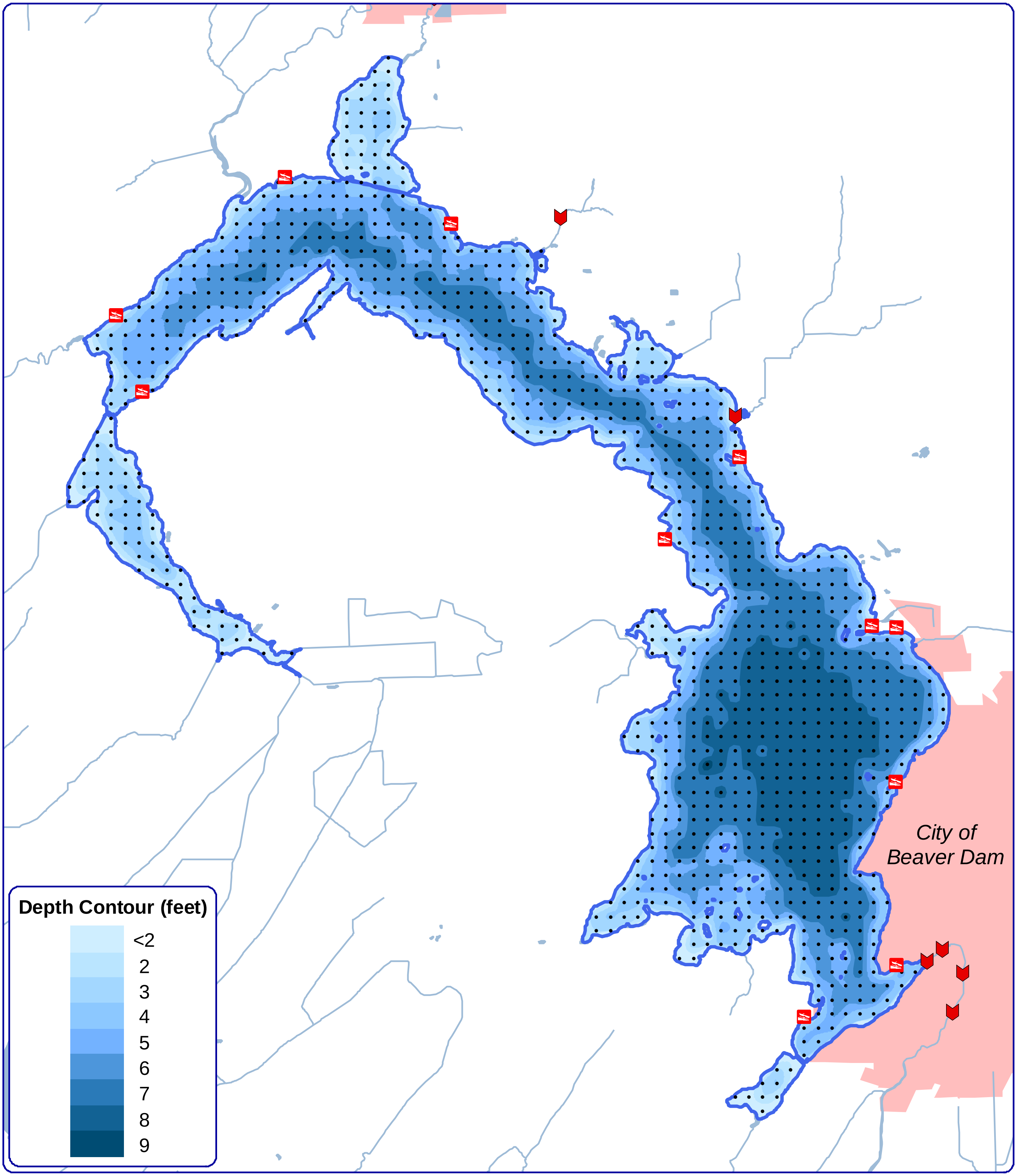
Weber, M.J., M.J. Hennen, and M.L. Brown. 2011. Simulated population responses of common carp to commercial exploitation. North American Journal of Fisheries Management. Vol. 31. 269–279.

Wisconsin Department of Natural Resources – Bureau of Endangered Resources. 2014. Wisconsin Endangered and Threatened Species Laws and List. PUBL-ER-001.

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.



N
W E
S

0.9
Miles

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Sources:
Roads, Hydro, Municipal: WDNR
Bathymetry: Onterra, 2014
Map Date: February 16, 2015
Filename: Map1_BDL_Location.mxd

