Crystal Lake

Marquette County, Wisconsin

Comprehensive Management Plan

July 2020

Sponsored by:

Crystal Lake Club

Marquette County

WDNR Grant Program

LPL-1673-18

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Onterra, LLC
Lake Management Planning

Crystal Lake

Marquette County, Wisconsin

Comprehensive Management Plan

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

Crystal Lake Planning Committee

Jim Audiss	Craig Beske	John Church
Tim Clay	Nancy Collopy	Mike Fisher
John Livermore	Sandy Livermore	

Organization

Crystal Lake Club

Wisconsin Dept. of Natural Resources

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1.0 INTRODUCTION

Crystal Lake, Marquette County, is a deep headwater spring-fed drainage lake with a maximum depth of 60 feet and a mean depth of 27 feet. The WDNR website lists Crystal Lake as 119 acres. At the time of this report, the most current orthophoto (aerial photograph) was from the *National Agriculture Imagery Program* (NAIP) collected in 2017. Based on heads-up digitizing of the water level from that photo, the lake was determined to be 123.3 acres. This oligotrophic lake has a relatively small watershed when compared to the size of the lake. A minimally developed public carry-in access managed by Marquette County is located on the northwest side of the lake. Although not actually a plant, but a type of macroalgae, muskgrasses have consistently been the most abundant species found in Crystal Lake. Two exotic plant species are known to exist in Crystal Lake or along its shores.

Field Survey Notes

Field crews enjoyed the serenity of Crystal Lake with its quiet and peaceful setting surrounded by large trees, numerous turtles, and minimal boat traffic. The lake's clear and cool water were a welcome relief while taking a break from completing aquatic plant surveys on a hot summer day.

Photograph 1.0-1 Crystal Lake, Marquette County

Lake at a Glance - Crystal Lake

Morphology	
Acreage	123
Maximum Depth (ft)	60
Mean Depth (ft)	27
Shoreline Complexity	1.7
Vegetation	
Early-season AIS Survey Date	June 21, 2018
Comprehensive Survey Date	July 31, 2018
Number of Native Species (2018)	17
Threatened/Special Concern Species	-
Exotic Plant Species	Hybrid and Eurasian watermilfoil, reed canary grass
Simpson's Diversity	0.69
Average Conservatism	6.0
Water Quality	
Trophic State	Oligotrophic
Limiting Nutrient	Phosphorus
Water Acidity (pH)	8.72
Sensitivity to Acid Rain	Not sensitive
Watershed to Lake Area Ratio	2:1

The Crystal Lake Club (CLC) was incorporated in 1927. The CLC is the primary management unit for Crystal Lake and has partnered with Marquette County to complete this management planning project. According to the Club's website, "The business and purpose of the Club is the promotion and encouragement of hunting and fishing, the promotion and practice of land conservation, forestry and selective tree farming, the encouragement of the game of golf and other lawful games and sports" (http://www.clc1927.org/info.php?pnum=2).

2.0 STAKEHOLDER PARTICIPATION

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

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

General Public Meetings

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

Kick-off Meeting

On June 9, 2018, a project kick-off meeting was held to introduce the project to the general public. The meeting was announced through a mailing and personal contact by board members. The approximately 50 attendees observed a presentation given by Todd Hanke and Tim Hoyman, aquatic ecologists with Onterra. Onterra's presentation started with an educational component regarding general lake ecology and ended with a detailed description of the project including opportunities for stakeholders to be involved. The presentation was followed by a question and answer session.

Project Wrap-up Meeting

A project wrap-up meeting was completed on August 8, 2020 through an online virtual platform. During the meeting, Onterra discussed the results of the project including the details of the Implementation Plan and addressed questions and comments put forth by the attendees.

Committee Level Meetings

Planning committee meetings, similar to general public meetings, were used to gather comments, create management goals and actions and to deliver study results. These two meetings were open only to the planning committee and were held during the week. The first, following the completion of the draft report sections of the management plan. The planning committee members were supplied with the draft report sections prior to the meeting and much of the meeting time was utilized to detail the results, discuss the conclusions and initial recommendations, and answer committee questions. The objective of the first meeting was to fortify a solid understanding of their lake among the committee members. The second planning committee meeting was held a few weeks after the first and concentrated on the development of management goals and actions that make up the framework of the implementation plan.

Planning Committee Meeting I

On June 17, 2019, Tim Hoyman and Todd Hanke of Onterra met with seven members of the Crystal Lake Planning Committee for nearly five hours. In advance of the meeting, attendees were provided an early draft of the study report sections to facilitate better discussion. The primary focus of this meeting was the delivery of the study results and conclusions to the committee. All study components including aquatic plant inventories, water quality analysis, and watershed modeling were presented and discussed. Many questions were raised by the committee, with water quality and aquatic plants being of particular interest.

Planning Committee Meeting II

On July 8, 2019, Tim Hoyman and Todd Hanke met for nearly five hours with the members of the Planning Committee to discuss the project and begin developing management goals and actions for the Crystal Lake management plan. Planning Committee members provided ideas, opinions, thoughts, and a list of challenges facing the CLC for discussion at the meeting.

Stakeholder Survey

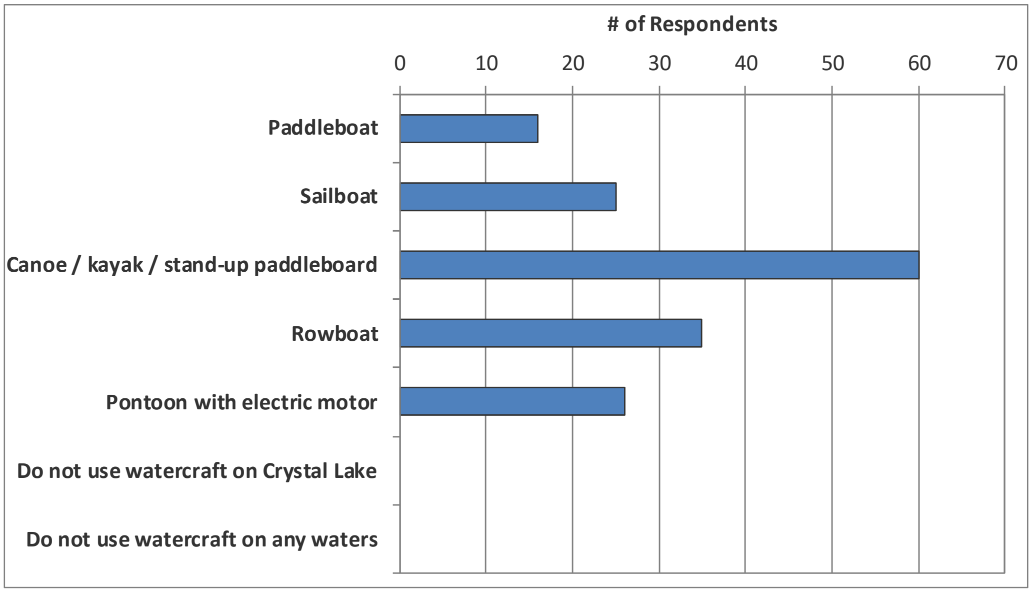
As a part of this project, a stakeholder survey was distributed to riparian property owners/lake group members around Crystal Lake. The survey was designed by Onterra staff and the Crystal Lake planning committee and reviewed by a WDNR social scientist. During September 2018, the eight-page, 27-question survey was posted online through Survey Monkey for property owners to answer electronically. If requested, a hard copy was sent to the property owner with a self-addressed stamped envelope for returning the survey anonymously. The returned hardcopy surveys were entered into the online version for analysis. Eighty-six percent of the surveys were returned. A benchmark of a 60% response rate is required to portray population projections accurately and make conclusions with statistical validity. The response rate for Crystal Lake exceeds this. 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 Crystal Lake. Forty-five percent of survey respondents indicated they utilize their property on Crystal Lake as a year-round vacation home, while 24% live on the lake year-round, 15% use it as a seasonal vacation home, 11% use it for a seasonal residence, and 5% use it as a summer-only residence. Sixty-nine percent of stakeholders 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 with respect these particular topics. Figures 2.0-1 and 2.0-2 highlight several other questions found within this survey. Ninety-five percent of survey respondents indicated that they use either a canoe, kayak, or stand-up paddleboard on Crystal Lake. Fifty-six percent use a rowboat, 41% use a pontoon with electric motor, 40% use a sailboat, and 25% use a paddleboat (Question 9). On a relatively small lake such as Crystal Lake, the importance of responsible boating activities is increased. The need for responsible boating increases during weekends, holidays, and during times of nice weather or good fishing conditions as well, due to increased traffic on the lake.

Two concerns of stakeholders that were noted throughout the stakeholder survey (see Question 23 and survey comments – Appendix B) were water quality and overabundant aquatic plant growth within Crystal Lake. These topics are touched upon in the Summary & Conclusions section as well as within the Implementation Plan.

Question 9: What types of watercraft do you currently use on Crystal Lake?



Question 12: Please rank up to three activities that are important reasons for owning your property on Crystal Lake.

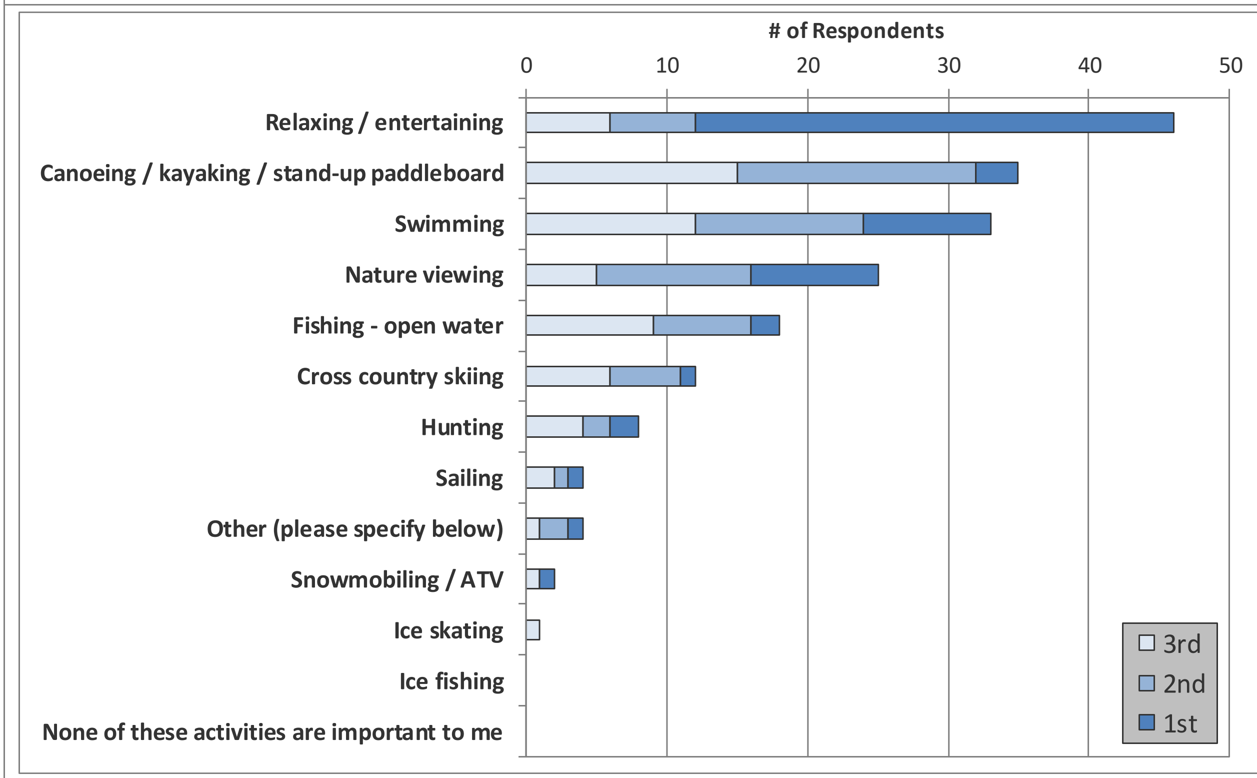
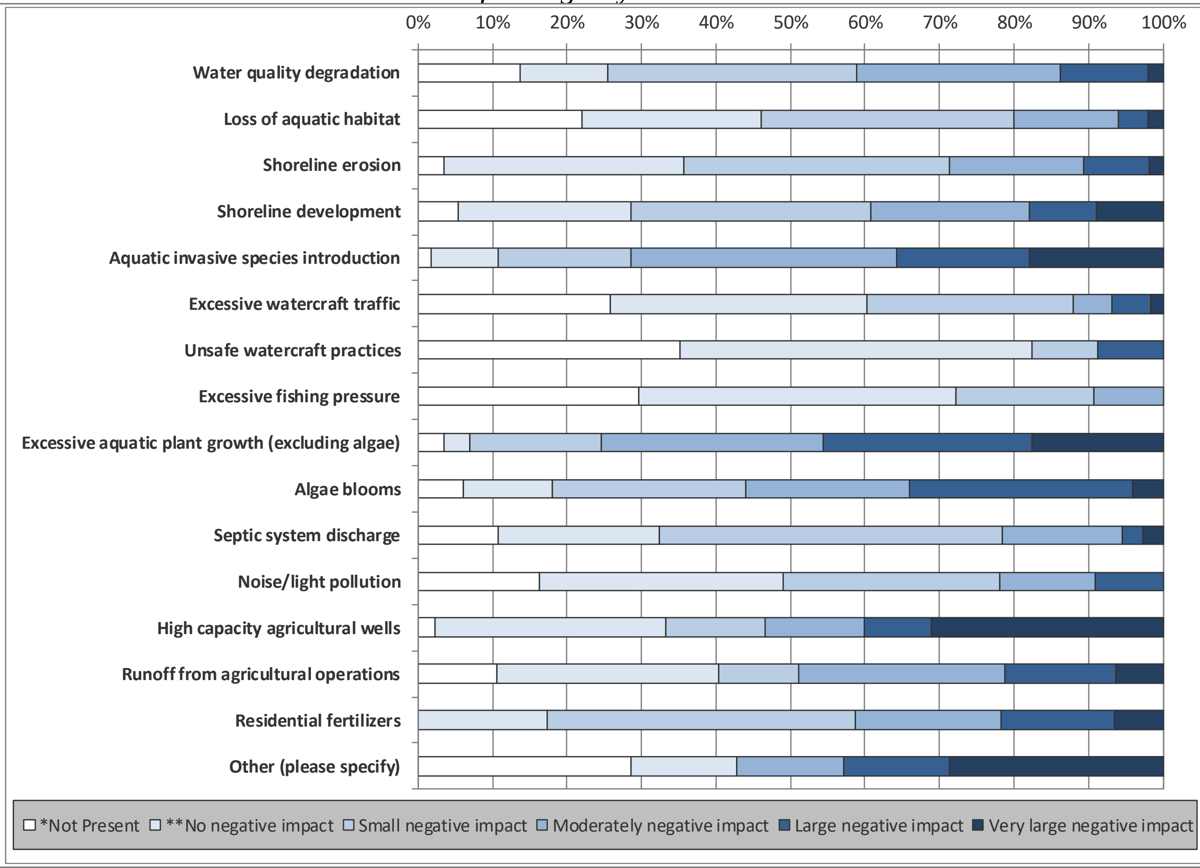


Figure 2.0-1. Select survey responses from the Crystal Lake Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

Question 22: To what level do you believe these factors may currently be negatively impacting Crystal Lake?



