Waupaca Chain O' Lakes

Waupaca County, Wisconsin

Comprehensive Management Plan

December 2021

Sponsored by:

Waupaca Chain O' Lakes District

WDNR Grant Program

AEPP-473-16

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Onterra, LLC
Lake Management Planning

Waupaca Chain O' Lakes

Waupaca County, Wisconsin

Comprehensive Management Plan

December 2021

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Lakes Represented by the Waupaca Chain O' Lakes District Board and the Planning Committee:

Dake, Lime Kiln, Long, Manomin, Marl, McCrossen, Miner, Orlando, Rainbow, Taylor, and Youngs

Wisconsin Dept. of Natural Resources

Ted Johnson

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1.0 INTRODUCTION

Photograph 1.0-1. Waupaca Chain O' Lakes (Long Lake), Waupaca County, Wisconsin.

The Waupaca Chain O' Lakes consists of 22 lakes in Waupaca County, Wisconsin (Photograph 1.0-1, Map 1). According to the 1965 recording sonar Wisconsin Department of Natural Resources (WDNR) lake survey map, the Chain is approximately 724 acres. The WDNR website lists the Chain lakes to be approximately 809 acres and according to the WDNR Geographic Information System (GIS) lake shapes, the Chain is approximately 839 acres. At the time of this report, the most current orthophoto (aerial photograph) was from the National Agriculture Imagery Program (NAIP) collected in 2015. Based upon heads-up digitizing of the water level from that photo, the Chain was determined to be approximately 792 acres, which is the figure used within the analysis reported upon here.

The Chain lakes are quite diverse in their morphology, ecology, and recreational use. Fifteen of the lakes hold WDNR designated Critical Habitat Areas, while three lakes are considered Areas of Special Natural Resource Interest. The Chain boasts one of the most diverse fish communities in Central Wisconsin, with species from all major fish assemblages - warmwater, coolwater, and coldwater species.

The Chain is a biologically diverse system with numerous documented natural features; however, the Chain is heavily used for a variety of recreational purposes and human disturbance is evident through shoreland development, erosion, and the presence of numerous aquatic invasive species. The Waupaca Chain O' Lakes District (WCOLD) has sponsored past grant-funded projects to examine the ecosystem, including a series of 1991-1992 lake management planning projects, a 2003 aquatic plant management plan, and a 2005 aquatic invasive species education, prevention and control project (AIS-EPC funded). Over the past few years, the WCOLD has sponsored EWM monitoring and control on the Chain, including an approximate 17-acre herbicide treatment in 2015 which was paid for out-of-pocket by the District.

With the assistance of Onterra, the WCOLD was awarded a WDNR AIS-Education, Planning and Prevention Grant in 2015 to aid in funding studies aimed at documenting the current state of the Chain's native and non-native aquatic plant populations to guide the development of future management strategies. The WCOLD also wanted to gain a more holistic understanding of how the Chain functions ecologically. In addition to aquatic plant studies, data were also collected to assess the Chain's water quality, watershed, and shoreland habitat. An anonymous stakeholder survey was also distributed to collect data pertaining to lake use, perceptions, and concerns. This report discusses the results of these studies. Also included is an Implementation Plan which includes management goals and actions specific to the Waupaca Chain O' Lakes' current and future management that were developed by members of the WCOLD Planning Committee, WCOLD Board of Commissioners, 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 what they expect of the lakes, how they use the lakes, and how they would like to be involved in managing them. All of this information is communicated through multiple meetings that involve the lake group as a whole, or a focus group called a Planning Committee, and annual AIS monitoring reports.

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 6, 2016, a project kick-off meeting was held in the Marden Memorial Center of the Wisconsin Veterans Home in King. The meeting was announced through a mailing and public notice. The 24 attendees observed a presentation by Tim Hoyman, an aquatic ecologist with Onterra, LLC. Mr. Hoyman 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. Mr. Hoyman's presentation was followed by a question and answer session.

Patrick Goggin, UW-Extension Lakes, followed Mr. Hoyman with an approximately 30-minute presentation about the Healthy Lakes Grant Program, a program designed to increase nearshore habitat and nutrient buffering capacity.

Prior to the meeting, Mr. Hoyman met with approximately 8 people from the WCOLD who were interested in serving on the project's Planning Committee.

WCOLD Board Meeting – AIS Control Planning Meeting

On October 22, 2016, Eddie Heath and Tim Hoyman of Onterra met with the WCOLD Board of Commissioners and Planning Committee members for nearly four hours. The primary focus of this meeting was the delivery of the study results and conclusions pertaining to aquatic plants of the Chain and aquatic invasive species (AIS) management. At this meeting, an outline of a three-year AIS control and monitoring plan was created for submittal to the WDNR in November. Submittal and acceptance of that AIS strategy would make the WCOLD eligible to apply for state grants in February 2017 to fund the three-year program. Much of the same information was revisited when the WCOLD requested that Onterra staff facilitate a meeting with WDNR Water Resource Specialist Ted Johnson in December 2016.

Planning Meeting I

On April 21, 2017, Tim Hoyman and Eddie Heath met with the WCOLD Planning Committee, members of the Board of Commissioners, and several district members to present and discuss the information that was collected and compiled regarding the Chain's water quality, surface watershed, aquatic plants, and fishery. Many questions were answered during a meeting on a variety of subjects. The primary goal of the meeting was to create a solid understanding of the Chain with the Planning Committee members to prepare them to make appropriate management decisions which would ultimately be reflected in the Chain's management plan.

Planning Meeting II

The primary objective of Planning Meeting II is to create a framework of management goals and actions that would be used to create the full implementation plan that would be included in the Chain management plan. The meeting was to take place during the summer of 2017; however, the WCOLD Board of Commissioners elected not to hold the meeting.

Project Wrap-Up Meeting

On August 12, 2017, Tim Hoyman presented the hybrid watermilfoil control strategy and preliminary results to approximately 30 WCOLD members.

Management Plan Review and Adoption Process

In November 2016, an official first draft of the Waupaca Chain O' Lakes Comprehensive Management Plan was supplied to the WDNR, Waupaca County, and the WCOLD Planning Committee for review. This draft only included reporting and project goals as it pertained to AIS management. By submittal of this draft plan more than 60 days prior to the February 1, 2017 AIS-EPC Grant Application deadline, the WCOLD became eligible to apply for an AIS-EPC Grant during that cycle to fund AIS control and monitoring plan outlined within the Implementation Plan Section (5.0).

In March 2017, the first draft of the management plan, which included the primary EWM control strategy, was provided to the WCOLD Board for review, comments, and use during the planning process that began that summer. In March of 2019, an updated version of the plan, which included two sets of edits requested by the WCOLD, was supplied to the District for review. Over the course of the next 29 months, three additional versions were created to include WCOLD -requested edits. In September 2021, the WCOLD accepted the fifth version of the October 2019 edition and it was provided to the WDNR as the First Official Draft (OFD) for their review. The WDNR approved the OFD in December 2021 (see WDNR approval letter in Appendix H).

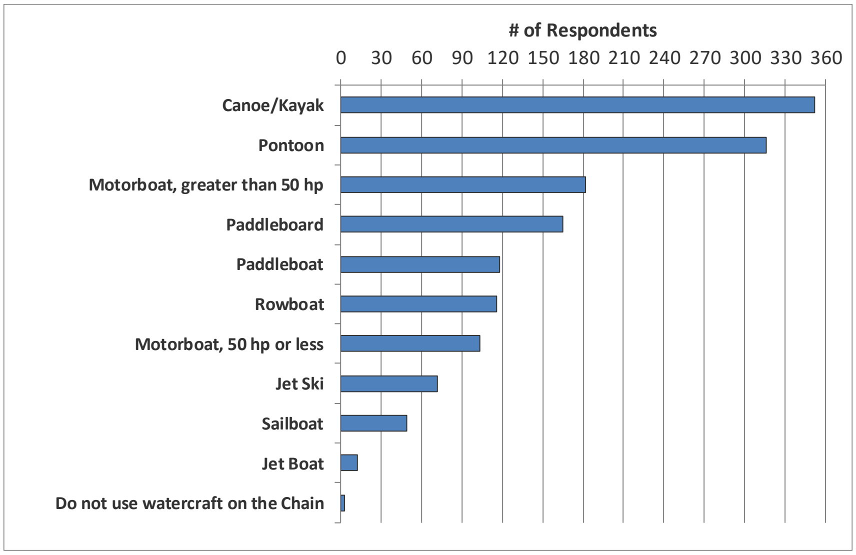
Stakeholder Survey

As a part of this project, a stakeholder survey was distributed to WCOLD District members around the Waupaca Chain O' Lakes. The survey was designed by Onterra staff and the WCOLD Planning Committee, and reviewed by a WDNR social scientist. During April 2017, the 28-question survey was mailed to property owners. The returned surveys were entered into the online version by WCOLD volunteers for analysis. Fifty-four percent of the surveys were returned. Please note that typically a benchmark of a 60% response rate is required to portray population projections accurately and to make conclusions with statistical validity. The data were analyzed and summarized by Onterra for use at the planning meetings and within the management plan. The full survey and results can be found in Appendix B, while discussion of those results is integrated within the appropriate sections of the management plan and a general summary is discussed below.

Based upon the results of the Stakeholder Survey, much was learned about the people who use and care for the Waupaca Chain O' Lakes. The majority of stakeholder respondents (41%) live on the lake seasonally, 34% are year-round residents, 17% visit on weekends throughout the year, 3% own rental properties, and less than 1% own undeveloped properties. Sixty-nine percent of stakeholder respondents have owned their property for over 15 years, and 48% have owned their property for over 25 years.

The following sections (Water Quality, Watershed, Aquatic Plants and Fisheries Data Integration) discuss the stakeholder survey data in reference to these particular topics. Figures 2.0-1 highlights two questions found within this survey. More than half of survey respondents indicated that they use either a pontoon boat, canoe, or kayak on the Waupaca Chain O' Lakes (Question 12). Large motor boats and paddleboards were also popular options. On relatively small lakes, such as some of the lakes in the Waupaca Chain O' Lakes, the importance of responsible boating activities is increased. The need for responsible boating increases during weekends, holidays, and during times of nice weather or good fishing conditions, due to increased traffic on the lake. Many respondents ranked watercraft traffic as having a negative or somewhat negative impact on the Waupaca Chain O' Lakes (Question 15).

Question 12: What types of watercraft do you use on the Chain?



Question 15: What type of effect has each of the following factors caused to the Chain waters?

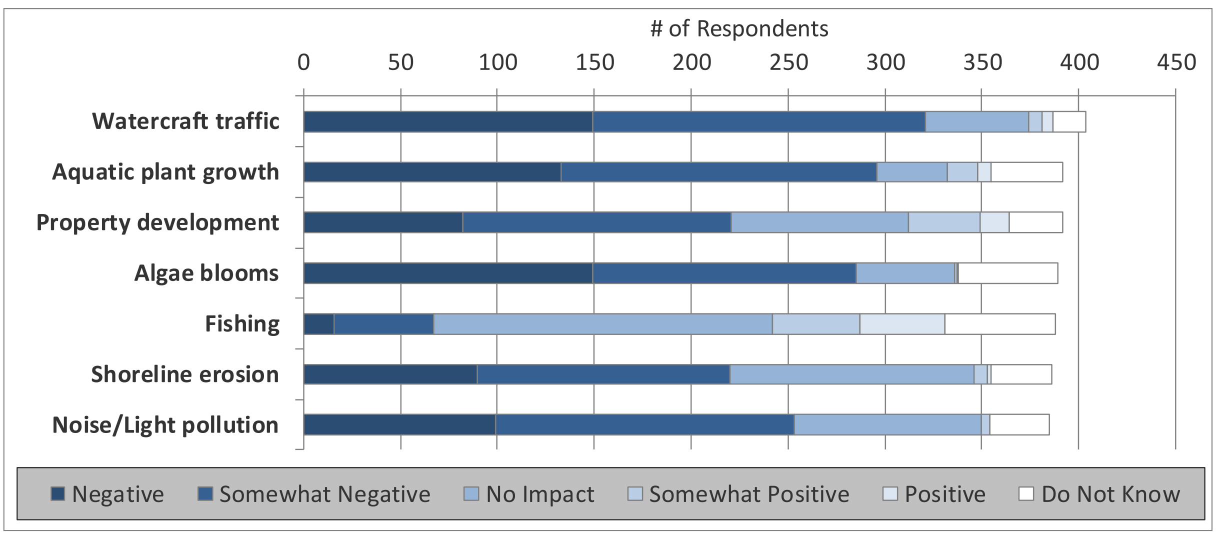


Figure 2.0-1. Select survey responses from the Waupaca Chain O' Lakes Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

3.0 RESULTS & DISCUSSION

3.1 Lake Water Quality

Primer on Water Quality Data Analysis and Interpretation

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

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

As mentioned above, chemistry is a large part of water quality analysis. In most cases, listing the values of specific parameters really does not lead to an understanding of a lake's water quality, especially in the minds of non-professionals. A better way of relating the information is to compare chemistry values 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 the Waupaca Chain O' Lakes is compared to other lakes in the state with similar characteristics as well as to lakes within the northern region (Appendix C). In addition, the assessment can also be clarified by limiting the primary analysis to parameters that are important in the lake's ecology and trophic state. (See below.) Three water quality parameters are focused upon in the Waupaca Chain O' 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 help 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 quadrants (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.

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 complete understanding of the lake's trophic state while facilitating clearer long-term tracking. Carlson (1977) presented a trophic state index that gained great acceptance among lake managers.

Limiting Nutrient

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

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

Temperature and Dissolved Oxygen Profiles

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

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

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

Internal Nutrient Loading*

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

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

Non-Candidate Lakes

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

Candidate Lakes

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

Specific to the final bullet-point above, 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 the Waupaca Chain O' Lakes will be compared to lakes in the state with similar physical characteristics. The WDNR groups Wisconsin's lakes into ten natural communities (Figure 3.1-1).

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

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

Drainage Lakes have surface water inflow and/or outflow in the form of rivers and/or streams.

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

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

The Waupaca Chain O' Lakes contain lakes in more than one classification. The Upper Chain lakes are classified as deep, lowland drainage lakes (category 5) because they have a large watershed with Hartman and Emmons creeks draining into the lakes. Other lakes, such as Ottman and Youngs lakes are classified as shallow, headwater drainage lakes (category 2). The larger lakes, e.g. Long and Rainbow lakes, are considered two-story fishery lakes (category 9). Most of the other lakes are deep, headwater drainage lakes (category 3).

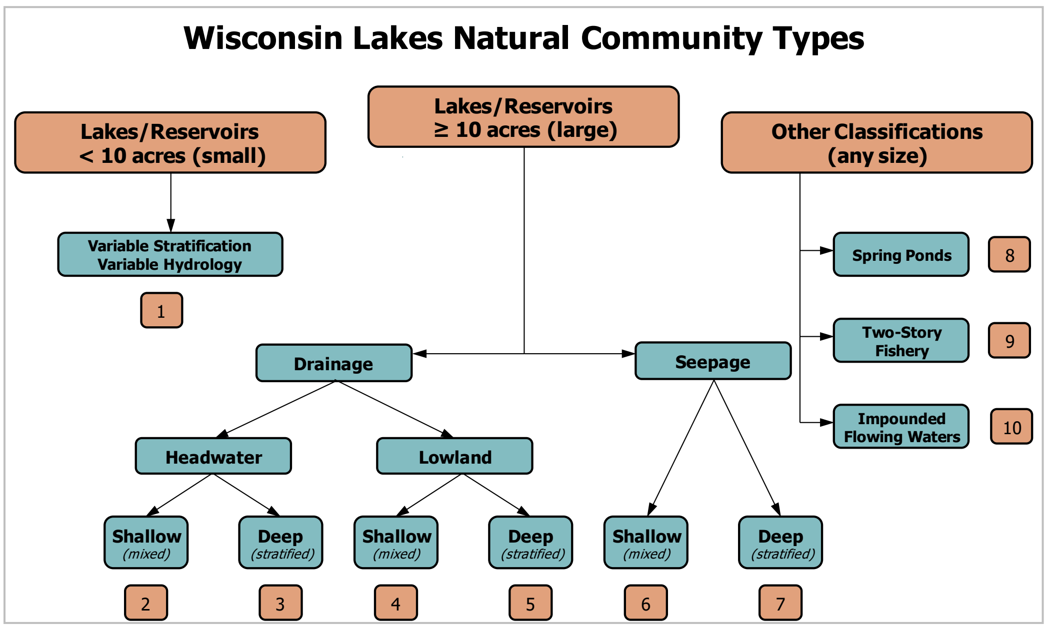


Figure 3.1-1. Wisconsin Lake Natural Communities. Adapted from WDNR 2013A.

Garrison, et. al (2008) developed statewide 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. The Waupaca Chain O' Lakes is within the North Central Hardwood Forests ecoregion.

The Wisconsin 2014 Consolidated Assessment and Listing Methodology document also helps stakeholders understand the health of their lake compared to other lakes within the state. Looking at pre-settlement diatom population compositions from sediment cores collected from numerous lakes around the state, researchers were able to infer a reference condition for each lake's water quality prior to human development within each lake's watershed. 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.

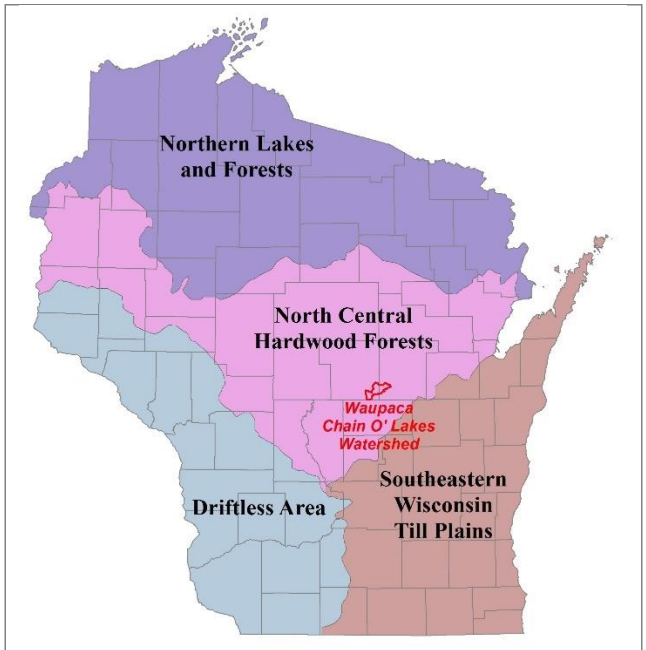


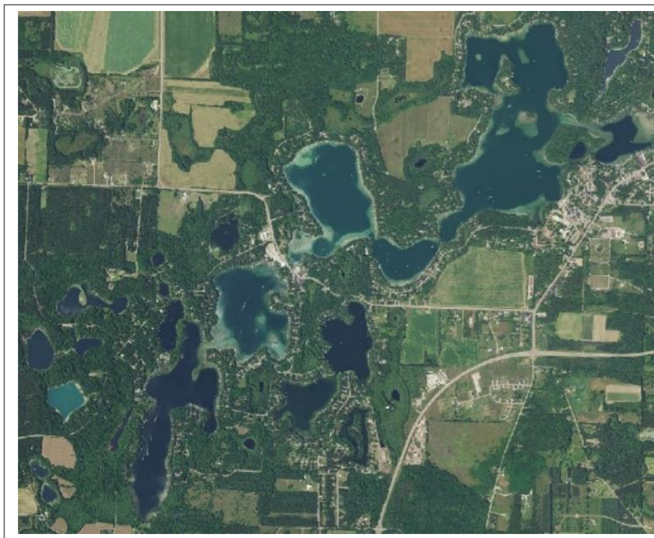
Figure 3.1-2. Location of Waupaca Chain O' Lake's watershed within the ecoregions of Wisconsin. After Nichols 1999.

These data along with data corresponding to statewide natural lake means, and historic, current, and average data from the Waupaca Chain O' Lakes are displayed in Figures 3.1-3 - 3.1-11. 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.

Waupaca Chain O' Lakes Water Quality Analysis

Waupaca Chain O' Lakes Nutrient Content and Clarity

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 lack 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.



Photograph 3.1-1. Aerial view of Waupaca Chain O' Lakes showing turquoise color of the marl lakes. Aerial photography: NAIP, 2015.

The Waupaca Chain O' Lakes are marl lakes which means they naturally possess a large amount of calcium in their water. These types of lakes are generally found only in the glaciated region of the

Laurentian Great Lakes. They naturally have very hard water and are low in nutrients, e.g. phosphorus, resulting in clear water which often gives the lakes a turquoise color (Photograph 3.1-1). The high amount of calcium in the water combines with phosphorus and coprecipitates to the lake bottom. This mechanism reduces phosphorus levels in the water and thus reduces algal growth. Submerged plants are usually covered with a "crust" of this calcium carbonate, and the nearshore sediments are often gray in color.

During 2016, Onterra staff sampled all 22 lakes in the Waupaca Chain O' Lakes. Trophic parameters, near surface total phosphorus, chlorophyll-*a*, and Secchi disk transparency were sampled during July. Long, Rainbow, Miner, and Pope lakes were sampled for trophic parameters in April, June, August, and October. A near-bottom sample for total phosphorus was collected at the same time to assess the potential for internal phosphorus loading. When the lakes were visited for trophic parameters, profiles of temperature and dissolved oxygen were also collected. Samples were collected in the deepest areas of the lake with the exception of Columbia Lake where the July sample was collected in a part of the lake that was shallower (45 vs 72 feet).

Referencing the results of the 2016 samplings, the Waupaca Chain O' Lakes generally had low phosphorus concentrations (Figure 3.1-3). The phosphorus levels classified most of the lakes in the *excellent* category. Otter, Ottman, and Pope lakes had phosphorus concentrations that were higher than the other Chain lakes. Otter Lake is a deep headwater lake and its phosphorus concentration placed it in the *good* category. Ottman Lake is a shallow headwater lake and its phosphorus concentration placed it in the *excellent* category. Pope Lake is a deep, lowland drainage lake and its phosphorus concentration placed it in the *good* category. The lakes with the lowest phosphorus levels were Lime Kiln and Round at 9 µg/L. The lake with the highest phosphorus concentration was Ottman Lake at 24 µg/L, followed by Pope Lake at 20 µg/L. The rest of the lakes had a concentration of 17 µg/L or less. The phosphorus concentrations in all of the Chain lakes were significantly less than the median value for other lakes in the NCHF ecoregion (Figure 3.1-3). The total phosphorus concentrations in most of the deep headwater drainage lakes in the Chain were also less than the statewide median for deep headwater drainage lakes, and all of the deep lowland drainage lakes in the Chain are less than the statewide median for deep lowland drainage lakes. The low concentration is due in part to these lakes being marl lakes. Pope Lake was below the statewide median value (23 µg/L) for this lake type. Likewise, the phosphorus concentration in Ottman Lake, which is a shallow headwater drainage lake, was below the statewide median value (29 µg/L) for this lake type.

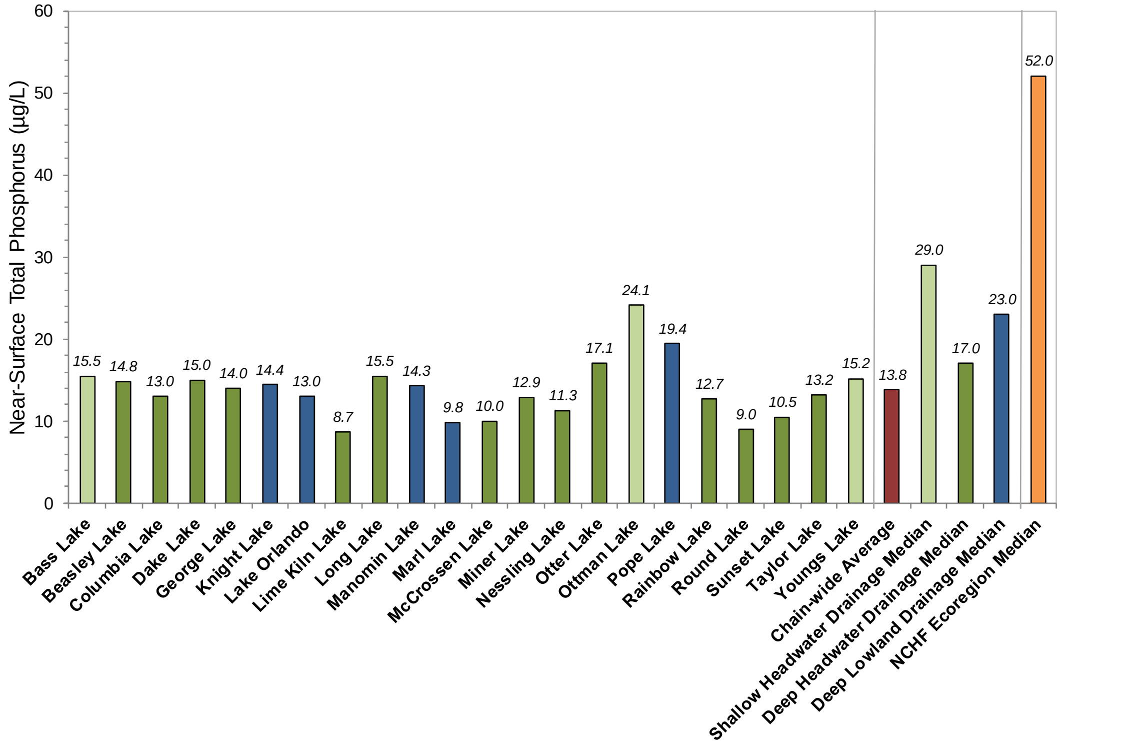


Figure 3.1-3. Waupaca Chain O' Lakes and regional total phosphorus concentrations. Also displayed are the median near-surface total phosphorus concentrations for statewide deep headwater drainage lakes (DHDL) and Northcentral Hardwood Forest (NCHF) ecoregion lakes. Chain mean values calculated with July 2016 near-surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

The summer chlorophyll-*a* concentrations were very low and ranged from 0.4 µg/L in Youngs and Marl lakes, to 10.5 µg/L in Pope Lake (Figure 3.1-4). Chlorophyll-*a* placed more lakes in the oligotrophic classification than phosphorus and reflects the fact that these are marl lakes. As mentioned above, in marl lakes, phosphorus combines with calcium carbonate and makes this nutrient unavailable for algal uptake, which results in lower chlorophyll-*a* concentrations than would be expected compared with phosphorus levels. Most of the lakes fell into the *excellent* category. The only lake not in the *excellent* category was Pope Lake. This lake is a deep lowland drainage lake and its chlorophyll-*a* value placed it on the border between *good* and *fair*. Chlorophyll-*a* concentrations in all of the lakes were significantly below the median value for lakes in the NCHF ecoregion. With the exception of Pope Lake, the chlorophyll-*a* values for the deep lowland drainage lakes in the Chain were below the statewide median for deep lowland drainage lakes (Figure 3.1-4). All of the shallow headwater drainage lakes and the deep headwater drainage lakes in the Chain were lower than the median values in their respective categories.

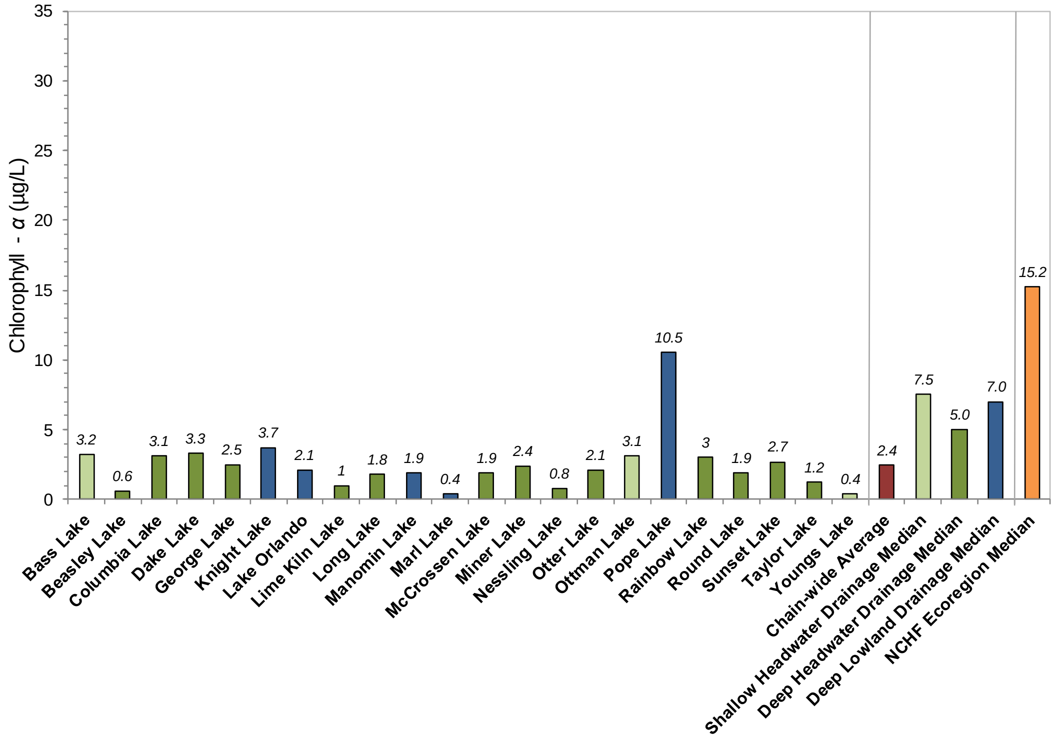


Figure 3.1-4. Waupaca Chain O' Lakes and regional chlorophyll-*a* concentrations. Also displayed are the median near-surface chlorophyll-*a* concentrations for statewide deep headwater drainage lakes (DHDL) and Northcentral Hardwood Forest (NCHF) ecoregion lakes. Chain mean values calculated with July 2016 near-surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

The 2016 Secchi disk transparency values placed many of the lakes in the *excellent* category. Lakes with the best water clarity were Beasley and Orlando, although Knight, Long, Marl, and Miner also had very good clarity. Although phosphorus and chlorophyll concentrations for most of the lakes were below the statewide median value for deep headwater drainage lakes, this was not the case for Secchi disk transparency. The lakes mentioned above, with the addition of Manomin and Youngs, had water clarity better than the statewide median value. All of the lakes, with the exception of Nessling Lake, had better water clarity than the median value for the NCHF ecoregion lakes (Figure 3.1-5). One factor that influences Secchi disk transparency values is whether the lake possesses a metalimnetic oxygen maximum. As discussed below, in lakes with such a maximum, there is a relatively large algal community in the metalimnion in these lakes. When the Secchi disk is lowered into this algal layer, it quickly disappears. This means that the Secchi disk value underestimates the water clarity in the epilimnion. For example, Beasley and Orlando lakes had the greatest Secchi disk transparency values, but neither lake had a metalimnetic oxygen maximum.

While Secchi transparency usually is impacted most by the amount of algae in the water, it is also influenced by suspended materials other than algae. A study conducted in 1994 on Columbia and Long lakes found that water clarity was worse on the weekends compared with clarity during the week (Asplund 1996). This was attributed to increased motorboat activity on the weekend which suspended the sediments into the water column. In Long Lake, the number of motorboats increased from about 3.5 per 100 acres during the week to 17 boats per 100 acres on the weekend. The density of boats during the weekend was similar on Columbia Lake. In Long Lake, transparency was reduced, on average, almost 1.5 feet on the weekends, while it was less on

Columbia Lake at a little more than 0.5 feet. This study also found that phosphorus and chlorophyll-*a* levels were slightly higher on the weekend compared with during the week. In the Chain, high-speed motorboat activity is only allowed on four lakes: Columbia, Long, Rainbow, and Round. Only on these lakes is it likely that motorboats are adversely affecting water clarity. The Asplund study also found that in hard water lakes like in the Chain, sediment suspended by motorboat activity does not result in increased algal growth. This is because the suspended sediment phosphorus is combined with calcium, making it unavailable for algal uptake.

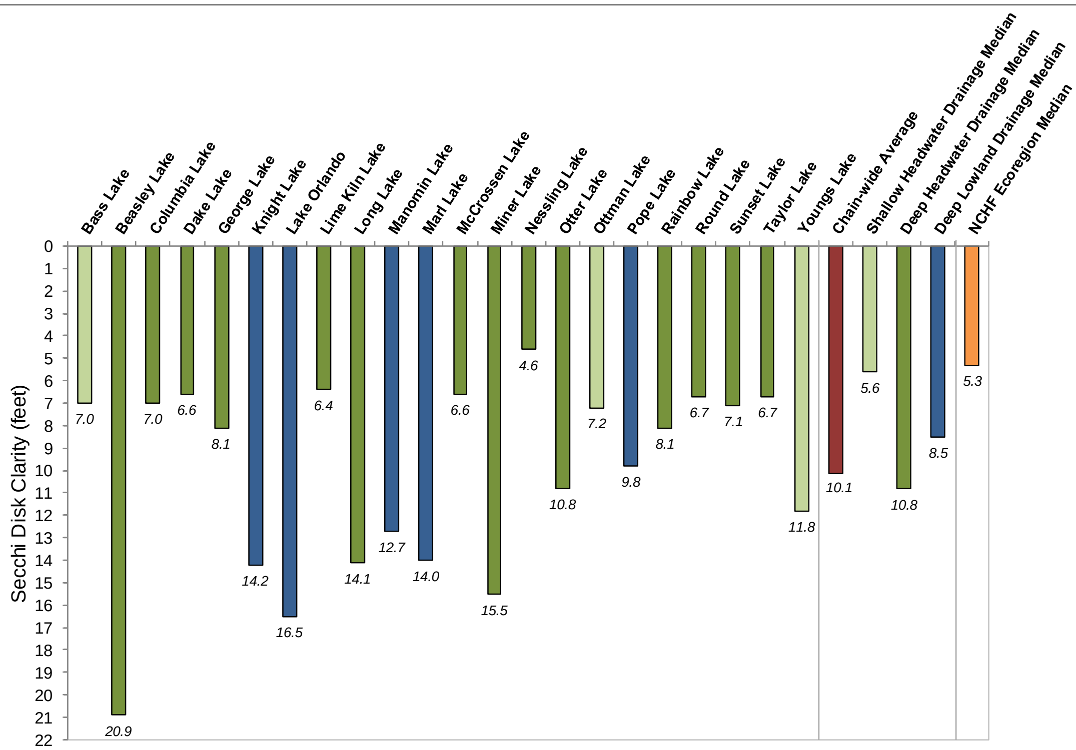


Figure 3.1-5. Waupaca Chain O' Lakes and regional Secchi disk transparency values. Also displayed are the median Secchi disk transparency values for state-wide deep, headwater drainage lakes (DHDL) and Northcentral Hardwood Forest (NCHF) ecoregion lakes. Chain mean values calculated with July 2016 near-surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

Limiting Plant Nutrient of the Waupaca Chain O' Lakes

In July 2016, nitrogen and phosphorus concentrations were measured in all of the lakes in the Waupaca Chain. Nitrogen:phosphorus ratios ranged from 40:1 to 227:1. This finding indicates that all of the lakes are indeed phosphorus limited as are the vast majority of Wisconsin lakes. In general, this means that cutting phosphorus inputs may limit plant growth within the lake.