Project Location in Wisconsin

Legend

Beaver Dam Lake ~6,542 acres
WDNR Definition

Point-Intercept Survey Location
160-meter spacing, 1,072 total points

Public Access

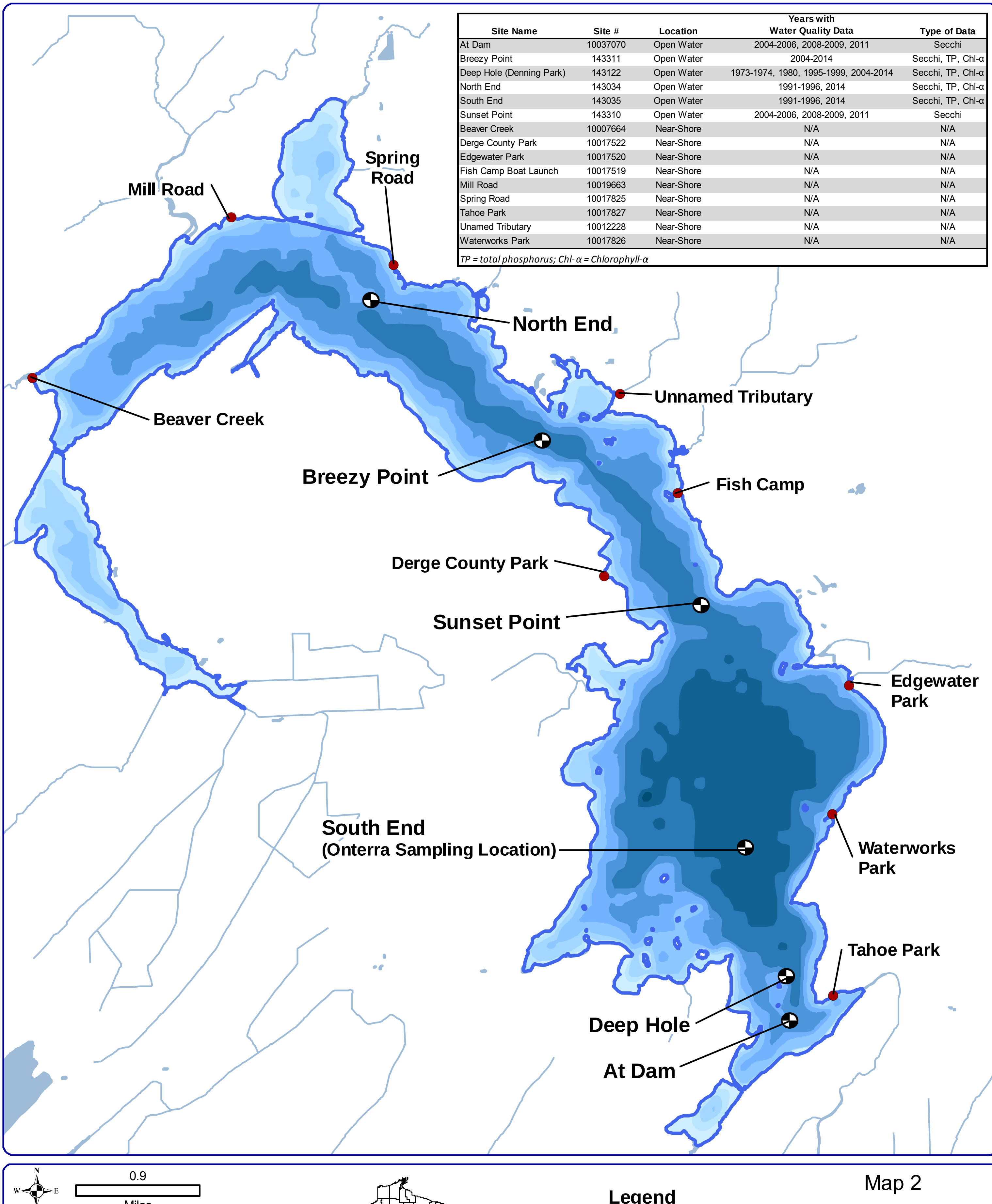
Dam Location

Map 1
Beaver Dam Lake
Dodge County, Wisconsin

Project Location & Lake Boundaries

Site Name	Site #	Location	Years with Water Quality Data	Type of Data
At Dam	10037070	Open Water	2004-2006, 2008-2009, 2011	Secchi
Breezy Point	143311	Open Water	2004-2014	Secchi, TP, Chl-α
Deep Hole (Denning Park)	143122	Open Water	1973-1974, 1980, 1995-1999, 2004-2014	Secchi, TP, Chl-α
North End	143034	Open Water	1991-1996, 2014	Secchi, TP, Chl-α
South End	143035	Open Water	1991-1996, 2014	Secchi, TP, Chl-α
Sunset Point	143310	Open Water	2004-2006, 2008-2009, 2011	Secchi
Beaver Creek	10007664	Near-Shore	N/A	N/A
Derge County Park	10017522	Near-Shore	N/A	N/A
Edgewater Park	10017520	Near-Shore	N/A	N/A
Fish Camp Boat Launch	10017519	Near-Shore	N/A	N/A
Mill Road	10019663	Near-Shore	N/A	N/A
Spring Road	10017825	Near-Shore	N/A	N/A
Tahoe Park	10017827	Near-Shore	N/A	N/A
Unamed Tributary	10012228	Near-Shore	N/A	N/A
Waterworks Park	10017826	Near-Shore	N/A	N/A

TP = total phosphorus; Chl-α = Chlorophyll-α



Project Location in Wisconsin

Legend

Monitoring Stations

- Open Water - Data Available
- Near-Shore - No Data

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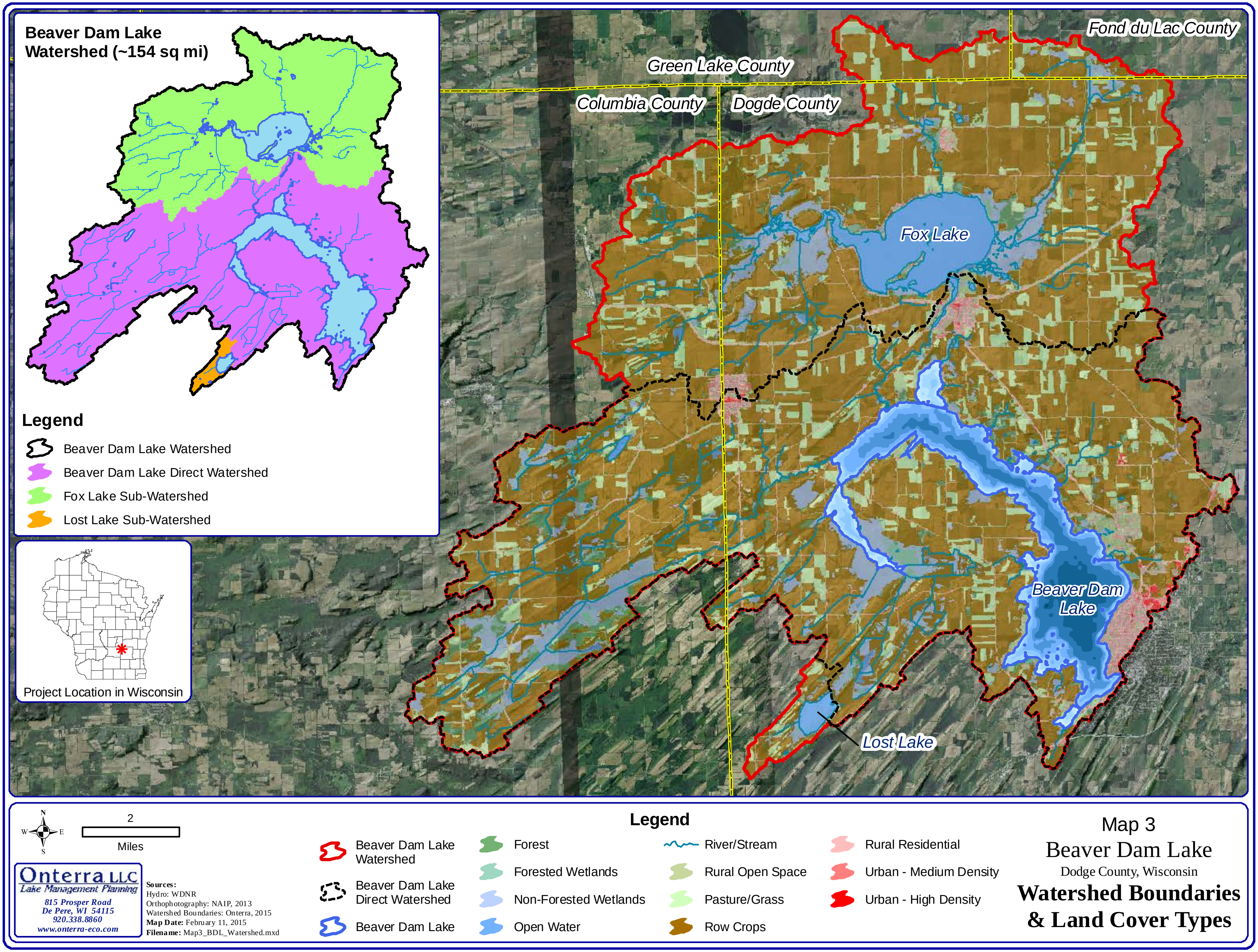
Sources:
Hydro: WDNR
Bathymetry: Onterra, 2014
Map Date: February 16, 2015
Filename: Map2_BDL_WQ_Locations.mxd