Question 23: Please rank your top three concerns regarding Crystal Lake.

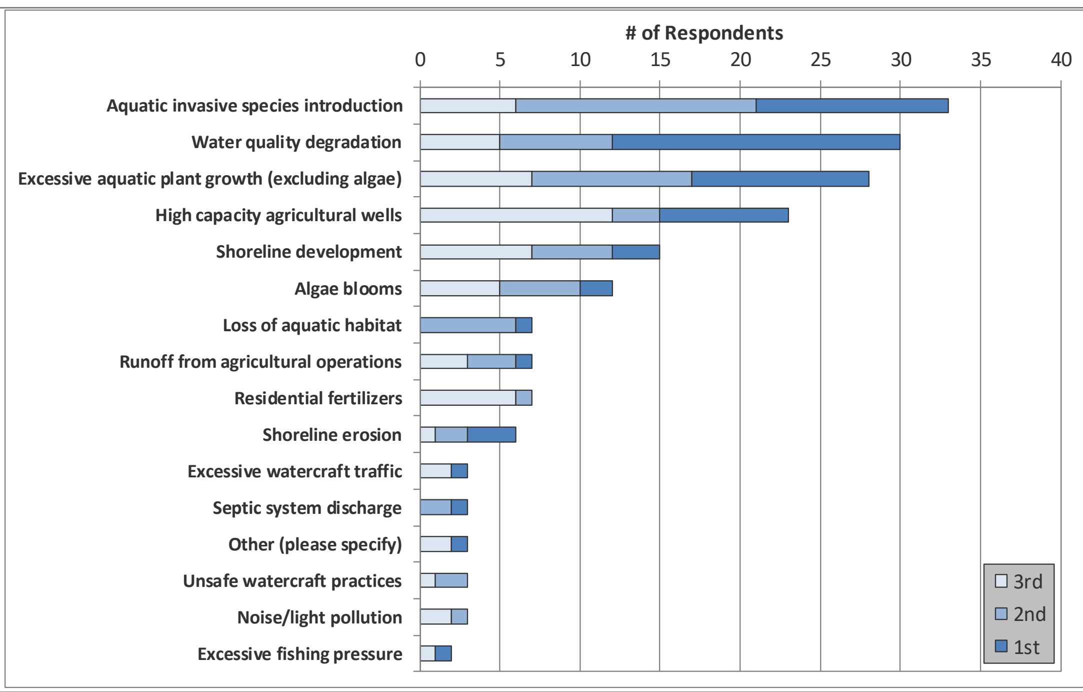


Figure 2.0-2. Select survey responses from the Crystal Lake Stakeholder Survey, continued. Additional questions and response charts may be found in Appendix B.

Management Plan Review and Adoption Process

On October 23, 2019, a draft of the Implementation Plan was provided to the Planning Committee for review. During the course of the next few months, discussions continued between Onterra and the Planning Committee as the Implementation Plan was edited, updated, and modified to reflect the feedback provided by the Committee.

The Official First Draft of the Management Plan was compiled in late February 2020 and distributed to WDNR, Marquette County, the CLC, and other project partners for official review.

Comments on the Official First Draft were received from Marquette County and Golden Sands RC&D shortly thereafter, with additional comments received from WDNR in Late-June 2020. The comments and edits received following the Official First Draft were integrated into the Final Plan issued in July 2020.

3.0 RESULTS & DISCUSSION

3.1 Lake Water Quality

Water Quality Data Analysis and Interpretation

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

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

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

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

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

Limiting Nutrient

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

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

Temperature and Dissolved Oxygen Profiles

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

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

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 the phosphorus sources entering the lake. Internal nutrient loading may be one of the additional contributors that may need to be assessed with further water quality analysis and possibly additional, more intense studies.

Non-Candidate Lakes

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

Candidate Lakes

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

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

Comparisons with Other Datasets

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

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

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

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

Because of its depth and hydrology, Crystal Lake is classified as a deep headwater drainage lake (category 3 on Figure 3.1-1).

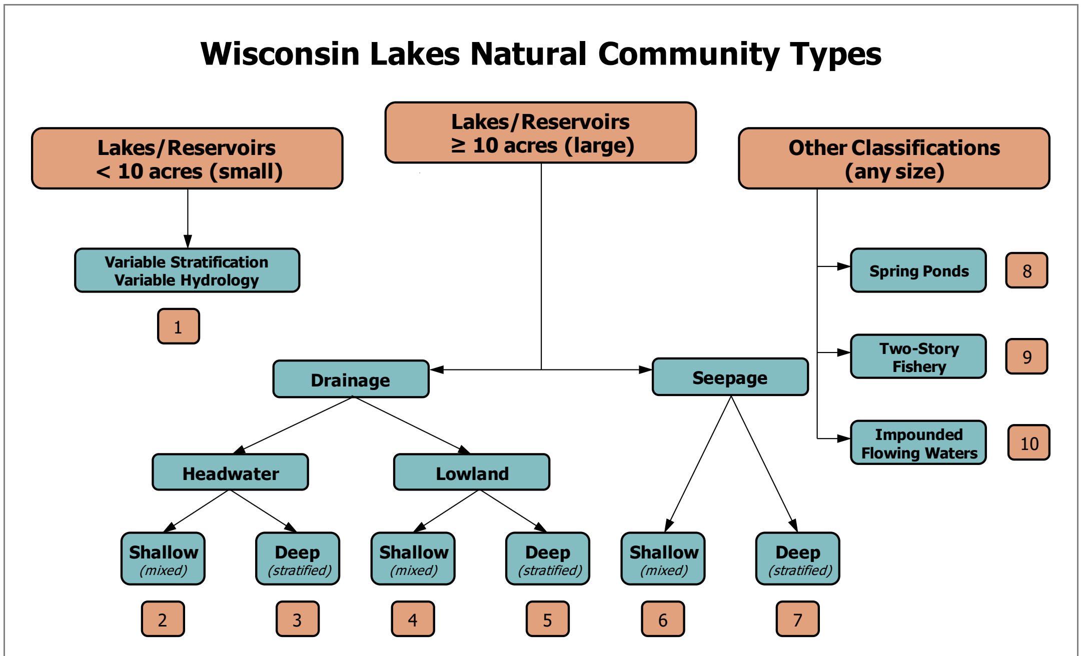


Figure 3.1-1. Wisconsin Lake Natural Communities. Adapted from WDNR 2017.

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

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

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

These data along with data corresponding to statewide natural lake means, historic, current, and average data from Crystal Lake is displayed in Figures 3.1-3 - 3.1-6. 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.

Crystal Lake Water Quality Analysis

Crystal Lake Water Quality Trends

Historical water quality data is available for Crystal Lake for 1987 through 2017. However, none of it falls within the summer months when statewide and ecoregional comparison data are available. Instead the data was collected during spring and fall turnover (Figure 3.1-3). The turnover concentrations are variable ranging from a high of 65 µg/L in spring 1988 to a low in spring 2002 of 3µg/L. The 2002 value seems unusually low but there are other values less than 10 µg/L in other years. The average turnover phosphorus concentration is 15.2 µg/L which places the lake in the *excellent* category. The high numbers probably reflect the variability of concentrations that can occur during spring and fall turnover. For example, spring turnover concentrations can be variable depending upon how soon samples are collected after ice out. If samples are collected immediately following ice out there could still be debris from the ice or the lake may not have been completely mixed yet. Higher levels in the fall can reflect how much internal loading has occurred during the summer. Some lakes like Crystal Lake can have elevated algal concentrations in the middle of the water column. This occurs because the lake has relatively good water clarity which allows sufficient light to reach this part of the water column allowing algal growth to occur. During turnover, these algae are mixed into the surface waters. If the fall sample is collected soon after the beginning of turnover, higher phosphorus concentrations will occur since the phosphorus in the elevated algal levels is being measured. It is important to look at concentrations over several years so that years with unusual concentrations do not give an erroneous assessment of a lake's trophic status.

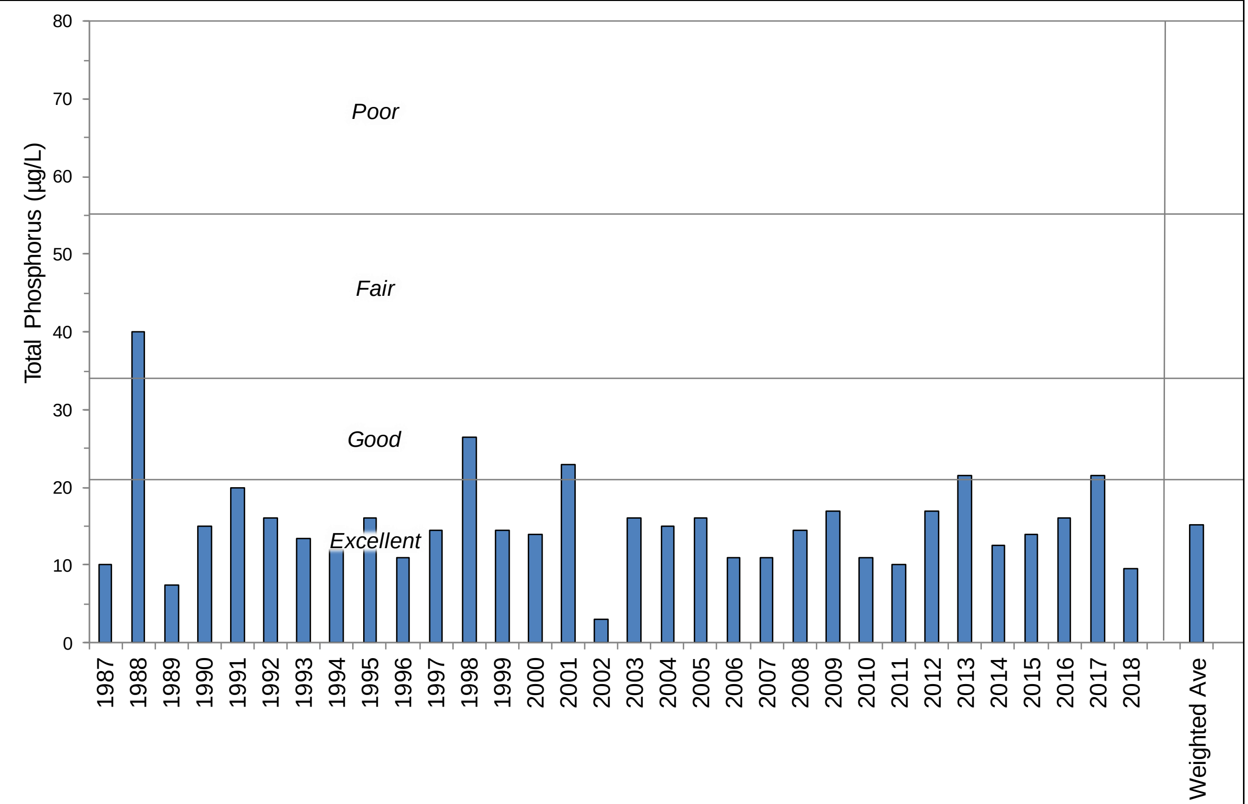


Figure 3.1-3. Mean turnover total phosphorus concentrations for Crystal Lake. Values are the annual mean for spring and fall turnover.

Historically, spring phosphorus concentrations were used in predictive models to estimate the amount of algal growth that could occur during the summer. Because of the higher variability that can occur during spring turnover, it is now more common to use summer mean phosphorus concentrations to assess a lake's condition. The WDNR now assesses a lake's water quality using the mean summer concentration of total phosphorus. This does not mean the data from spring and fall turnover is not useful. Because there is a long record of these data for Crystal Lake, it is useful to look at any long-term trends. The occasional higher values do not mean the lake is getting worse but instead something unique occurred at that time while the overall trend is that phosphorus does not appear to be increasing.

The only year that summer, as well as turnover data, are available for Crystal Lake is 2018 (Figure 3.1-4). The mean total phosphorus (TP) in 2018 was 9.6 µg/L during the growing season, and 8.1 µg/L during the summer. Both of these averages fall within the *excellent* category and are below the ecoregion median and the median for lakes of this type in the state.