Waupaca Chain O' Lakes Trophic State

Figure 3.1-6 contain the TSI values for all of the lakes in the Waupaca Chain O' Lakes. The TSI values calculated with Secchi disk, chlorophyll-*a*, and total phosphorus values range from 22 to 55. Using the total phosphorus and chlorophyll-*a* values, it can be concluded that the lakes are either in the oligotrophic or mesotrophic range. Using only chlorophyll-*a* to determine trophic state would indicate that more of the lakes are in the oligotrophic range. This is probably more realistic since these are marl lakes. As discussed previously, the calcium in the water combines with phosphorus, meaning some of this nutrient is not available for algal growth. Using chlorophyll-*a* to determine trophic state, 14 of the 22 lakes are in the oligotrophic state. All of the lakes except Pope Lake are in a less productive trophic state than the median for deep, headwater drainage lakes (Figure 3.1-6). All of the lakes are much better than the median values for all lakes in the NCHF ecoregion. Using Secchi disk transparency to determine trophic state, it would appear that nearly all of the lakes are in the mesotrophic state. As mentioned above, water clarity in these lakes is partially determined by suspended sediments both from motorboats and wind-generated waves. Marl tends to be very flocculent and is easily suspended. Also, the presence of a relatively large metalimnetic algal community in many of these lakes adversely affects the Secchi disk transparency values. Therefore, in these lakes, Secchi disk transparency is not an accurate measure of trophic state.

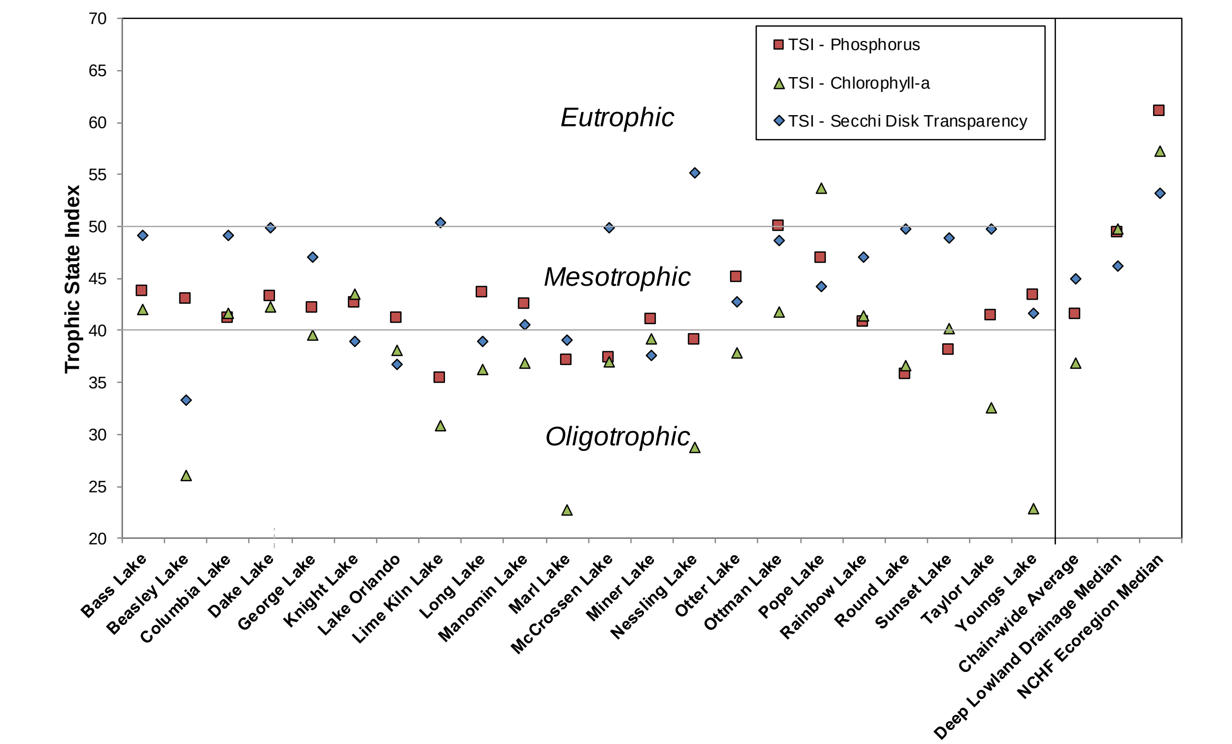


Figure 3.1-6. Waupaca Chain O' Lakes and regional TSI values. Also displayed are the median TSI values for statewide deep, headwater drainage lakes (DHDL) and Northcentral Hardwood Forest (NCHF) ecoregion lakes with sample data. Values calculated with July 2016 near-surface sample data using WDNR PUB-WT-193.

Long-term Trends

Twelve of the lakes in the Waupaca Chain O' Lakes were sampled during the summers of 1993 and 1994 for near-surface total phosphorus, chlorophyll-*a*, and Secchi disk transparency. These lakes, as well as the other ten lakes were sampled in 2016. In 2016, all but four of the lakes were sampled only in July. When comparing trophic parameters in 2016 and 1993-94, samples taken near the end of July were used.

In all of the lakes except Bass Lake, phosphorus concentrations were higher in 2016 compared with 22 years earlier. The lakes that have experienced the greatest increase are Rainbow, Miner and Pope lakes (Figure 3.1-7). In the eleven lakes which showed an increase in phosphorus, the mean increase was nearly 4 μg/L. In the case of Pope and Manomin lakes, it is doubtful that the increase is the result of increased loading from Hartman Creek since phosphorus concentrations in 1993-94 were similar to the period 2011-14.

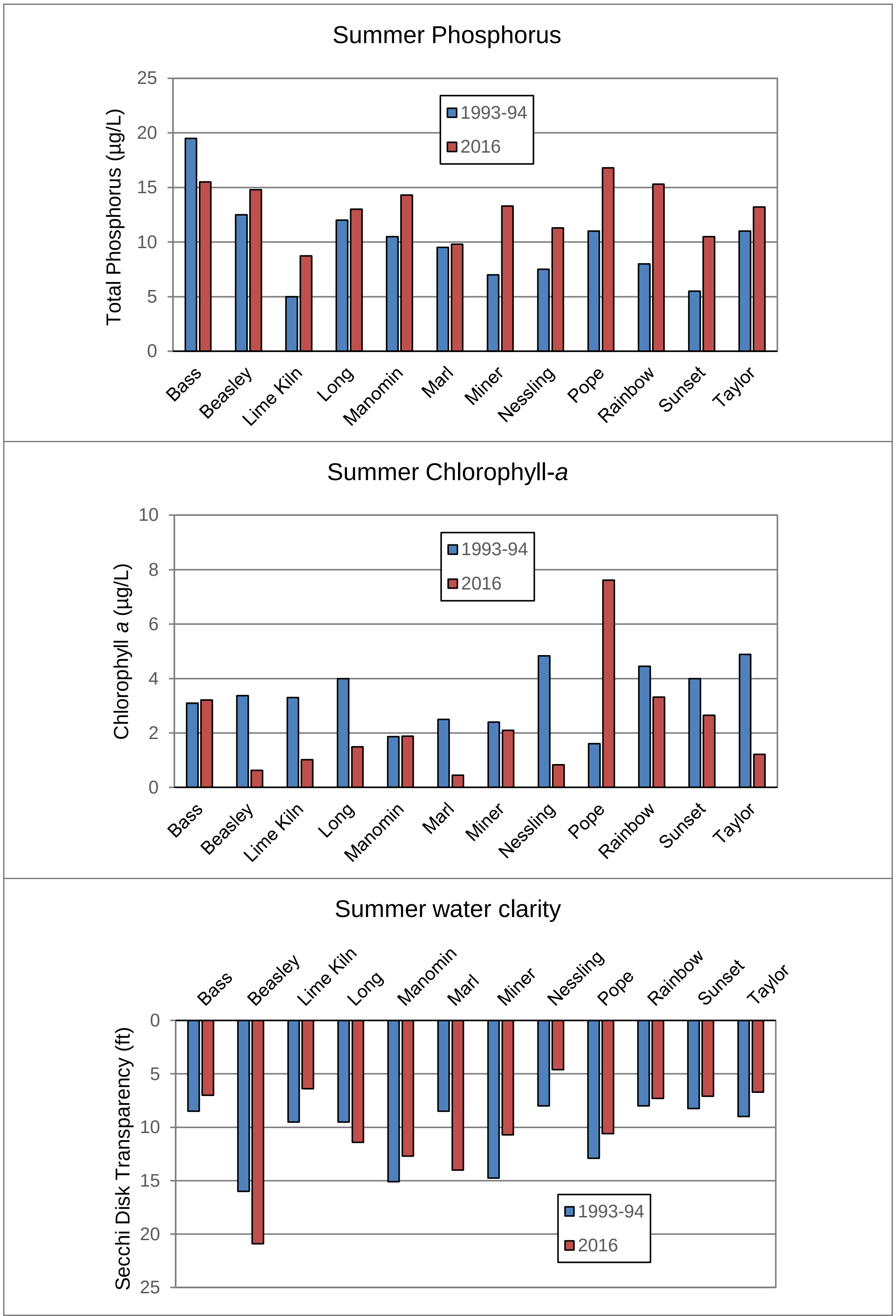


Figure 3.1-7. Comparison of total phosphorus, chlorophyll-*a*, and Secchi disk transparency for 1993-94 and 2016.

With exception of Pope, Manomin, and Bass lakes, 2016 chlorophyll-*a* concentrations were lower than they previously were in 1993-94. It is not clear why phosphorus concentrations would increase, but not chlorophyll-*a*. In Pope Lake, there was a large increase in 2016 compared with 1993-94 (Figure 3.1-7). A chlorophyll-*a* concentration of 36 µg/L was measured in August 2016. This value was probably elevated due to algae that were originally in the metalimnion being redistributed to the near surface waters as the lake cooled and the top of the thermocline moved downward and intercepted the upper part of the metalimnetic chlorophyll-*a* maximum. The value of 7.6 µg/L measured in July is likely a better indicator of summer chlorophyll-*a* concentrations in the surface water. Apparently, chlorophyll-*a* levels in recent years are elevated in Pope Lake.

In 2016, Secchi disk transparency was worse than in 1993-94 in 9 of the 12 lakes (Figure 3.1-7). The average decrease in water clarity was over 2 feet. The lakes with improved water clarity were Beasley, Long, and Marl. It is likely the improvement in Marl Lake was an anomaly as summer Secchi disk transparency in other years in Marl Lake was similar to what was measured in 2016. In Pope Lake, the decrease in Secchi disk transparency was not as great as the increase in chlorophyll-*a*, but all three trophic parameters indicate that the lake's water quality has degraded in the last 22 years.

Pope Lake has a long record of Secchi disk transparency values, beginning in 1992 (Figure 3.1-8). As described above, the Secchi values are not necessarily a true indication of surface water clarity because of the higher algal levels in the metalimnion. The Secchi disk transparency is, in part, a reflection of the intensity and depth of the upper metalimnetic algal layer. The deepest Secchi in the record occurred in 2009 and 2010. Secchi disk transparencies generally were better throughout the Chain in 2009 and 2010. It is not clear why water clarity was better those years, but it is likely the metalimnetic algal community was reduced. In 2016 the Secchi disk transparency was less than for most of the earlier years, with the exception of 2002. This likely was because measurements were only taken in August and water clarity tends to be worse during this month.

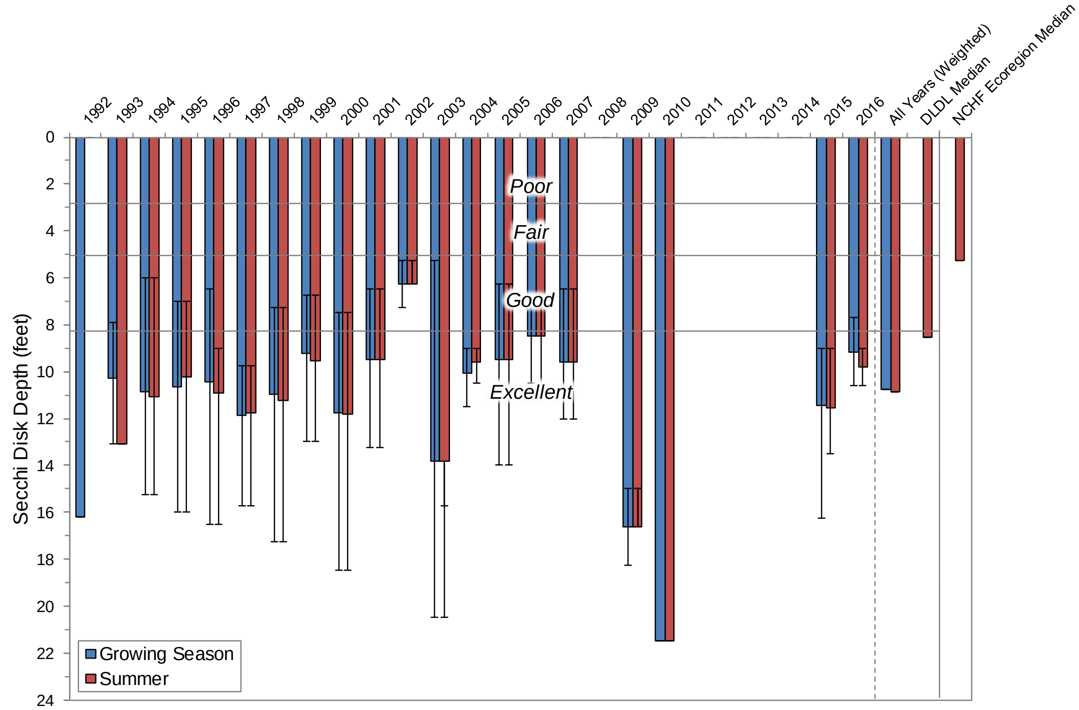


Figure 3.1-8. Pope Lake growing season and summer average Secchi disk transparency. Also displayed are median Secchi disk transparency values for statewide deep lowland drainage lakes (DLDL) and Northcentral Hardwood Forest (NCHF) ecoregion lakes**.** Water Quality Index values adapted from WDNR PUB WT-913.

Changes in dissolved oxygen profiles can also be indicative of changes in a lake's water quality. As is discussed in the following section, many of the lakes in the Chain experience metalimnetic oxygen maxima during the summer. This type of profile occurs because there is a large algal community in the metalimnion. Lakes that exhibit this profile need to have good water clarity in the epilimnion so that sufficient light reaches the metalimnion to support photosynthesis. Algae thrive in this deeper water because there is sufficient light and higher amounts of nutrients, e.g. phosphorus, in these deeper waters. If there is sufficient light reaching the metalimnion, but there is not a large algal community, this indicates that nutrient levels are low in this part of the water column. If lakes have a greater metalimnetic oxygen maxima now compared with earlier years, it is an indication that nutrient levels are higher at the present time in the deeper waters. Some of the Waupaca Chain O' Lakes were sampled during the 1970s by the WDNR. Two of these lakes were Rainbow and Round lakes. Figure 3.1-9 compares the oxygen profiles in 1972, 1974, and 1978 with 2016. These profiles were taken in July with the exception of 1978, which was taken on August 3. In both lakes, the dissolved oxygen maxima was greater in 2016, suggesting nutrients were higher in the more recent year. In Round Lake, the maxima may be at a shallower depth, suggesting that water clarity was better in the 1970s.

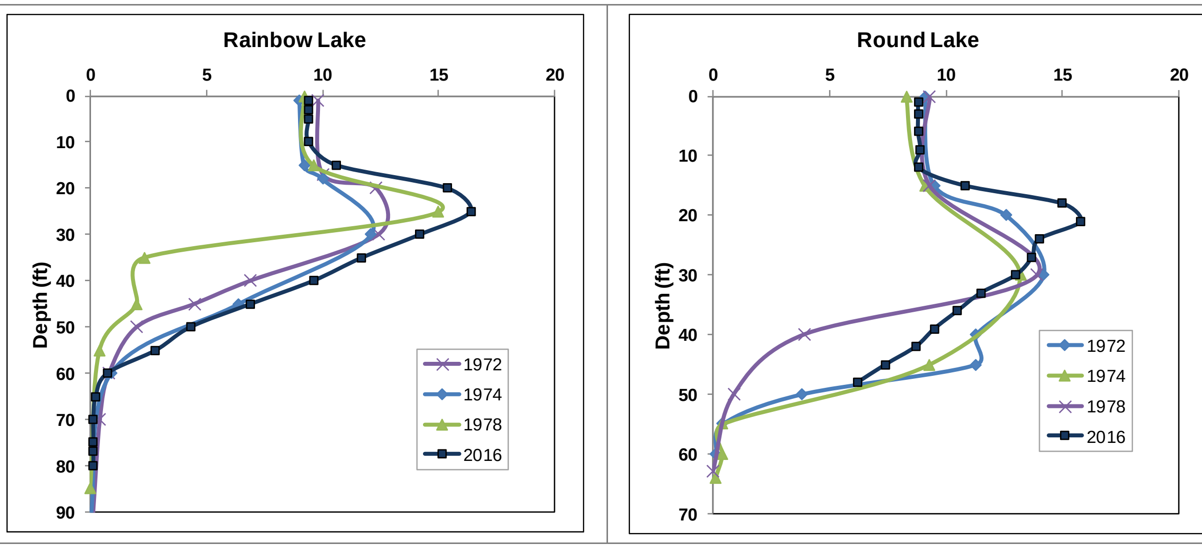


Figure 3.1-9. Dissolved oxygen profiles from Rainbow and Round lakes in the 1970s and 2016. Profiles were taken in July with the exception of 1978 which was collected in early August.

Although the trophic state of the Waupaca Chain O' Lakes at the present time is very good, Marl Lake, and by implication the other deep lakes, were even better prior to Euro-American settlement in the mid-1800s. As part of the U.S. EPA National Lake Assessment in 2007 and 2012, a sediment core was taken from Marl Lake. The diatom community (a type of algae which is preserved in the sediments) at the bottom of the core, which was deposited prior to 1850, revealed that at that time phosphorus concentrations were around 3 to 4 µg/L and there was almost no algae in the water column of the lake. This is not true at the present time when phosphorus concentrations are around 10 µg/L in Marl Lake. As part of the 2012 U.S. EPA National Lake Assessment, a sediment core was taken from Youngs Lake. The core revealed that historically the phosphorus concentration of this shallow lake was only slightly less than it is at the present time.

Although most of the lakes in the Waupaca Chain O' Lakes have very good water quality as the sediment core from Marl Lake showed, prior to European settlement the water quality was even better. At the present time, the water quality is not as good as prior to European settlement because of nutrient inputs from shoreland development, agricultural activities in the watershed, and other sources. The water quality of these lakes is good because they are marl lakes and the high levels of calcium carbonate help to make some of the phosphorus unavailable for algal uptake. Marl lakes can become eutrophic if enough phosphorus enters the lake. This likely happened to lakes such as Lake Mendota, which originally was a marl lake, but there was so much phosphorus entering the lake over time that the buffering capability of the marl was overcome and the lake became eutrophic. This is not likely to happen in the Waupaca Chain O' Lakes unless phosphorus loading were to greatly increase.

Dissolved Oxygen and Temperature in the Waupaca Chain O' Lakes

Dissolved oxygen and temperature were measured by Onterra staff during water quality sampling visits to the Waupaca Chain O' Lakes. For all of the lakes, with the exception of Long, Miner, Pope, and Rainbow, profiles were taken only in July 2016. For the other four lakes, profiles were taken in April, June, July, August, and October of 2016, as well as in February 2017. July profiles depicting these data are displayed in Figure 3.1-10a-c.

These lakes exhibit a range of dissolved oxygen profiles. Shallow lakes exhibit nearly similar concentrations from top to bottom, while *clinograde* profiles of dissolved oxygen present in the epilimnion, but depleted from the hypolimnion, were found in Dake, Beasley and Miner lakes (Figure 3.1-10a-c). Positive *heterograde* profiles were documented in many of the deeper lakes as shown by an increase in dissolved oxygen in the metalimnion due to phytoplankton photosynthesis (i.e. Manomin, Pope, and Taylor lakes). Bass, Ottman, Youngs, and Dake lakes are considered *polymictic* because they are too shallow to thermally stratify and can mix throughout the growing season. Even though there was no oxygen in the bottom waters of Dake Lake when it was sampled in July, the temperature at the bottom was over 20°C indicating that this lake frequently mixes. In George Lake the temperature at the bottom is higher than the deeper lakes which may indicate this lake does not stratify until later in the summer and likely experiences fall overturn earlier than the other deeper lakes. Manomin Lake, even though it has the same maximum depth as George Lake, is clearly *dimictic* (mixes twice a year - once in the spring following ice-off and again in the fall with cooling temperatures). The bottom temperature was around 10°C and the lake experiences a metalimnetic oxygen maximum. Manomin Lake has a positive heterograde dissolved oxygen profile. This lake likely does not mix during the summer because it is protected from wind by its small size and is surrounded by hills and trees. At the time of sampling, the oxygen saturation was 200% at 15 feet. This high level of oxygen is the result of planktonic algal production in the metalimnion where oxygen production from photosynthesis exceeds respiration. Although chlorophyll-*a* was not analyzed in the metalimnion, it is very likely these concentrations would be much higher than in the surface waters. Nutrient levels are higher in the metalimnion because they tend to be higher in the deeper waters where there is no algal uptake and phosphorus in organic form is broken down into a form that can be utilized by algae. This phosphorus found in the deep water slowly moves upward and is available to algae growing in the metalimnion. As described earlier, algae grow at this depth because there is sufficient light for photosynthesis and nutrient levels are often higher than in the epilimnion.

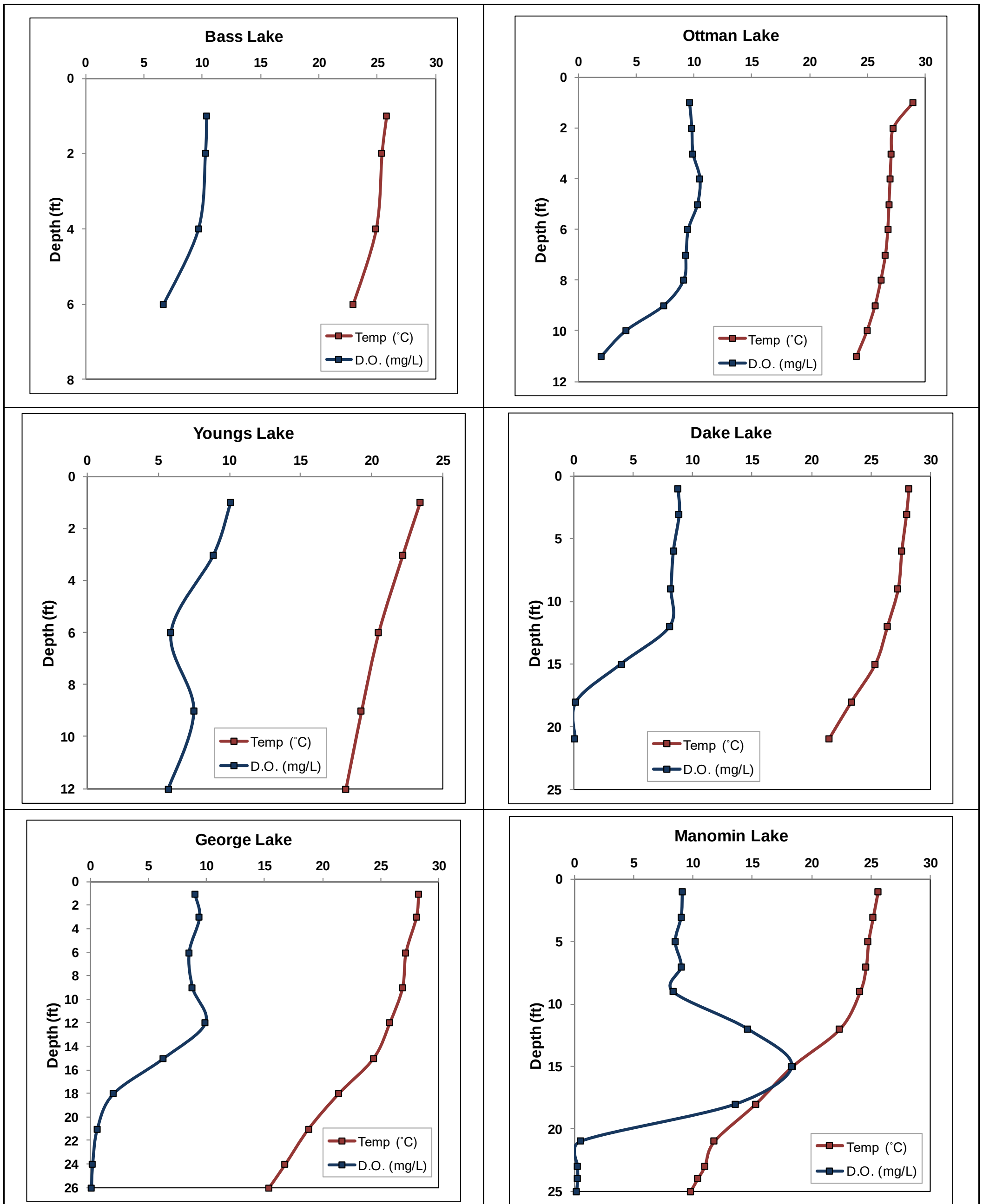


Figure 3.1-10a. July 2016 dissolved oxygen and temperature profiles for lakes in the Waupaca Chain O' Lakes. Lakes are generally arranged from shallow to deep.

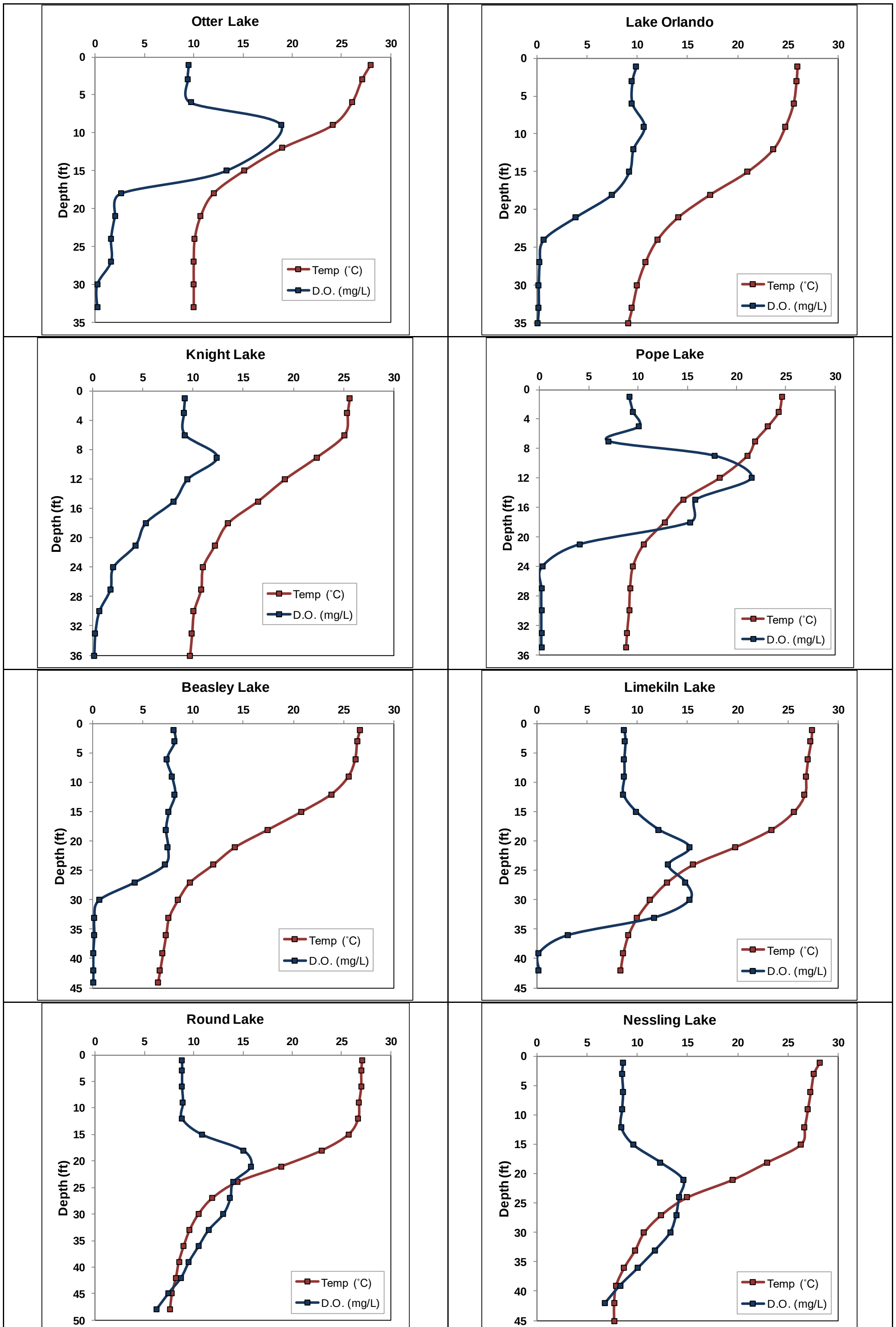


Figure 3.1-10b. July 2016 dissolved oxygen and temperature profiles for lakes in the Waupaca Chain O' Lakes. Lakes are generally arranged from shallow to deep.

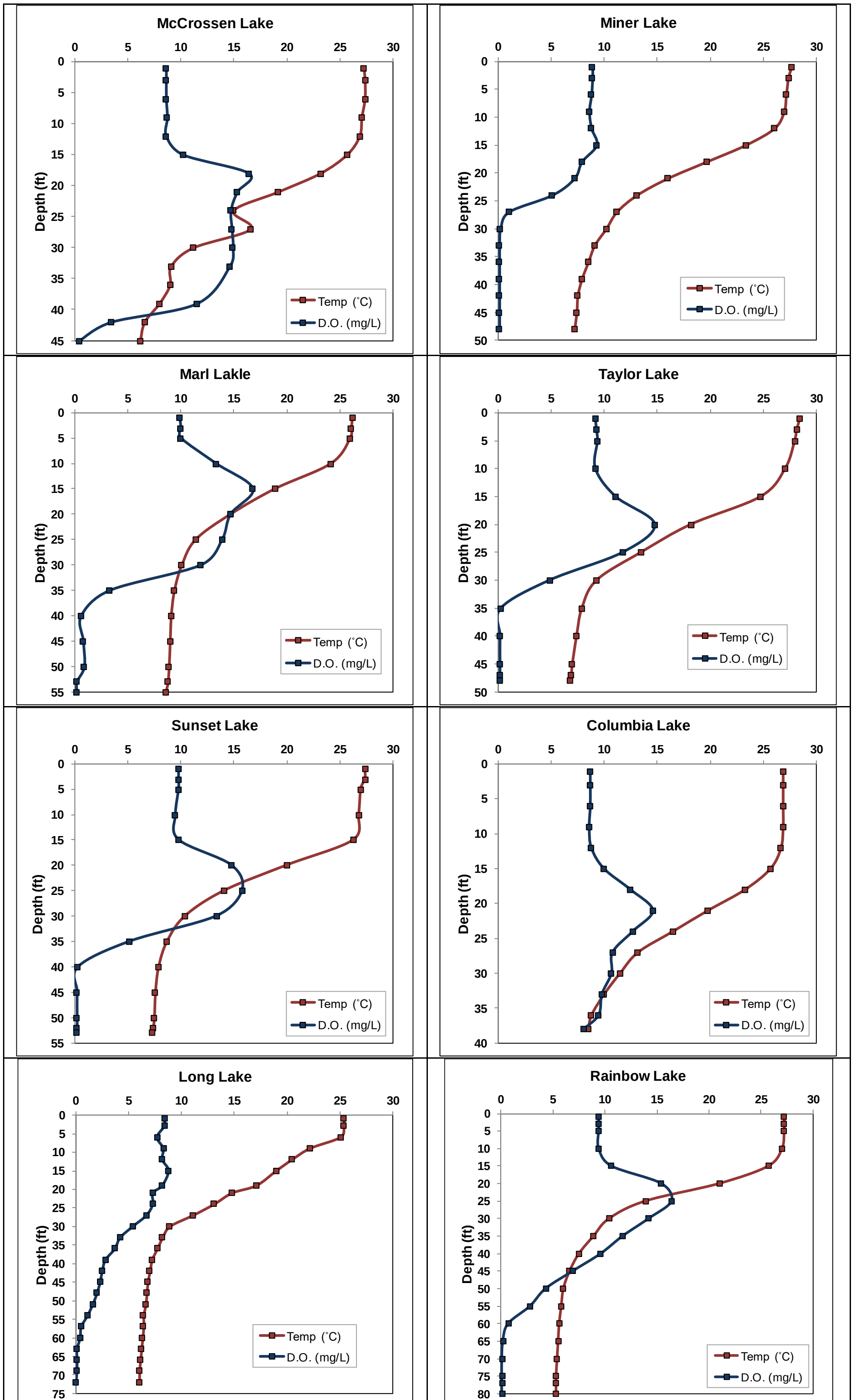


Figure 3.1-10c. July 2016 dissolved oxygen and temperature profiles for lakes in the Waupaca Chain O' Lakes. Lakes are generally arranged from shallow to deep.