Map 2
Beaver Dam Lake
Dodge County, Wisconsin

Monitoring Station Locations



Beaver Dam Lake Watershed (~154 sq mi)
Legend
Beaver Dam Lake Watershed
Beaver Dam Lake Direct Watershed
Fox Lake Sub-Watershed
Lost Lake Sub-Watershed
Project Location in Wisconsin
Green Lake County
Fond du Lac County
Columbia County
Dogde County
Fox Lake
Beaver Dam Lake
Lost Lake
N
W
E
S
2
Miles
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De Pere, WI 54115
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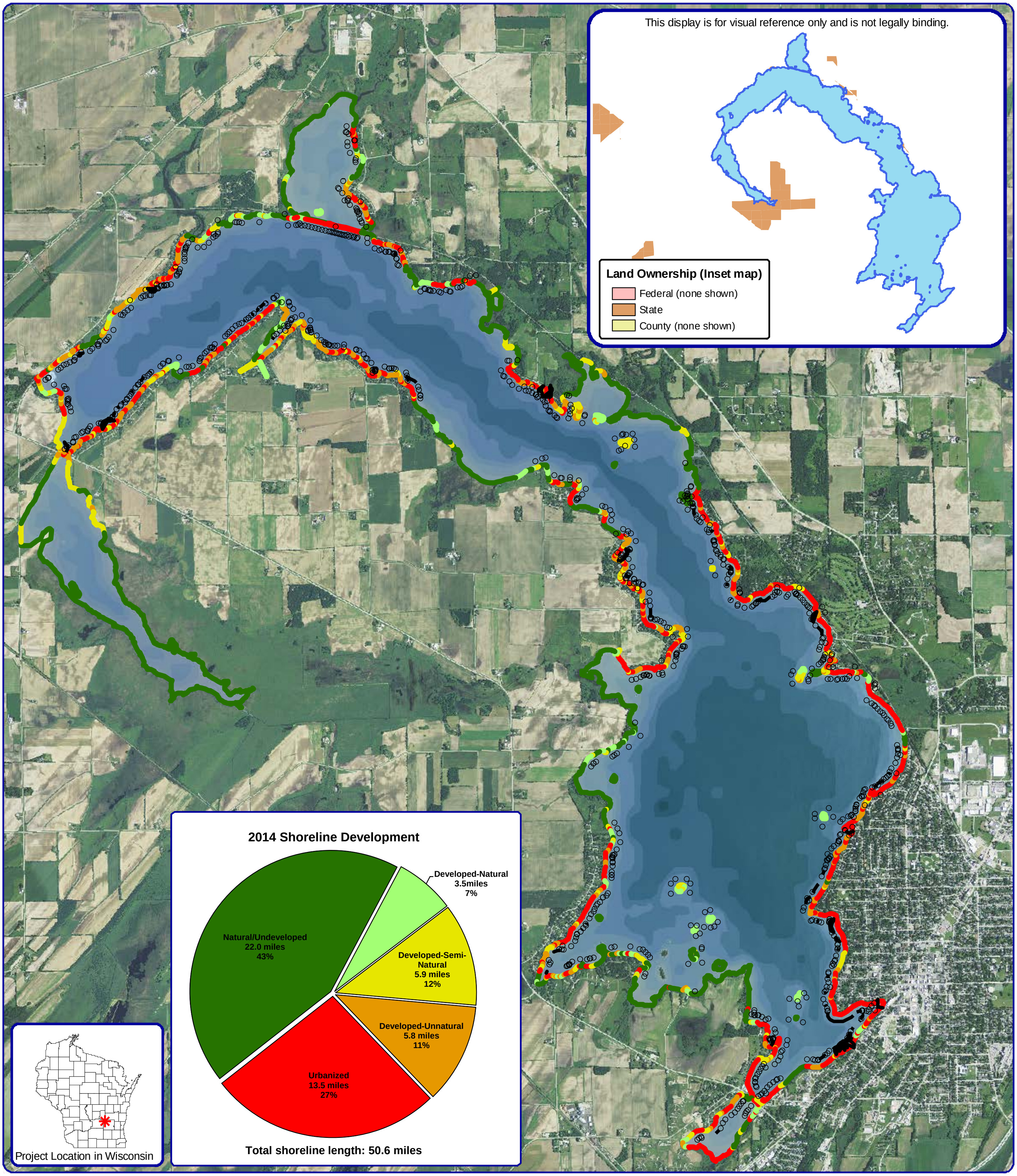
Sources:
Hydro: WDNR
Orthophotography: NAIP, 2013
Watershed Boundaries: Onterra, 2015
Map Date: February 11, 2015
Filename: Map3_BDL_Watershed.mxd
Legend
Beaver Dam Lake Watershed
Beaver Dam Lake Direct Watershed
Beaver Dam Lake
Forest
Forested Wetlands
Non-Forested Wetlands
Open Water
River/Stream
Rural Open Space
Pasture/Grass
Row Crops
Rural Residential
Urban - Medium Density
Urban - High Density
Map 3
Beaver Dam Lake
Dodge County, Wisconsin
Watershed Boundaries & Land Cover Types



N
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S
4,800
Feet

Legend

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

Seawall
Masonry/Metal/Wood
Rip-Rap

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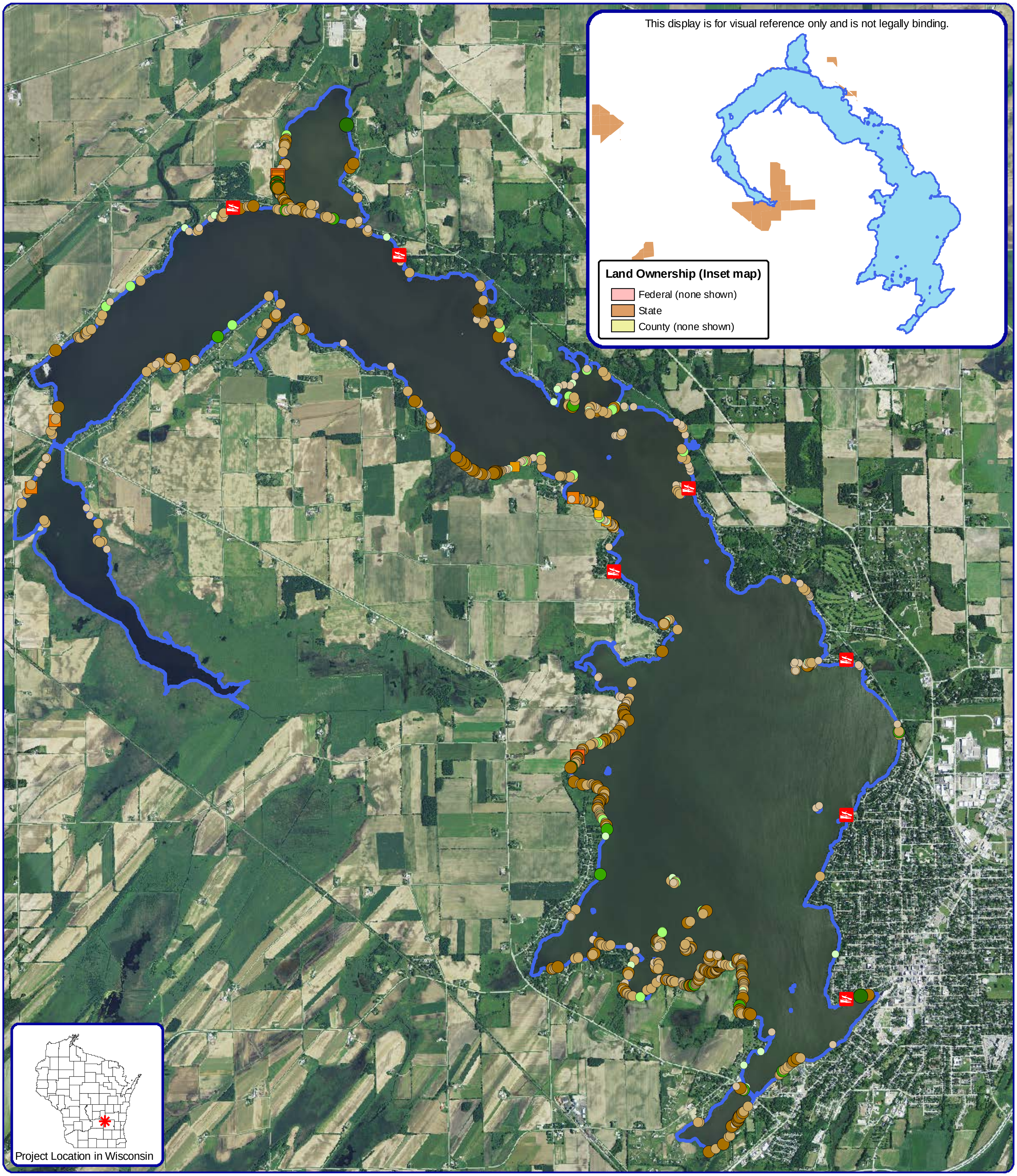
Sources:
Roads and Hydro: WDNR
CWH Survey: Onterra, 2014
Ortho: WDNR, 2013
Map Date: October 22, 2014
Filename: Map4_BeaverDam_SCA_Summer14.mxd