The water quality of the lake is good because Crystal Lake is a marl lake 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 with so much phosphorus entering the lake over time, the buffering capability of the marl was saturated and the lake became eutrophic.

Chlorophyll-*a* concentration data are only available for 2018 (Figure 3.1-5). The growing season mean was 2.4 µg/L and the summer mean was 1.6 µg/L. These values also fall within the *excellent* category and are below the NCHF ecoregion median and the median for deep headwater drainage lakes within the state.

Annual Secchi disk data, which indicate water clarity, are available from 2016-2018 (Figure 3.1-6). Growing season means ranged from 11.2 – 17.3 feet, and summer means ranged from 13.3 feet – 20 feet. All of these mean values fall within the excellent category for Secchi disk depth in Wisconsin's deep headwater drainage lakes. The averages exceeded the median values or lakes within the NCHF ecoregion as well.

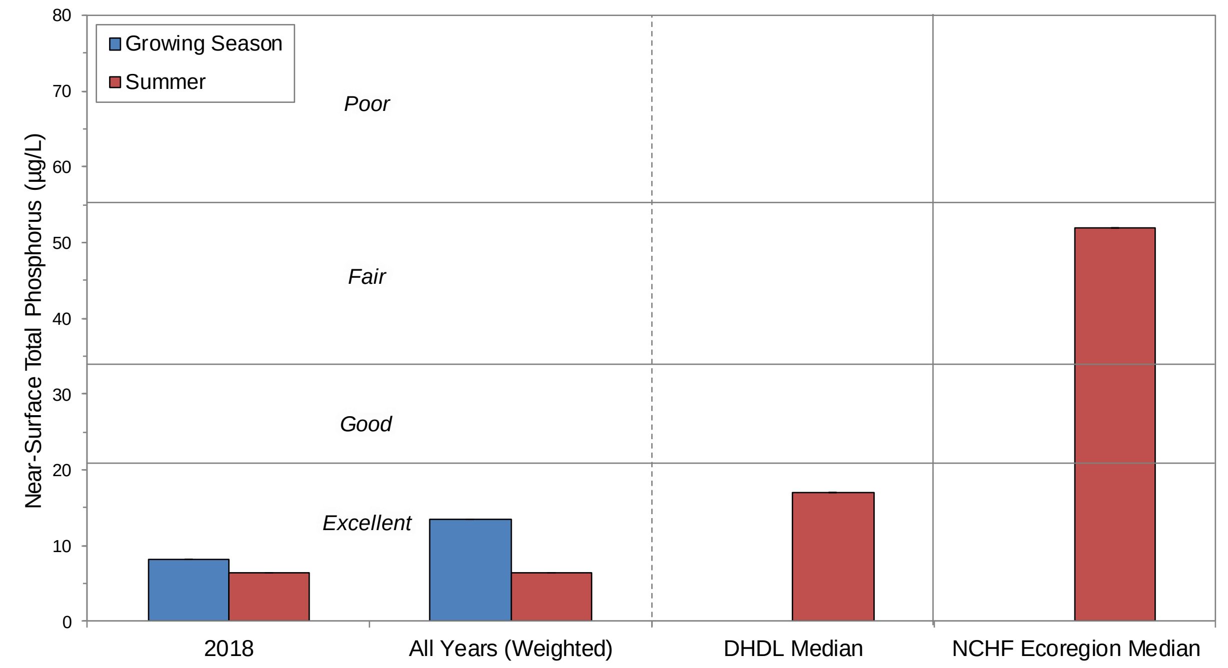


Figure 3.1-4. Crystal Lake, deep headwater drainage lakes, and regional total phosphorus concentrations. Mean values calculated with summer month surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

To determine if internal nutrient loading (discussed in the primer section) is a significant source of phosphorus in Crystal Lake, near-bottom phosphorus concentrations are compared against those collected from the near-surface (Figure 3.1-7). The higher concentrations of phosphorus near the bottom occurred when Crystal Lake was stratified and the bottom layer of water (hypolimnion) was anoxic. These higher concentrations near the bottom are an indication that phosphorus is being released from bottom sediments into overlying water during periods of anoxia.

Crystal Lake is a dimictic lake; therefore, the lake mixes twice each year during the spring and fall turnover events. During the summer, while phosphorus is being released from the sediments, the phosphorus is not being utilized by algae because it is trapped in the hypolimnion, well below the depths the algae populate.

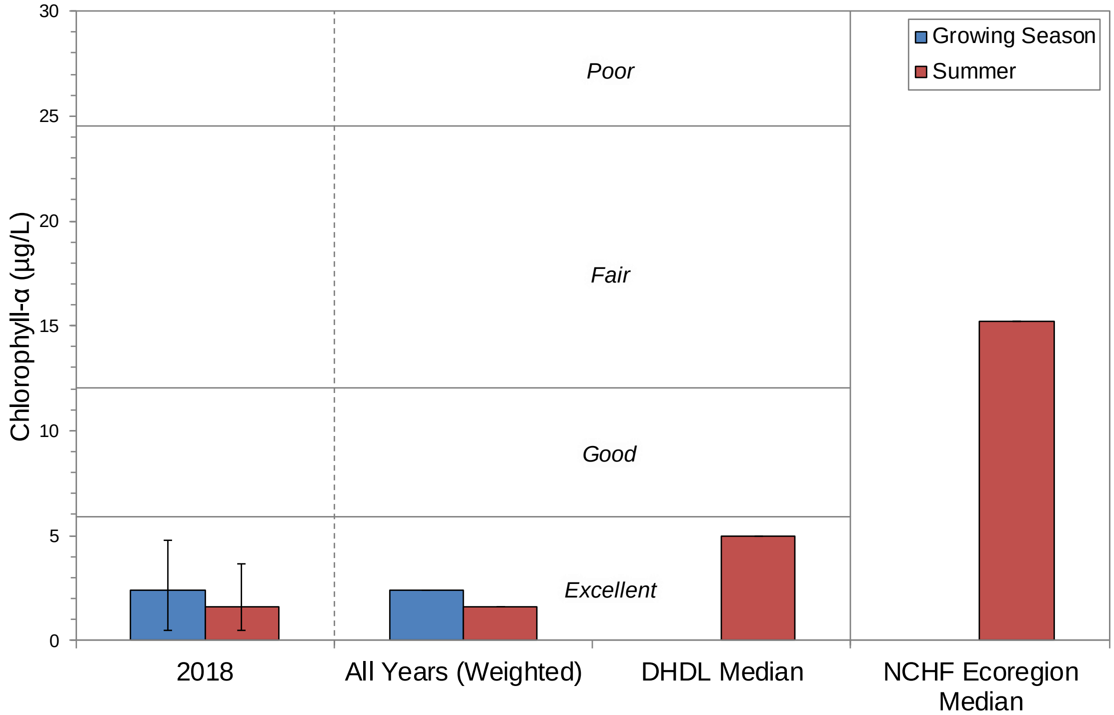


Figure 3.1-5. Crystal Lake, state-wide deep headwater drainage lakes, and regional (NCHF) chlorophyll-a concentrations. Mean values calculated with summer month surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

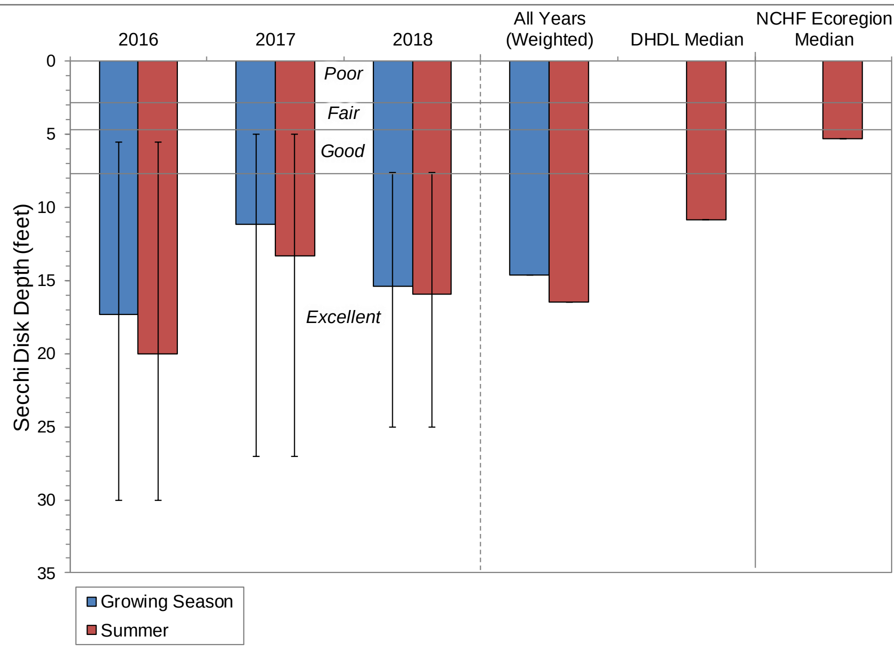


Figure 3.1-6. Crystal Lake, state-wide deep headwater drainage lakes, and regional (NCHF) Secchi disk clarity values. Mean values calculated with summer month surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

Further, most lakes, dimictic and polymictic (lakes that mix several times throughout the open water season) have some level of nutrient recycling occurring. In dimictic lakes, a general rule is that if the hypolimnetic values exceed 400 µg/L, then internal loading may be a significant contributor to the lake's annual phosphorus budget. While this process may be contributing some phosphorus to Crystal Lake's water column, the impacts of internal loading are not significant as the hypolimnetic values are well below 200 µg/L. In addition, the hypolimnion of the lake is small compared to the rest of the lake volume, so when the lake mixes in the fall the higher phosphorus concentrations in the bottom waters are diluted.

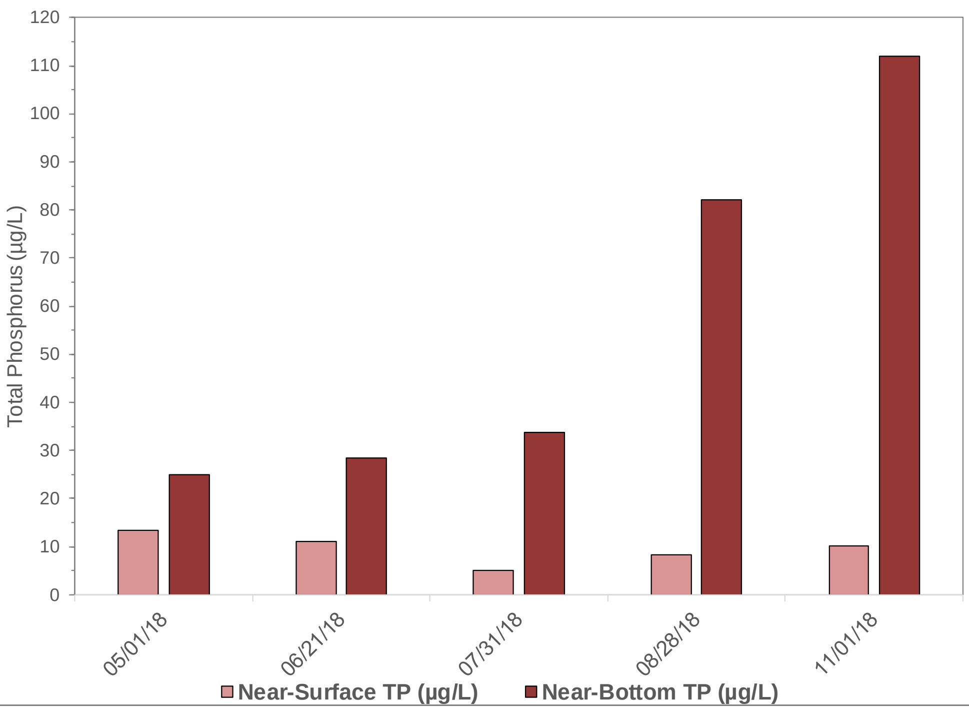


Figure 3.1-7. Crystal Lake near-surface and near-bottom total phosphorus concentrations in 2018.

Limiting Plant Nutrient of Crystal Lake

Using midsummer nitrogen and phosphorus concentrations from Crystal Lake, a nitrogen:phosphorus ratio of 76:1 was calculated. This finding indicates that Crystal Lake is indeed phosphorus limited as are the vast majority of Wisconsin lakes. In lakes with plant and algae issues, this means that cutting phosphorus inputs may limit their growth within the lake. Phosphorus is the most important nutrient for determining the amount of algal growth since even with abundant nitrogen and other essential nutrients, there is not enough phosphorus to cause additional algal growth.

Crystal Lake Trophic State

Figure 3.1-8 contains the Trophic State Index (TSI) values for Crystal Lake. The TSI values are calculated using summer near-surface total phosphorus, chlorophyll-*a*, and Secchi disk transparency data collected as part of this project. In general, the best values to use in judging a lake's trophic state are the biological parameters measured during the growing season; therefore, relying primarily on total phosphorus and chlorophyll-*a* TSI values, it can be concluded that

Crystal Lake is in an oligotrophic state. Crystal Lake is less productive than a majority of other deep headwater drainage lakes in the state and is less productive than most other lakes in the NCHF ecoregion.