In Lime Kiln and McCrossen lakes, the metalimnetic oxygen maximum extends over considerable depth. Much of this dissolved oxygen is the result of photosynthesis, but a portion is likely a remnant of oxygen gained during spring turnover. This would indicate that these lakes experience a spring algal bloom, which elevates oxygen levels at the start of stratification. This oxygen remains in the lake at high concentrations because of the lake's morphometry and relatively low productivity.

Lakes that exhibit metalimnetic oxygen maxima are probably more productive than those that do not. Although the relative depth and location in the landscape can influence whether a maximum occurs, all of these lakes have a comparatively large relative depth. Lakes with a sizable metalimnetic algal community indicate good water clarity in the epilimnion and allow sufficient light to reach the metalimnion, but sufficient nutrients in the deeper waters support the increased algal production.

Oxygen profiles were taken from Long, Miner, Pope and Rainbow lakes four times during stratification (Figure 3.1-11). Rainbow and Pope exhibited the metalimnetic oxygen maxima, while the other two lakes only exhibited a small maximum in June. In Rainbow and Pope lakes, the maxima persisted through August, but was gone by mid-October because the epilimnion had moved downward with cooler fall temperatures. These profiles likely indicate that Rainbow and Pope lakes are more productive than Miner and Long lakes.

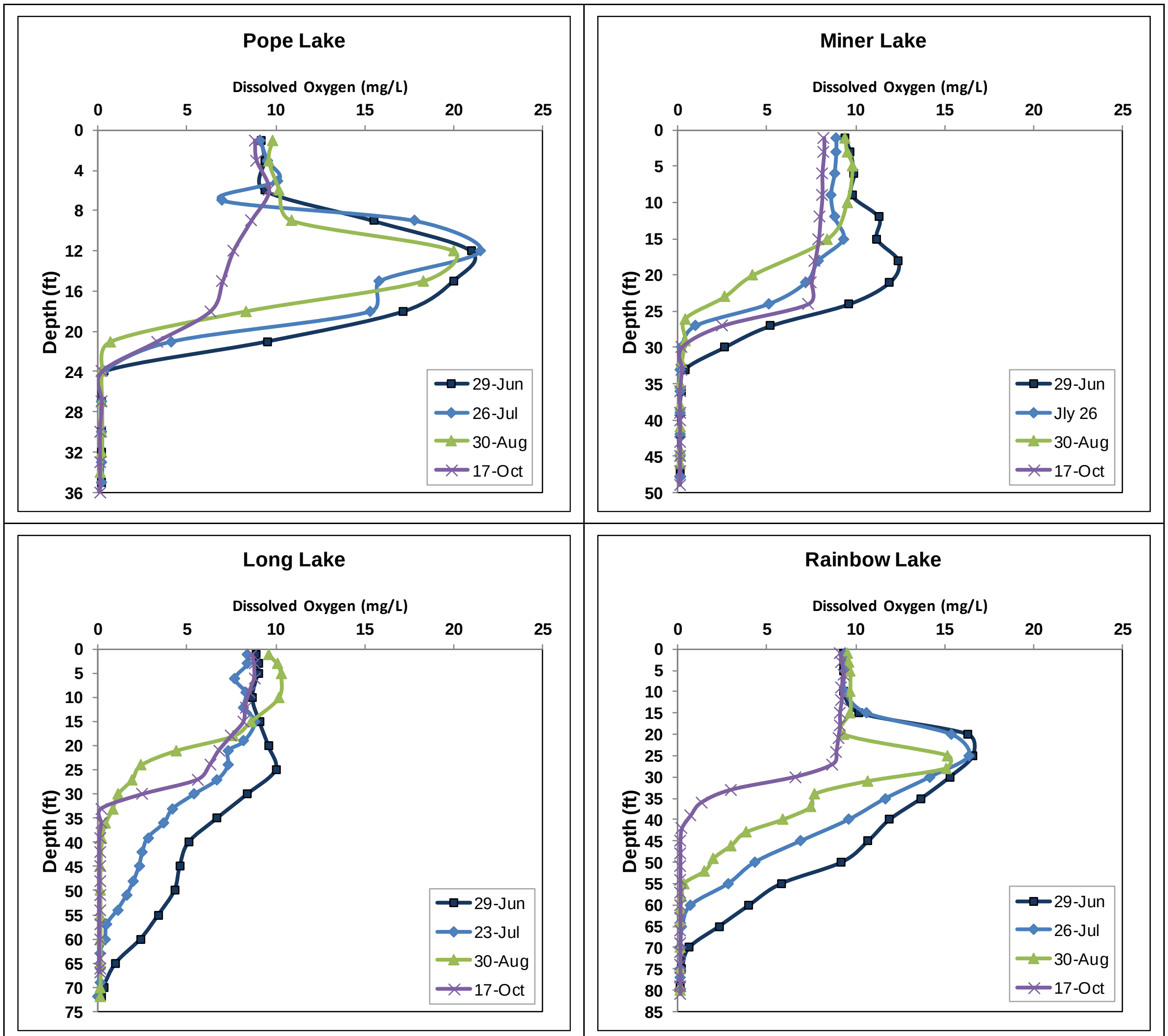


Figure 3.1-11. Dissolved oxygen profiles throughout the stratification period for four of the lakes in the Waupaca Chain O' Lakes. Two of the lakes experience a metalimnetic oxygen maximum throughout the summer while the others do not. This likely indicates that Rainbow and Pope lakes are more productive than the other two lakes.

Most of the lakes were anoxic in the near-bottom waters during sampling in July. The amount of oxygen depletion in the hypolimnion is dependent upon organic matter production in the upper waters as well as the water volume of the hypolimnion. A lake with a larger volume will lose oxygen at a slower rate given the same productivity than a lake with a small hypolimnetic volume. Lakes that still had oxygen in the bottom waters in July were Round, Nessling, and McCrossen (Figures 3.1-10b,c).

On February 16, 2017, temperature and dissolved oxygen profiles were collected from the four lakes discussed in the previous paragraph. These profiles were collected to determine if oxygen levels during the winter became low enough to endanger the fish community. As can be seen in Figure 3.1-12, oxygen levels were high enough throughout most of the water column in all of the lakes to support the fishery.

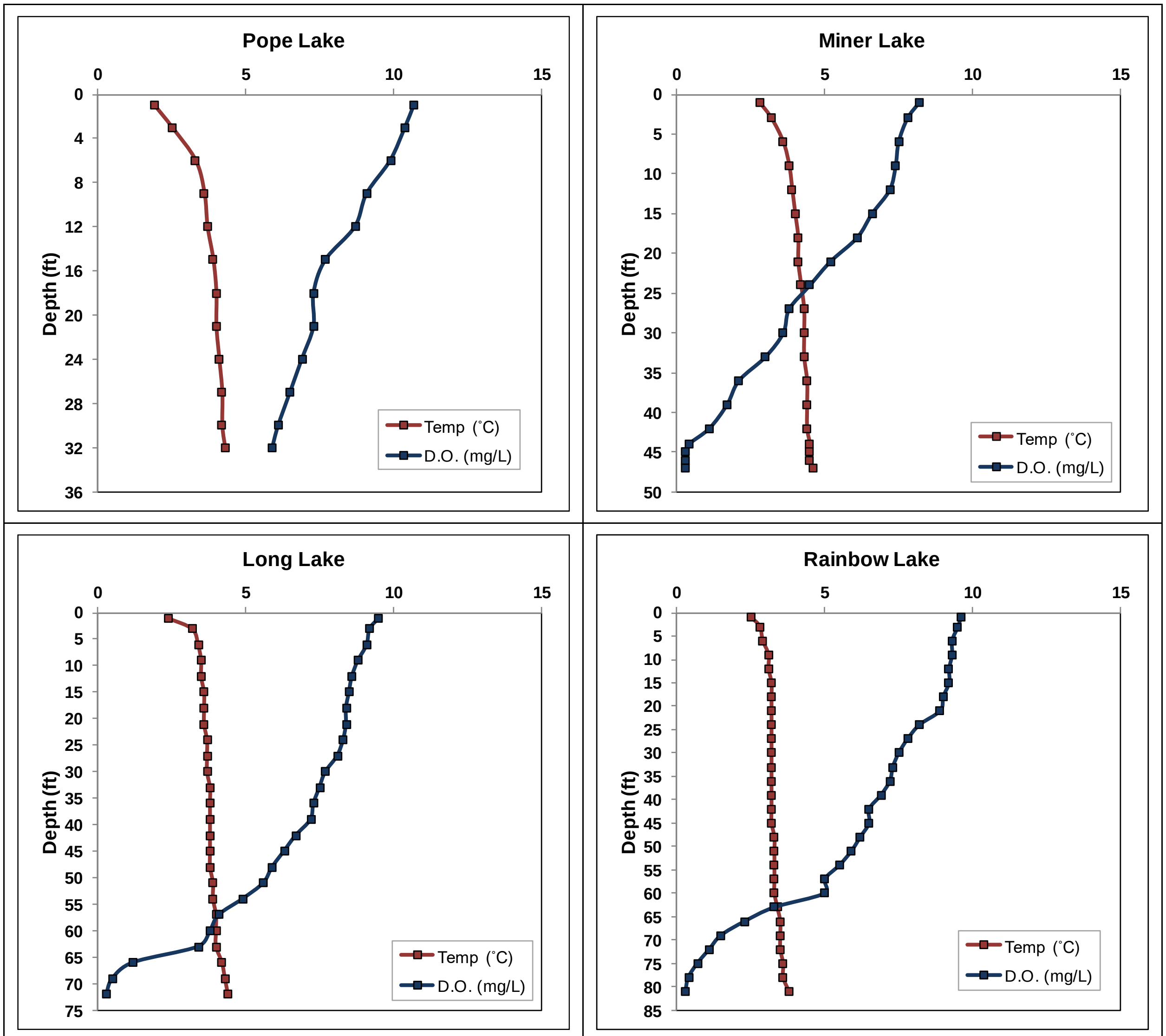


Figure 3.1-12. February 2017 dissolved oxygen profiles throughout the stratification period for four of the lakes in the Waupaca Chain O' Lakes. Oxygen levels were sufficient in all of the lakes to support the fishery.

In summary, the lakes in the northeastern part of the Chain tend to have slightly lower phosphorus and chlorophyll-*a* concentrations than the Upper Chain lakes and Long Lake because the latter lakes have perennial streams entering them. Most of the lakes have not seen a significant increase in phosphorus at the present time compared with the 1990s. Most of the lakes have seen a decline in chlorophyll-*a* over this time period, although it is not clear why. Because of the good water clarity in the epilimnion and high algal concentration in the metalimnion, it is not possible to use Secchi disk transparency to determine if there is a trend in water clarity in the surface waters. As explained earlier, the deep algal layer restricts Secchi disk transparency and does not give a true indication of water clarity in the surface waters. Miner Lake, which does not have a deep algal layer, has shown a small increase in the last 3 years compared with the 1990s. Most of the stratified lakes have a metalimnetic oxygen maximum because of higher algal populations in the metalimnion, which is an early sign of eutrophication as phosphorus is starting to increase in the deeper waters due to low oxygen levels. This phosphorus moves into the metalimnion where it is available for algal uptake. If phosphorus levels continue to increase, the water clarity would decline to the point where sufficient light would not reach the metalimnion to support algal productivity. Although Orlando, Knight, Beasley and Long lakes do not have a metalimnetic oxygen maximum, this likely indicates these lakes are not as productive as the other lakes since water clarity is good enough for light to reach the metalimnion.

Additional Water Quality Data Collected at the Waupaca Chain O' Lakes

The water quality section is centered on lake eutrophication. However, parameters other than water clarity, nutrients, and chlorophyll-*a* were collected from Long, Miner, Pope and Rainbow lakes as part of the project. These other parameters were collected to increase the understanding of general water quality of the Waupaca Chain O' Lakes and are recommended as a part of the WDNR long-term lake trends monitoring protocol. These parameters include pH, alkalinity, and calcium.

The pH scale ranges from 0 to 14 and indicates the concentration of hydrogen ions (H^+) within the lake's water and is an index of the lake's acidity. Water with a pH value of 7 has equal amounts of hydrogen ions and hydroxide ions (OH^-) and is considered to be neutral. Water with a pH of less than 7 has higher concentrations of hydrogen ions and is considered to be acidic, while values greater than 7 have lower hydrogen ion concentrations and are considered basic or alkaline. The pH scale is logarithmic, meaning that for every 1.0 pH unit the hydrogen ion concentration changes tenfold. The normal range for lake water pH in Wisconsin is about 5.2 to 8.4, though values lower than 5.2 can be observed in some acid bog lakes and higher than 8.4 in some marl and productive softwater 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 four lakes ranged from 8.3 to 8.7 and fall within the normal range for Wisconsin Lakes.

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 with a pH of around 5.0 naturally due to dissolved carbon dioxide from the atmosphere. Consequently, lakes with low alkalinity have lower pH due to their inability to buffer against acid inputs. The alkalinity in the four lakes ranged from 115 to 165 (mg/L as $CaCO_3$), indicating that the lakes have a substantial capacity to resist fluctuations in pH and have a low sensitivity to acid rain.

Like associated pH and alkalinity, the concentration of calcium within a lake's water depends on the geology of the lake's watershed. Recently, the combination of calcium concentration and pH has been used to determine what lakes can support zebra mussel populations if they are introduced. The commonly accepted pH range for zebra mussels is 7.0 to 9.0, so these lakes with their pH values of around 8.5 fall within this range. Lakes with calcium concentrations of less than 12 mg/L are considered to have very low susceptibility to zebra mussel establishment. The calcium concentration in these four lakes ranged from 23 to 37 mg/L, falling within the optimal range for zebra mussels.

Zebra mussels (*Dreissena polymorpha*) are small, bottom-dwelling mussels native to Europe and Asia that found their way to the Great Lakes region in the mid-1980s. They are thought to have come into the region through ballast water of ocean-going ships entering the Great Lakes, and they have the capacity to spread rapidly. Zebra mussels can attach themselves to boats, boat lifts, and docks, and can live for up to five days after being taken out of the water. These mussels can be identified by their small size, D-shaped shell and yellow-brown striped coloring. Once zebra mussels have entered and established in a waterway, they are nearly impossible to eradicate. Best practice methods for cleaning boats that have been in zebra mussel infested waters is inspecting and removing any attached mussels, spraying the boat down with diluted bleach, power-washing, and letting the watercraft dry for at least five days.

Researchers at the University of Wisconsin - Madison have developed an AIS suitability model called smart prevention (Vander Zanden and Olden 2008). In regards to zebra mussels, this model relies on measured or estimated dissolved calcium concentration to indicate whether a given lake in Wisconsin is suitable, borderline suitable, or unsuitable for sustaining zebra mussels. Within this model, suitability was estimated for approximately 13,000 Wisconsin waterbodies and is displayed as an interactive mapping tool (www.aissmartprevention.wisc.edu). Based upon this analysis the Waupaca Chain O' Lakes was considered suitable for mussel establishment and as discussed in the Aquatic Invasive Species Section, all the Chain lakes, except Ottman, are known to contain zebra mussels.

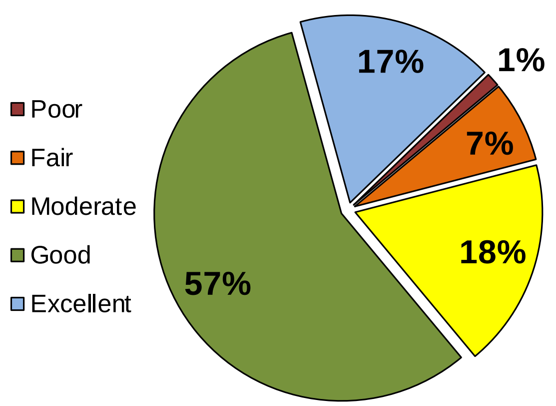
Stakeholder Survey Responses to the Waupaca Chain O' Lakes Water Quality

As discussed in section 2.0, the stakeholder survey asked many questions pertaining to perception of the Waupaca Chain O' Lakes and how it may have changed over the years. Of the 804 surveys distributed to Waupaca Chain O' Lakes stakeholders, 437 (54%) were returned.

Figure 3.1-13 displays the responses of Waupaca Chain O' Lake stakeholders to questions regarding water quality and how it has changed over their years visiting the Chain. When asked how they would describe the current water quality of the Waupaca Chain O' Lakes, the majority of respondents (57%) indicated *good*, 18% indicated *moderate*, 17% indicated *excellent*, 7% indicated *fair*, and 1% indicated *poor*.

When asked how they believe the current water quality has changed since they first visited the Chain the majority of respondents (39%) indicated it was *slightly worse*, 38% indicated it has remained the *same*, 13% indicated it was *degraded*, 5% indicated it has *slightly improved*, and 5% indicated it has *improved* (Figure 3.1-13). As discussed in the previous section, the Waupaca Chain O' Lakes has good water quality. The proportion of stakeholder respondents who indicated the lakes' water quality has become slightly worse or degraded may be taking into account the Eurasian watermilfoil growth or other aquatic plant growth in the lakes. As seen in Question 15 in Appendix B, many respondents ranked aquatic plant growth as having a negative or somewhat negative effect on the Waupaca Chain O' Lakes.

16. How would you describe the current water quality of the Chain?



17. How has the water quality changed since you first visited the Chain?

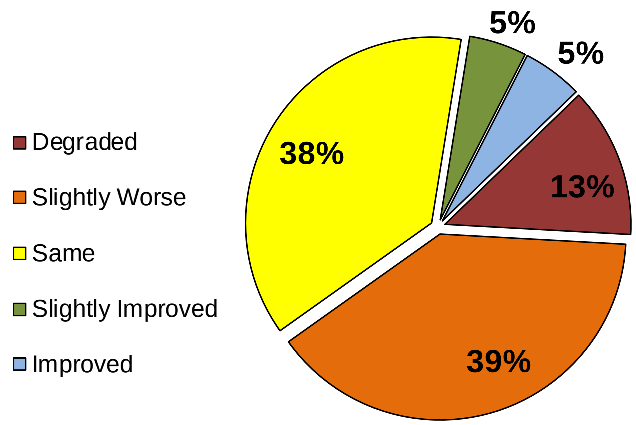


Figure 3.1-13. Waupaca Chain O' Lake stakeholder survey responses to questions regarding perceptions of lake water quality.

3.2 Watershed Assessment

Watershed Modeling

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 drain 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.

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 are 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.

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 into 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, and potential runoff, 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 may 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, if present.

Waupaca Chain O' Lakes Watershed Assessment

The Waupaca Chain O' Lakes total watershed encompasses an area of approximately 30,539 acres; however, part of the watershed likely does not contribute water or nutrients to the Chain because of small lakes and wetlands (Map 2). In these parts of the watershed, runoff from the landscape remains in these isolated waterbodies and does not enter the Waupaca Chain O' Lakes. After examining topographical maps and aerial photographs, the watershed used for the modeling was reduced to approximately 2,228 acres (Figure 3.2-1). Ottman Lake was not included in the watershed analysis because it is connected to Youngs Lake with an intermittent stream that only flows during the wettest years; therefore, any impact the Ottman outflow has on the Chain would be considered negligible. There are two perennial streams which enter the southwestern portion of the Chain: Hartman Creek which enters Pope Lake, and Emmons Creek which enters Long Lake. For this study, modeling was not completed for individual lakes. Instead, lakes were separated into four groups for modeling purposes (Figure 3.2-1). This was done because many of the lakes are adjacent to each other and in some cases the lakes could be considered a bay of a larger lake (e.g. Lime Kiln and Round lakes). The composition of four lake groups are given in Table 3.2-1.

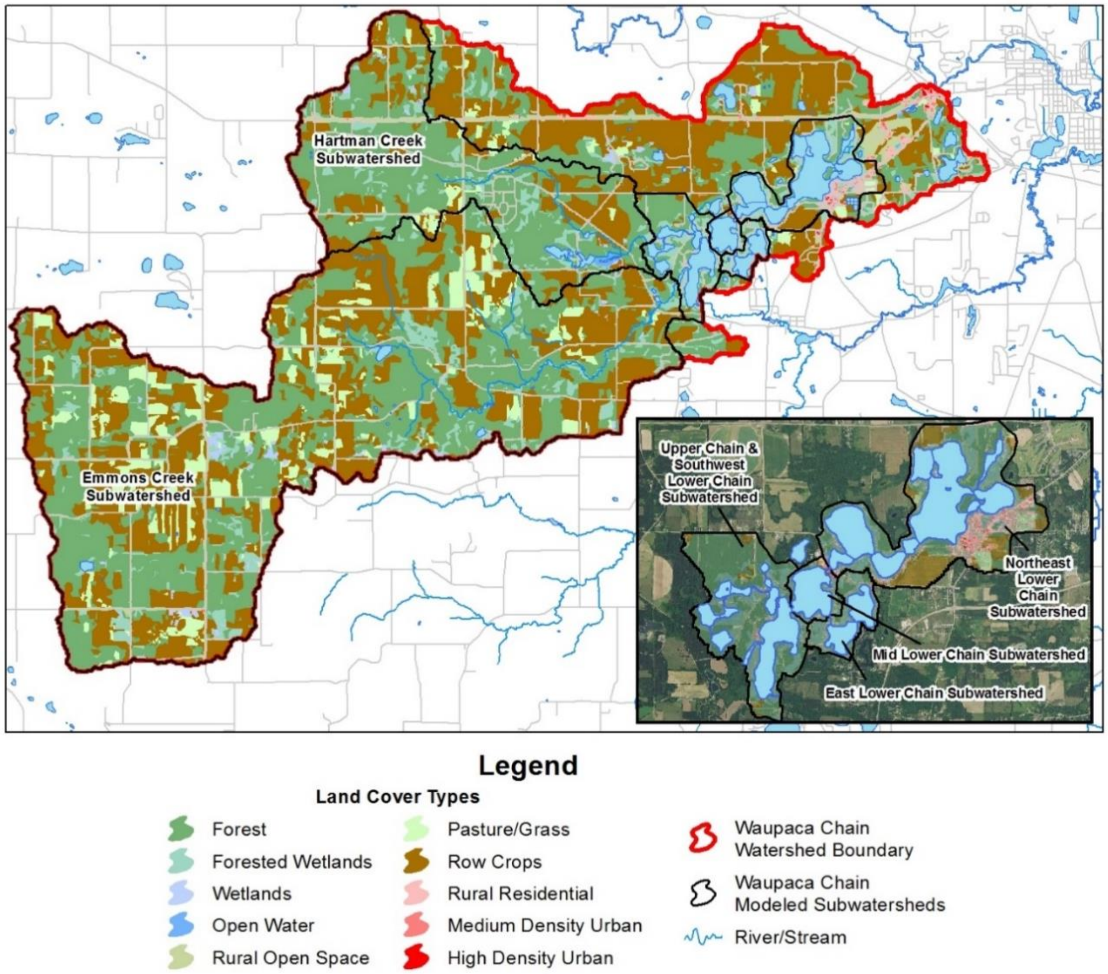


Figure 3.2-1. Land cover in the topographical watershed for Waupaca Chain O' Lakes. Black bold lines depict the four subwatersheds used in the WiLMS modeling. The watershed was reduced in size because some of the landscape is internally drained into small lakes and wetlands and the water and pollutants do not enter the Waupaca Chain O' Lakes. Land cover is based upon National Land Cover Database (NLCD – Fry et. al 2011).

Table 3.2-1. Four subwatersheds used in WiLMS modeling for the Waupaca Chain O' Lakes. Except for Mid Lower Chain Subwatershed, the subwatersheds contain multiple lakes.

Subwatershed	Lakes
Northeast Lower Chain	Taylor, George, Sunset, Rainbow, Nessling, McCrossen, Round, Lime Kiln, Otter
Mid Lower Chain	Columbia
East Lower Chain	Miner, Dake
Upper Chain and Southwest Lower Chain	Marl, Pope, Manomin, Knight, Orlando, Youngs, Bass, Beasley, Long

Flow estimates were measured in Hartman Creek at Rural Road in 2011-2016 and total phosphorus samples were taken at the same site in 1994-1995 and 2015-2016. In Emmons Creek at Rural Road, flow estimates were measured from 2010-2014. Total phosphorus concentrations were collected at the same site in 1994 and 1995. In all of the years, the measurements were made on a monthly basis May through August and again in October. The average phosphorus concentrations in both creeks in the 1994-95 and 2015-16 samples were very similar at about 22 µg/L and the variability was low. Therefore, this concentration was used to estimate annual phosphorus loading from both creeks. Since flows were not measured for the whole year, annual discharge from the Tomorrow River, which was continuously measured by the USGS, was used to develop the relationship between annual flow in the Tomorrow River and Hartman and Emmons creeks. The estimated phosphorus loading from the two creeks was compared with the loading from the WiLMS modeling. It was expected that actual flows would be greater than the model results because there is high groundwater flow in the region due to an abundance of permeable soils. It was also expected that modeling would over estimate the amount of phosphorus being delivered from the watersheds to the lakes because of these well-drained soils.

Table 3.2.-2 compares the results of the measured loading and the model results. In both creeks, more flow was measured than the model predicted, likely because of the large amount of groundwater in the region. In Hartman Creek, measured phosphorus loading was 39% of the model estimate while in Emmons Creek the measured load was 15% of the model estimate. Since the Emmons Creek watershed is much larger than Hartman Creek and the size of the other subwatersheds is much smaller than either of the creek watersheds, the percentage of phosphorus loading measured in Hartman Creek was used to compare the modeled estimate (39%) in the WiLMS modeling for the other subwatersheds. For example, in the Northeast Lower Chain subwatershed, WiLMS model estimated a phosphorus load of 342 pounds, but this was reduced to 285 lbs.

Table 3.2-2. Comparison of measured and modeled annual hydrologic and phosphorus loading from Hartman and Emmons creeks.

		Water (m3)	Phosphorus (kg)
Hartman Creek	Measured	12,222,028	267
	WiLMS model	5,670,000	686
Emmons Creek	Measured	19,944,792	461
	WiLMS model	18,100,000	3,098

The measured input of phosphorus from Emmons and Hartman creeks, as well as the input from the rest of the watershed as estimated with the WiLMS modeling, found that 2,111 pounds of phosphorus enter the Waupaca Chain O' Lakes in a year (Figure 3.2-2). As would be expected, the subwatershed with the greatest input of phosphorus (81%) was the Upper Chain and Southwest Lower Chain since Hartman and Emmons creeks are in this subwatershed. Additional phosphorus sources to the Chain include agricultural areas and runoff from shoreland development. The next largest subwatershed was the Northeast Chain which includes the largest number of lakes, but no perennial inflowing streams. All WiLMS output data can be found in Appendix D.

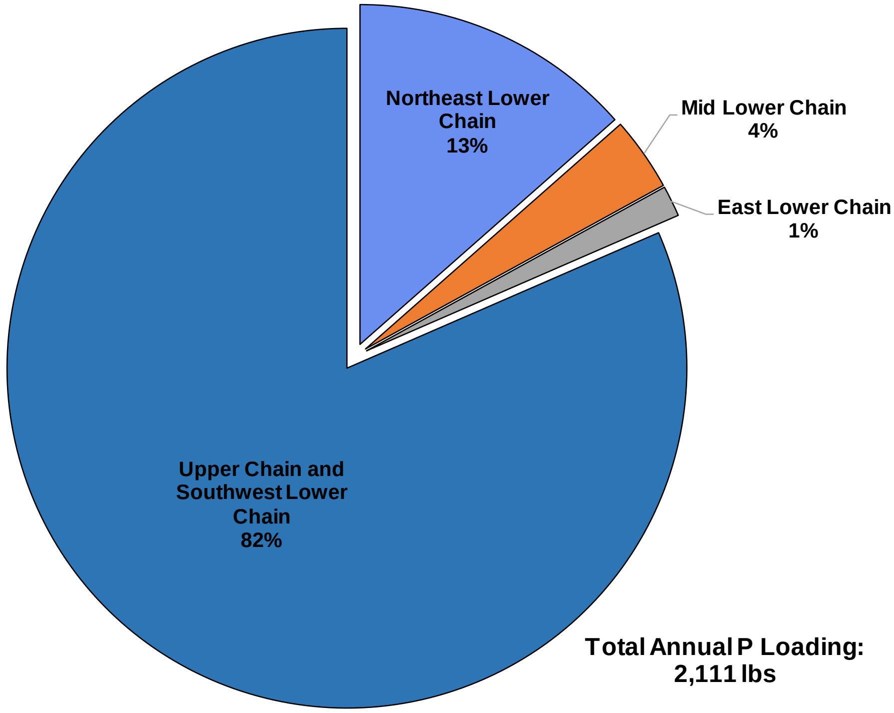


Figure 3.2-2. Waupaca Chain O' Lakes watershed phosphorus loading in pounds. Based upon Wisconsin Lake Modeling Suite (WiLMS) estimates and measured loading from Emmons and Hartman creeks.

With the exception of the Upper Chain, the lake surface is a significant portion of the annual phosphorus load in the Waupaca Chain O' Lakes. This source includes input of dust and precipitation from the atmosphere (Figure 3.2-3). Another large source is runoff from shoreland development. This is primarily runoff from lawns and impervious surfaces, such as dwelling roofs and driveways. While the atmospheric input is not controllable, inputs from shoreland development can be reduced with buffers on the lakeshore and diversion of runoff away from the lake when possible.

A potential source of phosphorus to a lake is from internal loading, with most of the phosphorus originating from lake sediments. When the bottom waters lose their oxygen and become anoxic, iron-bound phosphorus is released into the overlying water. As discussed in the Water Quality Section, most of the lakes that stratify become anoxic by mid-summer. During the sampling in July 2016, a near-bottom sample for phosphorus analysis was collected from all the lakes that were stratified. The only lakes that had elevated phosphorus concentrations were Orlando, Otter, Miner, and Pope lakes. The latter two lakes were also sampled in mid-October near the end of stratification when the highest phosphorus concentrations would be expected in the bottom waters. In both of the lakes, the phosphorus concentration was nearly twice as high in October compared with July. It is likely the phosphorus concentration in Orlando Lake in October would also be higher than it was in July. While it is not possible to calculate the amount of internal loading from just top and bottom samples, it is likely that there is some internal loading occurring in both Pope and Miner lakes. Near bottom samples were collected in the 1990s in both lakes and elevated phosphorus concentrations were present (Figure 3.2-4). The phosphorus concentrations in the bottom water appear to be highly variable from year-to-year; however, this is likely due to variability in sampling depth and not actual phosphorus content in the hypolimnion. In lakes where phosphorus is released from bottom sediments into the hypolimnion, higher concentrations of phosphorus are found closer to the sediments. Therefore, a sample taken closer to the sediments would have a higher total phosphorus concentration than a sample taken at a higher depth. In reality, neither concentrations truly represent the phosphorus mass in the hypolimnion.