Map 4

Beaver Dam Lake

Dodge County, Wisconsin

2014 Shoreland Condition Assessment



N W E S

4,800

Feet

Legend

2-8 Inch Pieces	8+ Inch Pieces	Cluster of Pieces
No Branches	No Branches	No Branches
Minimal Branches	Minimal Branches	Minimal Branches
Moderate Branches	Moderate Branches	Moderate Branches
Full Canopy	Full Canopy	Full Canopy

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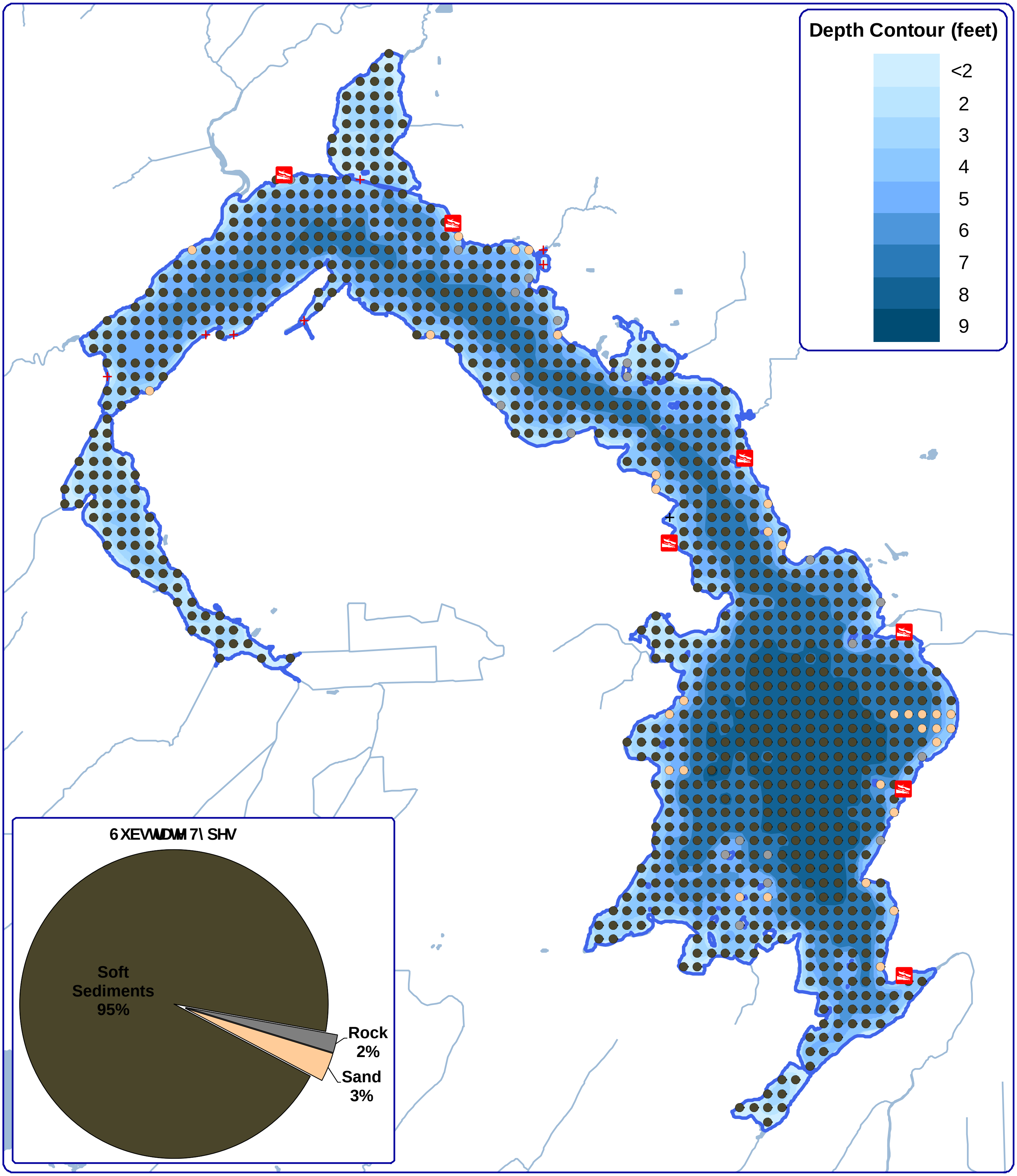
Sources:
Roads and Hydro: WDNR
CWH Survey: Onterra, 2014
Ortho: WDNR, 2013
Map Date: October 21, 2014
Filename: Map5_BeaverDam_CWH_Summer14.mxd

Map 5

Beaver Dam Lake

Dodge County, Wisconsin

2014 Coarse Woody Habitat



N
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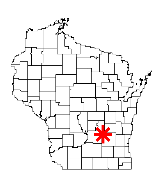
4,800
Feet