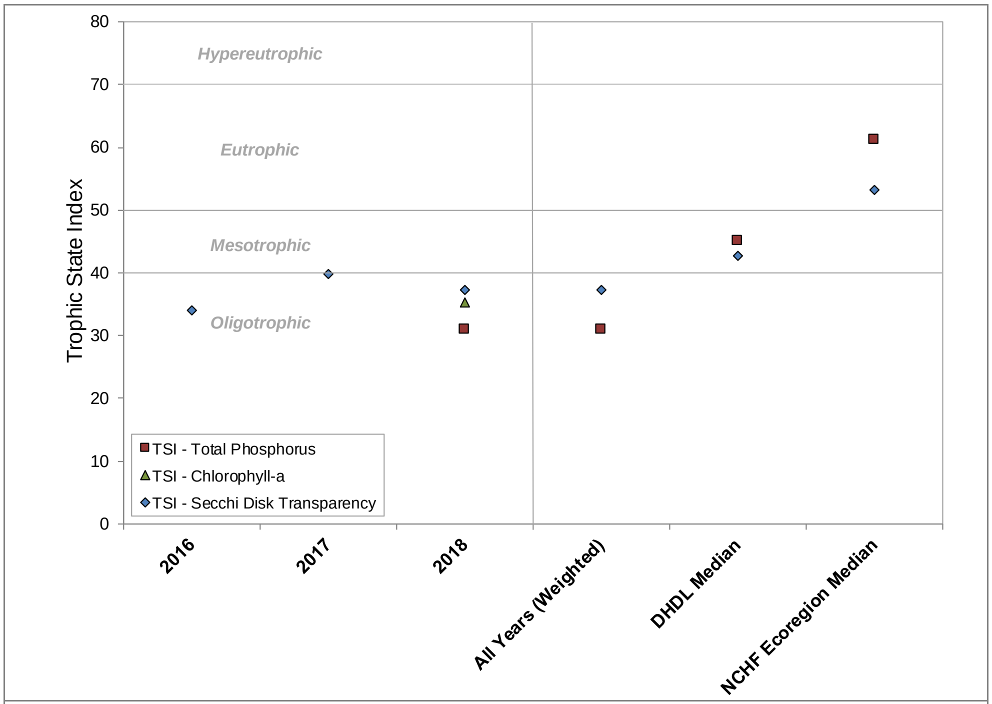


Figure 3.1-8. Crystal Lake, state-wide deep headwater drainage lakes, and regional Trophic State Index values. Values calculated with summer month surface sample data using WDNR PUB-WT-193.

Dissolved Oxygen and Temperature in Crystal Lake

Dissolved oxygen and temperature were measured during water quality sampling visits to Crystal Lake by Onterra staff. Profiles depicting these data are displayed in Figure 3.1-9. Crystal Lake is *dimictic*, meaning the lake remains stratified during the summer (and winter) and completely mixes, or turns over, during the spring and fall. During the summer, the surface of the lake warms and becomes less dense than the cold layer below, and the lake thermally stratifies. Given Crystal Lake's deeper nature, wind and water movement are not sufficient during the summer to mix these layers together, only the warmer upper layer will mix. As a result, the bottom layer of water no longer receives atmospheric diffusion of oxygen and decomposition of organic matter within this layer depletes available oxygen.

In the fall, as surface temperatures cool and become denser, the entire water column is again able to mix, which re-oxygenates the hypolimnion. During the winter, the coldest temperatures are found just under the overlying ice as water is densest at 39 °F, while oxygen gradually declines once again towards the bottom of the lake. The data also indicate that there was sufficient oxygen throughout the water column under the ice to support the fishery during late-winter sampling (Figure 3.1-9).

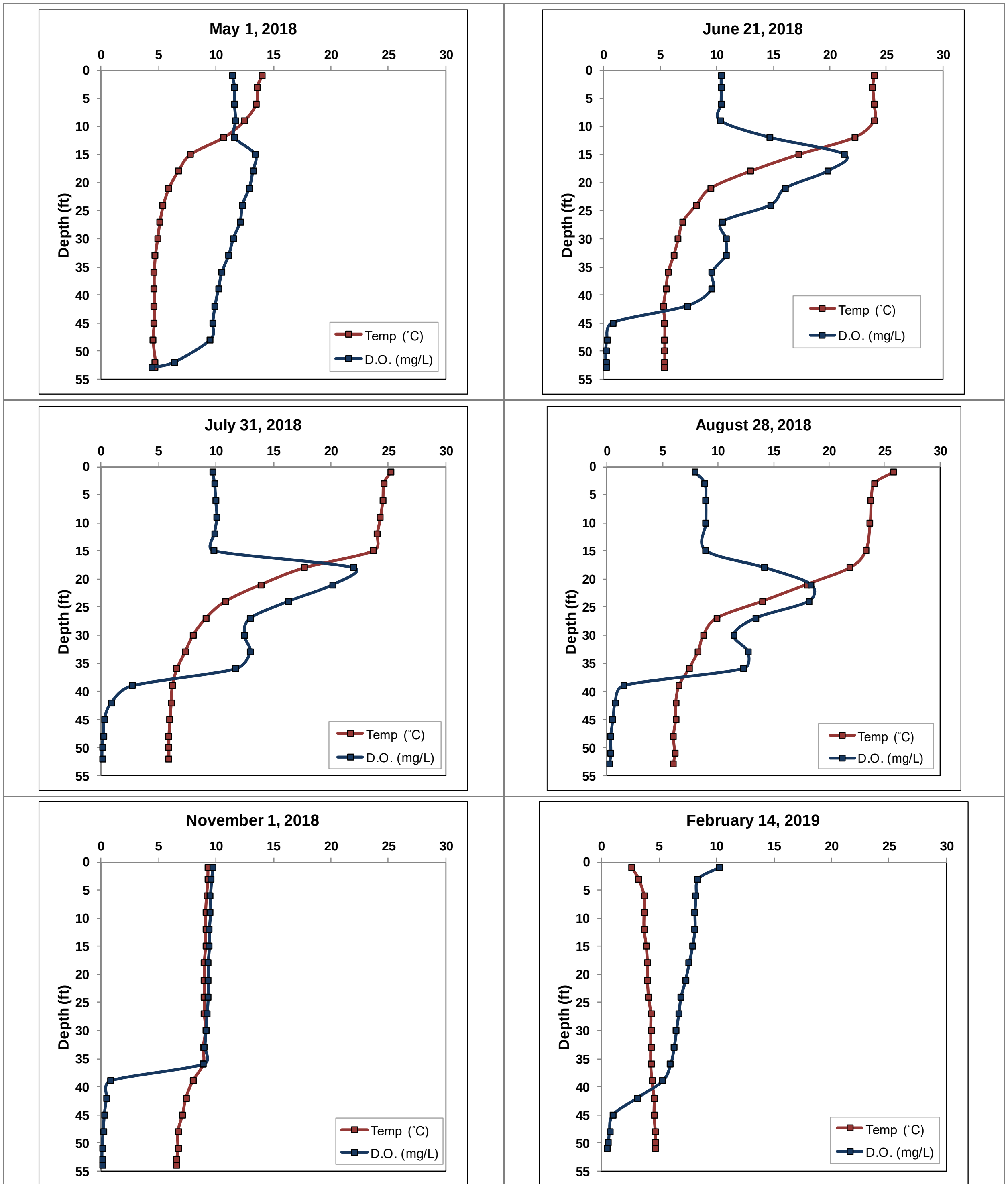


Figure 3.1-9. Crystal Lake dissolved oxygen and temperature profiles.

During the summer, Crystal Lake exhibits a metalimnetic oxygen maximum. This high level of oxygen in the middle of the water column 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 highly 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 the 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. The metalimnetic oxygen maximum indicates that the lake has good water clarity since enough light must reach these deeper depths in order for photosynthesis to occur. If nutrient levels increase sufficiently, the increased algal growth in the surface waters would provide adequate light from reaching the metalimnion for algal growth. The water quality data collected by Onterra during 2018-2019 can be found in Appendix C.

Additional Water Quality Data Collected at Crystal Lake

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

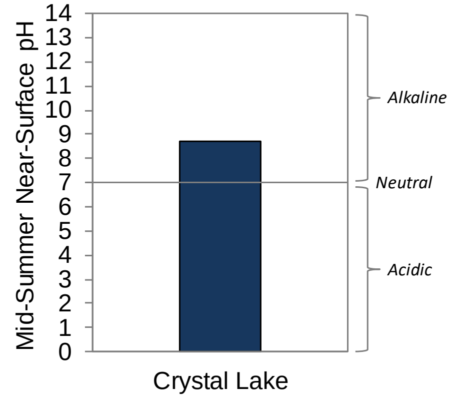


Figure 3.1-10. Crystal Lake mid-summer near-surface pH value.

The pH scale ranges from 0 to 14 and indicates the concentration of hydrogen ions (H^+) within the lake's water and is an index of the lake's acidity. Water with a pH value of 7 has equal amounts of hydrogen ions and hydroxide ions (OH^-), and is considered to be neutral. Water with a pH of less than 7 has higher concentrations of hydrogen ions and is considered to be acidic, while values greater than 7 have lower hydrogen ion concentrations and are considered basic or alkaline. The pH scale is logarithmic; meaning that for every 1.0 pH unit the hydrogen ion concentration changes tenfold. The normal range for lake water pH in Wisconsin is about 5.2 to 8.4, though values lower than 5.2 can be observed in some acid bog lakes and higher than 8.4 in some marl lakes. In lakes with a pH of 6.5 and lower, the spawning of certain fish species such as walleye becomes inhibited (Shaw and Nimphius 1985). The mid-summer pH of the water in Crystal Lake was found to be alkaline with a value of 8.7 and falls just outside the normal range for Wisconsin Lakes (Figure 3.1-10).

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 ($CaMgCO_3)_2$). A lake's pH is primarily determined by the amount of alkalinity. Rainwater in northern Wisconsin is slightly acidic naturally due to dissolved carbon dioxide from the atmosphere with a pH of around 5.0. Consequently, lakes with low alkalinity have lower pH due to their inability to buffer against acid inputs. The alkalinity in Crystal Lake was measured at 130.0 (mg/L as $CaCO_3$), indicating that the lake has a substantial capacity to resist fluctuations in pH and is not sensitive to acid rain (Figure 3.1-11).

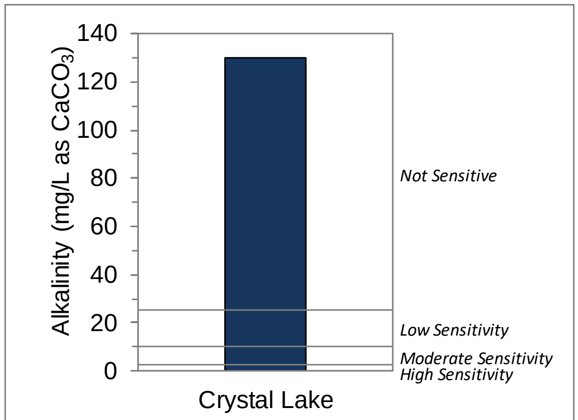


Figure 3.1-11. Crystal Lake average growing season total alkalinity and sensitivity to acid rain. Samples collected from the near-surface.

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 Crystal Lake's pH of 8.7 falls just inside this range. Lakes with calcium concentrations of less than 12 mg/L are considered to have very low susceptibility to zebra mussel establishment. The calcium concentration of Crystal Lake was found to be 20.9 mg/L, falling within the optimal range for zebra mussels (Figure 3.1-12).

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

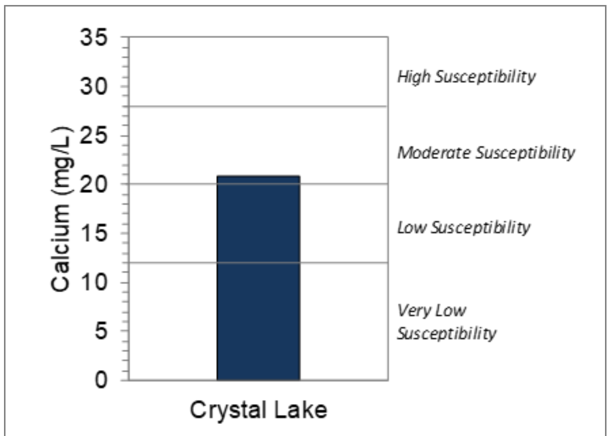


Figure 3.1-12. Crystal Lake spring calcium concentration and zebra mussel susceptibility. Samples collected from the near-surface.

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).

Plankton tows were completed by Onterra ecologists in Crystal Lake in 2018 which underwent analysis for the presence of zebra mussel veligers, their planktonic larval stage. The samples analyzed were negative for zebra mussel veligers, and Onterra ecologists did not observe any adult zebra mussels during the 2018 surveys.

During the years 1987 through 2018, turnover samples were analyzed for pH, specific conductance, alkalinity, total hardness, turbidity, water color, chloride, sulfate, sodium, and potassium as well as phosphorus and nitrogen species. Other than the nutrients, these parameters are considered *conservative* elements, meaning that their concentrations typically change very little during the season and from year to year. Because the concentrations of these elements are stable, it is not necessary to measure the concentrations every year. Table 3.1-1 shows the mean turnover values for the various parameters discussed. These values indicate that Crystal Lake is a hardwater lake with low water color and minimal turbidity. As was found during the summer of 2018, the pH values are within the normal range for Wisconsin lakes. Chloride concentrations, which can be elevated by runoff from road salt are relatively low. The concentrations for the rest of the parameters are in the normal range for Wisconsin lakes.

Table 3.1-1. Mean turnover concentrations for 1987-2018.

Parameter	Concentration (mg/L)
pH	8.1
Conductivity (µS/cm)	268
Alkalinity	143
Hardness	145
Chloride	2.0
Sulfate	7.6
Sodium	2.6
Potassium	0.8
Total Phosphorus	0.016
Total Nitrogen	0.88
Turbidity (NTU)	2.5
Color (SU)	5

Paleocore Collection and Analysis on Crystal Lake

Primer on Paleoecology and Interpretation

Questions often arise concerning how a lake's water quality has changed through time as a result of watershed disturbances. In most cases, there is little or no reliable long-term data. Riparians also want to understand when the changes occurred and what the lake was like before the transformations began. Paleoecology offers a way to address these questions. The paleoecological approach depends upon the fact that lakes act as partial sediment traps for particles that are created within the lake or delivered from the watershed. The sediments of the lake entomb a selection of fossil remains that are more or less resistant to bacterial decay or chemical dissolution. These remains include frustules (silica-based cell walls) of a specific algal group called diatoms, cell walls of certain algal species, and subfossils from aquatic plants. The diatom community are especially useful in reconstructing a lake's ecological history as they are highly resistant to degradation and are ecologically diverse. Diatom species have unique features as shown in Photo 3.3.1, which enable them to be readily identified. Certain taxa are usually found under nutrient poor conditions while others are more common under elevated nutrient levels. Some species float in the open water areas while others grow attached to objects such as aquatic plants or the lake bottom.