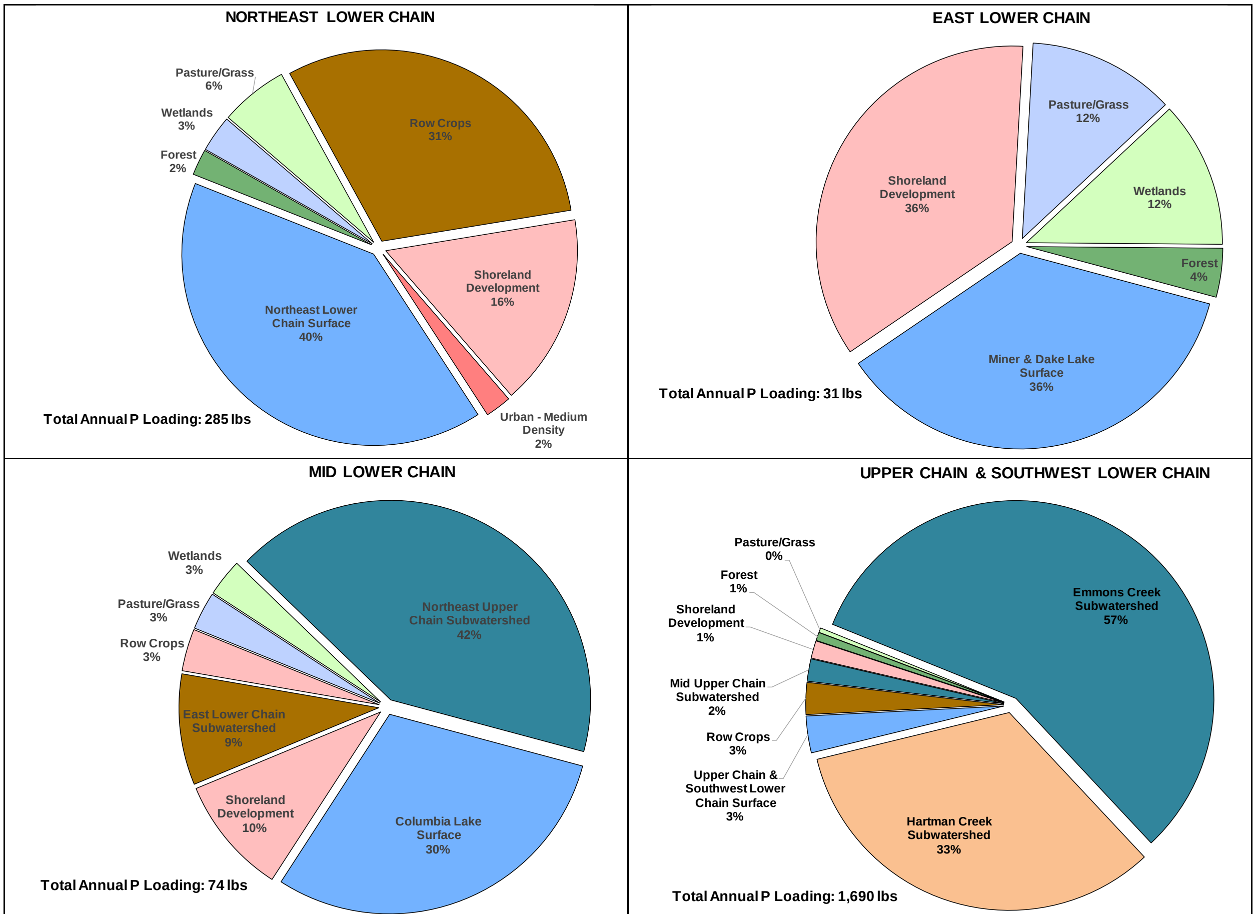
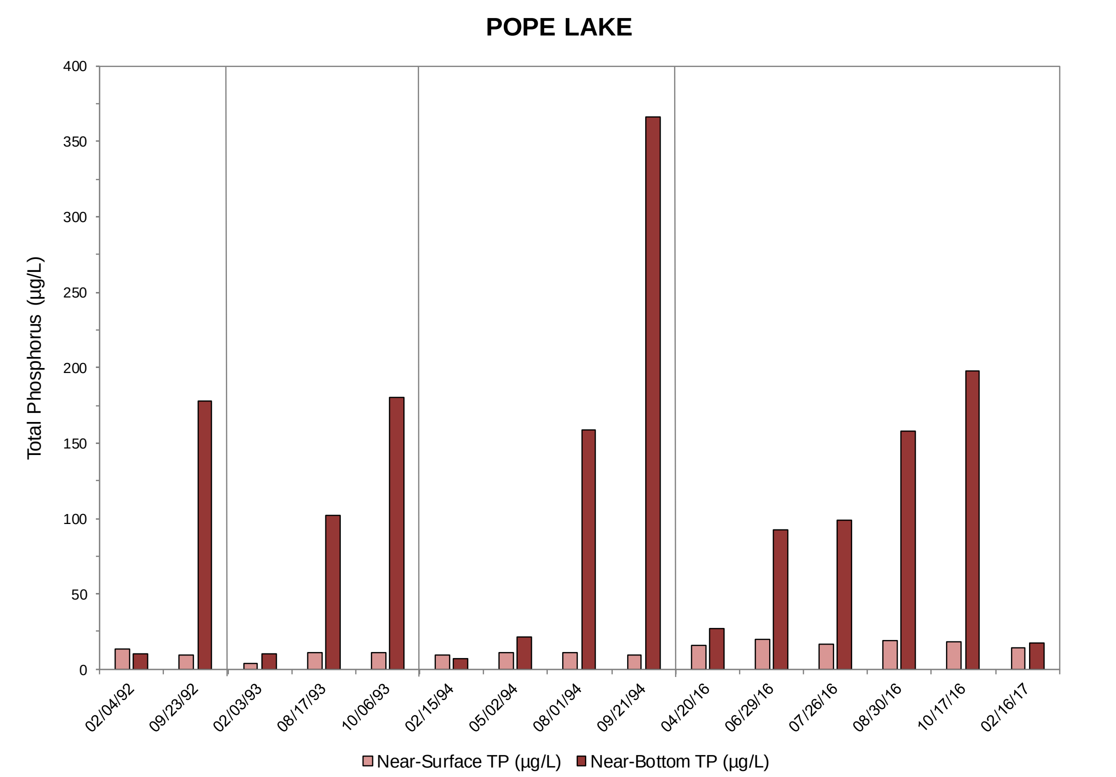


Figure 3.2-3. Annual phosphorus loading in each of the four subwatersheds of the Waupaca Chain O' Lakes.

WiLMS was utilized to estimate the growing season mean (GSM) total phosphorus concentration for the last lake in each subwatershed in the Chain. This is a good way to check the accuracy of the modeling and determine if internal loading is significant. In none of the four watersheds was the predicted GSM phosphorus significantly higher than the measured values. This implies that internal loading is not a significant contributor to the annual phosphorus load of the lakes in the four subwatersheds. This analysis was completed specifically for Pope and Miner lakes where phosphorus concentrations in the bottom waters were elevated. In Pope Lake, the predicted GSM phosphorus concentration was 20 µg/L which is exactly what was measured in 2015 and 2016. In Miner Lake, the observed GSM phosphorus concentration was less than the model predicted.



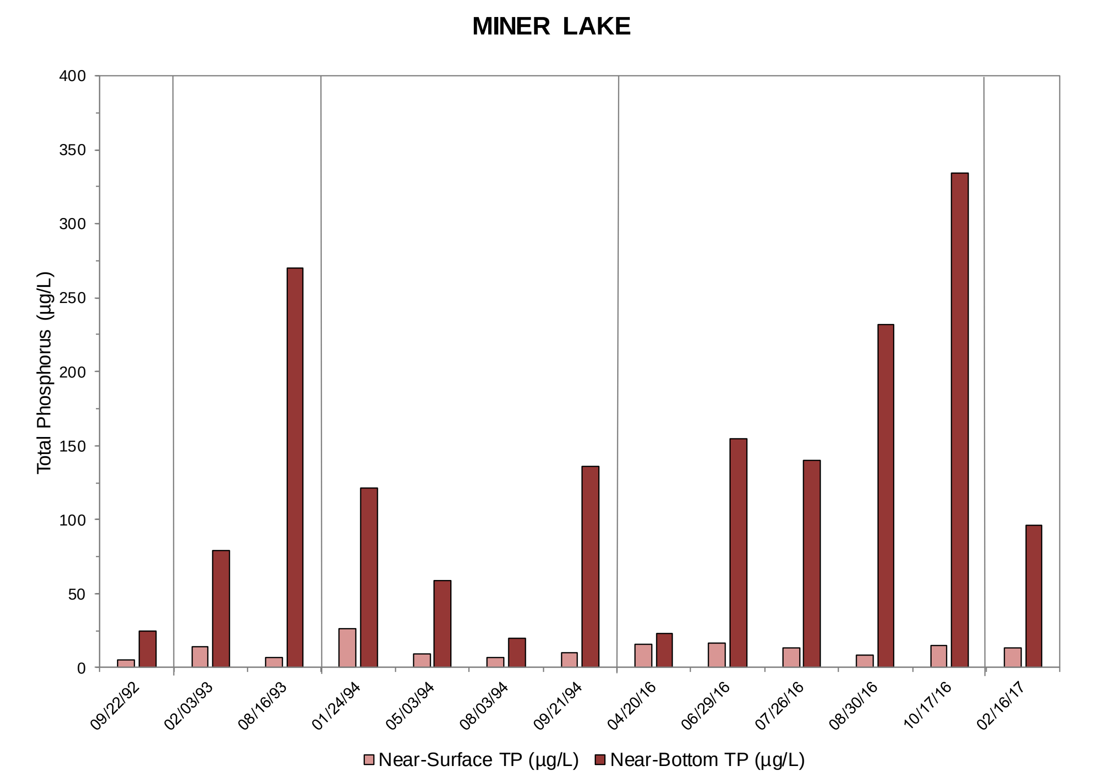


Figure 3.2-4. Top and bottom total phosphorus samples from Pope and Miner lakes. The concentrations differ between years most likely because the samples with the higher concentrations were collected closer to the bottom sediment than samples collected in similar months in other years.

3.3 Shoreland Condition

Lake Shoreland Zone and its Importance

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

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

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

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

Shoreland Zone Regulations

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

Wisconsin-NR 115: Wisconsin's Shoreland Protection Program

Wisconsin's shoreland zoning rule, NR 115, sets the minimum standards for shoreland development. First adopted in 1966, the code set a deadline for county adoption of January 1, 1968. By 1971, all counties in Wisconsin had adopted the code and were administering the shoreland ordinances it specified. Interestingly, in 2007 it was noted that many (27) counties had recognized inadequacies within the 1968 ordinance and had actually adopted stricter shoreland ordinances. Revised in February of 2010, and again in October of 2014, the finalized NR 115 allowed many standards to remain the same, such as lot sizes, shoreland setbacks and buffer sizes. However, several standards changed as a result of efforts to balance public rights to lake use with private property rights. The regulation sets minimum standards for the shoreland zone, and requires all counties in the state to adopt shoreland zoning ordinances. Counties were previously able to set their own, stricter, regulations to NR 115 but as of 2015, all counties have to abide by state regulations. Minimum requirements for each of these categories are described below.

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

- Impervious surface standards: In general, the amount of impervious surface is restricted to 15% of the total lot size, on lots that are within 300 feet of the ordinary high-water mark of the waterbody. If a property owner treats their run off with some type of treatment system, they may be able to apply for an increase in their impervious surface limit, up to 30% for residential land use. Exceptions to this limit do exist if a county has designated highly-developed areas, so it is recommended to consult county-specific zoning regulations for this standard.

- Nonconforming structures: Nonconforming structures are structures that were lawfully placed when constructed, but do not comply with distance of water setback. Originally, structures within 75 ft of the shoreline had limitations on structural repair and expansion. Language in NR-115 allows construction projects on structures within 75 feet. Other specifications must be met as well, and local zoning regulations should be referenced.

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

2009 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. Groundwater 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 found that green frog density was negatively correlated with development density in Wisconsin lakes (Woodford and Meyer 2003). 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, Gillum and Meyer 2002). And studies on shoreland development and fish nests show that undeveloped shorelands are preferred as well. In a study conducted on three Minnesota lakes, researchers found that only 74 of 852 black crappie nests were found near shorelines that had any type of dwelling on it (Reed 2001). The remaining nests were all located along undeveloped shoreland.

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

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

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

With development of a lake's shoreland zone, much of the coarse woody habitat that was once found in Wisconsin lakes has disappeared. Prior to human establishment and development on lakes (mid to late 1800's), the amount of coarse woody habitat in lakes was likely greater than under completely natural conditions due to logging practices. However, with changes in the logging industry and increasing development along lake shorelands, coarse woody habitat has decreased substantially. Shoreland residents are removing woody debris to improve aesthetics or for recreational opportunities such as 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 nation's 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.*" These results indicate that stronger management of shoreline development is absolutely necessary to preserve, protect, and restore lakes. Shoreland protection will become increasingly important as development pressure on lakes continues to 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) (Elias and Meyer 2003). Many homeowners significantly decrease the number of trees and shrubs along the water's edge in an effort to increase their view of the lake. However, this has been shown to locally increase water temperatures, and decrease infiltration rates of potentially harmful nutrients and pollutants. Furthermore, the dumping of sand to create beach areas destroys spawning, cover and feeding areas utilized by aquatic wildlife (Scheuerell and Schindler 2004).

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

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

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

Wisconsin's Healthy Lakes & Rivers Action Plan

Starting in 2014, a program was enacted by the WDNR and UW-Extension to promote riparian landowners to implement relatively straight-forward shoreland restoration activities. This program provides education, guidance, and grant funding to promote installation of best management practices aimed to protect and restore lakes and rivers in Wisconsin. The program has identified five best practices aimed at improving habitat and water quality (Figure 3.3-1).

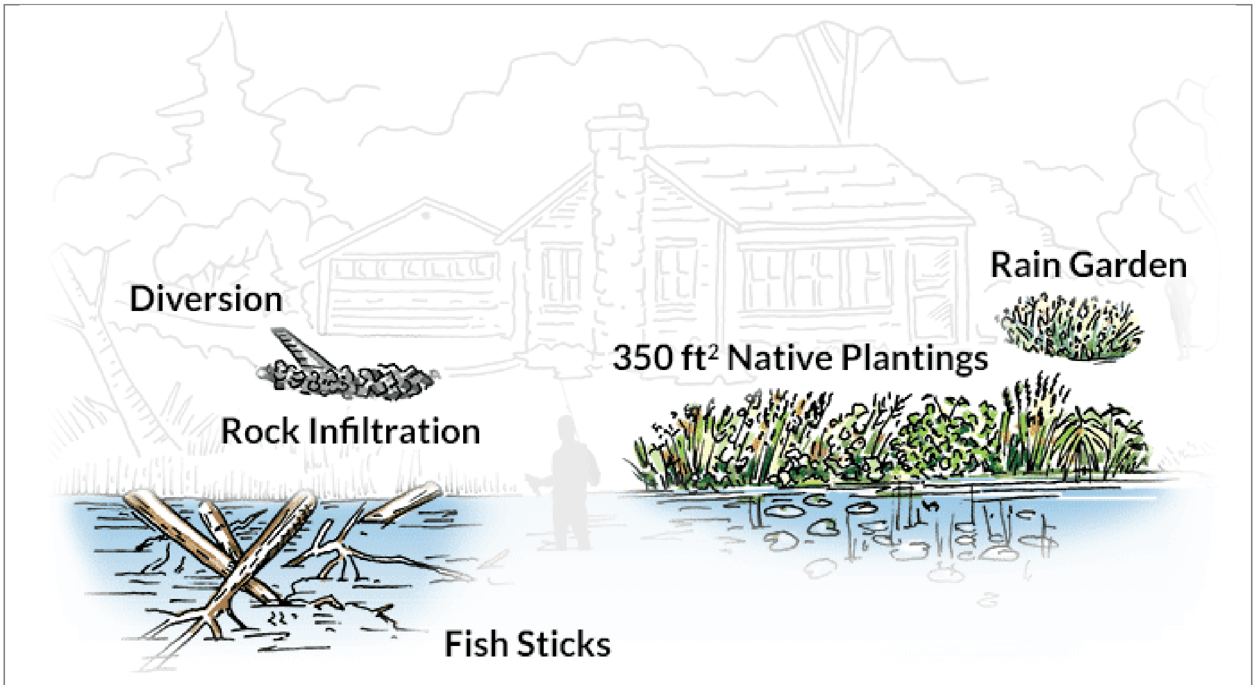


Figure 3.3-1. Healthy Lakes & Rivers 5 Best Practices. Illustration by Karen Engelbretson, extracted from healthylakeswi.com.

- Rain Gardens: This upland best practice consists of a landscaped and vegetated shallow depression aimed at capturing water runoff and allowing it to infiltrate into the soil.
- Rock Infiltration: This upland best practice is an excavated pit or trench, filled with rock, that encourages water to infiltrate into the soil. This practice is strategically placed along a roof line or the downward sloping area of a driveway.
- Diversion: This best practice can occur in the transition or upland zone. This practice uses berms, trenches, and/or treated lumber to redirect water that would otherwise move downhill into a lake. Water diversions may direct water into a Rock Infiltration or Rain Garden to provide the greatest reductions in runoff volumes.
- Native Plantings: This best practice aims to installing native plants within at least 350 square-foot shoreland transition area. This will slow runoff water and provide valuable habitat. One native planting area per property per year is eligible.
- Fish Sticks: This in-lake best practice involves woody habitat structures that provide feeding, breeding, and nesting areas for wildlife. Fish sticks consist of multiple whole trees grouped together and anchored to the shore. Trees are not felled from the shoreline, as existing trees are valuable in place, but brought from a short distance or dragged across the ice. In order for this practice to be eligible, an existing vegetated buffer or pledge to install one is required.

The Healthy Lakes and Rivers Grant program provides partial cost coverage for implementing best practices. The program allows a 75% state/25% sponsor cost share up to $1,000 per practice. Multiple practices can be included per grant application, with a $25,000 maximum award per year to Waupaca County Land and Water Department, the grant sponsor. This grant program is designed for relatively simple, low-cost and shovel-ready projects, limiting 10% of the grant award for technical assistance. The landowner must sign a Conservation Commitment pledge to leave the practice in place and must provide continued maintenance for 10 years. The grant application deadline is November 1 each year and the award date is March 1 of the following year. The grant is a reimbursement grant based on yearly expenses. More information on this program can be found at healthylakeswi.com.

Waupaca Chain O' Lakes Shoreline Condition

Shoreline Development

On the Waupaca Chain O' Lakes, the development stage of the shoreline was surveyed in 2014 by the Waupaca County Land and Water Conservation Department (LWCD). The shoreline was surveyed using a WDNR Lake Shoreland Habitat Monitoring Field Protocol on a parcel-by-parcel basis. Some protocol modifications were made, such as considering the area of shoreline 50 feet inland from the water's edge instead of 35 feet, in accordance with the local zoning ordinance. Shoreline areas were defined by natural vegetation such as trees, shrubs, and grasses, and human disturbances such as mowed lawns, structures, impervious surfaces, rip-rap, and erosion. In general, developed shorelines impact a lake ecosystem in a negative manner, while definite benefits occur from shorelines that are left in their natural state.

The Waupaca Chain O' Lakes has stretches of shoreline that range from completely developed to completely natural. Of the 22 miles of shoreline surveyed, approximately 20% is in a completely natural state (Figure 3.3-1). This shoreline type provides the most benefit to a lake and should be left in its natural state if at all possible. Approximately 6% of the Chain's shoreline is in a completely developed state. If restoration of the Waupaca Chain O' Lakes shoreline is to occur, primary focus should be placed on these developed shoreline areas as they currently provide little benefit to and actually may harm the lake ecosystem. On the Chain, approximately 5.6 miles of the shoreline surveyed was composed of hard armor, such as rip-rap or seawall, which correlates to approximately 25% of the shoreline length. Map 3 displays the location of these shoreline categories around the entire Waupaca Chain O'Lakes.

The shoreline assessment was presented by Dan McFarlane to the WCOLD and his presentation is located in Appendix E.

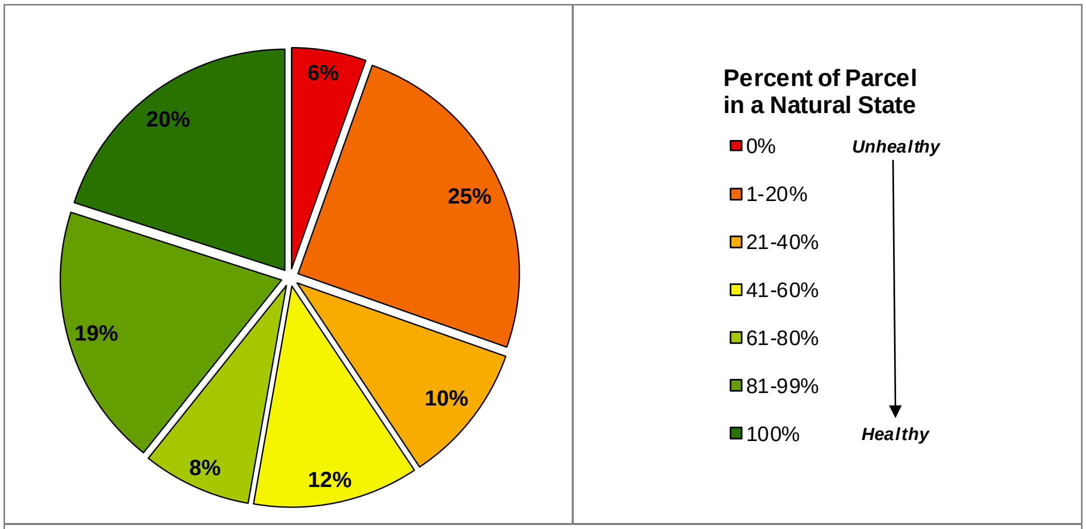


Figure 3.3-1. Waupaca Chain O' Lakes shoreline categories. Based upon a Waupaca County LWCD 2014 survey. Please note that George, Youngs, and Ottman lakes of the Lower Chain were not surveyed.

Overall, more development and less natural shoreline were observed on the Lower Chain of Lakes; however, it should be noted that much of the Upper Chain lakes shoreline is composed of state land. Approximately 61% and 14% of the areas surveyed in the Upper Chain and Lower Chain, respectively, are composed of completely natural shorelines. Approximately 1% of the shoreline surveyed on the Upper Chain is completely developed compared to approximately 6% of the Lower Chain. The Upper Chain also had fewer miles of shoreline with hard armor, less than one mile, compared to the Lower Chain which has approximately 5.5 miles of shoreline with hard armor.

While producing a completely natural shoreline 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. Allowing tree falls and other natural habitat features to remain along a shoreline may result not only in reducing shoreline erosion, but also in creating wildlife habitat.

Coarse Woody Habitat

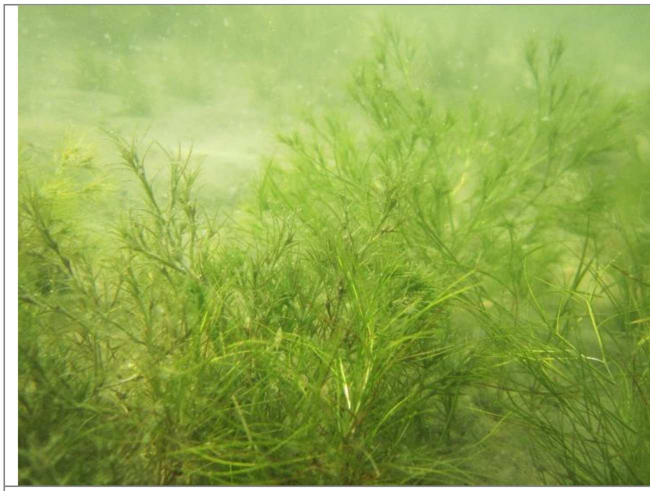
The Waupaca Chain O' Lakes was surveyed in the spring of 2016 by the Waupaca County LWCD, using the same WDNR protocol discussed previously, to determine the extent of its coarse woody habitat. Only a portion of the Lower Chain was visited during the survey. As discussed earlier, research indicates that 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 the survey, 420 total pieces of coarse woody habitat were observed along 18.1 miles of shoreline, which, in total, gives the surveyed lakes a coarse woody habitat to shoreline mile ratio of 23:1. Locations of coarse woody habitat are displayed on Map 4. To put this into perspective, Wisconsin researchers have found that in completely undeveloped lakes, an average of 345 coarse woody habitat structures may be found per mile (Christensen et al. 1996).

3.4 Aquatic Plants

Introduction

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



Photograph 3.4-1. Native aquatic plant community. Pictured are slender naiad (*Najas flexilis*) and sago pondweed (*Stuckenia pectinata*).

Diverse aquatic vegetation provides habitat and food for many kinds of aquatic life, including fish, insects, amphibians, waterfowl, and even terrestrial wildlife (Photograph 3.4-1). For instance, wild celery (*Vallisneria americana)* and wild rice (*Zizania* spp.) 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.

Aquatic 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 bottom 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 nutrient levels that may lead to phytoplankton blooms. Lake plants also produce oxygen through photosynthesis and use nutrients that may otherwise be used by phytoplankton, which helps to minimize nuisance phytoplankton blooms.

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

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

Aquatic Plant Management and Protection

Many times, an aquatic plant management plan is aimed at controlling only 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.

Important Note:
Even though most of these techniques are not applicable to the Waupaca Chain O' Lakes, 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 the Waupaca Chain O' Lakes are discussed in the Summary and Conclusions sections, and the Implementation Plan found near the end of this document.

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 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.

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

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 is to begin these activities 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*
• Is very cost effective for clearing areas around docks, piers, and swimming areas. • Is relatively environmentally safe if treatment is conducted after mid-June. • Allows for selective removal of undesirable plant species. • Provides immediate relief in localized area. • Removes plant biomass from waterbody.	• Is labor intensive. • Is impractical for larger areas or dense plant beds. • May require subsequent treatments as plants recolonize and/or continue to grow. • Stirs bottom sediments when uprooting plants making it difficult to conduct action. • May disturb benthic organisms and fish-spawning areas. • May spread 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***
• Provides immediate and sustainable control. • Has low long-term costs. • Is excellent for small areas and around obstructions. • Provides reuse of materials. • Prevents fragmentation and subsequent spread of plants to other areas.	• May be difficult to install over dense plant beds and in deep water. • Is not species specific. • Disrupts benthic fauna. • May be navigational hazard in shallow water. • Requires high initial costs. • Is labor intensive due to the seasonal removal and reinstallation requirements. • Does not remove plant biomass from lake. • Is not practical in large-scale situations.

Water Level Drawdown

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

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

Advantages	*Disadvantages*
• Inexpensive if outlet structure exists. • May control populations of certain species, like Eurasian watermilfoil for a few years. • Allows some loose sediment to consolidate, increasing water depth. • May enhance growth of desirable emergent species. • May allow other work, like dock and pier repair to 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 to have significant effects on fish and other aquatic wildlife. • May alter adjacent wetlands 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. • Is non-selective.

Mechanical Harvesting

Photograph 3.4-3. Mechanical harvester.

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

Cost

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

Advantages	*Disadvantages*
• Results are immediate. • 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 interfered 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 also acceptable, if implemented properly.

Photograph 3.4-4. Granular herbicide application.

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 which falls 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 as 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 preliminary findings, lake managers have adopted two main treatment strategies: 1) whole-lake treatments, and 2) spot treatments.

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

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

Cost

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

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

Biological Controls

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

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

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

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

Wisconsin has approved the use of two species of leaf-eating beetles (*Galerucella calmariensis* and *G. pusilla*) to battle purple loosestrife. These beetles were imported from Europe and used as a biological control method for purple loosestrife. Many cooperators, such as county conservation departments or local UW-Madison Division of 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, go to extension.wisc.edu or contact the Waupaca County Extension office.

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***
• This is an 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 is described in more detail in the methods section, multiple aquatic plant surveys were completed on the Waupaca Chain O' Lakes. 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

The **Littoral Zone** is the area of the lake where sunlight is able to penetrate to the sediment providing aquatic plants with sufficient light to carry out photosynthesis.

Native aquatic plants are an important element in every healthy aquatic ecosystem, providing food and habitat to wildlife, improving water quality, and stabilizing bottom sediments. Because most aquatic plants are rooted in place and are unable to relocate in the wake of environmental alterations, they are often the first community to indicate that changes may be occurring within the system. Aquatic plant communities can respond in a variety of ways; there may be increases or declines in the occurrences of some species or a complete loss. Certain growth forms, such as emergent and floating-leaf communities, may disappear from certain areas of the waterbody. With periodic monitoring and proper analysis, these changes are relatively easy to detect and provide relevant information for making management decisions.

The point-intercept method as described in the Wisconsin Department of Natural Resources Bureau of Science Services, PUB-SS-1068 2010 (Hauxwell et al. 2010) was used to complete the whole-lake point-intercept surveys on the Waupaca Chain O' Lakes in 2016. The sampling location spacing (resolution) and resulting total number of locations varied by lake and were created based upon guidance from the WDNR.

At each point-intercept location within the *littoral zone*, information regarding the depth, substrate type (soft sediments, sand, or rock/gravel), and the plant species sampled along with their relative abundance (Figure 3.4-1) on the sampling rake was recorded. A pole-mounted rake was used to collect the plant samples, depth, and sediment information at point locations of 14 feet or less. A rake head tied to a rope (rope rake) was used at sites greater than 14 feet. Depth information was collected using graduated marks on the pole of the rake or using an onboard sonar unit at depths greater than 14 feet. Also, when a rope rake was used, information regarding substrate type was not collected due to the inability of the sampler to accurately feel the bottom with this sampling device. The point-intercept survey produces a great deal of information about a lake's aquatic vegetation and overall health. These data are analyzed and presented in numerous ways; each is discussed in more detail in the following section.

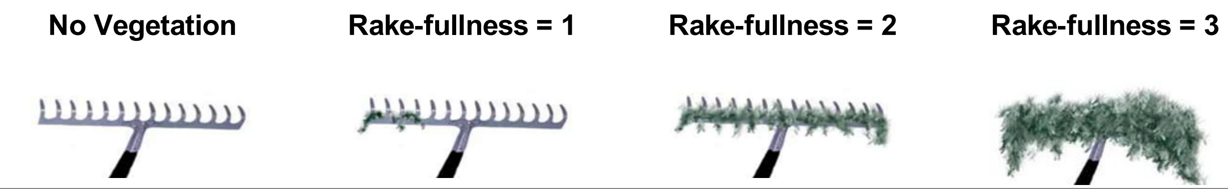


Figure 3.4-1. Aquatic plant rake fullness ratings. Adapted from Hauxwell et al (2010).

Species List

The species list is simply a list of all of the species, both native and non-native, that were located during the surveys completed on the Waupaca Chain O' Lakes. The list also contains the growth-form of each plant found (e.g. submergent, emergent, etc.), its scientific name, common 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 growth forms that are present, can be an early indicator of changes in the 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 the whole-lake point-intercept surveys completed on the Waupaca Chain O' Lakes, plant samples were collected from plots laid out on a grid that covered each lake. Using the data collected from these plots, an estimate of occurrence of each plant species can be determined. In this section, the occurrences of aquatic plant species are displayed as their *littoral 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) and is displayed as a percentage.

Floristic Quality Assessment

The floristic quality of a lake is calculated using its species richness and average species conservatism. 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 (C-value) for each of those species in its calculation. A species coefficient of conservatism value indicates that species' likelihood of being found in an undisturbed system. The values range from 1 to 10. Species that can tolerate environmental disturbance and are located in disturbed systems have lower coefficients, while species that are less tolerant to environmental disturbance and are restricted to high quality systems have higher values. For example, coontail (*Ceratophyllum demersum*), a submergent native aquatic plant species with a C-value of 3, has a higher tolerance to disturbed conditions, often thriving in lakes with higher nutrient levels and low water clarity, while other species like algal-leaf pondweed (*Potamogeton confervoides*) with a C-value of 10, are intolerant of environmental disturbance and require high quality environments to survive.

On their own, the species richness and average conservatism values for a lake are useful in assessing a lake's plant community; however, the best assessment of the lake's plant community health is determined when the two values are used to calculate the lake's floristic quality. The floristic quality is calculated using the species richness and average conservatism value of the aquatic plant species that were solely encountered on the rake during the point-intercept surveys. The Waupaca Chain O' Lakes falls within the North Central Hardwood Forests Ecoregion of Wisconsin, and the floristic quality of the lakes' aquatic plant communities are compared to other natural lakes within this ecoregion and the state.

Species Diversity

Species diversity is probably the most misused value in ecology because it is often confused with species richness. As defined previously, 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 species diversity also takes into account how evenly the species are distributed 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.

An aquatic system with high species diversity is much more stable than a system with a low diversity. This is analogous to a diverse financial portfolio in that a diverse aquatic plant community can withstand environmental fluctuations much like a diverse portfolio can handle economic fluctuations. 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

If a lake has a diversity index value of 0.90, it means that if two plants were randomly sampled from the lake there is a 90% probability that the two individuals would be of a different species. The Simpson's Diversity Index values from the Waupaca Chain O' Lakes is compared to data collected by Onterra and the WDNR Science Services on 85 lakes within the North Central Hardwood Forests ecoregion and on 392 lakes throughout Wisconsin. Comparisons are displayed in the individual lake report sections using *boxplots* that display median values and upper/lower quartiles of lakes in the same ecoregion and in the state.

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.

Emergent and Floating-leaf Community Mapping

A key component of the aquatic plant surveys is the delineation of the emergent and floating-leaf aquatic plant communities within each lake as these plants are often underrepresented during the point-intercept survey. This survey creates a snapshot of these important communities within each lake as they existed during the survey and is valuable in the development of the management plan and in comparisons with future surveys. Examples of emergent plants include cattails, rushes, sedges, grasses, bur-reeds, and arrowheads, while examples of floating-leaf species include the water lilies and watershield. Submersed aquatic plants species are often mixed throughout large areas of the lake and are often not visible from the surface, and therefore do not lend themselves well to mapping. However, the point-intercept survey allows for a general understanding of the distribution of submersed species within each lake.

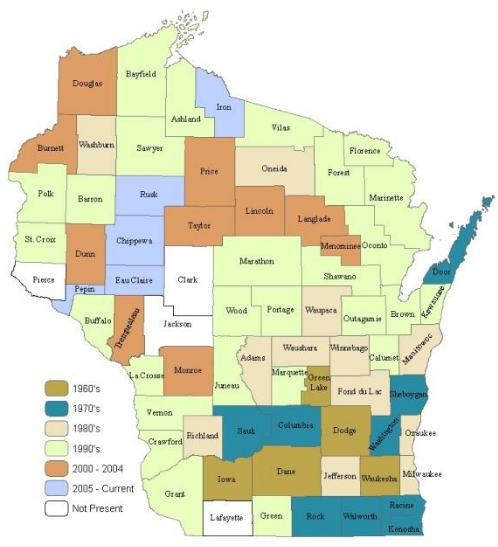


Figure 3.4-2. Spread of Eurasian watermilfoil within WI counties. WDNR Data mapped by Onterra (2011).