Legend

2014 Point-intercept Survey

- Non-navigable
- Soft Sediments
- Sand
- Rock

Map 6

Beaver Dam Lake

Dodge County, Wisconsin

2014 PI Survey: Substrate Types

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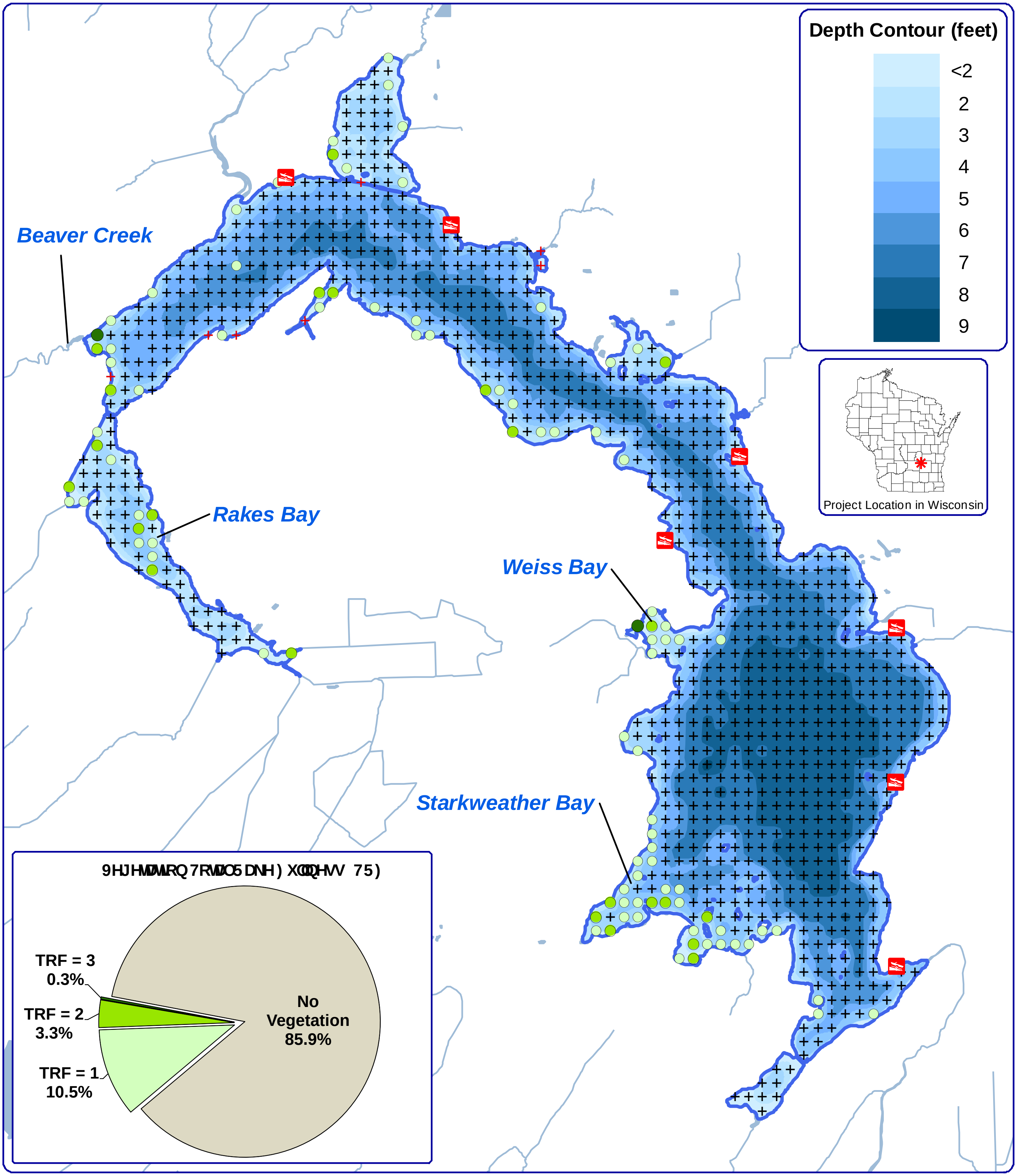
Sources:
Hydro: WDNR
Bathymetry: Onterra, 2014
PI Survey: Onterra, 2014
Map Date: December 15, 2014
Filename: Map6_BDL_SedimentPI_2014.mxd



N
W E
S
4,900
Feet

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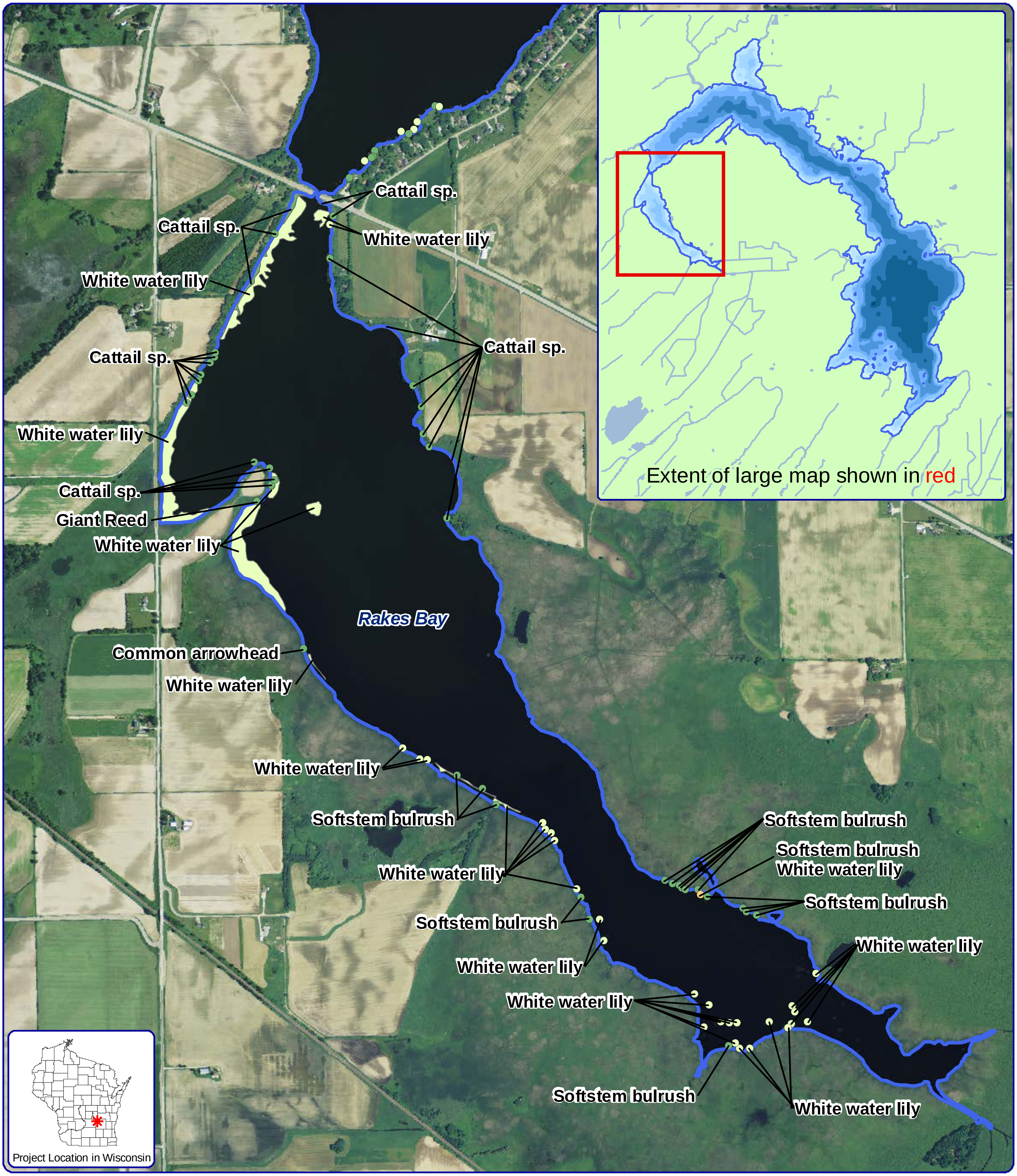
Sources:
Hydro: WDNR
Bathymetry: Onterra, 2014
Aquatic Plants: Onterra, 2014
Map Date: December 15, 2014
Filename: Map7_BDL_TRFPI_2014.mxd

Legend

2014 Point-intercept Survey

- \+ No Vegetation
- Total Rake Fullness = 1
- Total Rake Fullness = 2
- Total Rake Fullness = 3
- \+ Greater than Max Depth of Plants (6 ft)
- \+ Non-navigable

Map 7
Beaver Dam Lake
Dodge County, Wisconsin
2014 PI Survey: Aquatic Vegetation Distribution



N W E S

1,400

Feet

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Sources:
Hydro: WDNR
Orthophotography: NAIP, 2013
Aquatic Plants: Onterra, 2014
Map Date: February 27, 2015
Filename: Map8_BDL_Comm_RakesBay.mxd