The chemical composition of the sediments may indicate the composition of particles entering the lake as well as the past chemical environment of the lake itself. By collecting an intact sediment core, sectioning it off into layers, and utilizing all of the information described above, paleoecologists can reconstruct changes in the lake ecosystem over any period of time since the establishment of the lake.

One often used paleoecological technique is collecting and analyzing top/bottom cores. The top/bottom core only analyzes the top (usually 1 cm) and bottom sections. The top section represents present day conditions and the bottom section is hoped to represent pre-settlement conditions by having been deposited at least 100 years ago. While it is not possible to determine the actual date of deposition of bottom samples, a determination of the radionuclide lead-210 estimates if the sample was deposited at least 100 years ago. The primary analysis conducted on this type of core is the diatom community leading to an understanding of past nutrients, pH, and general macrophyte coverage.

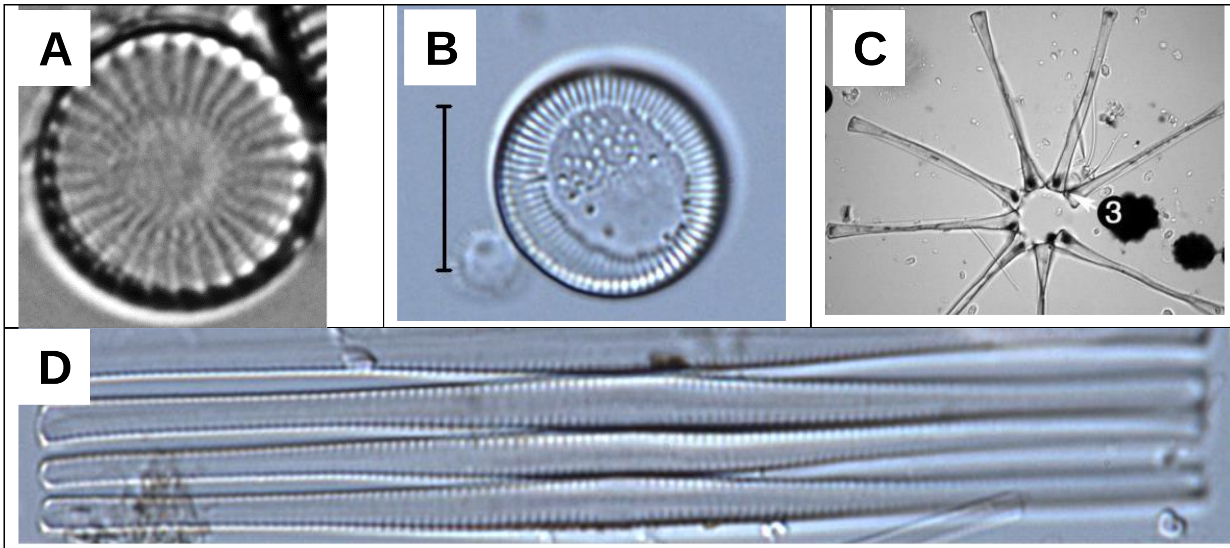
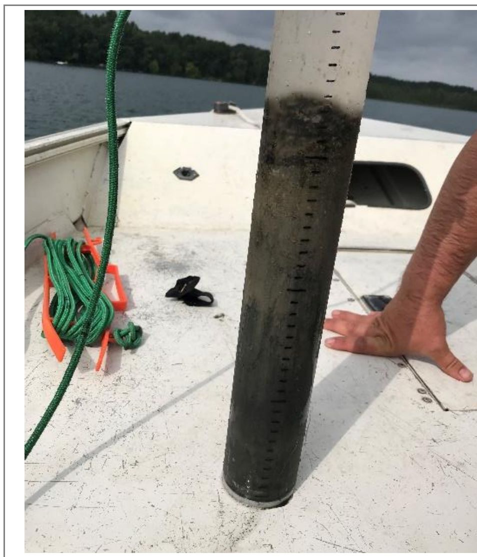


Photo 3.1-1. Photomicrographs of the diatoms commonly found in the sediment core from Crystal Lake. The top diatom (A) *Stephanodiscus minutulus* was the dominant diatom in the bottom sample. *Cyclotella michiganiana* (B) grows in the metalimnion of the lake and was found in the top and bottom samples. *Asterionella formosa* (C) and *Fragilaria crotonensis (D)* are more common with moderate phosphorus levels but indicates higher nitrogen concentrations. These diatoms were most common in the top sample.

Crystal Lake Paleoecological Results

A sediment core was collected from the deep area in Crystal Lake by Onterra staff on August 28, 2018. The upper 16 cm were medium gray in color, while below 16 cm the color was dark gray (Photo 3.1-2). The color change likely indicates when Euroamerican settlement began to impact the lake as the increased delivery of nutrients from the watershed would have increased marl deposition which is light gray in color. The total length of the core was 35 cm. The top 1 cm was kept for analysis and it is assumed this represents present day water quality conditions in the lake. A bottom sample was analyzed and this is assumed to represent conditions before the arrival Euroamerican settlers in the middle of the nineteenth century.



Photograph 3.1-2. Sediment core collected from Crystal Lake. Photo credit Onterra.

Diatom Community Changes

The diatom community in the top and bottom samples of Crystal Lake were dominated by planktonic diatoms which is not surprising since the lake is relatively deep. The dominant diatom in the bottom sample was *Stephanodiscus minutulus* (Photo 3.1-1 A). This diatom often is prominent in high productivity lakes because with higher phosphorus levels, the important nutrient for diatoms, silica, is severely depleted. *S. minutulus* is able to out compete most other diatoms for this essential nutrient. In the case of Crystal Lake, its dominance in the bottom sample likely signals low silica levels because of the low input of phosphorus and silica in this lake. High levels of this diatom have been found in bottom samples of other hardwater lakes in Wisconsin. The other common diatom in the bottom sample was *Cyclotella michiganiana* (Photo 3.1-1B), which usually grows in the metalimnion of the lake. The presence of this diatom indicates that water clarity was good as sufficient light must reach the metalimnion for this diatom to flourish.

The diatom community in the bottom sample of the Crystal Lake core was dominated by diatoms that grow on the lake sediments (Figure 3.1-13.). The dominant diatom was *Staurosirella pinnata* (Photo 3.1-1A). This has been found in other marl lakes in Wisconsin (Garrison and Wakeman 2000, Garrison 2012) and indicates excellent water clarity and low phosphorus concentrations. In the top sample, *S. pinnata* numbers are greatly reduced, but benthic diatoms are still dominant even though Crystal Lake is relatively deep. This demonstrates that the lake still possesses good water clarity and relatively low phosphorus concentrations. Even though the diatom community is still dominated by the benthic community at the present time, there are more planktonic diatoms present. This typically happens as nutrient levels increase. Water clarity becomes reduced so light is not able to reach as much of the lake bottom and there is less area for the diatoms to grow. The dominant planktonic diatom is *Cyclotella michiganiana* (Photo 3.1-1B) which usually grows in the metalimnion of the lake. This diatom is one of the first planktonic diatoms to increase with increased nutrients. Water clarity is still good as sufficient light must reach the metalimnion for this diatom to flourish.

In the top sample the diatom *Cyclotella comensis* (Photo 3.1-1C) was present in low numbers. It is believed this diatom is an introduced species from northern Europe (Stoermer 1993, 1998). This diatom has been found in sediments deposited since 1950 in the Great Lakes (Stoermer et al. 1985, 1990; 1993) as well as inland lakes in northern lower Michigan (Fritz et al. 1993; Wolin and Stoermer 2005) and over 20 lakes in Wisconsin. In lakes from New Jersey and New York, this diatom was only found in the top samples of the 26 lakes examined (Enache et al. 2012). The diatom *C. comensis* typically is found growing in the open water in the middle part of the water column. This means that this taxon is found in lakes with good water clarity but elevated nutrient levels in the deeper waters. Studies indicate that this diatom responds to increased phosphorus and nitrogen levels (Schelske et al. 1972; Wolin and Stoermer 2005). In Crystal Lake *C. comensis* was found at a concentration of 3.6% which is relatively low.

Lake Diatom Condition Index

The Lake Diatom Condition Index (LDCI) was developed by Dr. Jan Stevenson, Michigan State University (Stevenson et al. 2013). The LDCI uses diatoms to assess the ecological condition of lakes. The LDCI ranges from 0 to 100 with a higher score representing better ecological integrity. The index is weighted towards nutrients, but also incorporates ecological integrity by examining species diversity where higher diversity indicates better ecological condition. The index also incorporates taxa that are commonly found in undisturbed and disturbed conditions. The breakpoints (poor, fair, good) were determined by the 25^{th} and 5^{th} percentiles for reference lakes in the Upper Midwest. The LDCI was used in the 2007 National Lakes Assessment to determine the biological integrity of the nation's lakes.

The LDCI in the top sample places Crystal Lake in the good category (Figure 3.1-14). The bottom sample places the lake in the fair category. The apparent worse condition in the bottom sample reflects the historical oligotrophic condition of the lake. The dominance of *S. minutulus* in the bottom sample is interpreted in the LDCI calculation as relatively poor conditions, but this is not true for historical conditions in Crystal Lake. As discussed previously, this diatom is common because of the low silica levels in the lake at the time.

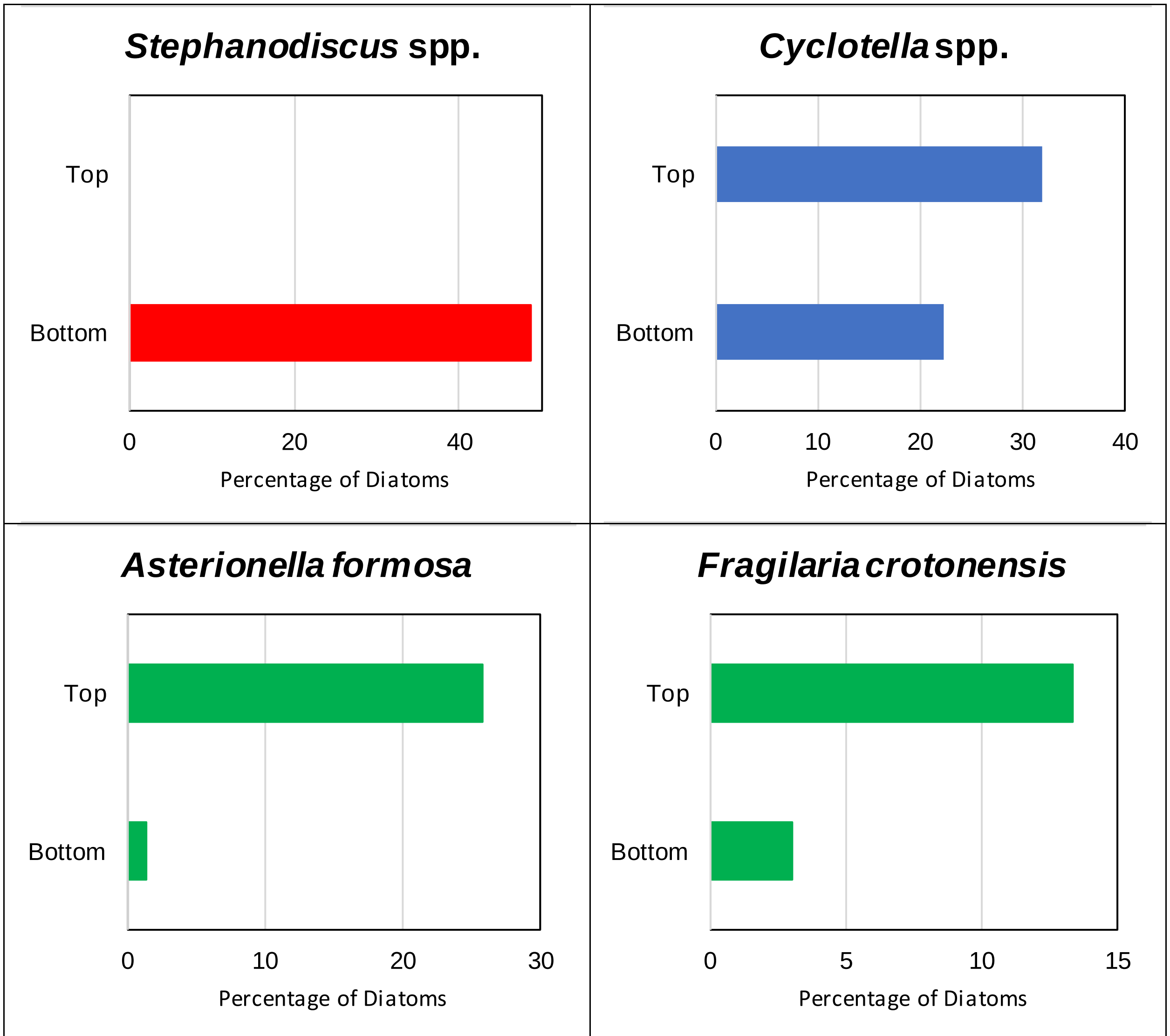


Figure 3.1-13. Changes in abundance of important diatoms found in the top and bottom of the sediment core from Crystal Lake. Two common diatoms in the top sample were *A. formosa and F. crotonensis* which indicate moderate levels of nutrients, especially nitrogen

Inference models

Diatom assemblages have been used as indicators of trophic changes in a qualitative way (Bradbury 1975, Carney 1982, Anderson et al. 1990), but quantitative analytical methods exist.