Exotic Plants

Because of their tendency to upset the natural balance of an aquatic ecosystem, exotic species are given particular attention during the aquatic plant surveys. Two exotics, curly-leaf pondweed and Eurasian watermilfoil, are the primary targets of this extra attention. Eurasian watermilfoil is an invasive species, native to Europe, Asia and North Africa, that has spread to most Wisconsin counties (Figure 3.4-2). Eurasian watermilfoil is unique in that its primary mode of propagation is not by seed. It actually spreads by shoot fragmentation, which has supported its transport between lakes via boats and other equipment. In addition to its propagation method, Eurasian watermilfoil has two other competitive advantages over native aquatic plants: 1) it starts growing very early in the spring when water temperatures are cool and the majority of native plants are still dormant and 2) in some instances once its stems reach the water surface, it does not stop growing like most native plants and instead continues to grow along the surface creating a canopy that blocks light from reaching native plants. Eurasian watermilfoil can create dense stands and dominate submergent communities, reducing important natural habitat for fish and other wildlife, and impeding recreational activities such as swimming, fishing, and boating.

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

Four surveys aimed at assessing the aquatic plant communities of the Waupaca Chain O' Lakes were completed in 2016 (Photograph 3.4-5). During these surveys, a total of 48 aquatic plant species were located (Table 3.4-1). These include 15 emergent species, four floating-leaf species, 27 submergent species, one submergent/emergent species, and one free-floating species. Of the 48 species located, five are considered to be non-native, or exotic species: sweetflag, pale-yellow iris, purple loosestrife, Eurasian watermilfoil, and curly-leaf pondweed. These non-native wetland and aquatic plants are discussed in detail in the subsequent Non-Native Aquatic Plant section. None of the native aquatic plants located in 2016 are listed as endangered, threatened, or special concern in Wisconsin.

Photograph 3.4-5. Emergent, floating-leaf, and submergent aquatic plant communities in the Waupaca Chain O' Lakes. Photo credit: Onterra, 2016.

Lakes in Wisconsin vary in their morphology, water chemistry, substrate composition, and recreational use, and all of these factors influence aquatic plant community composition. During the whole-lake point-intercept surveys, the maximum depth of aquatic plants ranged from 29.0 feet in Columbia, Round, Rainbow, and Sunset lakes, to 11.0 feet in Ottman Lake (Figure 3.4-3). The Chain-wide average maximum depth of aquatic plant growth was 21.5 feet. Please note that this average does not include the maximum depth of aquatic plant growth from Bass Lake (7.0 feet) as this also represents the maximum depth of this lake.

Typically, light availability for aquatic plants extends to a depth of approximately two to three times the average Secchi disk depth. Lakes with higher water clarity allow sunlight to penetrate deeper into the water column and support aquatic plants at deeper depths. The variation in maximum depth of aquatic plant growth between the lakes, particularly between the upper and lower lakes within the Chain, likely reflect differences in water clarity. The littoral frequency of occurrence of aquatic vegetation ranged from 100% in Beasley Lake, Lake Orlando, Manomin Lake, Marl Lake, and Nessling Lake to 59% in McCrossen Lake (Figure 3.4-4). Of the 1,218 sampling locations that fell at or below the maximum depth of plant growth (29 feet) Chain-wide, 918 or 75% contained vegetation (Map 5). This indicates that the majority of littoral areas in the Waupaca Chain O' Lakes are vegetated.

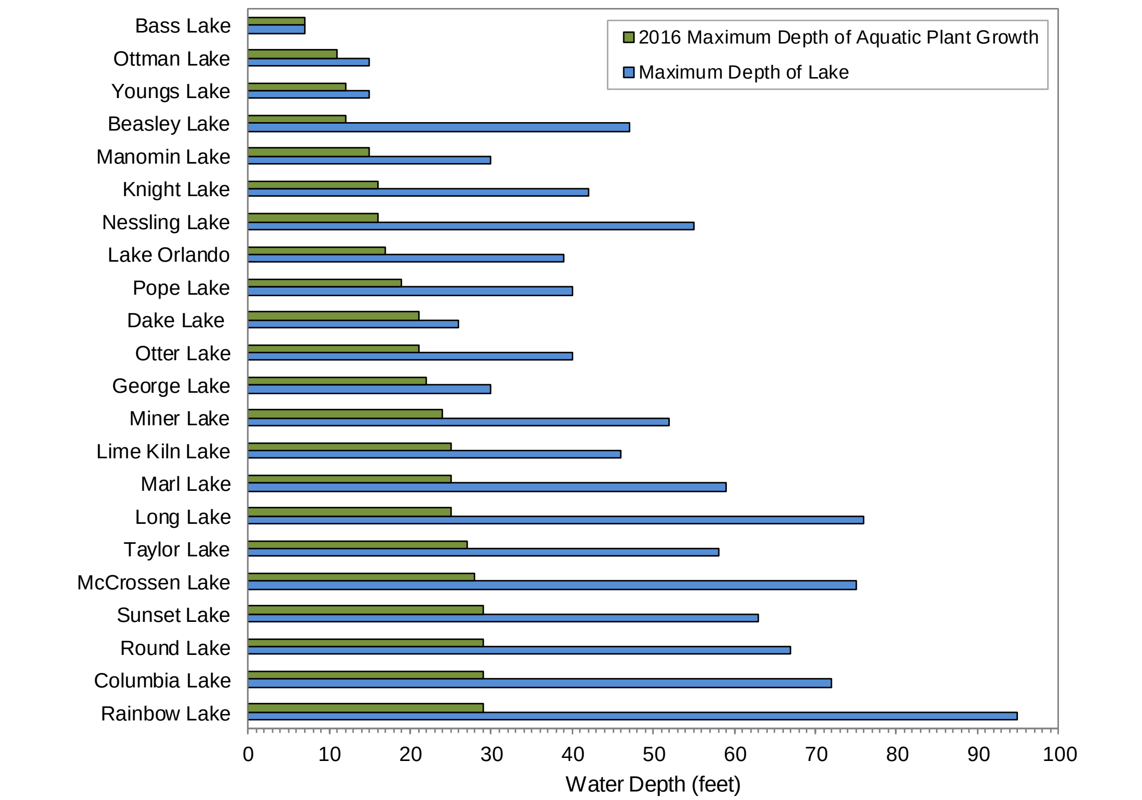


Figure 3.4-3. Waupaca Chain O' Lakes 2016 maximum depth of aquatic plant growth. Created using data from 2016 aquatic plant point-intercept surveys.

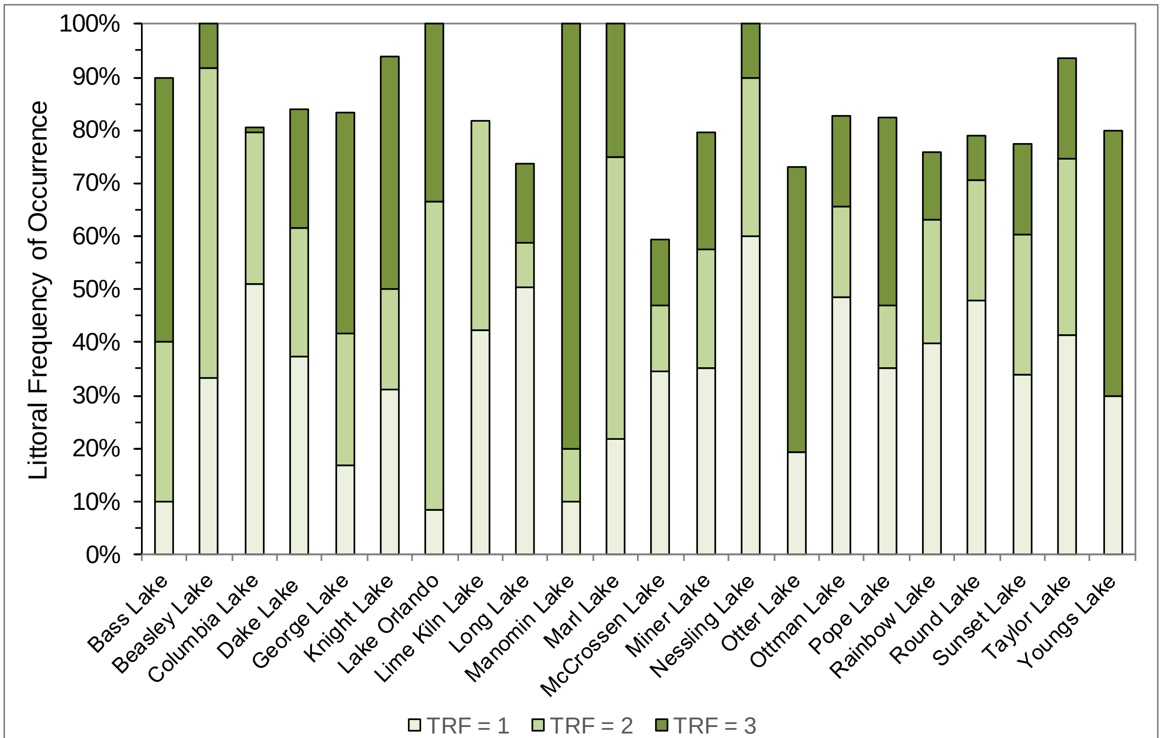


Figure 3.4-4. Waupaca Chain O' Lakes 2016 littoral frequency of occurrence of aquatic vegetation and total rake fullness (TRF) ratings. Created using data from 2016 aquatic plant point-intercept surveys.

Table 3.4-1. List of aquatic plant species located in the 22 Waupaca Chain O' Lakes during 2016 surveys.

Growth Form	Scientific Name	Common Name	Coefficient of Conservatism (C)	Number of Lakes
Emergent	*Acorus calamus*	Sweetflag	Naturalized	1
	Calla palustris	Water arum	9	2
	Carex comosa	Bristly sedge	5	2
	Cladium mariscoides	Smooth sawgrass	10	2
	Decodon verticillatus	Water-willow	7	13
	Eleocharis palustris	Creeping spikerush	6	2
	Iris pseudacorus	Pale-yellow iris	Exotic	19
	Iris versicolor	Northern blue flag	5	5
	Lythrum salicaria	Purple loosestrife	Exotic	16
	Sagittaria latifolia	Common arrowhead	3	2
	Sagittaria rigida	Stiff arrowhead	8	3
	Schoenoplectus acutus	Hardstem bulrush	5	9
	Schoenoplectus pungens	Three-square rush	5	1
	Schoenoplectus tabernaemontani	Softstem bulrush	4	2
	Typha spp.	Cattail spp.	1	16
FL	*Brasenia schreberi*	Watershield		1
	Nuphar variegata	Spatterdock	6	11
	Nymphaea odorata	White water lily	6	22
	Persicaria amphibia	Water smartweed	5	1
Submergent	*Ceratophyllum demersum*	Coontail	3	12
	Chara spp.	Muskgrasses	7	22
	Elodea canadensis	Common waterweed	3	10
	Heteranthera dubia	Water stargrass	6	6
	Myriophyllum sibiricum	Northern water milfoil	7	12
	Myriophyllum spicatum	Eurasian water milfoil	Exotic	16
	Najas flexilis	Slender naiad	6	14
	Nitella spp.	Stoneworts	7	9
	Potamogeton amplifolius	Large-leaf pondweed	7	3
	Potamogeton crispus	Curly-leaf pondweed	Exotic	11
	Potamogeton foliosus	Leafy pondweed	6	4
	Potamogeton friesii	Fries' pondweed	8	6
	Potamogeton gramineus	Variable-leaf pondweed	7	8
	Potamogeton illinoensis	Illinois pondweed	6	7
	Potamogeton gramineus x *illinoensis**	Variable-leaf x Illinois pondweed hybrid	N/A	2
	Potamogeton natans	Floating-leaf pondweed	5	5
	Potamogeton nodosus	Long-leaf pondweed	5	1
	Potamogeton pusillus	Small pondweed	7	2
	Potamogeton richardsonii	Clasping-leaf pondweed	5	6
	Potamogeton strictifolius	Stiff pondweed	8	1
	Potamogeton zosteriformis	Flat-stem pondweed	6	7
	Ranunculus aquatilis	White water crowfoot	8	2
	Sagittaria sp. (rosette)	Arrowhead sp. (rosette)	N/A	2
	Stuckenia pectinata	Sago pondweed	3	17
	Utricularia gibba	Creeping bladderwort	9	1
	Utricularia vulgaris	Common bladderwort	7	1
	Vallisneria americana	Wild celery	6	12
S/E	*Eleocharis acicularis*	Needle spikerush	5	1
FF	*Spirodela polyrhiza*	Greater duckweed	5	1

FL = Floating Leaf; FL/E = Floating Leaf and Emergent; S/E = Submergent and Emergent; FF = Free Floating
X = Located on rake during point-intercept survey; I = Incidental Species
** = Specimens sent in for DNA analysis; results will be available spring of 2017*

The total number of native aquatic plant species (species richness) ranged from 22 in Long Lake to three in McCrossen Lake (Figure 3.4-5). Two species, muskgrasses and white-water lily, were located in all 22 lakes. Other common aquatic plants located in the majority of the lakes include slender naiad, wild celery, sago pondweed, Eurasian watermilfoil, and common waterweed. The field data sheets showing TRF values for each species present, by lake, can be found in Appendix F. When comparing a lake's aquatic plant community to other lakes within the ecoregion and the state, only the native species that were directly encountered on the rake during the whole-lake point-intercept survey are used in the analysis. For example, while a total of 22 native aquatic plant species were located in Long Lake, 12 were directly encountered on the rake during the point-intercept survey while 10 were located *incidentally*. An incidentally-located species means the plant was not directly sampled on the rake during the point-intercept survey, but was observed in the lake by Onterra ecologists and was recorded/collected. The majority of incidentally-located plants typically include emergent species growing along the lakes' margins and submersed species that are relatively rare within the lakes' plant community.

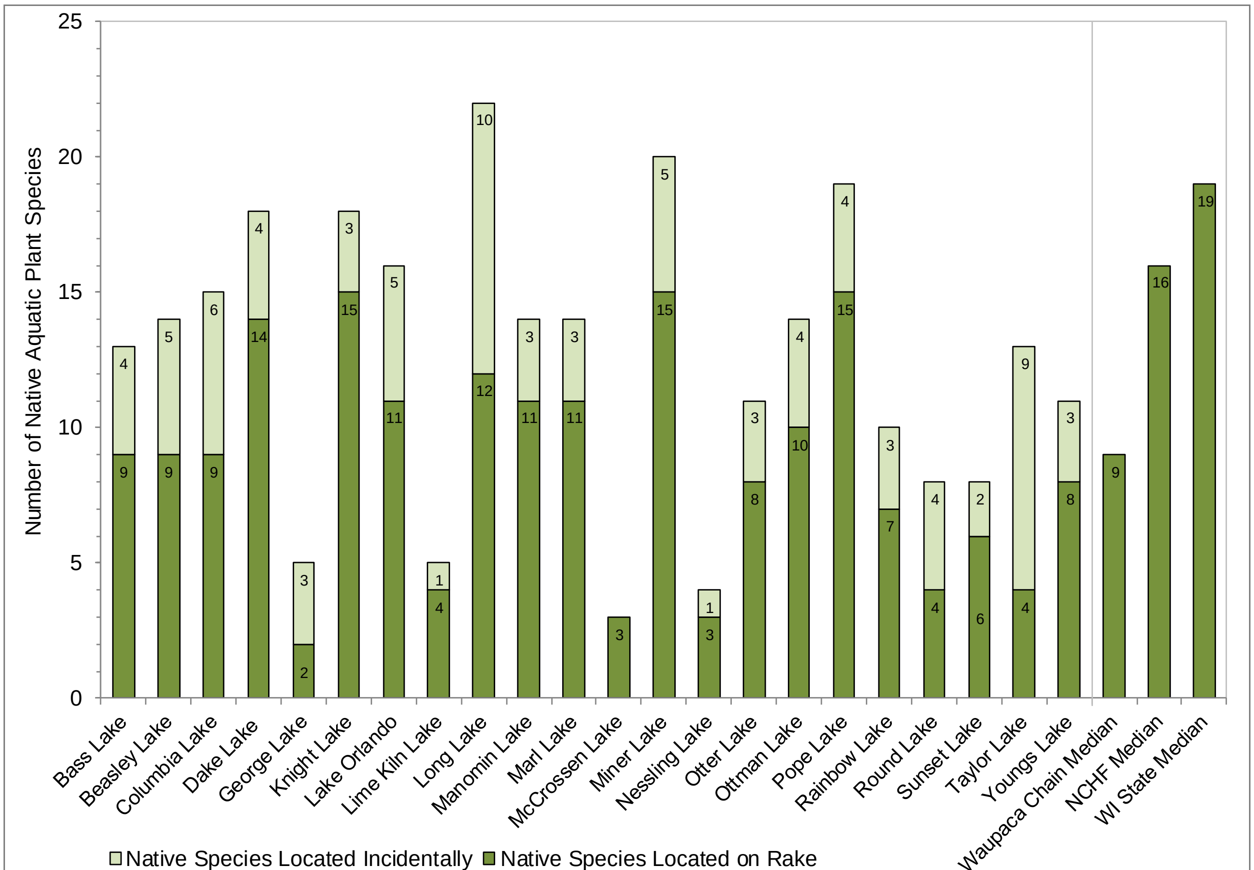


Figure 3.4-5. Waupaca Chain O' Lakes native aquatic plant species richness and median species richness for North Central Hardwood Forests (NCHF) ecoregion lakes and Wisconsin lakes. Created using data from 2016 aquatic plant surveys.

Looking at the native aquatic plants that were located on the rake (not incidentals) during the 2016 point-intercept surveys indicates the Waupaca Chain O' Lakes has a median value of nine native aquatic plant species per lake, significantly lower than the median value of 16 for lakes within the North Central Hardwood Forests (NCHF) ecoregion and the median value of 19 for lakes throughout Wisconsin (Figure 3.4-5). The lower native aquatic plant species richness found in the

Waupaca Chain O' Lakes is likely due to a combination of both natural and anthropogenic factors, which are discussed further in this section.

Figure 3.4-6 compares the average conservatism values of the native aquatic plant species located on the rake during each of the point-intercept surveys conducted on the Waupaca Chain O' Lakes. Average conservatism values ranged from 7.0 in Nessling Lake to 5.2 in Bass, Beasley, and Sunset lakes, with a Chain-wide median value of 5.8. The median value for average conservatism in the Waupaca Chain O' Lakes is even with the median value of 5.8 for lakes within the NCHF ecoregion and lower than the median value of 6.3 for lakes throughout Wisconsin. This indicates that the Waupaca Chain O'Lakes has a similar number of aquatic plant species that are considered sensitive to environmental disturbance (higher C-values) compared to aquatic plant species in other lakes within the region, but has a lower number when compared to aquatic plant species in lakes statewide.

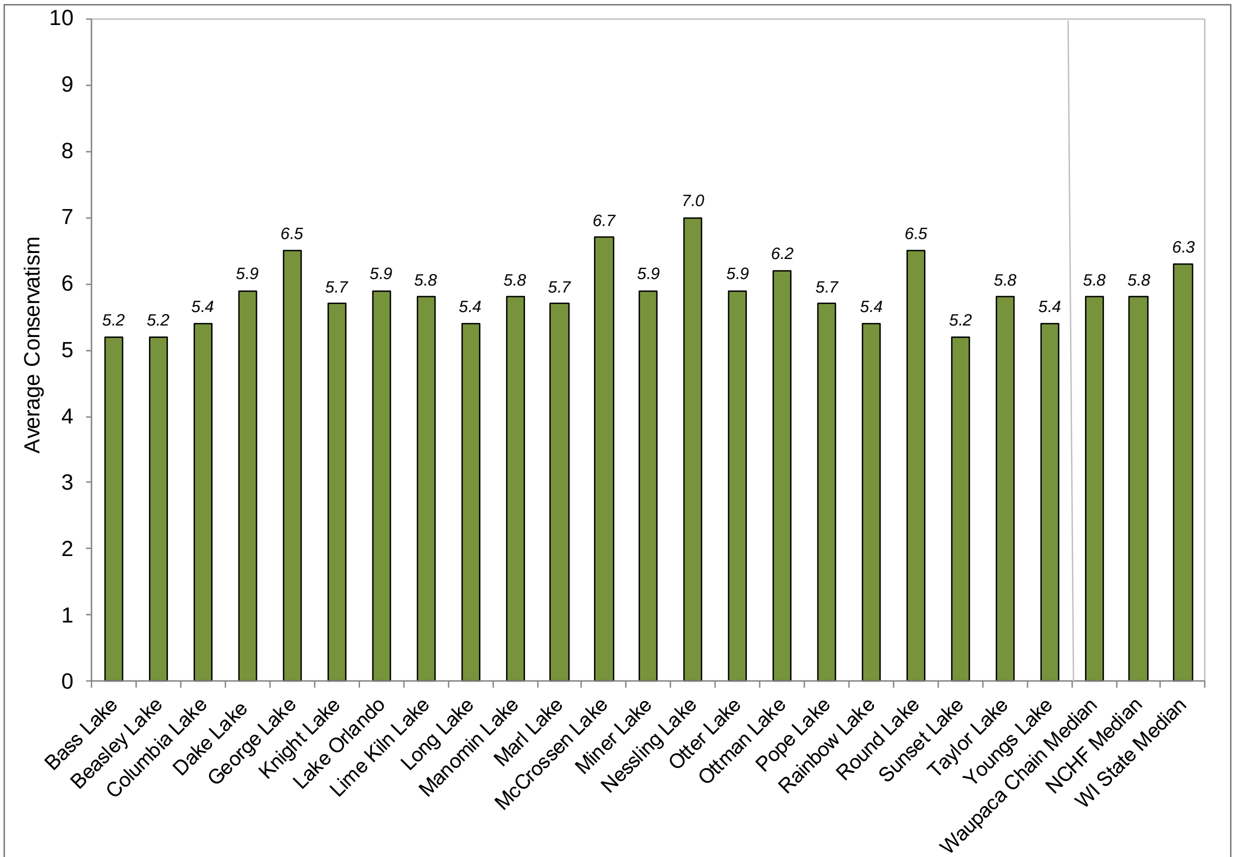


Figure 3.4-6. Waupaca Chain O' Lakes 2016 native aquatic plant average coefficients of conservatism. Created using conservatism values of native aquatic plant species located on the rake during the 2016 whole-lake point-intercept surveys. Analysis follows Nichols (1999).

As discussed in the Primer section, the calculations used to create the Floristic Quality Index (FQI) for a lake's aquatic plant community are based on the aquatic plant species that were encountered on the rake during the point-intercept survey and do not include incidental species. The number of native species encountered on the rake during the whole-lake point-intercept surveys and the species' conservatism values were used to calculate the FQI of the Waupaca Chain O' Lakes' aquatic plant communities. The equation is shown below.

FQI = Average Coefficient of Conservatism * √ Number of Native Species

Figure 3.4-7 displays the FQI values for the Waupaca Chain O' Lakes and compares them to median values of lakes within the NCHF ecoregion and lakes throughout Wisconsin. Floristic Quality Index values for the Waupaca Chain O' Lakes in 2016 ranged from 22.7 in Miner Lake to 9.2 in George Lake, with a Chain-wide median value of 15.9. The Chain-wide median Floristic Quality Index value falls below both the median value of 23.6 for lakes within the NCHF ecoregion and the median value of 27.2 for lakes throughout Wisconsin. As discussed previously, species conservatism in the Waupaca Chain O' Lakes is comparable to other lakes within the NCHF ecoregion, but species richness is significantly lower. The lower species richness found within the Chain is the reason Floristic Quality Index values were also lower. Overall, this analysis indicates that the aquatic plant communities of the Waupaca Chain O' Lakes are of lower quality than the majority of lakes within the NCHF ecoregion and the majority of lakes in Wisconsin.

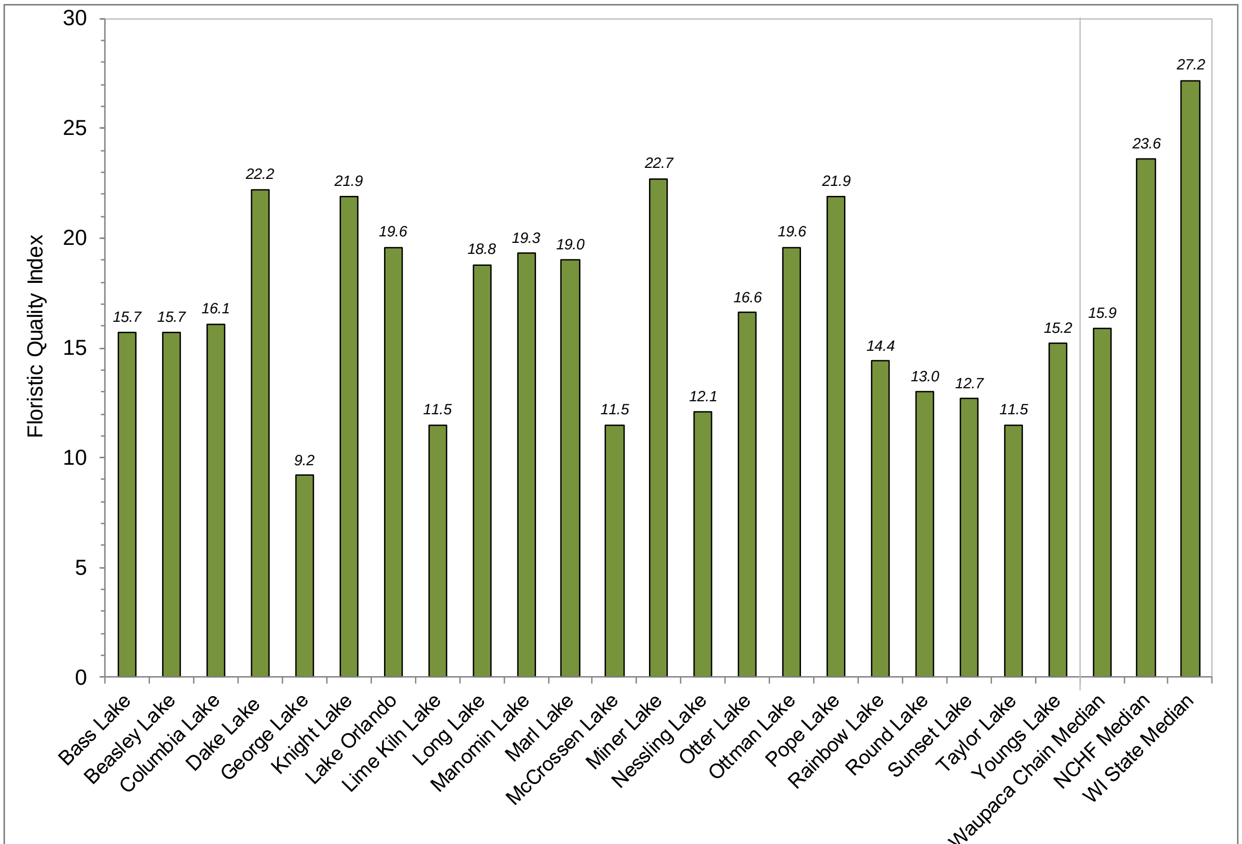


Figure 3.4-7. Waupaca Chain O' Lakes 2016 Floristic Quality Index values. Created using conservatism values and number of native aquatic plant species located on the rake during the whole-lake point-intercept surveys. Analysis follows Nichols (1999).

As discussed earlier, the number of native aquatic plants located during the aquatic plant surveys on the Waupaca Chain O' Lakes in 2016 is on average lower when compared to other lakes within the NCHF ecoregion and the state. One reason for this lower species richness is believed to be due to the Chain's calcium-rich water, the result of groundwater passing though calcareous sediments before entering the lakes. Lakes rich in calcium are often termed *marl lakes* and in general have lower aquatic productivity and diversity (Cole and Weihe 2016). A group of macroalgae called charophytes (*Chara* and *Nitella* spp.; Photograph 3.4-6) have been found to be more competitive against vascular aquatic plants (e.g. pondweeds) in lakes with higher concentrations of calcium carbonate in the sediment and tend to dominate the aquatic plant community (Kufel and Kufel 2002; Wetzel 2001). In the Waupaca Chain O' Lakes, muskgrasses were the most frequently encountered aquatic plant with a Chain-wide littoral frequency of occurrence of 64% (Figure 3.4-8).

Photograph 3.4-6. The aquatic macroalgae muskgrasses (Chara spp.). Photo credit Onterra.

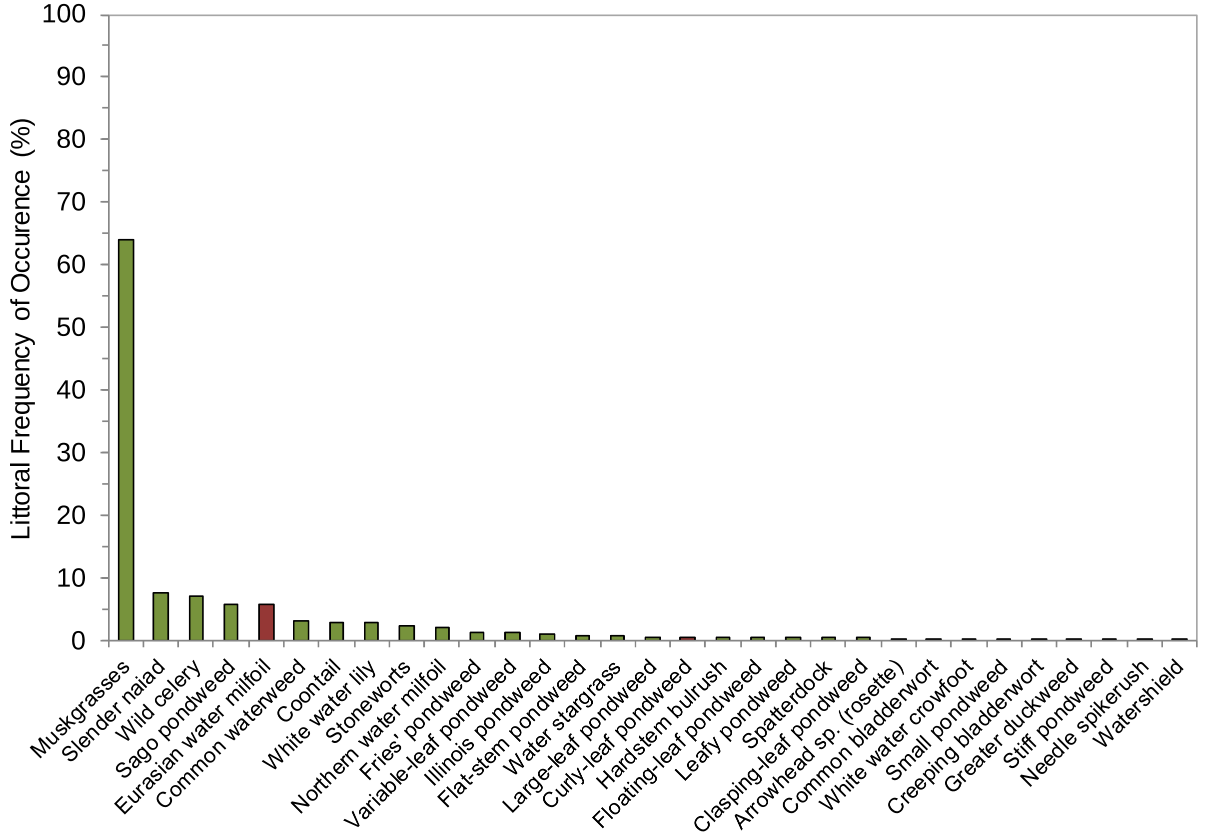


Figure 3.4-8. Waupaca Chain O' Lakes 2016 littoral frequency of occurrence of aquatic plant species. Non-native species indicated with red. Created using 2016 aquatic plant point-intercept survey data. Number of littoral sampling locations = 1, 218.

Figure 3.4-9 compares the relative frequency of occurrence of charophytes to vascular plants within each lake. As illustrated, charophytes comprise greater than 50% of the aquatic plant communities in 12 of the Chain's 22 lakes. The occurrence of charophytes in the Chain's upper lakes with the exception of Marl Lake tended to be lower, indicating these lakes may have lower concentrations of calcium carbonate when compared to lakes lower in the Chain.