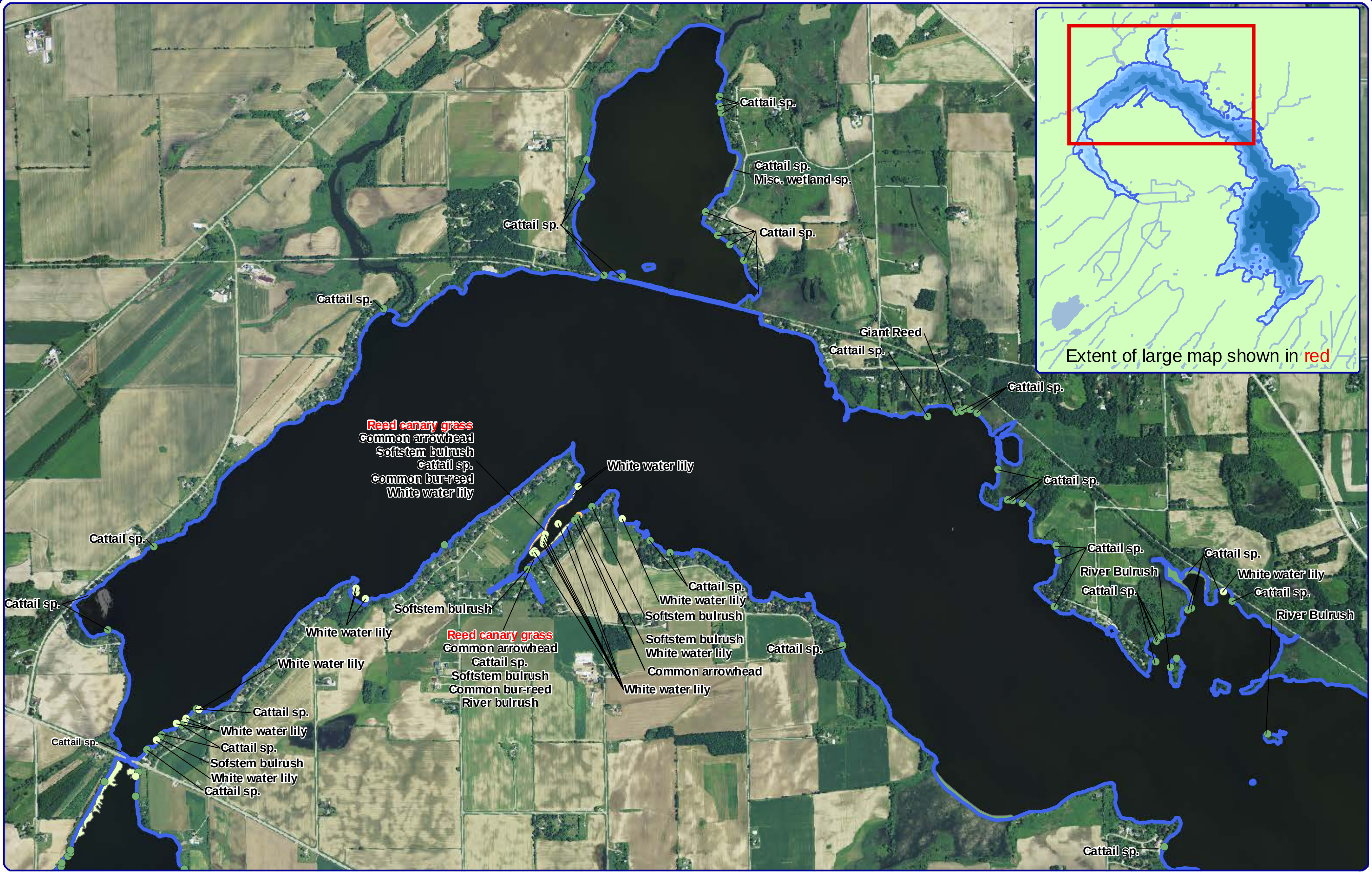
Legend

Small Plant Community	Large Plant Community
Emergent	Emergent
Floating-Leaf	Floating-Leaf
Mixed Emergent & Floating-Leaf	Mixed Emergent & Floating-Leaf

Map 8

Beaver Dam Lake - Rakes Bay
Dodge County, Wisconsin

Emergent & Floating-Leaf Aquatic Plant Communities



N
W E
S

2,400

Feet

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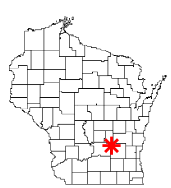
Sources:
Hyrdro: WDNR
Orthophotography: NAIP, 2013
Aquatic Plants: Onterra, 2014
Map Date: February 27, 2015
Filename: Map9_BDL_Comm_North.mxd



Project Location in Wisconsin

Legend

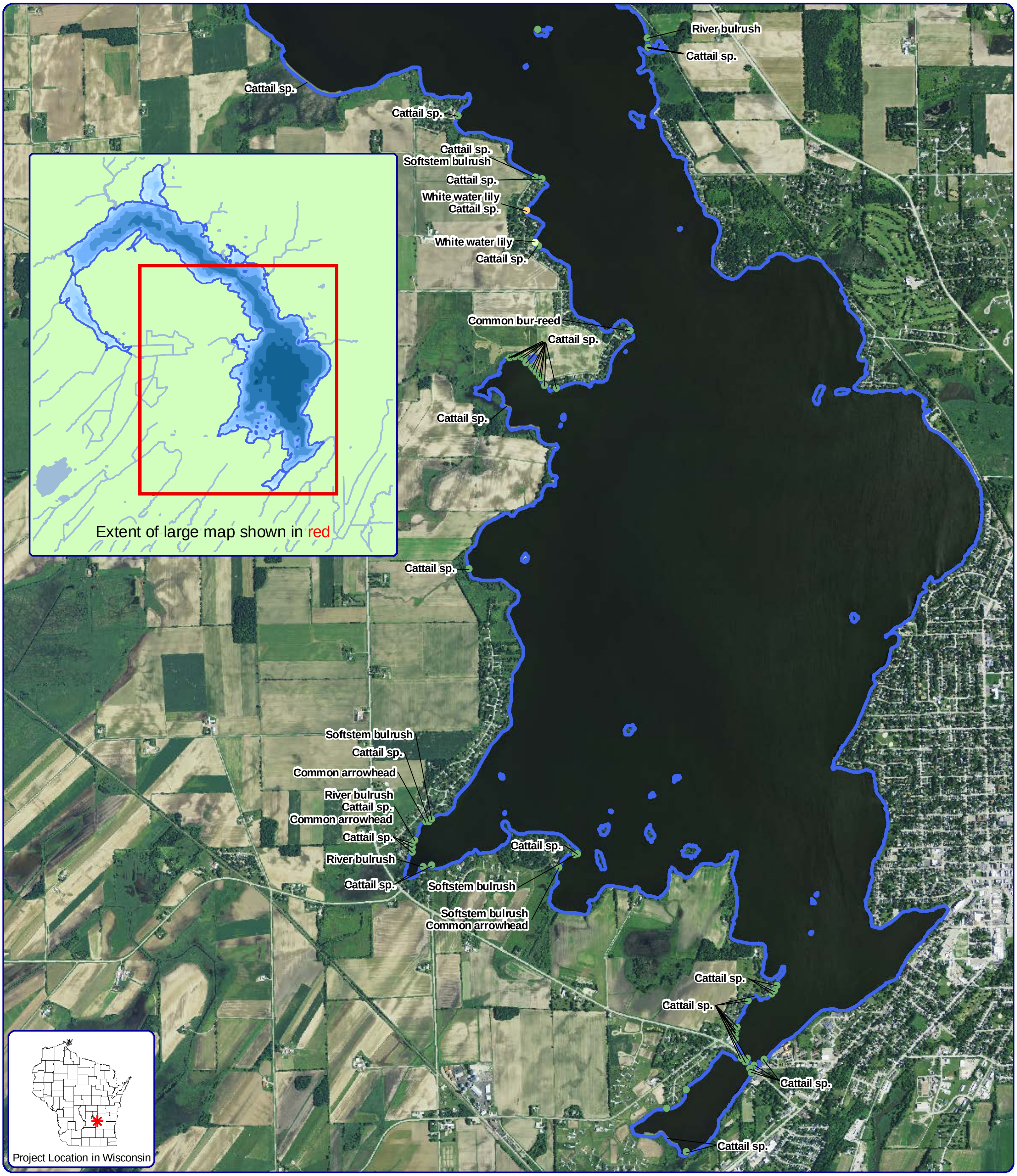
Small Plant Community	Large Plant Community
Emergent	Emergent
Floating-Leaf	Floating-Leaf
Mixed Emergent & Floating-Leaf	Mixed Emergent & Floating-Leaf