Ecologically relevant statistical methods have been developed to infer environmental conditions from diatom assemblages. These methods are based on multivariate ordination and weighted averaging regression and calibration (Birks et al. 1990). Ecological preferences of diatom species are determined by relating modern limnological variables to surface sediment diatom assemblages. The species-environment relationships are then used to infer environmental conditions from fossil diatom assemblages found in the sediment core.

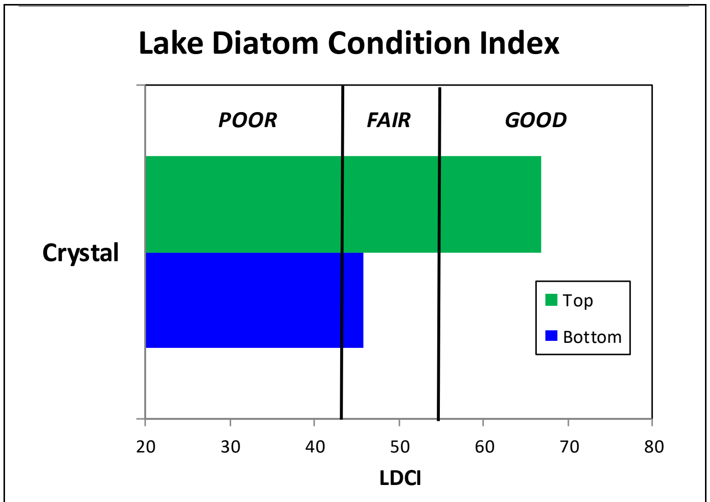


Figure 3.1-14. The Lake Diatom Condition Index (LDCI) for Crystal Lake. The biotic integrity is better in the top sample compared with the bottom sample because historically the lake had low silica levels which favored diatoms that are often found in eutrophic lakes. It is likely that historically the lake's biotic condition was good.

Weighted averaging calibration and reconstruction (Birks et al., 1990) were used to infer historical water column summer average phosphorus in the sediment cores. A training set that consisted of 60 stratified lakes was used. Training set species and environmental data were analyzed using weighted average regression software (C2; Juggins 2014).

The estimated phosphorus concentrations in the top and bottom samples of Crystal Lake are very similar at 15 and 14 µg/L, respectively (Table 3.1-2). The diatom inferred phosphorus concentration in the top sample is somewhat higher than the average summer phosphorus concentration of 8 µg/L measured in 2018. The model indicates that phosphorus levels in Crystal Lake are very similar to historical levels.

Table 3.1-2. Diatom inferred phosphorus concentrations in core samples (µg/L).

Lakes	Phosphorus
Crystal Top	15
Crystal Bottom	14

Stakeholder Survey Responses to Crystal Lake Water Quality

As discussed in section 2.0, the stakeholder survey asks many questions pertaining to perception of the lake and how it may have changed over the years. Figures 3.1-15 and 3.1-16 display the responses of members of Crystal Lake stakeholders to questions regarding water quality and how it has changed over their years visiting Crystal Lake.

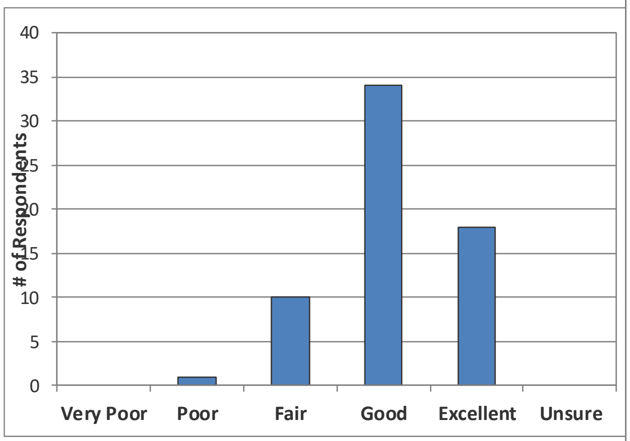


Figure 3.1-15. Stakeholder survey response Question #13. How would you describe the overall current water quality of Crystal Lake?

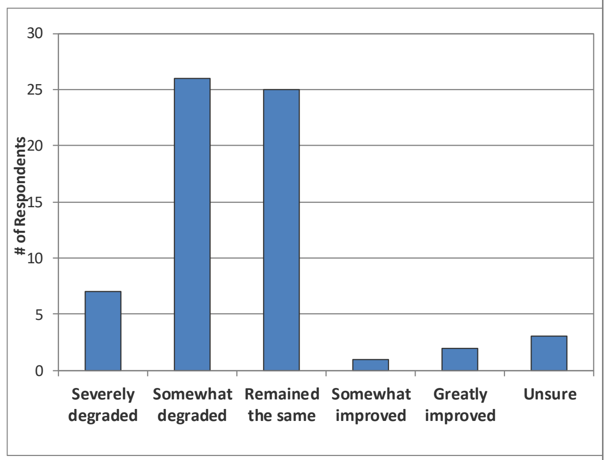


Figure 3.1-16. Stakeholder survey response Question #14. How has the overall water quality changed in Crystal Lake since you first visited the lake?

3.2 Watershed Assessment

Watershed Modeling

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

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

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

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

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

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

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

Crystal Lake Watershed Assessment

Crystal Lake's watershed encompasses an area of approximately 326 acres, yielding a small watershed to lake area ratio of about 2:1 (Map 2). In other words, approximately two acres of land drain to every one acre of Crystal Lake. Crystal Lake's watershed is composed of approximately: 38% lake surface, 29% forest, 26% wetlands, 3% pasture/grass, 3% rural residential areas, and 3% row crops (Figure 3.2-1). The WiLMS model estimates Crystal Lake to have a water flushing rate of 0.06 times per year which means that water remains in the lake for about 17 years before it leaves the lake (Appendix D). This seems like a very long residence time for a lake with a stream leaving the system. The model does not always accurately predict the hydrologic input in lakes without inflowing streams. The model can under estimate the amount of groundwater entering such a lake. It is more likely that the residence time in Crystal Lake is 3-5 years which would mean it has a flushing rate of 0.2 to 0.3 times per year.

Utilizing the land cover data described above, WiLMS was used to estimate the annual potential phosphorus load from Crystal Lake's watershed. What is listed as rural residential are homes near the shoreline. Studies conducted in Wisconsin have found that phosphorus runoff from this land use can be higher along lakeshores. This is especially true in Crystal Lake as the land around the lake is relatively steep. A runoff coefficient of 0.45 lbs /ac/year was used for shoreland homes. It was estimated that approximately 59 pounds of phosphorus are delivered to the lake from its watershed on an annual basis. Phosphorus loading from septic systems was also estimated using data obtained from the 2018 stakeholder survey of riparian property owners. Of the 59 total pounds of phosphorus being delivered to Crystal Lake, 56% is estimated to originate from direct atmospheric deposition into the lake, 11% from forest, 11% from wetlands, 10% from septic systems, 4% from row crops, 4% from pasture/grass, and 4% from runoff from shoreland homes (Figure 3.2-2).

Using predictive equations, WiLMS estimates Crystal Lake should have a growing season mean total phosphorus concentration of approximately 9 µg/L to 15 µg/L. The lower phosphorus concentration estimate is likely more realistic due to the lake's calcium-rich water, and is much closer to the measured growing season mean total phosphorus concentration in recent years of 9 µg/L. 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. Since the predicted phosphorus concentration is similar to the measured value it is likely that there is not significant internal phosphorus loading occurring. Even though phosphorus concentrations were elevated in the lake's deepest waters, this represents a small water volume and thus the load is insignificant.

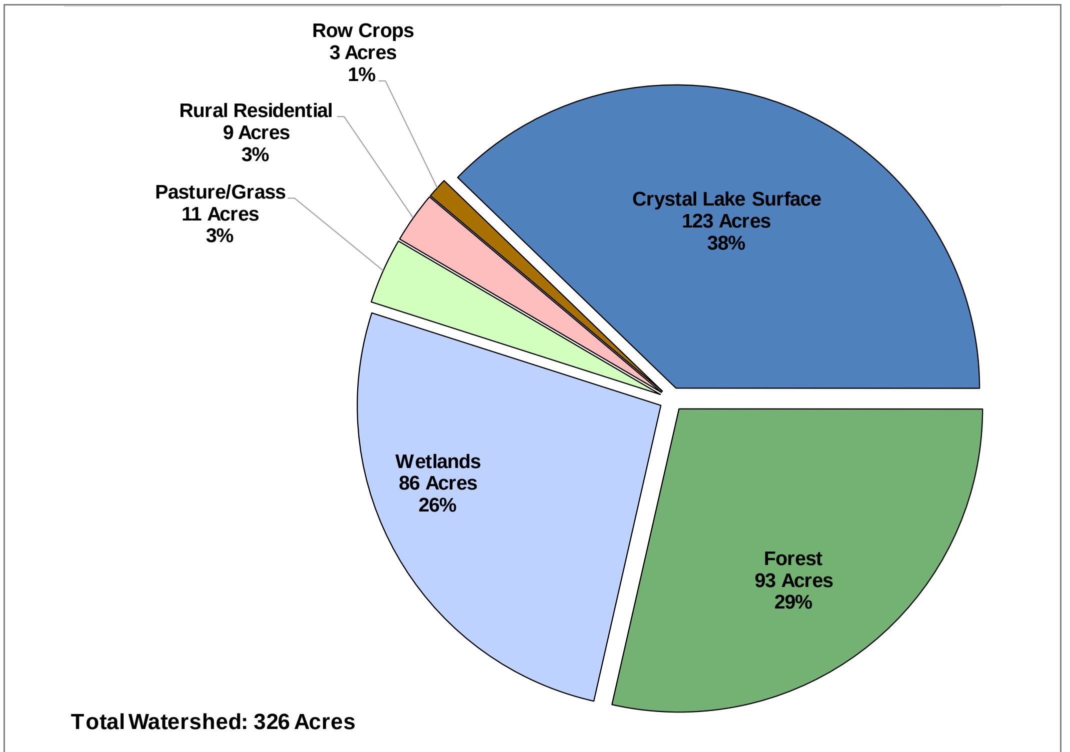


Figure 3.2-1. Crystal Lake watershed land cover types in acres. Based upon National Land Cover Database (NLCD – Fry et. al 2011).

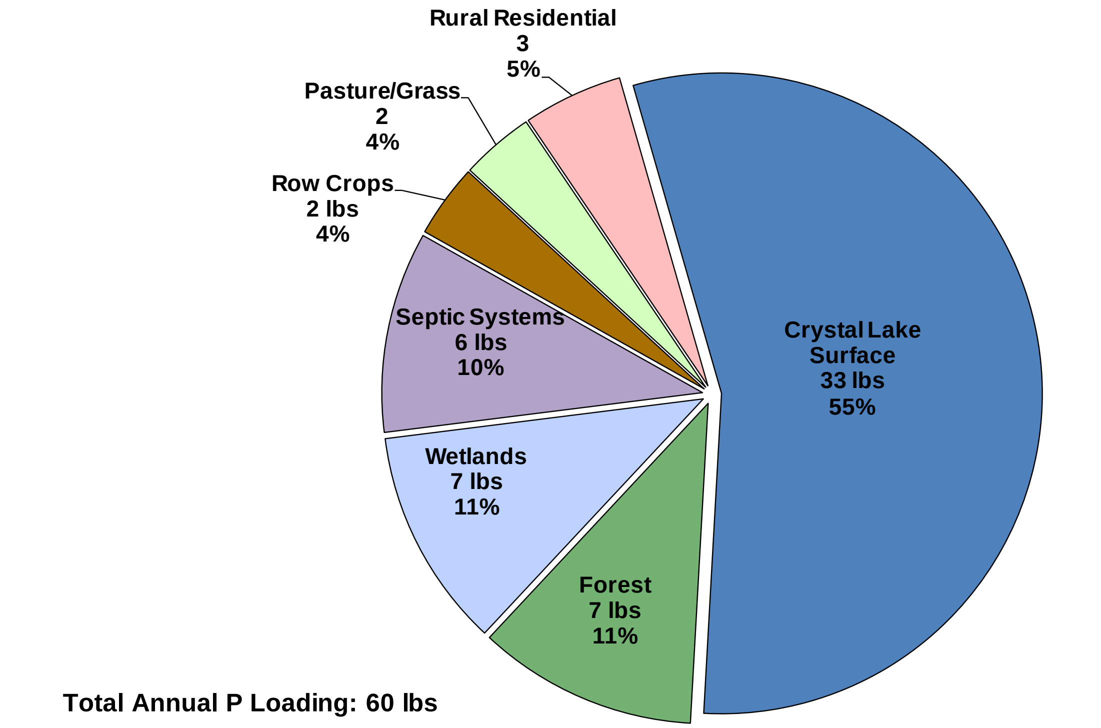


Figure 3.2-2. Crystal Lake watershed phosphorus loading in pounds. Based upon Wisconsin Lake Modeling Suite (WiLMS) estimates.