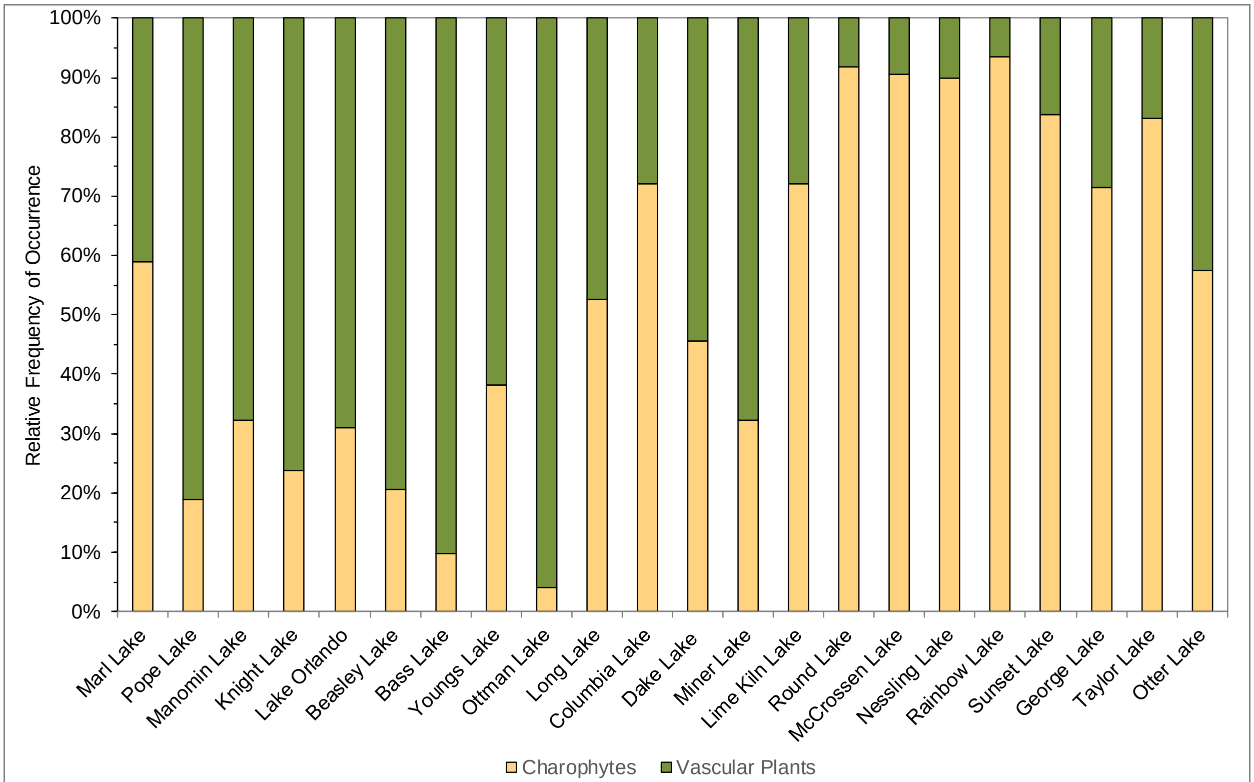


Figure 3.4-9. Waupaca Chain O' Lakes 2016 relative frequency of occurrence of charophytes (muskgrasses and stoneworts) and vascular plants. Please note that vascular plants include both native and non-native plants. Created using data from 2016 point-intercept surveys.

As explained previously, lakes with diverse aquatic plant communities have higher resilience to environmental disturbances and greater resistance to invasion by non-native plants. In addition, a plant community with a mosaic of species with differing morphological attributes provides zooplankton, macroinvertebrates, fish, and other wildlife with diverse structural habitat and various sources of food. If a lake has a high number of aquatic plant species, it does not necessarily mean that the lake will also have high species diversity as diversity is also influenced by how evenly the aquatic plant species are distributed within the community.

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 the Waupaca Chain O' Lakes' diversity values rank. Using data collected by Onterra and WDNR Science Services, quartiles were calculated from 85 lakes within the NCHF ecoregion (Figure 3.4-10). Using data collected from the 2016 whole-lake aquatic plant point-intercept surveys on the Waupaca Chain O' Lakes indicates that Simpson's diversity index values ranged from a low value of 0.22 in Rainbow Lake to a high value of 0.90 in Pope Lake (Figure 3.4-10). Looking at the Chain as a whole, the Simpson's diversity value is 0.67, falling below the median value of 0.84 for lakes within the NCHF ecoregion. The low species diversity found within the Waupaca Chain O' Lakes is due to the uneven distribution of species within the community. On a Chain-wide basis, over half of the Chain's aquatic plant community is comprised of charophytes.

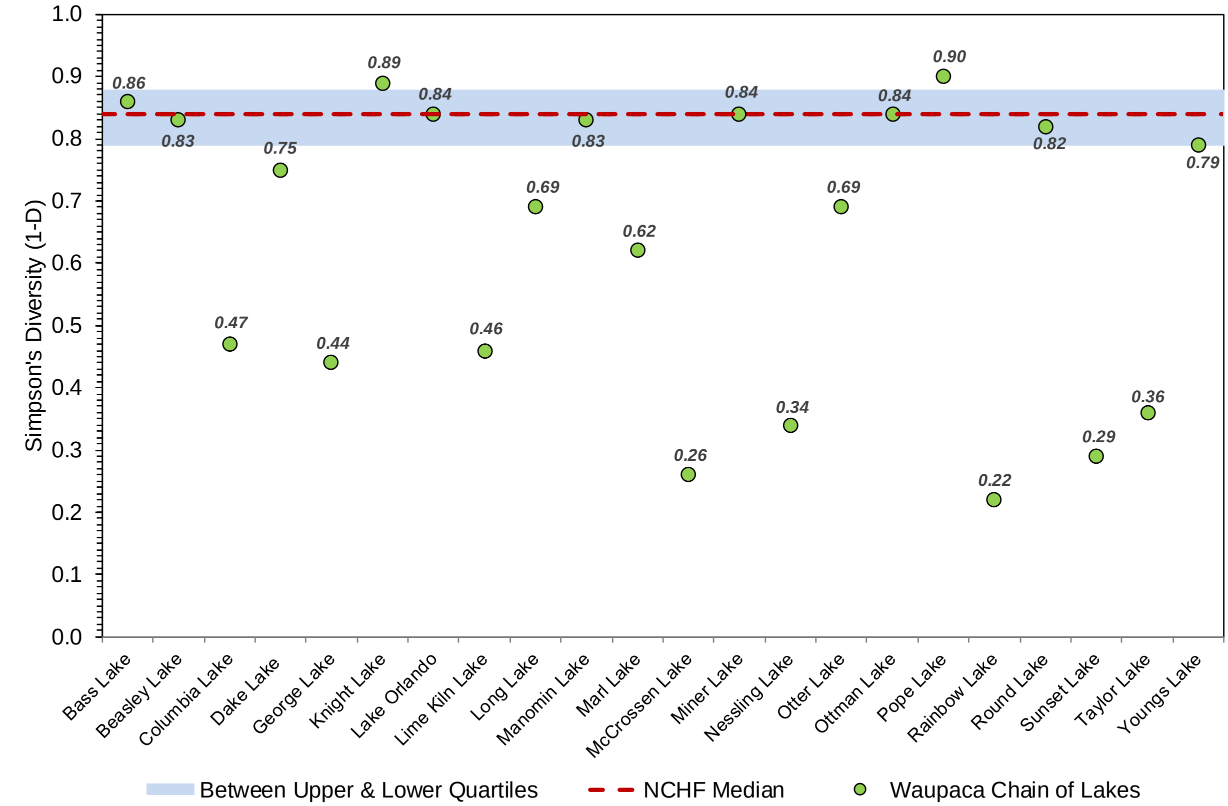


Figure 3.4-10. Waupaca Chain O' Lakes Simpson's Diversity Index. Created using data collected from 2016 aquatic plant point-intercept surveys. Ecoregion data calculated using Onterra and WDNR science services point-intercept survey data.

While the Waupaca Chain of Lake's natural water chemistry favors charophyte competition against vascular plants and their dominance within the aquatic plant community, many lakes within the NCHF ecoregion have similar water chemistry yet support a higher number of vascular aquatic plant species. It is believed that the high concentration of motorboat traffic on the Chain is also driving down aquatic plant species diversity. Waupaca County has over ten thousand registered watercrafts and the Chain is one of the county's most visited waterbodies (Waupaca County Sheriff, 2016). Over 76% of the people responding to the 2017 stakeholder survey indicated motor boating as a reason for owning property on the Chain. Roughly 56% indicated water skiing/tubing as a reason for owning their Chain property.

A study completed on Lake Ripley in southern Wisconsin found that when watercraft were excluded from small experimental plots that aquatic plant biomass, coverage, and shoot height significantly increased compared to experimental plots that were exposed (Asplund and Cook 1997). This study also indicated that the decline in aquatic plants outside of the enclosures was primarily the result of direct impacts from watercraft such as cutting from the prop and uprooting of plants through scouring of the bottom. The authors of this study also noted that taller aquatic plants (e.g. pondweeds) were more susceptible to cutting when compared to shorter plants (e.g. charophytes). Vascular plants in Lake Ripley have been declining since the mid-20th century, and the ones that remain were found to be in areas of the lake that were not subject to high watercraft use (Asplund and Cook 1997).

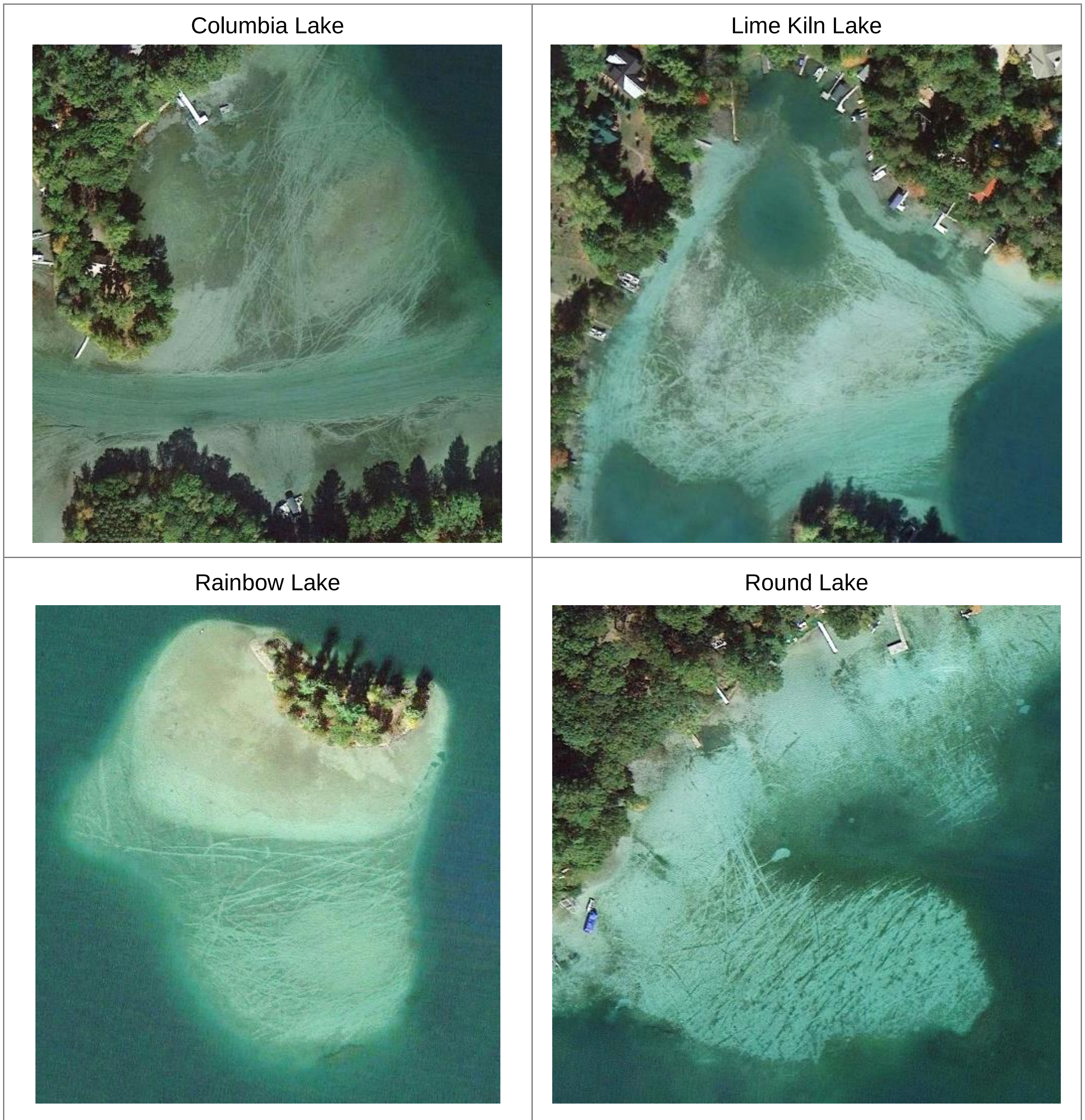


Figure 3.4-11. Aerial photos showing boat tracks or scars (sediment scouring) in shallow areas caused by motorboats in the Waupaca Chain O' Lakes. Aerial photography: NAIP, 2013.

During the surveys on the Waupaca Chain O' Lakes, Onterra ecologists noted many areas with visible boat tracks or "scars" traversing through shallow areas of the lakes (Figure 3.4-11). Continual motorboat traffic over these areas likely prevents taller vascular plants from establishing and maintains a plant community comprised of shorter, disturbance-tolerant species. While species richness and diversity tend to be lower in lakes with water chemistry like that found in the Waupaca Chain O' Lakes, it is also believed that the high concentration of motorboat traffic, particularly over shallower areas of the Chain, are negatively impacting the aquatic plant community through direct cutting of plants uprooting through scouring of the bottom.

Emergent and floating-leaf aquatic plant communities are also an important component of a lake's aquatic plant community. These communities provide valuable structural habitat and stabilize bottom and shoreland sediments. The 2016 emergent and floating-leaf aquatic plant community mapping surveys revealed that approximately 30 acres, or 4% of the Waupaca Chain O' Lakes surface area, contain these types of plant communities comprised of 19 species (Figure 3.4-12 and Maps 6-13). The acres of these communities ranged from 6.6 acres in Ottman Lake to 0.0 acres in George, McCrossen, Miner, Nessling, Rainbow, and Sunset Lake. While emergent and floating-leaf species were found in these lakes with 0.0 acres, these communities were too small to be mapped and measured with polygons.

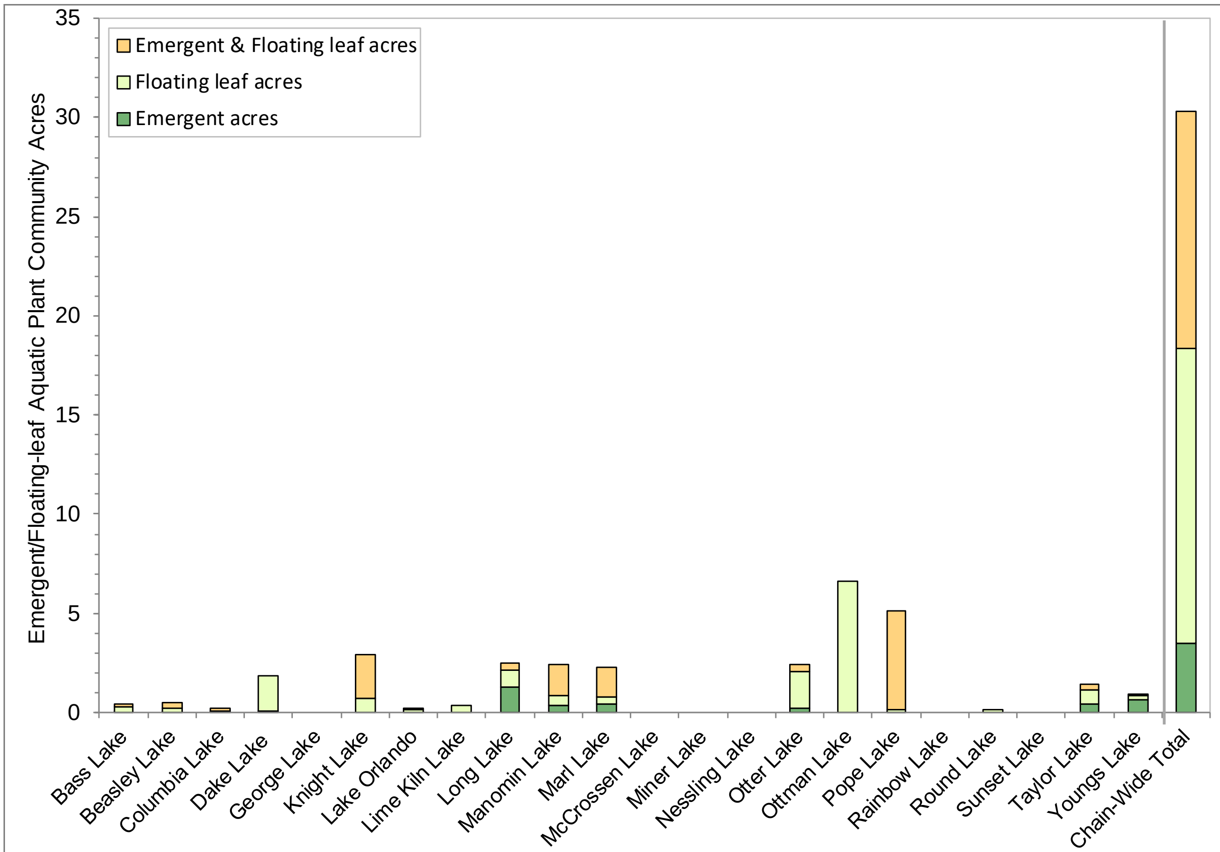


Figure 3.4-12. Waupaca Chain O' Lakes 2016 emergent and floating-leaf aquatic plant community composition. Locations of these aquatic plant communities can be found on Maps 6-13.

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 the Waupaca Chain O' Lakes. 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. Given the high recreational use and level of development on the Chain, it is likely emergent and floating-leaf aquatic plant communities have been adversely impacted.

Non-native Aquatic Plants in the Waupaca Chain O' Lakes

Curly-leaf pondweed

Curly-leaf pondweed (*Potamogeton crispus*; CLP) is listed as first being documented in the Chain in 2010 in Columbia Lake, and as of 2016 was recorded in 11 of the Chain's 22 waterbodies. Curly-leaf pondweed was not as widespread or as dense as Eurasian watermilfoil. The Chain-wide littoral frequency of occurrence of CLP in 2016 was 0.6%. The point-intercept surveys were completed in July following the natural die-back of CLP and its occurrence within the Chain may be slightly underestimated. However, areas of CLP were mapped in June when this plant is typically at or near its peak growth, and this mapping survey found the largest colonies were located within Bass and Long lakes, but were relatively sparse elsewhere in the Chain (Map 14).

Pale-yellow Iris

Pale yellow iris (*Iris pseudacorus*) is a large, showy iris with bright yellow flowers. Native to Europe and Asia, this species was sold commercially in the United States for ornamental use and has since escaped into Wisconsin's wetland areas forming large monotypic colonies and displacing valuable native wetland species. Pale-yellow iris was located along the shorelines of 19 of the Chain's 22 lakes in 2016 (Maps 6-13). The optimal time to locate pale-yellow iris is in May and June when the plants are in flower. Hand-pulling or cutting of these plants to below the water line appears to be the most effective method of control for this species at this time.

Purple Loosestrife

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

In the Waupaca Chain O' Lakes, purple loosestrife was located along the shorelines of 16 of the system's 22 lakes in 2016 (Maps 6-13). There are a number of effective control strategies for combating this aggressive plant, including herbicide application, biological control by native beetles, and hand removal. Chain volunteers have used biological methods to control purple loosestrife in recent years. While completing the aquatic plant community mapping survey during the summer of 2016, Onterra staff noted a small colony of purple loosestrife that was greatly damaged by the District's efforts. Continued monitoring and control will is needed to keep this exotic in check on the Chain.

Sweetflag

Sweetflag (*Acorus calamus*) is an emergent wetland plant that is native to Europe. While not native to North America, this plant is not considered to be invasive. Rather, it is designated as naturalized, meaning that it has integrated itself into the native plant community without imparting adverse ecological impacts. While there is a native species of sweetflag (*A. americanus*), the sweetflag located on the shores of Miner Lake in 2016 is the non-native species (Map 8). Given this species is not considered invasive, it is of little concern and control is not warranted at this time.

Eurasian watermilfoil

Eurasian watermilfoil (*Myriophyllum spicatum*, EWM) was first documented in the Waupaca Chain O' Lakes in 2001, and was found in 16 of the 22 lakes during the 2016 surveys (Maps 15-16). Of the 16 lakes where EWM was located in 2016, it was located on the rake during the point-intercept surveys in 14 lakes and located incidentally in two lakes (Nessling and Taylor). Of the 14 lakes where EWM was encountered on the rake, its littoral frequency of occurrence ranged from 80% in Bass Lake to 0.9% in Rainbow Lake (Figure 3.4-13). Combining the point-intercept survey data from all 22 lakes indicates that EWM was the fifth-most frequently encountered aquatic plant within the Chain in 2016, and had a Chain-wide littoral frequency of occurrence of approximately 6%.

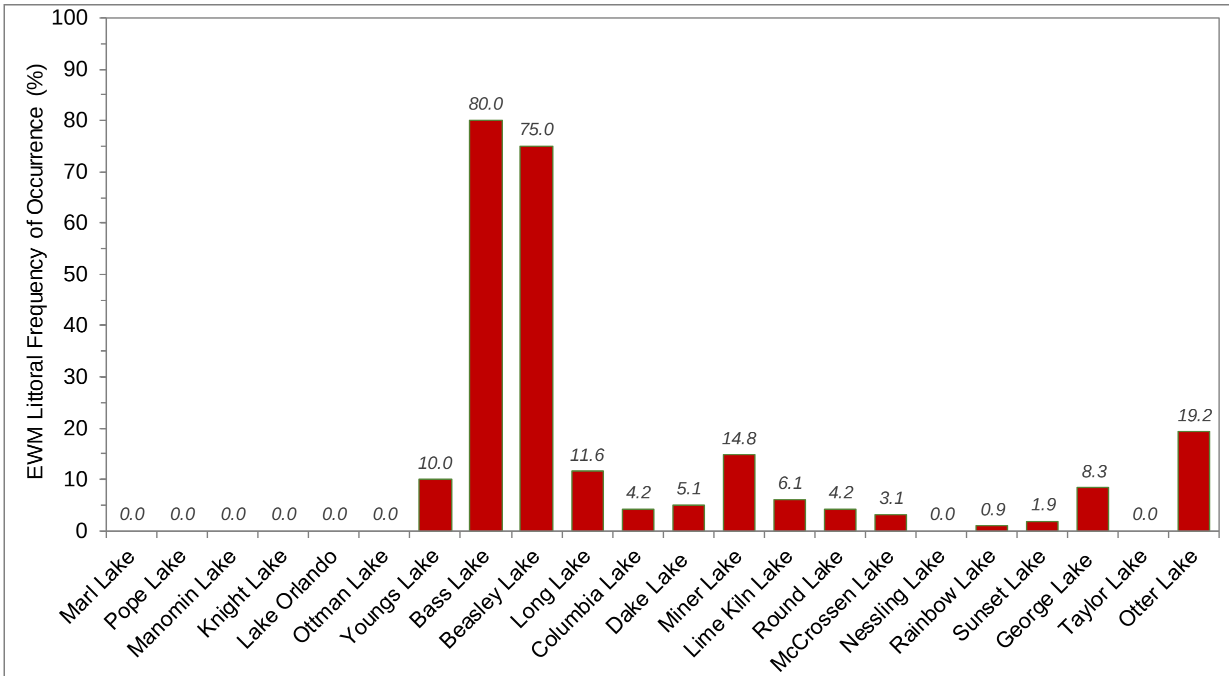


Figure 3.4-13. Waupaca Chain O' Lakes 2016 Eurasian watermilfoil littoral frequency of occurrence by lake. Created using data from 2016 aquatic plant point-intercept surveys.

The Late-Summer EWM Peak-Biomass Survey was completed on the Waupaca Chain O' Lakes on September 26 and October 3, 2016. During this survey, approximately 29 acres of colonized EWM (polygons) were located (Figure 3.4-14 and Maps 15-16). The majority of this acreage (67%) was comprised of EWM with a density rating of *dominant* or greater. Long Lake contained the largest acreage of EWM with 9.1 acres or 32% of the 29 total acres, with Beasley Lake containing the second highest proportion with 4.0 acres or 14%. Columbia Lake contained 2.8 acres (10%), Bass Lake contained 2.6 acres (9%), and Youngs Lake, Miner Lake, and Dake Lake contained approximately 2.0 acres (7%) each. The remaining nine lakes contained approximately 4.0 acres, or 14%.

In February 2017, with the assistance of Onterra, the WCOLD successfully applied for a WDNR AIS-Established Population Control (AIS-EPC) Grant. The grant funded AIS and native aquatic plant monitoring, control strategy development, and AIS control actions. Appendix G includes the annual reports for the AIS-EPC project. These reports contain important information regarding the work completed as a part of that project and how the EWM population changed over the three-year period.

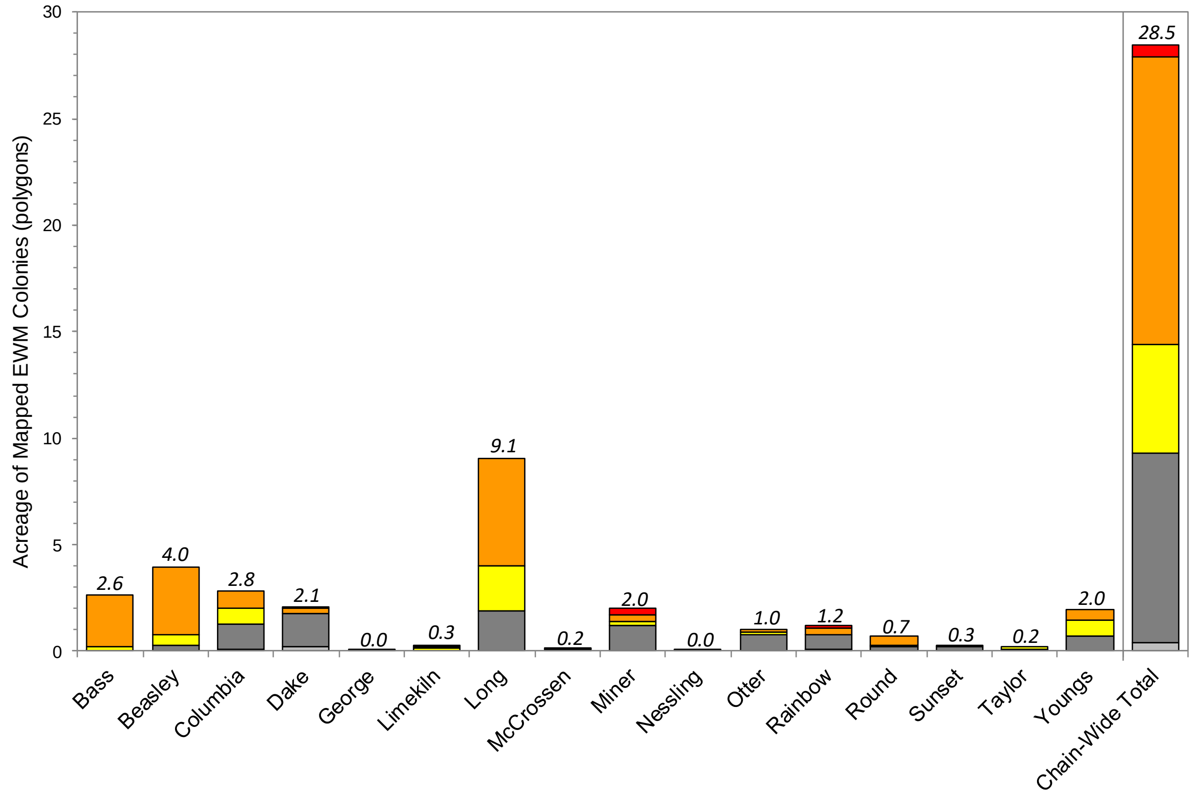


Figure 3.4-14. Waupaca Chain O' Lakes 2016 EWM colonial acreage. Created using data from 2016 Late-Summer EWM Peak-Biomass Survey.

WDNR Long-Term EWM Trends Monitoring Research Project

Starting in 2005, WDNR Science Services began conducting annual point-intercept aquatic plant surveys on a set of lakes to understand how EWM populations vary over time. This was in response to commonly held beliefs of the time that once EWM becomes established in a lake, its population would continue to increase over time. Because Wisconsin's waters are managed for multiple uses (Statue 281.11), the WDNR wanted to understand if EWM populations would increase and cause either: 1) ecological impacts to the lake and/or 2) reductions in ecosystem services (i.e. navigation, recreation, aesthetics, etc.) to lake users. As outlined in *The Science Behind the "So-Called" Super Weed* (Nault 2016), EWM population dynamics on lakes is not that simplistic.

Like other aquatic plants, EWM populations can be dynamic and annual changes in EWM frequency of occurrence have been documented in many lakes, including those that are not being actively managed for EWM control (no herbicide treatment or hand-harvesting program). Figure 3.4-15 shows the EWM population dynamics from the three lakes within the study that were in the same ecoregion as the Waupaca Chain O' Lakes. From these data, it is important to note that the EWM populations of all lakes do not simply increase over time. From 2006 to 2015, the EWM population of Crooked Lake remained below 5% of the littoral zone. Montana and Crystal lakes had populations that fluctuated over time, but largely maintained a steady population in absence of herbicide treatments or coordinated hand-harvesting programs.

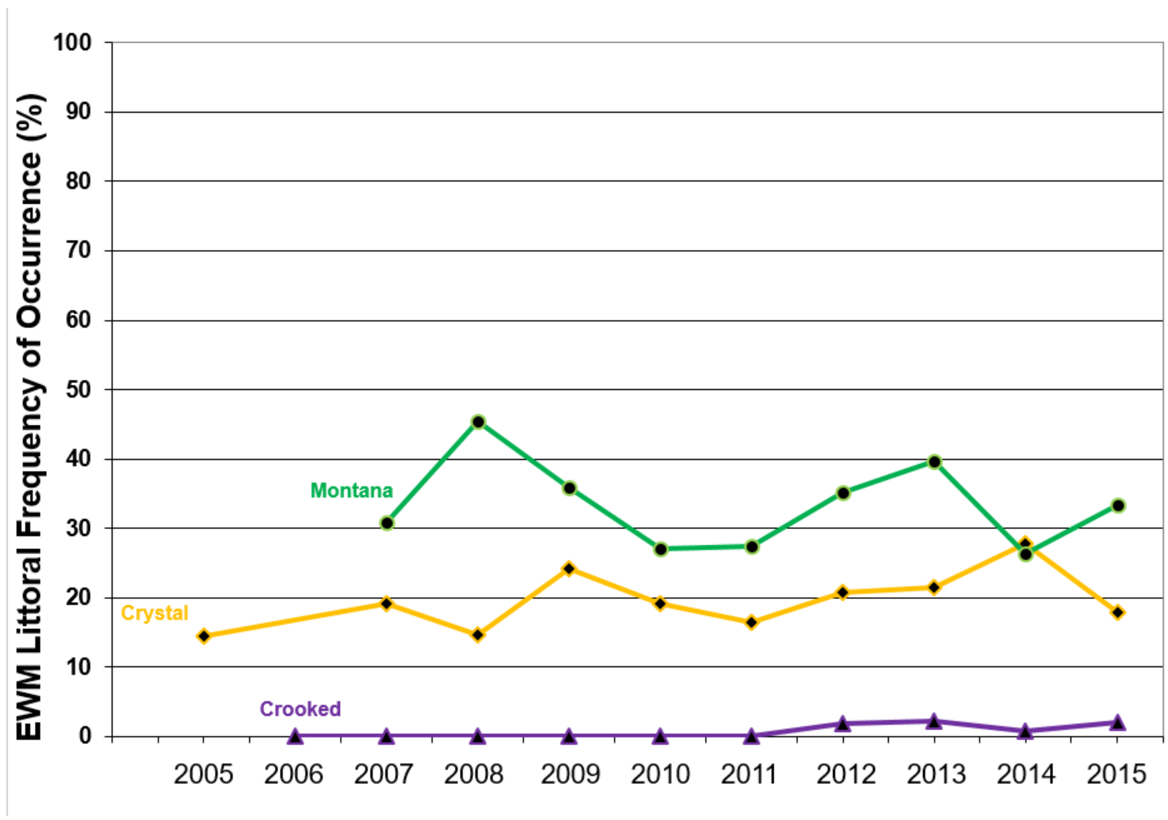


Figure 3.4-15. Littoral frequency of occurrence of EWM in the North Central Hardwood Forests Ecoregion without management. Data provided by and used with permission from the WDNR Bureau of Science Services.

The results of the entire 28-lake study indicate that EWM populations in unmanaged lakes can fluctuate greatly between years, especially in the Northern Lakes and Forests ecoregion. Following initial infestation, EWM expansion was rapid in some lakes, but overall was variable and unpredictable (Nault 2016). In some lakes, the EWM populations reached a relatively stable equilibrium whereas other lakes had more moderate year-to-year variation. Some lake managers interpret these data to suggest that in some circumstances, it is not appropriate to manage the EWM population as in some years the population may become less. However, even a lowered EWM population of approximately 10% exceeds the comfort level of many riparians because it is potentially approaching a level than can be impactful to the function of the lake as well as not allowing the lake to be enjoyed by riparians as it had been historically.

Some lake groups choose to manage the EWM population to keep it at an artificially lowered level. Following detection of an EWM population within a lake, it is common for a lake group to initiate management activities and not wait to see if the EWM population will become a problem in its lake. In other instances, the management strategy is simply to maintain a lower level population of EWM for the purposes of allowing the ecosystem to function as it had before the exotic was introduced to the lake. And yet other lakes are managed simply to alleviate the lost ecosystem services, most notably to manage for multiple human uses. As discussed within the Primer sub-section (pages 7-20), there are a number of different management techniques used for controlling EWM with the most commonly implemented being hand-harvesting and herbicide control. Since the early 2000s, active management of EWM has occurred on the Waupaca Chain O' Lakes, mostly with the use of herbicides.