Map 9

Beaver Dam Lake - North

Dodge County, Wisconsin

Emergent & Floating-Leaf Aquatic Plant Communities



3,300

Feet

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Sources:
Hydro: WDNR
Orthophotography: NAIP, 2013
Aquatic Plants: Onterra, 2014
Map Date: February 27, 2015
Filename: Map10_BDL_Comm_South.mxd

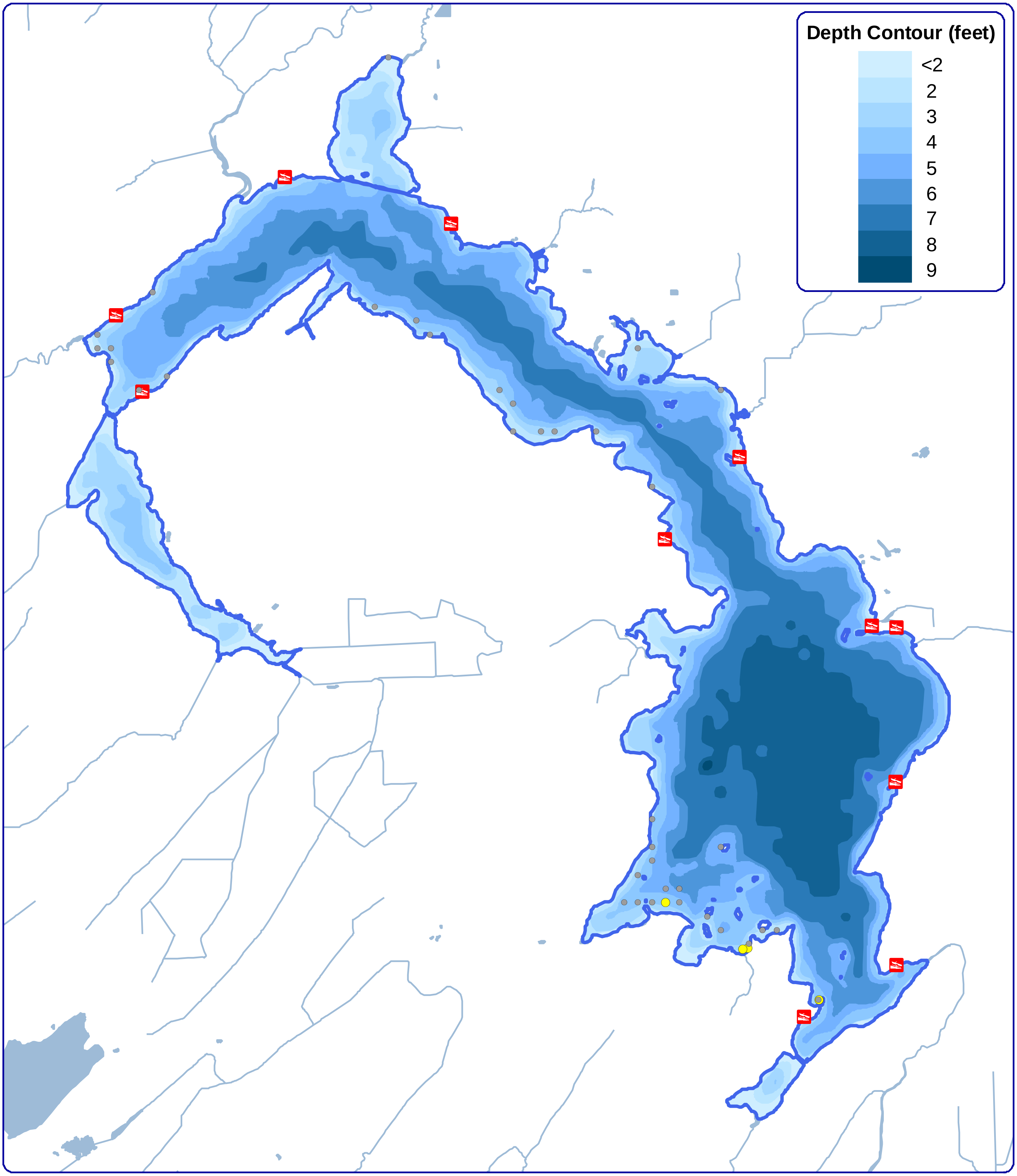
Legend

Small Plant Community	**Large Plant Community**
Emergent	Emergent
Floating-Leaf	Floating-Leaf
Mixed Emergent & Floating-Leaf	Mixed Emergent & Floating-Leaf

Map 10

Beaver Dam Lake - South
Dodge County, Wisconsin

Emergent & Floating-Leaf Aquatic Plant Communities



N
W E
S

4,700

Feet

Onterra LLC
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Sources:
Roads, Hydro, Municipal: WDNR
Bathymetry: Onterra, 2014
Aquatic Plants: Onterra, 2014
Map Date: February 16, 2015
Filename: Map11_BDL_CLP_2014.mxd