3.3 Shoreland Condition

Lake Shoreland Zone and its Importance

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

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

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

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

Shoreland Zone Regulations

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

Wisconsin-NR 115: Wisconsin's Shoreland Protection Program

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

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

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

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

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

Wisconsin Act 31

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

Shoreland Research

Studies conducted on nutrient runoff from Wisconsin lake shorelands have produced interesting results. For example, a USGS study on several Northwoods Wisconsin lakes was conducted to determine the impact of shoreland development on nutrient (phosphorus and nitrogen) export to these lakes (Graczyk et al. 2003). During the study period, water samples were collected from surface runoff and ground water and analyzed for nutrients. These studies were conducted on several developed (lawn covered) and undeveloped (undisturbed forest) areas on each lake. The study found that nutrient yields were greater from lawns than from forested catchments, but also that runoff water volumes were the most important factor in determining whether lawns or wooded catchments contributed more nutrients to the lake. 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 (2003) found that green frog density was negatively correlated with development density in Wisconsin lakes. As development increased, the habitat for green frogs decreased and thus populations became significantly lower. Common loons, a bird species notorious for its haunting call that echoes across Wisconsin lakes, are often associated more so with undeveloped lakes than developed lakes (Lindsay et al. 2002). And studies on shoreland development and fish nests show that undeveloped shorelands are preferred as well. In a study conducted on three Minnesota lakes, researchers found that only 74 of 852 black crappie nests were found near shorelines that had any type of dwelling on it (Reed, 2001). The remaining nests were all located along undeveloped shoreland.

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

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

Coarse woody habitat has shown to be advantageous for fisheries in terms of providing refuge, foraging area, as well as spawning habitat (Hanchin et al 2003). In one study, researchers observed 16 different species occupying coarse woody habitat areas in a Wisconsin lake (Newbrey et al. 2005). Bluegill and bass species in particular are attracted to this habitat type; largemouth bass stalk bluegill in these areas while the bluegill hide amongst the debris and often feed upon 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 nations lakes; over one-third exhibit poor shoreline habitat condition*" (USEPA 2009). Furthermore, the report states that "*poor biological health is three times more likely in lakes with* *poor lakeshore habitat.*" 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, and Elias & Meyer 2003). Many homeowners significantly decrease the number of trees and shrubs along the water's edge in an effort to increase their view of the lake. However, this has been shown to locally increase water temperatures, and decrease infiltration rates of potentially harmful nutrients and pollutants. Furthermore, the dumping of sand to create beach areas destroys spawning, cover and feeding areas utilized by aquatic wildlife (Scheuerell and Schindler 2004).

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

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

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

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).

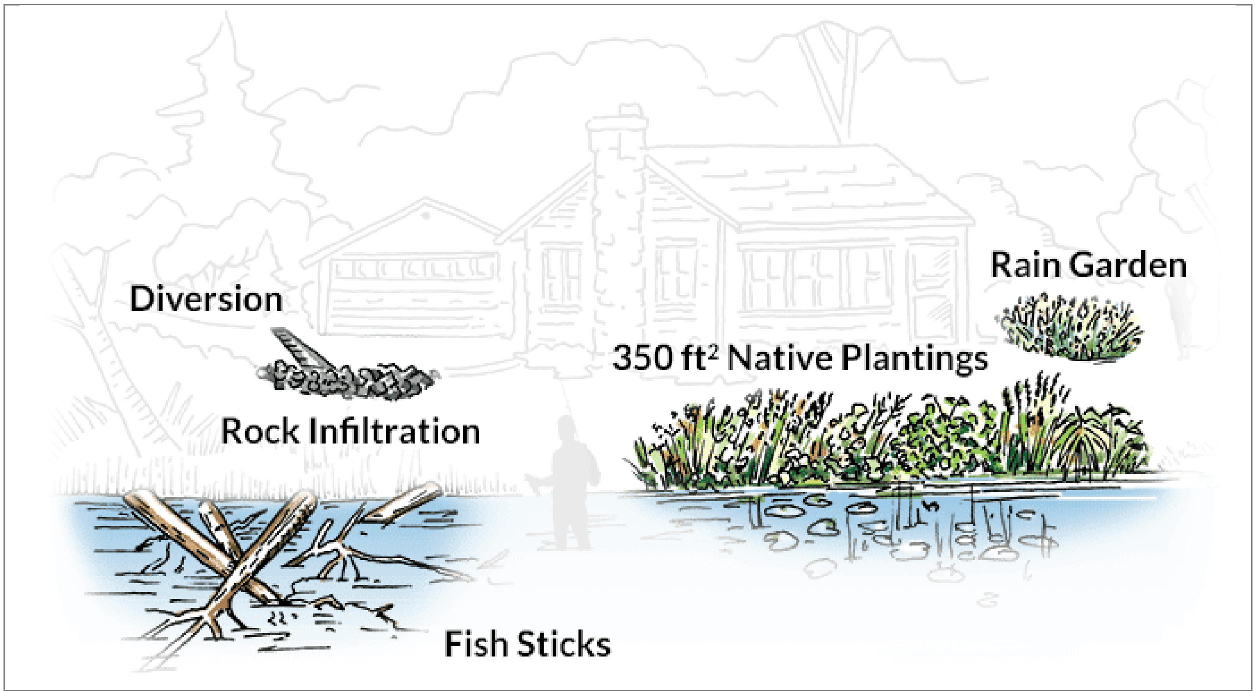


Figure 3.3-1. Healthy Lakes & Rivers 5 Best Practices. Illustration by Karen Engelbretson, extracted from healthylakeswi.com.

- <u>Rain Gardens</u>: 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.
- <u>Rock Infiltration</u>: This upland best practice is an excavated pit or trench, filled with rock, that encourages water to infiltrate into the soil. These practices are strategically placed at along a roof line or the downward sloping area of a driveway.
- <u>Diversion</u>: This best practice can occur in the transition or upland zone. These practices use 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.
- <u>Native Plantings</u>: 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 per property per year is eligible.
- <u>Fish Sticks</u>: These in-lake best practices (not eligible for rivers) are 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 allows partial cost coverage for implementing best practices. Competitive grants are available to eligible applicants such as lake associations and lake districts. The program allows a 75% state cost share up to $1,000 per practice. Multiple practices can be included per grant application, with a $25,000 maximum award per year. Eligible projects need to be on shoreland properties within 1,000 feet of a lake or 300 feet from a river. The landowner must sign a Conservation Commitment pledge to leave the practice in place and provide continued maintenance for 10 years. More information on this program can be found here:

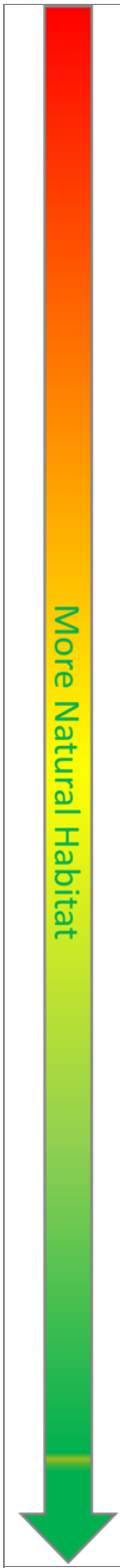
https://healthylakeswi.com/

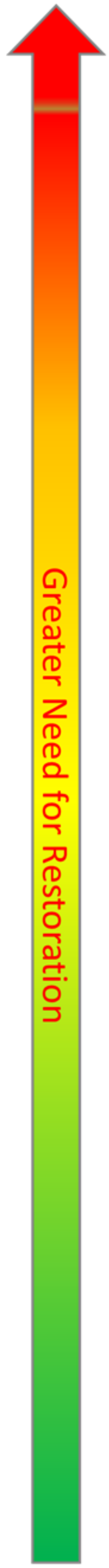
It is important to note that this grant program is intentionally designed for relatively simple, low-cost, and shovel-ready projects, limiting 10% of the grant award for technical assistance. Larger and more complex projects, especially those that require engineering design components may seek alternative technical direction and funding sources potentially through the Marquette County Land and Water Conservation Department. Small-Scale Lake Planning Grants can provide up to $3,000 to help build a Healthy Lakes and Rivers project. Eligible expenses in this grant program are surveys, planning, and design.

Crystal Lake Shoreland Zone Condition

Shoreland Development

Crystal Lake's shoreland zone can be classified in terms of its degree of development. In general, more developed shorelands are more stressful on a lake ecosystem, while definite benefits occur from shorelands that are left in their natural state. Figure 3.3-2 displays a diagram of shoreland categories, from "Urbanized", meaning the shoreland zone is completely disturbed by human influence, to "Natural/Undeveloped", meaning the shoreland has been left in its original state.





	**Urbanized**: This type of shoreline has essentially no natural habitat. Areas that are mowed or unnaturally landscaped to the water's edge and areas that are rip-rapped or include a seawall would be placed in this category.
	**Developed-Unnatural**: This category includes shorelines that have been developed, but only have small remnants of natural habitat yet intact. A property with many trees, but no remaining understory or herbaceous layer would be included within this category. Also, a property that has left a small (less than 30 feet), natural buffer in place, but has urbanized the areas behind the buffer would be included in this category.
	**Developed-Semi-Natural**: This is a developed shoreline that is mostly in a natural state. Developed properties that have left much of the natural habitat in state, but have added gathering areas, small beaches, etc within those natural areas would likely fall into this category. An urbanized shoreline that was restored would likely be included here, also.
	**Developed-Natural**: This category includes shorelines that are developed property, but essentially no modifications to the natural habitat have been made. Developed properties that have maintained the natural habitat and only added a path leading to a single pier would fall into this category.
	**Natural/Undeveloped**: This category includes shorelines in a natural, undisturbed state. No signs of anthropogenic impact can be found on these shorelines. In forested areas, herbaceous, understory, and canopy layers would be intact.

Figure 3.3-2. Shoreland assessment category descriptions.

On Crystal Lake, the development stage of the entire shoreland was surveyed during fall of 2018, using a GPS unit to map the shoreland. Onterra staff only considered the area of shoreland 35 feet inland from the water's edge, and did not assess the shoreland on a property-by-property basis. During the survey, Onterra staff examined the shoreland for signs of development and assigned areas of the shoreland one of the five descriptive categories in Figure 3.3-2.

Crystal Lake has stretches of shoreland that fit all of the five shoreland assessment categories. In all, 2.0 miles of natural/undeveloped and developed-natural shoreland were observed during the survey (Figure 3.2-3). These shoreland types provide the most benefit to the lake and should be left in their natural state if at all possible. During the survey, 0.3 miles of urbanized and developed–unnatural shoreland were observed. If restoration of the Crystal Lake shoreland is to occur, primary focus should be placed on these shoreland areas as they currently provide little benefit to, and actually may harm, the lake ecosystem. Map 3 displays the location of these shoreland lengths around the entire lake.

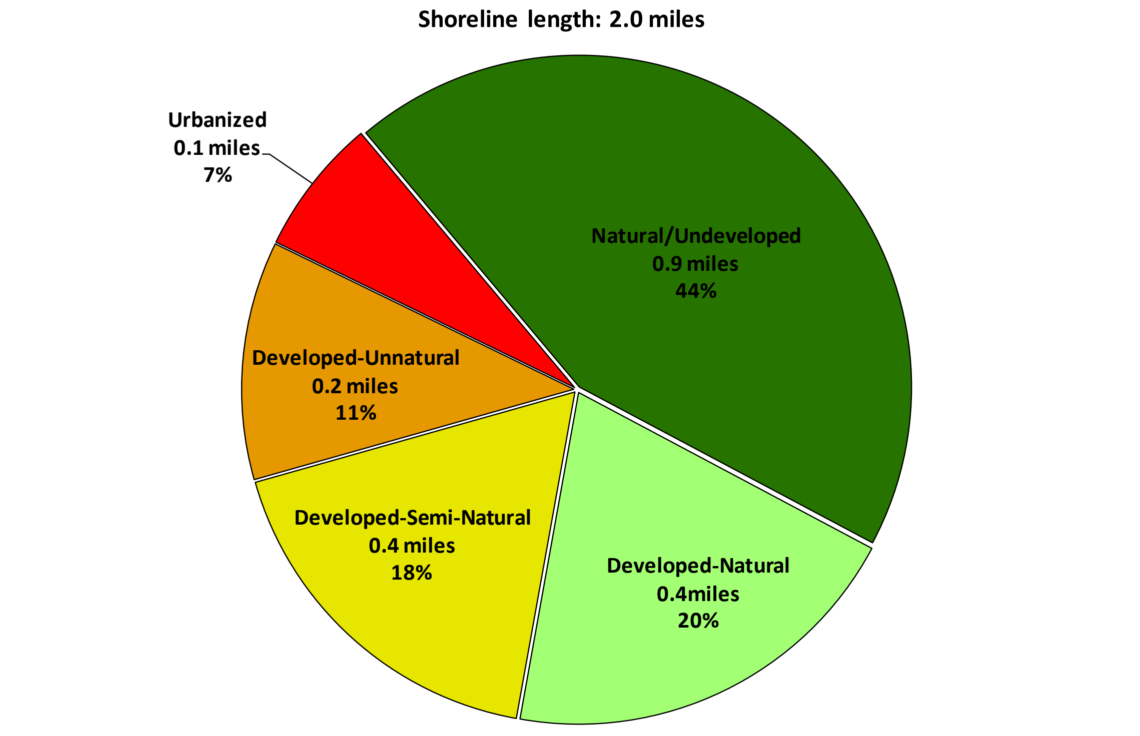


Figure 3.3-3. Crystal Lake shoreland categories and total lengths. Based upon a Fall 2018 survey. Locations of these categorized shorelands can be found on Map 3.