Background on Herbicide Application Strategy

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

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

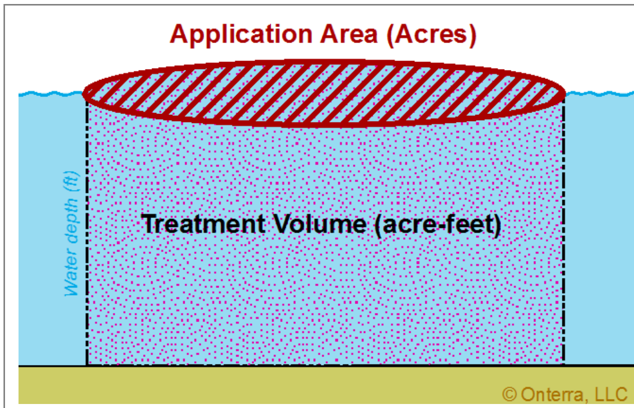


Figure 3.4-16. Herbicide Spot Treatment diagram.

Spot treatments are a type of control strategy where the herbicide is applied to a specific area (treatment site) such that when it dilutes from that area, its concentrations are insufficient to cause significant effects outside of that area. Herbicide application rates for spot treatment are formulated volumetrically, typically targeting EWM with 2,4-D at 3.0-4.0 ppm acid equivalent (ae). This means that sufficient 2,4-D is applied within the *Application Area* such that if it mixed evenly with the *Treatment Volume*, it would equal 3-4.0 ppm ae. This standard method for determining spot treatment use rates is not without flaw, as no physical barrier keeps the herbicide within the *Treatment Volume* and herbicide dissipates horizontally out of the area before reaching equilibrium (Figure 3.4-16). While lake managers may propose that a particular volumetric dose be used, such as 3.0-4.0 ppm ae, it is understood that actually achieving 3.0-4.0 ppm ae within the water column is not likely due to dissipation and other factors.

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

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

Large-scale treatments have become more widely utilized by many lake managers and public sector regulatory partners as they impact the entire EWM population at once. This minimizes the repeated need for exposing the lake to herbicides as is required when engaged in an annual spot treatment program. Properly implemented large-scale herbicide treatments can be highly effective, with minimal EWM, often zero, being detected for a year or two following the treatment (Figure 3.4-17). Some large-scale treatments have been effective at reducing EWM populations for 5-6 years following the application.

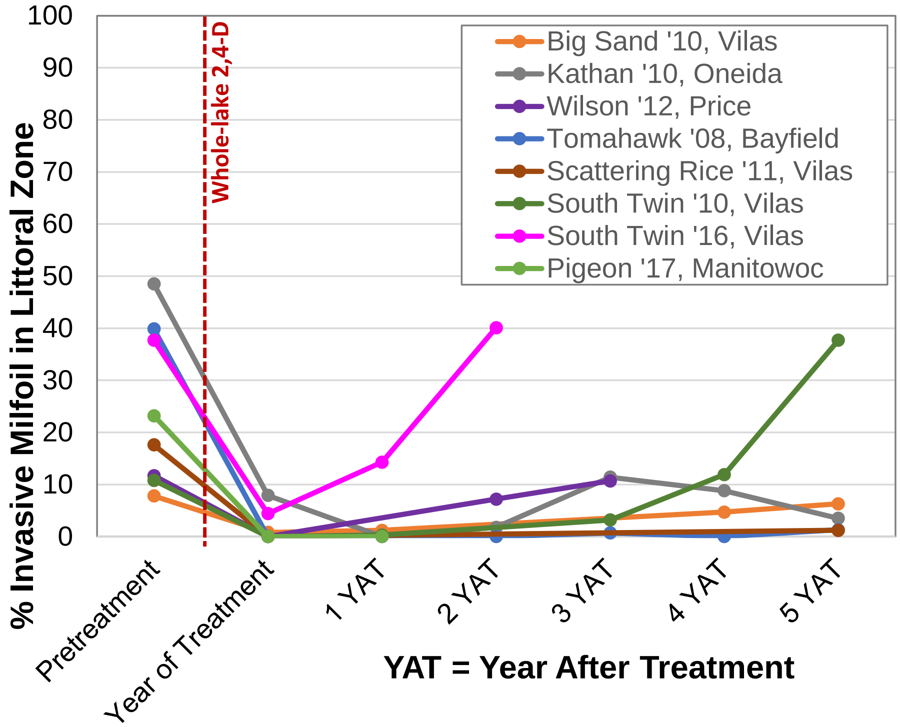


Figure 3.4-17. Littoral frequency of occurrence of EWM in lakes managed with large-scale 2,4-D treatments.

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

Due to distinct features of the EWM's morphology, Onterra field staff suspected that the EWM in the Waupaca Chain O' Lakes may be a hybrid, a cross between EWM and the indigenous northern watermilfoil (*Myriophyllum sibiricum*). Investigations yielded a single sample from Taylor Lake in 2013 had been sent by Golden Sands RC&D to the Annis Water Resources Institute at Grand Valley State University in Michigan for DNA analysis. Results confirmed that the milfoil sent in from Taylor Lake was a hybrid between EWM and the native northern watermilfoil. The WDNR was able to collect additional suspect milfoil samples from Sunset, Round, George, Rainbow, and Otter lakes in 2016 for genetic testing. All samples sent in were confirmed as being hybrid EWM (HWM).

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

Figure 3.4-18 shows the results of whole-lake 2,4-D treatments on a subset of HWM populations. During the year of treatment, HWM populations were reduced, but at a lesser percentage than similar pure EWM populations (Figure 3.4-17). In almost all HWM populations, rebound took less time and the rounded populations were at much higher frequency than EWM populations.

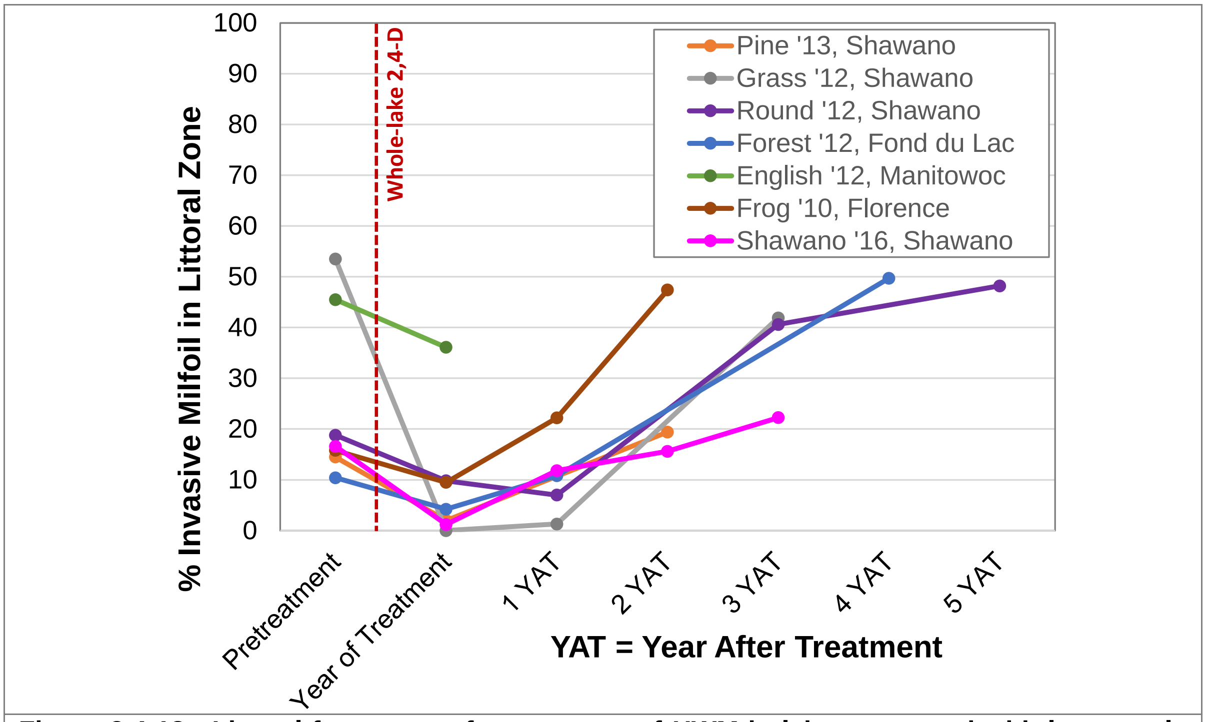


Figure 3.4-18. Littoral frequency of occurrence of HWM in lakes managed with large-scale 2,4-D treatments.

3.5 Aquatic Invasive Species in the Waupaca Chain O' Lakes

As is discussed in Section 2.0 Stakeholder Participation, the lake stakeholders were asked about aquatic invasive species (AIS) and their presence in the Waupaca Chain O' Lakes within the anonymous stakeholder survey. Onterra and the WDNR have confirmed that there are eleven AIS present (Table 3.5-1).

Table 3.5-1. AIS present within the Waupaca Chain O' Lakes

Type	Common name	Scientific name	Location within the report
Plants	Aquatic forget-me-not	*Myosotis scorpioides*	Section 3.5 Aquatic Invasive Species
	Eurasian watermilfoil	*Myriophyllum spicatum*	Section 3.4 – Aquatic Plants
	Curly-leaf pondweed	*Potamogeton crispus*	Section 3.4 – Aquatic Plants
	Japanese knotweed	*Fallopia japonica*	Section 3.5 Aquatic Invasive Species
	Pale yellow iris	*Iris pseudacorus*	Section 3.4 – Aquatic Plants
	Purple loosestrife	*Lythrum salicaria*	Section 3.4 – Aquatic Plants
	Sweetflag	*Acorus calamus*	Section 3.4 – Aquatic Plants
Invertebrates	Zebra mussel	*Dreissena polymorpha*	Section 3.1 – Water Quality
	Banded mystery snail	*Viviparous georgianus*	Section 3.5 Aquatic Invasive Species
	Rusty crayfish	*Orconectes rusticus*	Section 3.5 Aquatic Invasive Species
	Asiatic clam	*Corbicula fluminea*	Section 3.5 Aquatic Invasive Species

Figure 3.5-1 displays the 15 aquatic invasive species that Waupaca Chain O' Lakes stakeholders believe are in the Chain. Only the species present in the Waupaca Chain O' Lakes are discussed below or within their respective locations listed in Table 3.5-1. While it is important to recognize which species stakeholders believe to be present within their lake, it is more important to share information on the species present and possible management options. More information on these invasive species or any other AIS can be found at the following links:

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

Aquatic Animals

Rusty Crayfish

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

Mystery snails

There are two types of mystery snails found within Wisconsin waters, the Chinese mystery snail (*Cipangopaludina chinensis*) and the banded mystery snail (*Viviparus georgianus*). Both snails can be identified by their large size, thick hard shell and hard operculum (a trap door that covers the snail's soft body). These traits also make them less edible to native predators. These species thrive in eutrophic waters with very little flow. They are bottom-dwellers eating diatoms, algae and organic and inorganic bottom materials. One study conducted in northern Wisconsin lakes found that the Chinese mystery snail did not have strong negative effects on native snail populations (Solomon et al. 2010). However, researchers did detect negative impacts to native snail communities when both Chinese mystery snails and the rusty crayfish were present (Johnson et al. 2009).

Asiatic clam

The Asiatic clam (*Corbicula fluminea*) was first discovered in Wisconsin in 1977. It is believed that the Asiatic clam came from Asia through the food items of Chinese immigrants or through the importation of oysters. The clam is mainly consumed by fish and crayfish and it has been shown that native fish have altered their diet to eat the Asiatic clam (Garcia and Protogino 2005). Asiatic clams are found at or below the sediment surface and can withstand colder temperatures, causing swings in populations numbers. Unlike zebra mussels, the Asiatic clam does not have stripes, has a yellowish to dark shell, with the inside of the shell varying from white to purple.

Aquatic Plants

Aquatic forget-me-not

Aquatic forget-me-not (*Myosotis palustris*) is a low-lying, creeping plant with blue flowers with a yellow center. It can quickly become a monoculture, once escaped, and can crowd out native plants and has the ability to grow in all types of wetlands. There is currently no good control method for aquatic forget-me-not due to its abundant reproduction of seeds and how it spreads through runners (stolons).

Japanese knotweed

Like many other invasive species, Japanese knotweed (*Fallopia japonica)* was introduced to the United States as an ornamental plant. This perennial produces large, hollow stems that have the appearance of bamboo, and it is able to thrive in many different habitats where it out-competes native species. At this time, the best method of control is through a combination of cutting followed by an application of herbicide once in late spring and again in early fall. Often, several years of cutting/herbicide applications will be required to eradicate areas of this invasive plant.

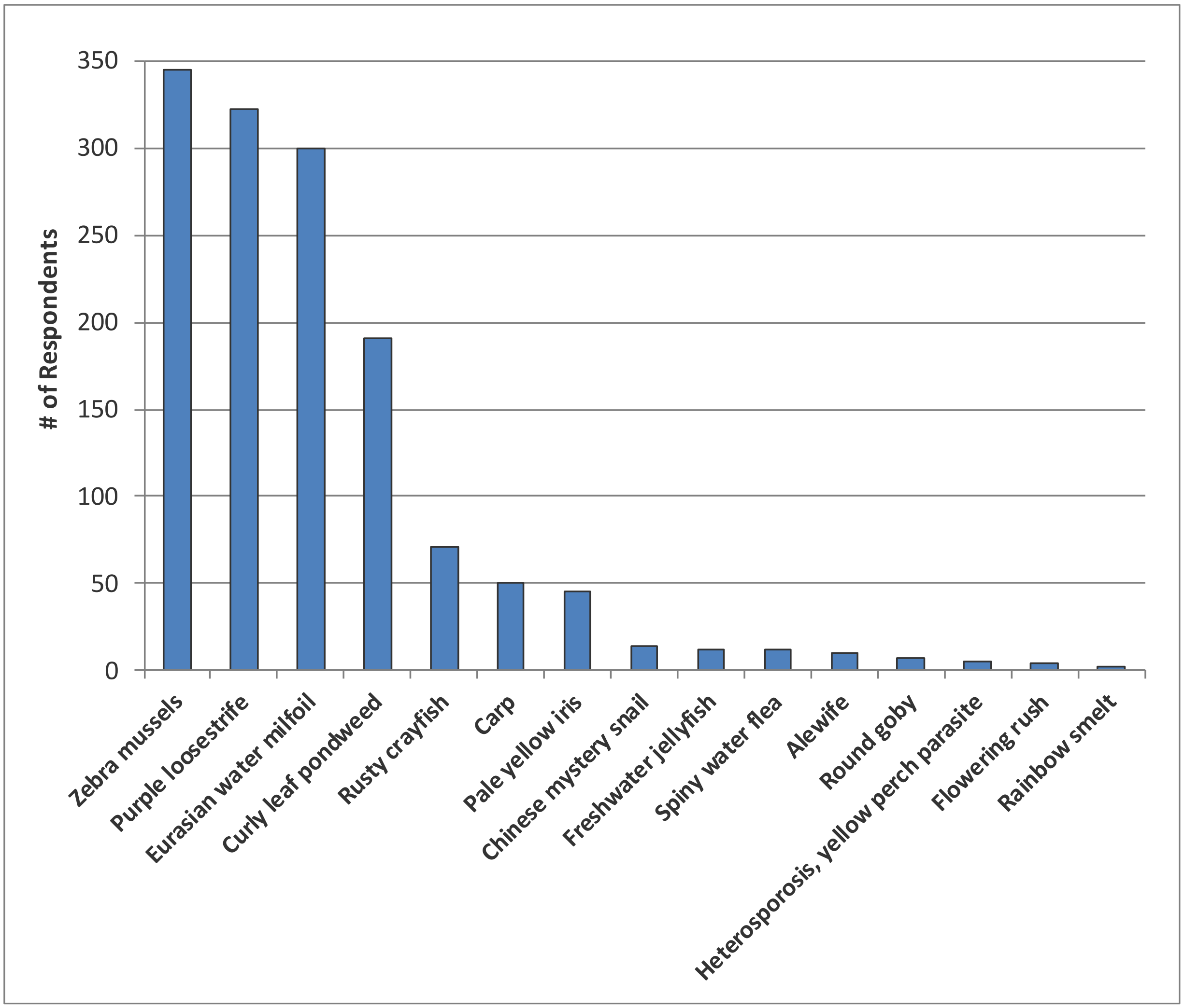


Figure 3.5-1. Stakeholder survey response to Question #20. *Which AIS do you think are in the Chain?*

3.6 Fisheries Data Integration

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

Waupaca Chain O' Lakes Fishery

Energy Flow of a Fishery

When examining the fishery of a lake, it is important to remember what drives that fishery, and what is responsible for determining its mass and composition. The gamefish in the Waupaca Chain O' Lakes 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, 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.

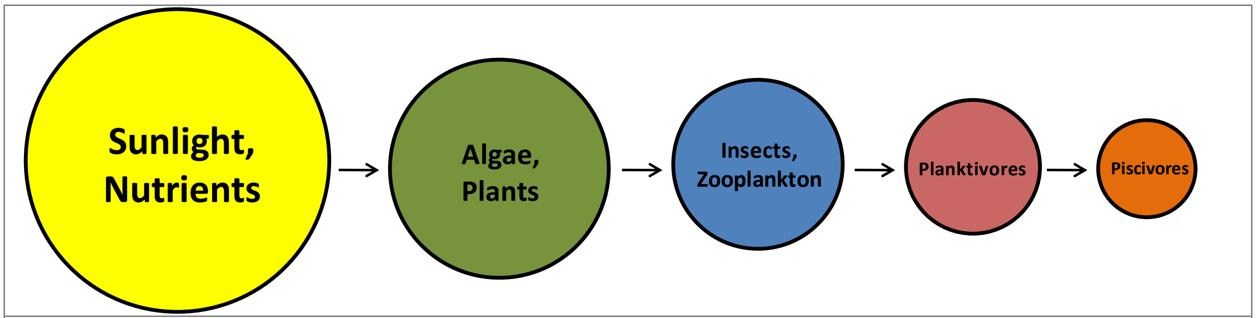


Figure 3.6-1. Aquatic food chain. Adapted from Carpenter et. al 1985.

As discussed in the Water Quality section, much of the Waupaca Chain O' Lakes is in an oligotrophic or mesotrophic state, meaning it has moderate to high water clarity, but a low or moderate amount of nutrients and thus low to moderate primary productivity. Simply put, this means it may be difficult for the lake to support a large population of predatory fish (piscivores) because the supporting food chain is relatively modest. Table 1 shows the popular game fish present in the system. Additional species that have been found in the Waupaca Chain include: banded killifish (*Fundulus diaphunus*), bowfin (*Amia calva*), greater redhorse (*Moxostoma valenciennesi*), northern hogsucker (*Hypentielium nigricans*) and white sucker (*Catostomus commersonii*).

Table 3.6-1. Gamefish present in the Waupaca Chain 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
Brook Trout (*Salvelinus fontinalis*)	6	October - December	Streams or spring-fed tributaries, gravel bottom	Aquatic insects, terrestrial insects, crustaceans, fish and worms
Brown Trout (*Salmo trutta*)	18	October - December	Large streams to small spring-fed tributaries with gravel bottom	Aquatic invertebrates, terrestrial insects, worms, fish, and crayfish
Cisco/Lake Herring (*Coregonus artedii*)	22	Late November - Early December	No clear substrate preference.	Microscopic zooplankton, aquatic insect larvae, adult mayflies, stoneflies, bottom-dwelling invertebrates.
Green Sunfish (*Lepomis cyanellus*)	7	Late May - Early August	Shelter with rocks, logs, and clumps of vegetation, 4 - 35 cm	Zooplankton, insects, young green sunfish and other small fish
Largemouth Bass (*Micropterus salmoides*)	13	Late April - Early July	Shallow, quiet bays with emergent vegetation	Fish, amphipods, algae, crayfish and other invertebrates
Muskellunge (*Esox masquinongy*)	30	Mid April - Mid May	Shallow bays over muck bottom with dead vegetation, 6 - 30 in.	Fish including other muskies, small mammals, shore birds, frogs
Northern Pike (*Esox lucius*)	25	Late March - Early April	Shallow, flooded marshes with emergent vegetation with fine leaves	Fish including other pike, crayfish, small mammals, water fowl, frogs
Orangespotted Sunfish (*Lepomis humilis*)	4	Late May - August	Shallow water with sand or gravel bottom	Crustaceans, copepods, mites and aquatic insects
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
White Crappie (*Pomoxis annularis*)	13	May - June	Within 10 m from shore, over hard clay, gravel, or roots	Crustaceans, insects, small fish
Yellow Bullhead (*Ameiurus natalis*)	7	May - July	Heavy weeded banks, beneath logs or tree roots	Crustaceans, insect larvae, small fish, some algae
Yellow Perch (*Perca flavescens*)	13	April - Early May	Sheltered areas, emergent and submergent veg	Small fish, aquatic invertebrates

Survey Methods

In order to keep the fishery of a lake healthy and stable, fisheries biologists must assess the current fish populations and trends. To begin this process, the correct sampling technique(s) must be selected to efficiently capture the desired fish species. A passive trap commonly used is a fyke net (Photograph 3.6-1). Fish swimming towards this net along the shore or bottom will encounter the lead of the net and be diverted into the trap and through a series of funnels which direct the fish further into the net. Once reaching the end, the fisheries technicians can open the net and sort the captured fish. Fyke nets were set on the Waupaca Chain targeting spawning northern pike, walleye, yellow perch and other panfish (Niebur 2015).

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

The other commonly used sampling method is electroshocking (Photograph 3.6-2). This is done, often at night, by using a specialized boat fit with a generator and two electrodes installed on the front touching the water. Once a fish comes in contact with the electrical current produced, *galvanotaxis* stimulates their nervous system and involuntarily causes them to swim toward the electrodes. When the fish are in the vicinity of the electrodes, they undergo *narcosis* (due to being stunned), making them easy for fisheries technicians to net and place into a livewell to recover. Contrary to what some may believe, electroshocking does not kill the fish and after being placed in the livewell fish generally recover within minutes. Electroshocking was conducted on the Waupaca Chain targeting walleye, largemouth bass, smallmouth bass and young of year walleye (Niebur 2015).

Photograph 3.6-2. Electroshocking boat (Photo from South Carolina Department of Natural Resources, SCDNR 2011)

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

Fish Stocking

To assist in meeting fisheries' management goals, the WDNR may stock fry, fingerling, or adult fish in a waterbody that were raised in nearby permitted hatcheries (Photograph 3.6-3). Stocking of a lake may be done to assist the population of a species due to a lack of natural reproduction in the system or to otherwise enhance angling opportunities. The Waupaca Chain has been heavily stocked since the 1970s with several different fish species. WDNR stocking efforts from 1972 to 2016 are displayed in Tables 3.6-2 and 3.6-3. Future stocking efforts of northern pike and walleye are likely to continue through the WDNR.

Photograph 3.6-3. Fall Fingerling Muskellunge.

Table 3.6-2. WDNR stocking data of fish species available for the Waupaca Chain O' Lakes (1972-2016).

Year	Stocked Waterbody	Species	Strain (Stock)	Age Class	# Fish Stocked	Avg Fish Length (in)
1972	Rainbow Lake	Brown Trout	Unspecified	Fingerling	10,000	5.0
1973	Rainbow Lake	Brown Trout	Unspecified	Adult	1,353	15.0
1973	Rainbow Lake	Brown Trout	Unspecified	Fingerling	5,000	5.0
1974	Round Lake	Brown Trout	Wild Rose	Fingerling	2,100	7.0
1980	Youngs Lake	Largemouth Bass	Unspecified	Fingerling	7,500	2.0
1972	Ottman Lake	Northern Pike	Unspecified	Fry	85,000	1.0
1976	Ottman Lake	Northern Pike	Unspecified	Fry	25,000	
2016	Chain O'Lakes	Northern Pike	Mud Lake-Madison	Large Fingerling	2,500	8.6
1979	Columbia Lake	Northern Pike x Muskellunge	Unspecified	Fingerling	1,200	10.0
1979	Taylor Lake	Northern Pike x Muskellunge	Unspecified	Fingerling	1,200	10.0
1986	Columbia Lake	Northern Pike x Muskellunge	Unspecified	Fingerling	800	8.0
1986	Taylor Lake	Northern Pike x Muskellunge	Unspecified	Fingerling	400	8.0
1987	Columbia Lake	Northern Pike x Muskellunge	Unspecified	Fingerling	900	9.0
1987	Miner Lake	Northern Pike x Muskellunge	Unspecified	Fingerling	1,800	9.0
1987	Taylor Lake	Northern Pike x Muskellunge	Unspecified	Fingerling	900	9.0
1988	Columbia Lake	Northern Pike x Muskellunge	Unspecified	Fingerling	400	8.0
1988	Miner Lake	Northern Pike x Muskellunge	Unspecified	Fingerling	400	8.0
1988	Taylor Lake	Northern Pike x Muskellunge	Unspecified	Fingerling	400	8.0
1972	Long Lake	Rainbow Trout	Unspecified	Yearling	300	7.0
1973	Rainbow Lake	Rainbow Trout	Unspecified	Yearling	1,590	13.0
1974	Round Lake	Rainbow Trout	Unspecified	Yearling	8,050	11.0

Table 3.6-3. WDNR stocking data of walleye available for the Waupaca Chain O' Lakes (1974-2016).

Year	Stocked Waterbody	Strain (Stock)	Age Class	# Fish Stocked	Avg Fish Length (in)
1974	Rainbow Lake	Unspecified	Fingerling	3,300	3.0
1974	Round Lake	Unspecified	Fingerling	3,300	3.0
1974	Sunset Lake	Unspecified	Fingerling	3,400	3.0
2001	Bass Lake	Unspecified	Small Fingerling	15,000	1.6
2001	Columbia Lake	Unspecified	Small Fingerling	20,000	1.6
2001	Miner Lake	Unspecified	Small Fingerling	15,000	1.6
2001	Taylor Lake	Unspecified	Small Fingerling	20,000	1.6
2003	Beasley Lake	Mississippi Headwaters	Small Fingerling	15,000	1.9
2003	Columbia Lake	Mississippi Headwaters	Small Fingerling	20,000	1.9
2003	Miner Lake	Mississippi Headwaters	Small Fingerling	15,000	1.9
2003	Taylor Lake	Mississippi Headwaters	Small Fingerling	20,000	1.9
2004	Bass Lake	Mississippi Headwaters	Small Fingerling	7,980	2.0
2004	Columbia Lake	Mississippi Headwaters	Small Fingerling	8,985	2.0
2004	Miner Lake	Mississippi Headwaters	Small Fingerling	8,985	2.0
2004	Taylor Lake	Mississippi Headwaters	Small Fingerling	8,985	2.0
2005	Beasley Lake	Unspecified	Small Fingerling	14,372	1.7
2005	Columbia Lake	Unspecified	Small Fingerling	15,888	17.0
2005	Miner Lake	Unspecified	Small Fingerling	15,898	1.7
2005	Taylor Lake	Unspecified	Small Fingerling	15,893	1.7
2006	Columbia Lake	Lake Michigan	Small Fingerling	6,321	1.4
2006	Miner Lake	Lake Michigan	Small Fingerling	6,323	1.4
2006	Taylor Lake	Lake Michigan	Small Fingerling	6,321	1.4
2006	Youngs Lake	Lake Michigan	Small Fingerling	6,325	1.4
2008	Columbia Lake	Mississippi Headwaters	Small Fingerling	12,678	1.5
2008	Taylor Lake	Mississippi Headwaters	Small Fingerling	12,677	1.5
2010	Columbia Lake	Mississippi Headwaters	Small Fingerling	8,145	1.4
2010	Rainbow Lake	Mississippi Headwaters	Small Fingerling	8,145	1.4
2010	Sunset Lake	Mississippi Headwaters	Small Fingerling	8,145	1.4
2010	Taylor Lake	Mississippi Headwaters	Small Fingerling	12,537	1.7
2011	Chain O' Lakes	Lake Michigan	Large Fingerling	7,248	5.6
2012	Chain O' Lakes	Lake Michigan	Large Fingerling	8,014	7.2
2014	Chain O' Lakes	Lake Michigan	Large Fingerling	3,826	7.0
2016	Chain O' Lakes	Upper Mississippi River	Large Fingerling	3,767	7.9

Fish Populations and Trends

Utilizing the above-mentioned fish sampling techniques and specialized formulas, WDNR fish biologists can estimate populations and determine trends of captured fish species. The data collected and calculated is then used by fish biologists to determine the best management plan for a lake or the Chain. One method used is calculating abundance and size structure of the fish populations and comparing them to area lakes with the same species. Table 3.6-4 includes a summary of fish species and their abundance and size structure reported by DNR fisheries biologists after the 2011 and 2015 surveys.

Table 3.6-4. Gamefish Abundance and Size Structure Information reported by Fisheries Biologists after the 2011 and 2015 fisheries surveys on the Waupaca Chain O' Lakes.

Fish Species	2011 Abundance	2015 Abundance	2011 Size Structure	2015 Size Structure
Largemouth Bass	High	Medium-High	High	Medium
Northern Pike	Low	Medium	Medium	Low
Walleye	Low	N/A	High	N/A
Smallmouth Bass	Low	Low	Medium	Low
Bluegill	High	Medium	Low	Low
Black Crappie	Medium	N/A	Medium	N/A

Waupaca Chain O' Lakes Fish Habitat

Two-Story Fishery

The Waupaca Chain O' Lakes is unique compared to most systems in Wisconsin in that it is a two-story fishery. A two-story fishery is capable of supporting both a warm water and cold water fishery. The top-story supports warmer water species such as bass and pike. The lower-story is colder, deeper, and well oxygenated and supports species such as cisco and trout. The cisco (or lake herring) population has been found in above average abundance during surveys on the Waupaca Chain O' Lakes (WDNR 2009). Cisco can prey on trout, pike, and walleye among other species. Brown trout are a coldwater species documented in the Waupaca Chain O' Lakes. This species has been documented spawning within Emmons Creek, a Class 1 tributary stream flowing into Long Lake on the Chain (WDNR 2009).

Substrate Composition

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

Substrate and habitat are critical to fish species that do not provide parental care to their eggs. Northern pike are one species that do not provide parental care to their 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 where they would suffocate as a result. Walleye are another species that does not provide parental care to its eggs. Walleye preferentially spawn in areas with gravel or rock in places with moving water or wave action, which oxygenates the eggs and prevents them from getting buried in sediment. Fish that provide parental care are less selective of spawning substrates. Species such as bluegill tend to prefer a harder substrate such as rock, gravel, or sandy areas if available, but have been found to spawn and care for their eggs in muck as well.

According to the point-intercept survey conducted by Onterra in 2016, most of the substrate sampled in the littoral zone of the Waupaca Chain O' Lakes was composed of soft sediments, with sand and rock being less common.

Coarse Woody Habitat & Fish Sticks Program

As discussed in the Shoreland Condition Section, the presence of coarse woody habitat is important for many stages of a fish's life cycle, including nesting or spawning, escaping predation as a juvenile, and hunting insects or smaller fish as an adult. Unfortunately, as development has increased on shorelines of Wisconsin lakes in the past century, this beneficial habitat has often been the first to be removed from the natural shoreland zone. Leaving these shoreland zones barren of coarse woody habitat can lead to decreased abundances and slower growth rates in fish (Sass 2009).

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

These projects are typically conducted on lakes lacking significant coarse woody habitat in the shoreland zone. A fall 2016 survey of the lower Chain conducted by the Waupaca County LWCD documented 420 pieces of coarse woody along its shores, resulting in a ratio of approximately 23 pieces per mile of shoreline.

Photograph 3.6-4. Fish Crib Example. (Photo courtesy of Silver Lake District 2009).

Like fish sticks, fish cribs provide the same benefits of adding woody habitat density to the lake. They are typically built using hardwood logs strapped together filled with branches inside (Photograph 3.6-4). A WDNR permit may be required to install a fish crib, depending on the size and location of placement.

The Waupaca Chain O' Lakes may be an excellent candidate to consider enhancing coarse woody habitat through the deployment of fish sticks or fish cribs.

Regulations and Management

Current (2016-2017) regulations for the Waupaca Chain O' Lakes gamefish species are displayed in Table 3.6-5. For specific fishing regulations on all fish species, anglers should visit the WDNR website (*www. http://dnr.wi.gov/topic/fishing/regulations/hookline.html)* or visit their local bait and tackle shop to receive a free fishing pamphlet that contains this information.

Table 3.6-5. WDNR fishing regulations for the Waupaca Chain O' Lakes (2016-2017).

Species	Season	Regulation
Panfish	Open All Year	None, Daily bag limit 25
Largemouth bass and smallmouth bass	June 18, 2016 to March 5, 2017	14", Daily bag limit 5
Northern pike	May 7, 2016 to March 5, 2017	26", Daily bag limit 2
Walleye, sauger, and hybrids	May 7, 2016 to March 5, 2017	15", Daily bag limit 5
Bullheads	Open All Year	None, Unlimited
Rock, yellow, and white bass	Open All Year	None, Unlimited
Rough fish	Open All Year	None, Unlimited

Mercury Contamination and Fish Consumption Advisories

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

General fish consumption guidelines for Wisconsin inland waterways are presented in Figure 3.6-2. There is an elevated risk for children as they are in a stage of life where cognitive development is rapidly occurring. As mercury and PCB both locate to and impact the brain, there are greater restrictions for women who may have children or may be nursing children, and also for children under 15.

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

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

Figure 3.6-2. Wisconsin statewide safe fish consumption guidelines. Graphic displays consumption guidance for most Wisconsin waterways. Figure adapted from WDNR website graphic (http://dnr.wi.gov/topic/fishing/consumption/)

Conclusions

After the 2011 fisheries survey, the WDNR changed walleye stocking quotas from small fingerling to large fingerling. This was done in an effort to increase stocked walleye survival when their abundance was estimated to be low in the 2011 survey (Niebur 2011). After the 2015 WDNR fisheries survey, a biennial large fingerling northern pike quota (15/acre) was recommended over the next 6 years (Niebur 2015). The first stocking of this northern pike recommendation occurred in 2016 and was the first stocking of northern pike since 1976. Additionally, improving the nearshore habitat by placement of fish sticks is also recommended by the WDNR (Niebur 2015). The Waupaca Chain O' Lakes is considered a "high-profile" system and is sampled every 4 years by the WDNR. The next comprehensive survey is planned for 2019.