Project Location in Wisconsin

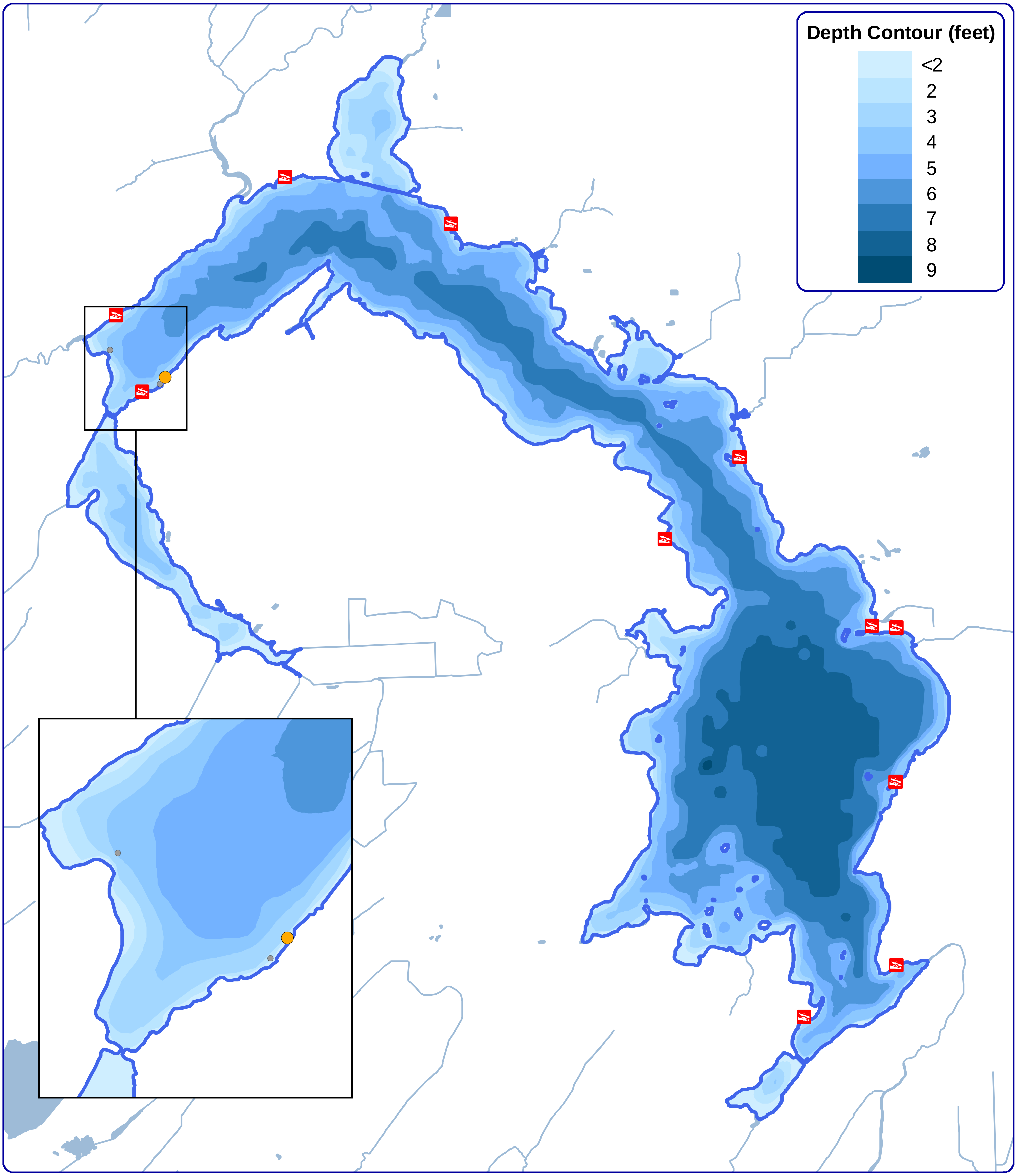
Legend

CLP (July 2014)
- Single or Few Plants
- Clumps of Plants
- Small Plant Colony
- Public Access

Map 11

Beaver Dam Lake
Dodge County, Wisconsin

2014 CLP Locations



4,750

Feet

Legend

EWM (July 2014)

- Single or Few Plants
- Clumps of Plants
- Small Plant Colony
- Public Access

Map 12

Beaver Dam Lake

Dodge County, Wisconsin

2014 EWM Locations

Project Location in Wisconsin

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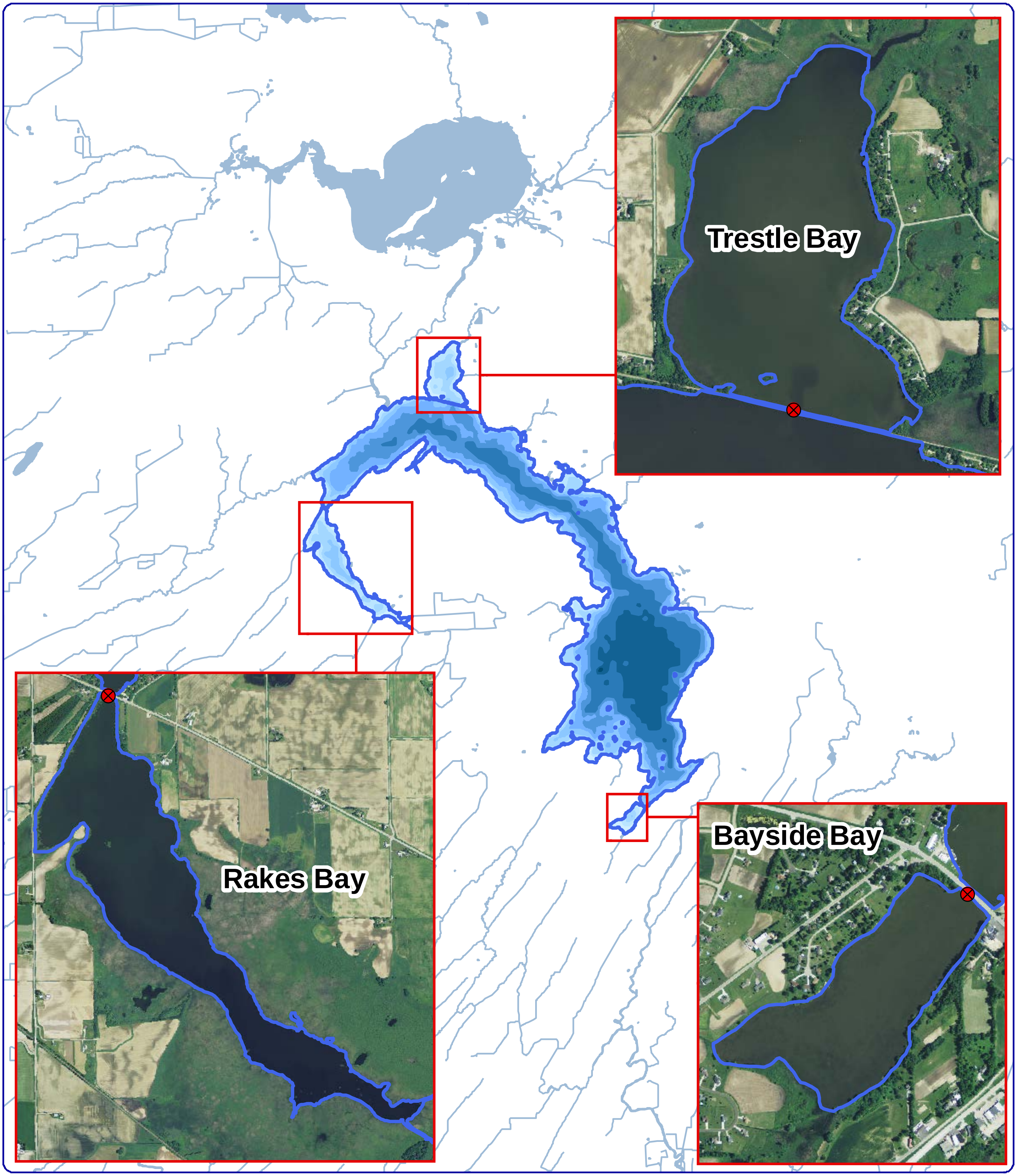
Sources:
Roads, Hydro, Municipal: WDNR
Bathymetry: Onterra, 2014
Aquatic Plants: Onterra, 2014
Map Date: February 16, 2015
Filename: Map12_BDL_EWM_2014.mxd



N
W E
S
2
Miles

Onterra LLC
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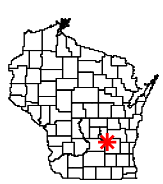
Sources:
Roads, Hydro, Municipal: WDNR
Bathymetry: Onterra, 2014
Map Date: June 1, 2015
Filename: Map13_BDL_CarpBarrierLocations.mxd


Project Location in Wisconsin

Legend

⊗ Proposed Carp Barrier Location

Map 13
Beaver Dam Lake
Dodge County, Wisconsin
Proposed Carp Barrier Locations