4.0 SUMMARY AND CONCLUSIONS

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

1) Collect baseline data to increase the general understanding of the Waupaca Chain O' Lakes ecosystem.
2) Collect detailed information regarding invasive plant species within the lake, with the primary emphasis being on hybrid watermilfoil.
3) Collect sociological information from WCOLD stakeholders regarding their use of the lakes and their thoughts pertaining to the past and current condition of the lakes and their management.

During the 2016 aquatic plant surveys conducted on the Waupaca Chain O' Lakes, 44 native aquatic plant species were identified. Also during those surveys, seven non-native plants consisting of Eurasian watermilfoil, curly-leaf pondweed, and five emergent species were located. Not surprisingly, the Chain's aquatic plant population is highly dominated by muskgrasses, which typically proliferate in clear, high-calcium lakes such as those found in the Chain. Overall, the Chain's aquatic plant community reflects the conditions found in the system, that being a waterbody with high amounts of recreation and high levels of shoreland development. As discussed in the Aquatic Plant Section 3.4, the Chain's plant population is likely impacted by the system's high use to some extent. The boating activity likely impacts that submergent community the most, while shoreland development likely impacts the floating-leaf and emergent communities. This is supported by the Radomski and Goeman (2001) study that found a 66% reduction in vegetation coverage on developed shorelines when compared to undeveloped shorelines in Minnesota lakes.

Over the past decade or more, the WCOLD has worked to manage Eurasian watermilfoil and curly-leaf pondweed populations through herbicide treatments and hand-harvesting efforts. The term *Best Management Practice (BMP)* is often used in environmental management fields to represent the management option that is currently supported by that latest science and policy. When used in an action plan, the term can be thought of as a placeholder with anticipation of being altered over time. As an example, a lake group may create a management goal to control nuisance quantities of native plants using BMPs. Perhaps twenty years ago the BMP would have been to use a harsh chemical and now may include mechanical harvesting, more selective herbicides, or manual removal. A primary objective of updating the Chain's plan by the WCOLD is to create a strategy for controlling Eurasian watermilfoil and other AIS plants utilizing BMPs. This is discussed in more detail within the Implementation Plan (Section 5.0).

The Waupaca Chain O' Lakes consist of three lake types: shallow, headwater drainage lakes (3) deep, headwater drainage lakes (14), and deep, lowland drainage lakes (5). The water quality of the Waupaca Chain O' Lakes is very good and almost always better than other lakes that are of a similar lake type and much better than lakes that are in the North Central Lakes and Forests ecoregion (NCHF). The median phosphorus concentration for lakes in the NCHF is 52 µg/L while the Chain-wide average is 13.5 µg/L. All of the lakes have phosphorus concentrations which are less than the median value for other lakes throughout the state of a similar lake type with the exception of Otter Lake, which is the same as other deep, headwater drainage lakes at 17 µg/L. The lake with the highest phosphorus concentration is Ottman Lake which is a shallow lake. These types of lakes tend to have higher concentrations because of their smaller lake volume in relation to their size. Of the deep lakes, Pope Lake has the highest phosphorus level at 19 µg/L, but this is less than the median for other lakes of a similar type.

The algal levels in the lakes, which are represented by chlorophyll-*a*, are also lower than the median value of other lakes of a similar lake type. The exception to this is Pope Lake, which experienced a higher algal concentration in August 2016 that elevated the summer average to 10.5 µg/L. The August value was much higher than levels recorded in June and July, and likely is the result of algae growing in the metalimnion and being entrained in the upper waters. Pope Lake, like many of the lakes in the Waupaca Chain O' Lakes, experiences a metalimnetic oxygen maxima. This is the result of elevated algal levels in the metalimnion. In clear water lakes such as those in the Chain, the relatively clear upper waters allow sufficient light to penetrate into the mid-depths where nutrient levels are higher and thus more algae grow.

The Waupaca Chain O' Lakes experiences very good water clarity because of its low nutrient levels supporting low algal growth. The Chain-wide average water clarity was 10.1 feet which is considerably better than the median value for lakes in the NCHF ecoregion of 5.3 feet. The lakes with the best water clarity tended to be deep lakes, although Youngs Lake, which is classified as a shallow lake, had excellent water clarity at 11.8 feet. The lake with the greatest water clarity was Beasley Lake where the summer average was 20.9 feet. Lake Orlando has the next best water clarity at 16.5 feet. Other lakes with excellent water clarity were Knight, Long, Manomin, Marl, and Miner lakes.

The three trophic parameters discussed above are used to determine a lake's trophic status using the Carlson Trophic State. All of the lakes are either oligotrophic or mesotrophic. This means the Chain lakes are low to moderately productive.

In general, very few lakes have water quality data that has been collected for more than a few years. Changes that may have occurred in water quality over the years can be estimated by collecting sediment cores and using fossil algae to determine historical phosphorus concentrations. This has been done in Marl and Youngs lakes as part of the U.S. EPA National Lake Assessments of 2007 and 2012. The analysis indicated that present day phosphorus concentrations in Youngs Lake are similar to what they were over 100 years ago. In deep Marl Lake, present phosphorus concentrations are low at 10 µg/L, but prior to the arrival of Euro-Americans the concentrations were about 3-4 µg/L. This suggests that even though present-day phosphorus levels in the deep lakes of the Waupaca Chain O' Lakes are low, historically they were even lower. Part of the reason for the relatively low phosphorus levels at the present time is the high calcium concentration in the lakes. This is the result of the surrounding geology. Marl lakes, like the Chain lakes, have good water clarity and often the color of the water is blue. The high calcium levels bind with phosphorus and settle to the lake bottom making the phosphorus unavailable for algal growth. If enough phosphorus enters the lake over time, the cleansing ability of the calcium is overwhelmed and the lake experiences algal blooms. An example of this is Lake Mendota in Madison, which is also calcium-rich and historically had much clearer water than it does at the present time.

As mentioned previously, many of the deep lakes in the Chain experience the highest dissolved oxygen concentrations in the metalimnion. In part, this reflects the good water clarity experienced in these lakes, which allows sufficient light to reach the metalimnion for algal growth. Dissolved oxygen and temperature profiles were collected during the summer in Rainbow and Round lakes during three years in the 1970s, as well as part of this study. In 2016 metalimnetic oxygen levels are higher than the 1970s suggesting that nutrient levels are higher at the present time.

The Waupaca Chain O' Lakes was divided into four subwatersheds for the watershed modeling analysis. The subwatersheds are: Upper Chain and Southwest Lower Chain, Northeast Lower Chain, Mid Lower Chain, and East Lower Chain. The two major tributaries, Hartman and Emmons creeks enter the Chain in the Upper Chain and Southwest Lower Chain subwatershed. The model utilized for the Chain watershed analysis was originally developed using lakes that do not receive as much groundwater as the Chain lakes. To account for the increased groundwater inputs, the model was calibrated by comparing flows and phosphorus concentrations measured in Hartman and Emmons creeks to the unmodified model output. Using the correction factors developed from Hartman Creek, the modeled phosphorus loading in the other three subwatersheds was reduced appropriately.

As would be expected, the subwatershed with the greatest phosphorus loading was the Upper Chain and Southwest Lower Chain because of the creek flow described above. The subwatershed with the second highest phosphorus loading was the Northeast Chain which contains the largest number of lakes. With the exception of the subwatershed where the major tributaries enter, the single largest source of phosphorus was atmospheric input onto the lake surfaces. In many of the lakes, runoff from shoreland development was an important source of phosphorus and undoubtedly phosphorus loading is higher at the present time compared with prior to the arrival of Euro-Americans.

5.0 IMPLEMENTATION PLAN

The Implementation Plan presented below was created through the collaborative efforts of the WCOLD Planning Committee and ecologist/planners from Onterra. It represents the path the WCOLD will follow in order to meet its 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 Waupaca Chain stakeholders as portrayed by the members of the Planning Committee, stakeholder survey, and numerous communications between Planning Committee members and the Chain stakeholders. The Implementation Plan is a living document in that it will be under constant review and adjustment depending on the condition of the lakes, the availability of funds, level of volunteer involvement, and the needs of the stakeholders.

Please note: An Aquatic Invasive Species Control and Monitoring Plan was completed at an accelerated timeline in order for a draft to be created and submitted to the WDNR by December 1, 2016. The draft was submitted prior to the deadline which made the WCOLD eligible to apply for AIS-Established Population Control (AIS-EPC) Grant funds by the February 1, 2017 deadline. The grant application was successful and all actions described in the draft Aquatic Invasive Species Control and Monitoring Plan have been implemented. The management goal and actions are included in their entirety in Appendix G. Progress and results of those actions, along with appropriate refinements to them, can be found in the annual reports completed as a part of AIS-EPC Grant project also included Appendix G.

Management Goal 1: Manage Aquatic Invasive Species in the Waupaca Chain O' Lakes

Management Action:	Control and Contain HWM Populations within the Waupaca Chain O' Lakes
Timeframe:	Continuation of current effort
Facilitator:	Waupaca Chain O' Lakes District Board of Commissioners
Description:	Building on the knowledge obtained over the course of the past several years of active AIS management in the Chain as a part of the three-year AIS-EPC Grant project, a greater understanding of the anticipated efficacy of different management techniques has been developed. Also during this same timeframe, a better understanding of the WCOLD's tolerance of HWM in the Chain has been developed. Table 5.0-1 outlines the management strategy criteria and the anticipated efficacy for an invasive watermilfoil population suppression program on the Chain. Please note that these criteria are generalized, but these criteria will be used as a starting point for an active management discussion. The table outlines the herbicide or hand-harvesting management strategies that would be expected to achieve various levels of efficacy spanning a timeframe from a less than seasonal to multiple years. In the table, seasonal control refers to approximately the period of time during the open-water growing season during which the majority of the recreational activities typically occur on the Chain.

The whole-lake treatments that occurred in Dake, Miner, Otter, Bass, and Beasley lakes in 2017-2018 attempted to achieve multiple year efficacy. Sufficient herbicide concentrations and exposure times (CETs) were achieved in Dake, Miner, and Otter lakes, whereas the influence of water exchange in Bass and Beasley was too great to achieve appropriate CETs for milfoil control. This suggests that Long Lake would also have difficulty reaching desired CETs with herbicide flushing down the Crystal River outlet. Future whole-lake treatments may be applicable to other protected lakes in the Chain and can be investigated for applicability if HWM populations reach levels where the financial and environmental costs of implementation are commensurate with the desired level of HWM population reduction.

Many of the herbicide spot treatments completed since 2017 have been limited to seasonal or less than seasonal HWM reductions. The largest factor limiting greater control is the small size of the treatment areas. Onterra's experience, along with ongoing studies, are suggesting that with small spot treatments, with a working definition of less than 5 acres, the herbicide dissipates too rapidly to cause HWM mortality if traditional systemic herbicides like 2,4-D are used. Even in some cases where larger treatment areas are planned, their narrow shape or exposed location within a lake may result in insufficient herbicide concentrations and exposure times for long-term control. Spot herbicide treatments will likely need to embrace herbicides or herbicide combinations found to be more effective under short exposure situations than with traditional weak-acid auxin herbicides, such as 2,4-D. Herbicide manufacturers have acknowledged the lack of successes conducting invasive watermilfoil spot treatments and are working towards new solutions. As new herbicide products become available, proper testing and vetting should occur before wide-scale acceptance on a given system. Table 5.0-1 outlines the predicted level of HWM suppression based upon specific site characteristics for herbicide spot treatments and the WCOLD will consider these limitations in developing future spot treatment strategies with their chosen applicator.

Hand-harvesting in the Chain has resulted in HWM population suppression; however, the length of population reduction has been shorter than desired especially considering the cost of implementation. If HWM occurrences were located in the Upper Chain, swift implementation of a sufficient effort of hand-harvesting (including DASH) may lead to multiple years of control. Follow-up hand-harvesting of rebounding HWM following a whole-lake treatment would also fall into this category, as was utilized on Dake, Miner, and Otter lakes as a part of the 2017-2019 AIS-EPC project. But when targeting established HWM populations, as exist in much of the remainder of the Chain, achieving seasonal or slightly longer control is the goal. This level of HWM suppression provides seasonal relief for riparians and may be an important component of future management on the Chain. While the cost of implementation is higher to achieve seasonal HWM suppression with hand-harvesting versus herbicide treatment, non-chemical methods are typically favored by lake managers and regulators as the risks are essentially zero.

On some lakes, a coordinated HWM population suppression program is not achievable considering the current lake management tools. For instance, the only way to target the entirety of the HWM population in Long Lake would be with a whole-lake treatment, but the results of the trials on Bass and Beasley lakes indicate that even with a combination of 2,4-D/endothall, achieving CETs to result in multiple years of control is not possible. Spot herbicide techniques may be applicable, but the narrow HWM bands will require a short CET requirement herbicide (e.g. diquat, diquat/endothall) to be implemented. These broad-spectrum herbicides have associated native plant impacts and are not advisable to target the entire littoral zone of a lake. Therefore, subjective selection of where to implement herbicide spot treatments in a scenario like Long Lake becomes more of nuisance control strategy. The strategy could result in seasonal HWM suppression that would alleviate the unwanted conditions in riparian corridors. The use of a mechanical harvester could also provide some level of seasonal control without the associated risks of herbicide treatment.

Integrated Pest Management Strategy: Whole-Lake Treatments

Whole-lake strategies to control invasive watermilfoils are often more predictable than spot treatments if implemented correctly. To correctly implement a whole-lake strategy, many factors must be considered, such as the current level of infestation, lake volume, flow, stratification, appropriate herbicide, and impacts to non-target species. As described above, whole-lake strategies used on Bass and Beasley lakes did not meet expectations likely due to high flows. This leads to the conclusion that Long Lake would not be a good candidate for a whole-lake treatment for the same reason. Whole-lake control strategies may be applicable on the other lakes in the Chain if the factors described above are fully considered. In general, the WCOLD will consider a whole-lake strategy in applicable lakes when HWM littoral frequency of occurrence reaches or exceeds 10%.

Integrated Pest Management Strategy Following Whole-Lake Treatments

As a part of an Integrated Pest Management strategy following the AIS-EPC project, and in an effort to prolong the gains that were made following the whole-lake treatments, areas within Dake, Miner, and Otter lakes may be considered for follow-up control activities, including herbicide spot treatments and/or hand-harvesting. As of 2019, no areas in Dake Lake or Miner Lake contain sufficient HWM densities to warrant an herbicide spot treatment; however, a hand-harvesting management strategy is appropriate to target the current population. Any HWM occurrences that are mapped as a *clump of plants* or larger in a late-summer mapping survey would be considered in a hand-harvesting strategy. The same strategy is appropriate for Otter Lake and in the years following whole-lake treatments in other Chain lakes in the future.

Integrated Pest Management Strategy: Spot Herbicide Treatments

As mentioned above, the majority of the spot treatments in 2017-2019 in the Chain led to seasonal HWM control rather than multi-year control. Further, the spot treatments in 2018 yielded no better results with Aquastrike® (diquat/endothall) than the 2017 diquat spot treatment. These results should be considered each year as the WCOLD formulates their strategy for the following season.

As outlined in Table 5.0-1, special scenarios where spot treatment sites are almost completely enclosed or protected from water movement and are of a larger and broader size or shape are the most likely to result in extended years of HWM control. Colonies that are mapped with area-based methodologies and are of at least a *dominant* or greater density meet the criteria for considering herbicide treatment. These treatment areas may also include adjacent occurrences of HWM for which at least a one-acre application area can be constructed with a reasonably sized buffer. Based on Table 5.0-1, the expected efficacy of these treatments would be seasonal control in most cases due to either size, location, or shape of the sites. For somewhat more protected sites, is it is reasonable to anticipate that a spot treatment may lead to control that extends beyond a single growing season (greater than seasonal efficacy).

A contact herbicide such as diquat could be considered for herbicide spot treatment of these areas. Commonly used brands of diquat have a 2 gallon/surface acre maximum application rate. When mixed with the water volume in deeper sites (approximately greater than 5 feet), the concentrations may be lower than needed to provide the desired level of impact. In these instances, herbicide applicators may consider the addition of a low dose of copper. Another option often considered is to couple diquat with endothall under the commercially available Aquastrike® herbicide. When this product received EPA registration, it configured the use-rates volumetrically. This allows diquat to reach the target concentration in all water depths coupled with endothall which has activity on invasive watermilfoils. As previously discussed, Aquastrike® has been used in recent years on the Waupaca Chain, whereas the combination of diquat and copper would be a newer approach to HWM management on the Chain.

In lakes with large HWM populations that may be impractical to target on a lake-wide basis, as discussed in the previous section, the WCOLD could support a strategy to improve the navigability within these lakes. This would be accomplished by designing common-use navigation lanes through HWM colonies that would be managed through herbicide spot treatments, mechanical harvesting, or professional hand-harvesting. The WCOLD would consider one of these forms of seasonal management for Beasley,

	Long, and other lakes if the strategy aligns with best management practices that are supported by professional lake managers. **Integrated Pest Management Strategy: Professional and/or Volunteer Hand-Harvesting** Much of the HWM population present in the Chain consists of isolated occurrences of relatively *small colonies* or *clumps of plants* that to do not meet the threshold for considering herbicide control as outlined above. However, the majority of these sites may be favorable for hand harvesting control efforts. Generally clear water coupled with modest native plant populations in many parts of the Chain make hand-harvesting a feasible control technique with a goal of achieving greater than seasonal control. In 2018 and 2019, the WCOLD selected a few high-use areas to implement this strategy when herbicide spot treatments were not likely to be effective. It is important to understand that each riparian owner can legally harvest HWM and native plant species in a 30' wide area of one's frontage directly adjacent to one's pier without a permit. A permit is required if an area larger than the 30' corridor is being harvested and that harvesting includes native species or if a mechanical assistance mechanism, like DASH, is being used. Professional services to remove HWM also do not require a permit unless DASH or a mechanical device is being used in the process. Simply wading into the lake and removing HWM by hand with or without the aid of snorkeling accessories can be helpful in managing HWM on a small and individual property-based scale. The WCOLD explored whether alleviating nuisance conditions in riparian zones would be feasible to implement for the entire Chain at the District's expense. The District ultimately determined not to pursue this idea due to the overwhelming increase in taxes, costs, and administrative time that would be associated with implementing this activity.
Action Steps:	
	See description above

Table 5.0-1. Invasive Milfoil Management Strategy Criteria and Anticipated Efficacy on Waupaca Chain O' Lakes

		Efficacy	**Herbicide**	**Hand-Harvesting**
Population Suppression	**Multi-Year**	**Multiple Year**	• Properly dosed whole-lake treatment with no flow impacts	• Early infestations • Extremely small populations
		>Seasonal	• Broad-shaped spot treatments with no flow impacts • 5 acres or greater in open water • 4 acres & protected on two sides • 1 acre & enclosed on three sides(bay)	• Typically the goal, but seldom achievable
	Single Year	**Seasonal**	• Broad-shaped spot treatments with no flow impacts • 3 acres in open water • 2 acres & protected on two sides	• Achievable on small sites (< ½ acre) with sufficient effort applied
		<Seasonal	• All herbicide treatments not meeting above criteria	• Not worth the cost of implementation

Management Action:	Investigate and Study Alternative Management Methodologies
Timeframe:	Continuous
Facilitator:	Waupaca Chain O' Lakes District Board of Commissioners
Description:	The WCOLD understand that management of HWM will be a long-term part of the management of the Chain. The WCOLD would like to be on the front edge of Best Management Practices for controlling HWM/EWM. What constitutes a Best Management Practice (BMP) changes in time as science and adaptive management progresses through science. For instance, small spot-treatments using 2,4-D was once the BMP for controlling HWM/EWM in Wisconsin waters. Science and monitoring has determined that these treatments rarely meet their target concentrations and are unpredictable on their effectiveness. National and regional aquatic plant management industries and trade associations have partnered with scientists (academia and government) to better understand control actions, their benefits and risks, and applicability. The WCOLD would continue to be updated on the management efforts being conducted in surrounding states as well as the nation when it pertains to invasive milfoil management. This would include, but not be limited to, new herbicide use-patterns and their potential environmental and human toxicological profile. Other emerging technologies may include non-herbicide options.
Action Steps:	
	See description above

Management Action:	Monitor CLP population within the Waupaca Chain O' Lakes
Timeframe:	Continuation of current effort
Facilitator:	Waupaca Chain O' Lakes District Board of Commissioners
Description:	As discussed in the Aquatic Plant Section (3.4), CLP is present throughout the entire Waupaca Chain O' Lakes (including the Upper Chain). This invasive species can cause great ecological and recreational impacts on some lakes. But in other lakes, the CLP population remains low and does not cause these impacts. At these low levels, there are likely no observable ecological impacts to the Chain and are no reductions in ecosystem services to lake users. Conducting CLP surveys every 3-5 years would allow the WCOLD to understand the CLP population dynamics within the system. A lake-wide assessment of curly-leaf pondweed will be completed during the June 2019 ESAIS survey while the plant is at its peak growth stage for the year. Comparing this survey with the one conducted in June 2016 will indicate if population expansion is occurring and if directed active management techniques should be explored.
Action Steps:	
	See description above

Management Action:	Continue Clean Boats Clean Waters (CBCW) watercraft inspections at Waupaca Chain O' Lakes public access location
Timeframe:	Continuation of current effort
Facilitator:	Waupaca Chain O' Lakes District Board of Commissioners
Description:	Currently, the WCOLD works in conjunction with Golden Sands Resource Conservation & Development Council to conduct boat inspections and distribute education to lake users at the public landings around the Chain. Since 2010, an average of over 200 hours of watercraft inspections have been conducted on the Waupaca Chain O' Lakes, the overwhelming majority occurring on Taylor Lake. The WCOLD has set a goal of 200 hours of watercraft inspections per year through a combination of paid and volunteer efforts. Projects that include this level of CBCW inspections receive priority funding within the WDNR's AIS Control Grant Program [NR198.22(1)(d)].
Action Steps:	
	See description above as this is an established program.

Management Action:	Coordinate Periodic Quantitative Vegetation Monitoring
Timeframe:	Point-Intercept Survey every 3-5 years, Community Mapping every 7-8 years
Facilitator:	Waupaca Chain O' Lakes District Board of Commissioners
Description:	Unless the WCOLD is conducting management actions at a lake-wide scale (e.g. large-scale herbicide treatments), conducting Chain-wide vegetation monitoring through a point-intercept survey would be conducted at a minimum of once every 5 years. This will allow an understanding of the submergent aquatic plant community dynamics within the Chain. Building this dataset over time will assist in understanding natural and unnatural population dynamics. Chain-wide point-intercept surveys were completed in 2019 as a part of the AIS-EPC project; therefore, the surveys should be repeated in 2024. In order to understand the dynamics of the emergent and floating-leaf aquatic plant communities in the Chain, a community mapping survey would be conducted every 8-10 years. The community mapping survey conducted on the Chain in 2016 serves as a comparative for future replicated surveys. This effort is typically conducted as part of each future lake management planning project update.
Action Steps:	
	See description above

Management Goal 2: Maintain Current Water Quality Conditions

Management Action:	Monitor water quality through WDNR Citizens Lake Monitoring Network.
Timeframe:	Continuation of current effort.
Facilitator:	Waupaca Chain O' Lakes District Board of Commissioners
Description:	Monitoring water quality is an important aspect of every lake management planning activity. Collection of water quality data at regular intervals aids in the management of each lake, and the Chain as a whole, by building a database that can be used for long-term trend analysis. Early discovery of negative trends may lead to the reason of why the trend is occurring. The CLMN is a WDNR program in which volunteers are trained to collect water quality information on their lake. The WCOLD would seek enrollment into this program, with a goal of collecting Secchi disk readings in each lake as a part of this program. In larger lakes with volunteer commitment, the WCOLD would investigate enrolling in the advanced CLMN program where water chemistry samples would also be collected (chlorophyll-*a*, and total phosphorus). Samples would be collected three times during the summer and once during the spring. Ted Johnson (920.424.2104) or the appropriate WDNR/UW Extension staff should be contacted to enroll in this program and to ensure the proper training occurs and the necessary sampling materials are received. 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 the Surface Water Integrated Monitoring System (SWIMS) by the volunteer.
Action Steps:	
1.	Trained CLMN volunteer(s) collects data and report results to WDNR and to District members during annual meeting.
2.	CLMN volunteer and/or WCOLD Board of Directors would facilitate new volunteer(s) as needed
3.	Coordinator contacts Ted Johnson to acquire necessary materials and training for new volunteer (s)

Management Goal 3: Increase WCOLD's Capacity to Communicate with Lake Stakeholders and Facilitate Partnerships with Other Management Entities

Management Action:	Use education to promote lake protection and enjoyment through stakeholder education
Timeframe:	Continuation of current efforts
Facilitator:	Waupaca Chain O' Lakes District Board of Commissioners
Description:	Education represents an effective tool to address many lake issues. The WCOLD maintains a website (www.waupacachainolakesdistrict.com) The WCOLD will continue to make the education of lake-related issues a priority. The WCOLD will give consideration to forming an Education Committee or Director to connect to stakeholders. These may include educational materials, awareness events, and demonstrations for lake users as well as activities which solicit local and state government support. The WCOLD will work with UW-Extension Lakes staff (Pat Goggin: Patrick.Goggin@wisconsin.gov) to use stock articles as appropriate to lessen the workload and ensure the messaging is accurate. *www.uwsp.edu/cnr-ap/UWEXLakes* *Example Educational Topics* • Aquatic invasive species identification • Basic lake ecology • Sedimentation • Boating safety (promote existing guidelines and ordinances) • Swimmers Itch • Shoreline habitat restoration and protection • Fireworks impact to the lake • Fishing regulations and overfishing • Minimization of disturbance to spawning fish.
Action Steps:	
	See description above as this is an established program.

Management Action:	Continue WCOLD's involvement with other entities that have responsibilities in managing (management units) the Chain.
Timeframe:	Continuation of current efforts
Facilitator:	Waupaca Chain O' Lakes District Board of Commissioners
Description:	The WCOLD was formed in 1991. It is an independent governmental body that can levy taxes, enter into contracts, obtain loans, accept grants and state aid, monitor water quality and treat aquatic plants. The reconstruction of the channel between Columbia and Dake Lakes was

	the Lake District's first major project. With the aid of a DNR grant, the second major project was the purchase and demolition of the motel across from the Indian Crossing Casino. The land was donated to the Waupaca County Park system. The Lake District has applied for and received DNR grants for Aquatic Invasive Species education and treatment and will continue to apply for additional DNR grants for lake projects. The waters of Wisconsin belong to everyone and therefore this goal of protecting and enhancing these shared resources is also held by other entities. Some of these entities are governmental while others organizations rely on voluntary participation. It is important that the WCOLD actively engage with all management entities to enhance the District's understanding of common management goals and to participate in the development of those goals. This also helps all management entities understand the actions that others are taking to reduce the duplication of efforts. Each entity will be specifically addressed in the table on the next page:
Action Steps:	
	See table guidelines on the next pages.

Partner	Contact Person	Role	Contact Frequency	Contact Basis
Waupaca Chain O'Lakes Association	President or Executive Secretary- chainolakesassociation@gmail.com	Non-government body for the Chain.	Check website (waupacachainolakesassociation.com) for updates.	Representation at annual meeting as well as periodic coordination
Towns of Farmington & Dayton	Farmington Town Clerk (715.258.2779) Dayton Town Clerk (715.258.0930)	The Chain falls within these townships.	Once a year or more as issues arise.	Town staff may be contacted regarding ordinance reviews or questions, and for information on community events.
Waupaca County	Sheriff/Water Patrol (715) 258-4466)	Patrols the Chain during the summer.	As needed.	The Water Patrol serves a valuable role in promoting safety on the Chain.
Golden Sands Resource Conservation & Development Council	Staff (715.343.6215)	Nonprofit organization that covers central WI. Provides CBCW inspector training.	Once a year or more as issues arise.	Provide information on conservation and natural resource preservation
Waupaca County Land Conservation Department/Committee	County Conservationist (Brian Haase - Brian.Haase@co.waupaca.wi.us)	Oversees conservation efforts for land and water projects.	Continuous as it relates to lake and watershed activities	Can provide assistance with shoreland restorations and habitat improvements
Wisconsin Department of Natural Resources	Fisheries Biologist (Jason Breeggemann – 920.420.4619)	Manages the fishery of the chain.	Once a year or more as issues arise.	Stocking activities, scheduled surveys, survey results, volunteer opportunities for improving fishery and fish structure
	Lakes Coordinator (Ted Johnson – 920.424.2104)	Oversees management plans, grants, all lake activities.	Continuous as it relates to lake management activities	Information on updating a lake management plan (every 5 years) or to seek advice on other lake issues including AIS management.
	Citizens Lake Monitoring Network contact (Sandra Wickman – 715.365.8951)	Provides training and assistance on CLMN monitoring, methods, and data entry.	Twice a year or more as needed.	<u>Early spring</u>: Arrange for training as needed, in addition to planning out monitoring for the open water season. <u>Late fall</u>: Report monitoring activities.
Wisconsin Lakes	General staff (800.542.5253)	Facilitates education, networking and assistance on all matters involving WI lakes.	As needed. May check website (www.wisconsinlakes.org) often for updates.	WCOLD members may attend WL's annual conference to keep up-to-date on lake issues. WL reps can assist on grant issues, AIS training, habitat enhancement techniques, etc.

Management Goal 4: Maintain and Improve Lake Resource of the Waupaca Chain O'Lakes

Management Action:	Educate Stakeholders on the Importance of Shoreland Condition and Shoreland Restoration
Timeframe:	Ongoing effort
Facilitator:	Waupaca Chain O' Lakes District Board of Commissioners

Description:	As discussed in the Shoreland Condition Section (3.3), the shoreland zone of a lake is highly important to the ecology of a lake. When shorelands are developed, the resulting impacts on a lake range from a loss of biological diversity to impaired water quality. Because of its proximity to the waters of the lake, even small disturbances to a natural shoreland area can produce ill effects.
	
	While producing a completely natural shoreland is ideal for a lake ecosystem, it is not always practical from a human's perspective. The WCOLD will continue to educate District members on what steps can be taken in ensuring their property's impact upon the lake is minimal.
	
	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 Waupaca County.
	
	• 75% state share grant with maximum award of $25,000; up to 10% state share for technical assistance
	• Shoreline Restoration Projects
	  ○ 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
	• Course Woody Habitat Projects (aka "fish sticks")
	  ○ 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 • Additional funding opportunities for water diversion projects and rain gardens (maximum of $1,000 per practice) also available
Action Steps:	
	See description above

Management Action:	Protect natural shoreland zones around the chain
Timeframe:	Ongoing effort
Facilitator:	Waupaca Chain O' Lakes District Board of Commissioners
Description:	Approximately 61% and 14% of the areas surveyed in the Upper Chain and Lower Chain are composed of completely natural shorelands, respectively. The WCOLD will work with appropriate entities to research grant programs and other pertinent information that will aid the WCOLD in preserving the Chain's shoreland. This would be accomplished through education of property owners or direct preservation of land through implementation of conservation easements or land trusts of which the property owner would approve. Valuable resources for this type of conservation work include the WDNR, UW-Extension, and Waupaca County Land and Water Conservation Department. Several websites of interest include: • Wisconsin Lakes website: (www.wisconsinlakes.org/shorelands) • Conservation easements or land trusts: (http://www.northwoodslandtrusts.org/) • UW-Extension Shoreland Restoration: (www.uwex.edu/ces/shoreland/Why1/whyres.htm) • WDNR Shoreland Zoning website: (http://dnr.wi.gov/topic/ShorelandZoning/)
Action Steps:	
1.	Recruit facilitator (potentially same facilitator as previous management action).
2.	Facilitator gathers appropriate information from sources described above.

6.0 METHODS

Lake Water Quality

Baseline water quality conditions were studied to assist in identifying potential water quality problems in the Waupaca Chain O' Lakes (e.g., elevated phosphorus levels, anaerobic conditions, etc.). Water quality was monitored at the deepest point in each of the lakes that would most accurately depict the conditions of the lake (Map 1). Samples were collected with a 3-liter Van Dorn bottle at the subsurface (S) and near bottom (B). Sampling occurred once in spring, fall, and winter and three times during summer for Long Lake, Miner Lake, Pope Lake, and Rainbow Lake. The other 18 lakes were sampled only during July. Bass Lake was only sampled at the subsurface due to the depth of the lake. Samples were kept cool and preserved with acid following standard protocols. All samples were shipped to the Wisconsin State Laboratory of Hygiene for analysis. The parameters measured included the following:

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

In addition, during each sampling event Secchi disk transparency was recorded and a temperature, pH, and dissolved oxygen profile was completed using a Hach LDO probe.

Watershed Analysis

The watershed analysis began with an accurate delineation of the Waupaca Chain O' Lakes' 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

Early-Season AIS Survey

The Early-Season AIS (ESAIS) survey occurs in mid-June to early-July of each year, when clear water and minimal native plant growth allows for better viewing of AIS. CLP and pale yellow iris are at their peak growth during this time. Visual inspections were completed throughout the Chain by completing a meander survey by boat.

Point-Intercept Survey

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.

Community Mapping

During the species inventory work, the aquatic vegetation community types within the Waupaca Chain (emergent and floating-leaved vegetation) were mapped using a Trimble 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 each lake within the Chain.

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