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

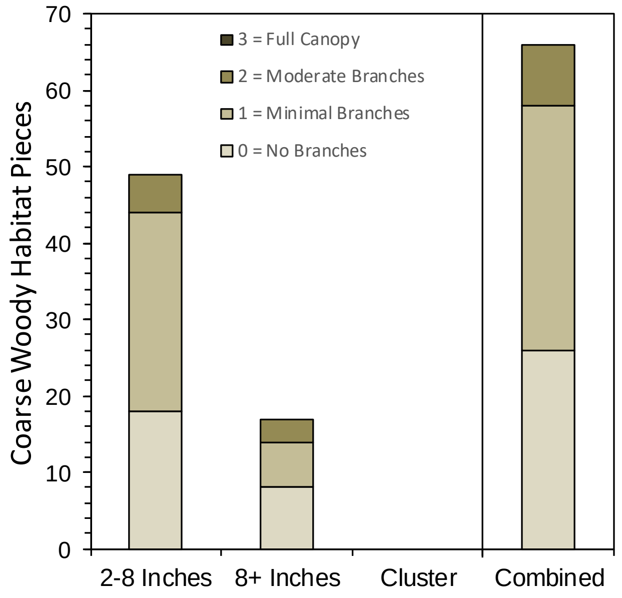
Coarse Woody Habitat

As part of the shoreland condition assessment, Crystal Lake was also surveyed to determine the extent of its coarse woody habitat. Coarse woody habitat was identified, and classified in three size categories (2-8 inches in diameter, 8+ inches in diameter, or clusters of pieces) as well as four branching categories: no branches, minimal branches, moderate branches, and full canopy. As discussed earlier, research indicates that fish species prefer some branching as opposed to no branching on coarse woody habitat, and increasing complexity is positively correlated with higher fish species richness, diversity and abundance (Newbrey et al. 2005).

During this survey, 66 total pieces of coarse woody habitat were observed along 2.0 miles of shoreline (Map 4), which gives Crystal Lake a coarse woody habitat to shoreline mile ratio of 33:1 (Figure 3.3-4). Only instances where emergent coarse woody habitat extended from shore into the water were recorded during the survey. 49 pieces of 2-8 inches in diameter pieces of coarse woody habitat were found, 17 pieces of 8+ inches in diameter pieces of coarse woody habitat were found, and no instances of clusters of coarse woody habitat were found.

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). Please note the methodologies between the surveys done on Crystal Lake and those cited in this literature comparison are much different, but still provide a valuable insight into what undisturbed shorelines may have in terms of coarse woody habitat.

Onterra has completed coarse woody habitat surveys on 98 lakes throughout Wisconsin since 2012, with the majority occurring in the NLFL ecoregion on lakes with public access. The number of coarse woody habitat pieces per shoreline mile in Crystal Lake falls within the 68th percentile of these 98 lakes. (Figure 3.3-4).



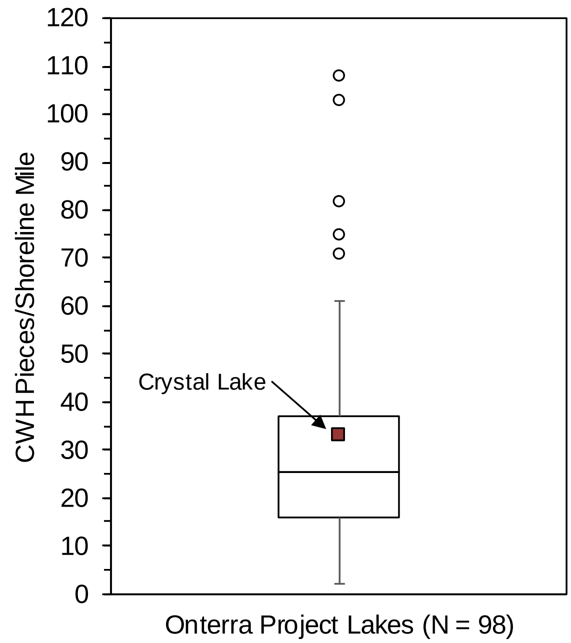
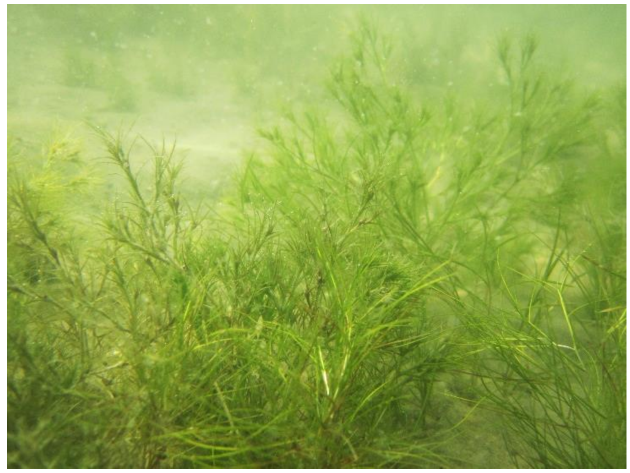


Figure 3.3-4. Crystal Lake coarse woody habitat survey results. Based upon a Fall 2018 survey. Locations of the Crystal Lake coarse woody habitat can be found on Map 4.

3.4 Aquatic Plants

Introduction

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



Photograph 3.4-1. 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. For instance, wild celery (*Vallisneria americana)* and wild rice (*Zizania aquatica* and *Z. palustris*) both serve as excellent food sources for ducks and geese. Emergent stands of vegetation provide necessary spawning habitat for fish such as northern pike (*Esox lucius*) and yellow perch (*Perca flavescens*). In addition, many of the insects that are eaten by young fish rely heavily on aquatic plants and the periphyton attached to them as their primary food source. The plants also provide cover for feeder fish and zooplankton, stabilizing the predator-prey relationships within the system. Furthermore, rooted aquatic plants prevent shoreland erosion and the resuspension of sediments and nutrients by absorbing wave energy and locking sediments within their root masses. In areas where plants do not exist, waves can resuspend bottom sediments decreasing water clarity and increasing plant nutrient levels that may lead to algae blooms. Lake plants also produce oxygen through photosynthesis and use nutrients that may otherwise be used by phytoplankton, which helps to minimize nuisance algal blooms.

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

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

Aquatic Plant Management and Protection

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

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

Permits

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

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

Manual Removal

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

Manual removal methods include hand-pulling, raking, and hand-cutting. Hand-pulling involves the manual removal of whole plants, including roots, from the area of concern and disposing them out of the waterbody. Raking entails the removal of partial and whole plants from the lake by dragging a rake with a rope tied to it through plant beds. Specially designed rakes are available from commercial sources or an asphalt rake can be used. Hand-cutting differs from the other two manual methods because the entire plant is not removed, rather the plants are cut similar to mowing a lawn; however, Wisconsin law states that all plant fragments must be removed.

Manual removal or hand-harvesting of aquatic invasive species has gained favor in recent years as an alternative to herbicide control programs. Professional hand-harvesting firms can be contracted for these efforts and can either use basic snorkeling or scuba divers, whereas others might employ the use of a Diver Assisted Suction Harvest (DASH) which involves divers removing plants and feeding them into a suctioned hose for delivery to the deck of the harvesting vessel. The DASH methodology is considered a form of mechanical harvesting and thus requires a WDNR approved permit. DASH is thought to be more efficient in removing target plants than divers alone and is believed to limit fragmentation during the harvesting process.

Cost

Contracting aquatic invasive species removal by a third-party firm can cost approximately $1,000 per day for traditional hand-harvesting methods whereas the costs can be closer to $2,000 or higher when DASH technology is used. Additional disposal, travel, and permitting fees may also apply.

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

Bottom Screens

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

Cost

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

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

Water Level Drawdown

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

Cost

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

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

Mechanical Harvesting


Photograph 3.4-3. Mechanical harvester.

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

Cost

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

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

Herbicide Treatment

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

Photograph 3.4-4. Granular herbicide application.

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

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

Aquatic herbicides can be classified in many ways. Organization of this section follows Netherland (2009) in which mode of action (i.e. how the herbicide works) and application techniques (i.e. foliar or submersed treatment) group the aquatic herbicides. Table 3.4-1 provides a general list of commonly used aquatic herbicides in Wisconsin and is synthesized largely from Netherland (2009).

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

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

Table 3.4-1. Common herbicides used for aquatic plant management.

	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; invasive watermilfoil control when mixed with auxin herbicides
		Diquat	Inhibits photosynthesis & destroys cell membranes	Nusiance species including duckweeds, targeted AIS control when exposure times are low
		Flumioxazin	Inhibits photosynthesis & destroys cell membranes	Nusiance species, targeted AIS control when exposure times are low
Systemic	Auxin Mimics	2,4-D	auxin mimic, plant growth regulator	Submersed species, largely for invasive watermilfoil
		Triclopyr	auxin mimic, plant growth regulator	Submersed species, largely for invasive watermilfoil
		Florpyrauxifen -benzyl	arylpicolinate auxin mimic, growth regulator, different binding afinity than 2,4-D or triclopyr	Submersed species, largely for invasive watermilfoil
	In Water Use Only	Fluridone	Inhibits plant specific enzyme, new growth bleached	Submersed species, largely for invasive watermilfoil
	Enzyme Specific (ALS)	Penoxsulam	Inhibits plant-specific enzyme (ALS), new growth stunted	Emergent species with potential for submergent and floating-leaf species
		Imazamox	Inhibits plant-specific enzyme (ALS), new growth stunted	New to WI, potential for submergent and floating leaf species
	Enzyme Specific (foliar use only)	Glyphosate	Inhibits plant-specific enzyme (ALS)	Emergent species, including purple loosestrife
		Imazapyr	Inhibits plant-specific enzyme (EPSP)	Hardy emergent species, including common reed

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

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

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

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

Cost

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

Advantages	***Disadvantages***
• Herbicides are easily applied in restricted areas, like around docks and boatlifts. • Herbicides can target large areas all at once. • If certain chemicals are applied at the correct dosages and at the right time of year, they can selectively control certain invasive species, such as Eurasian 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 people adamantly object to the use of herbicides in the aquatic environment; therefore, all stakeholders should be included in the decision to use them. • Many aquatic herbicides are nonselective. • Some herbicides have a combination of use restrictions that must be followed after their application. • Overuse of same herbicide may lead to plant resistance to that herbicide.

Biological Controls

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

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

Cost

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

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

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

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

Cost

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

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

Analysis of Current Aquatic Plant Data

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

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

Primer on Data Analysis & Data Interpretation

Species List

The species list is simply a list of all of the aquatic plant species, both native and non-native, that were located during the surveys completed in Crystal Lake in 2005-2018. 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 aquatic plant 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 survey completed on Crystal Lake, plant samples were collected from plots laid out on a grid that covered the lake. Using the data collected from these plots, an estimate of occurrence of each plant species can be determined. The occurrence of aquatic plant species is displayed as the *littoral frequency of occurrence*. Littoral frequency of occurrence is used to describe how often each species occurred in the plots that are within the maximum depth of plant growth (littoral zone), and is displayed as a percentage.

Floristic Quality Assessment

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

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

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

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

Species Diversity

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

An aquatic system with high species diversity is more stable than a system with a low diversity. This is analogous to a diverse financial portfolio in that a diverse aquatic plant community can withstand environmental fluctuations much like a diverse portfolio can handle economic fluctuations. A lake with a diverse plant community is also better suited to compete against exotic infestations than a lake with a lower diversity. However, in a recent study of 1,100 Minnesota lakes, researchers concluded that more diverse communities were not more resistant or resilient to invaders (Muthukrishnan et al. 2018). The diversity of a lake's aquatic plant community is determined using the Simpson's Diversity Index (1-D):

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

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

If a lake has a diversity index value of 0.90, it means that if two plants were randomly sampled from the lake there is a 90% probability that the two individuals would be of a different species. The Simpson's Diversity Index value from Crystal Lake 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.

Community Mapping

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

Exotic Plants

Because of their tendency to upset the natural balance of an aquatic ecosystem, exotic species are paid particular attention to during the aquatic plant surveys. Two exotics, curly-leaf pondweed and Eurasian watermilfoil are the primary targets of this extra attention.

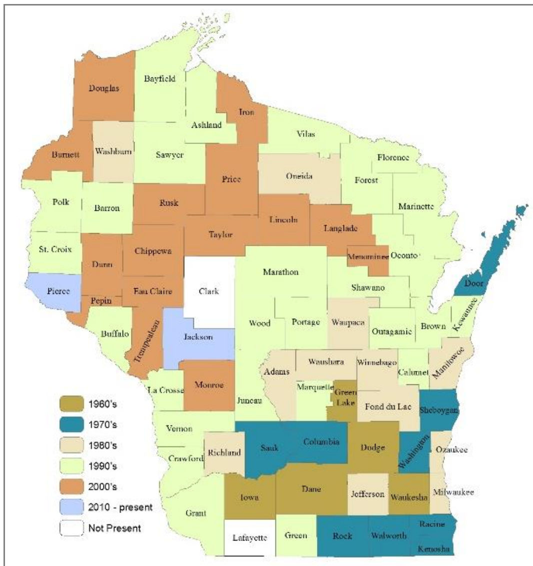


Figure 3.4-1. Spread of Eurasian watermilfoil within WI counties. WDNR Data 2015 mapped by Onterra.

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

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

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

Crystal Lake Aquatic Plant Survey Results

Since 2005, a number of aquatic plant surveys have been completed on Crystal Lake. Whole-lake aquatic plant point-intercept surveys have been completed on Crystal Lake by the WDNR in 2005, and 2007-2015 as a part of a WDNR long-term research project. Additional surveys were completed by Golden Sands Resource Conservation and Development Council, Inc. (RC&D) in 2016-2017, and by Onterra in 2018 as a part of the management planning project. The survey completed in 2018 during the management planning project is the focus of much of the detailed portions of this section. In addition to point-intercept surveys, Onterra also completed a survey in 2018 to assess Crystal Lake's emergent and floating-leaf aquatic plant communities. Onterra completed an Early Season AIS Survey in June 2018 on Crystal Lake to search the lake for any occurrences of CLP or pale-yellow iris, during which neither species were located.

Important Note:
While the majority of the aquatic plant studies completed as a part of the management planning project took place during 2018, a 2019 point-intercept survey was completed before this plan was finalized. The results of the 2019 plant survey are integrated into this section as appropriate.

Over the course of the surveys from 2005-2019, a total of 29 aquatic plant species were located in or along the margins of Crystal Lake (Table 3.4-2). Three genera of emergent plants (*Carex*, *Sagittaria*, and *Typha*) were only identified to genus level in some of the surveys whereas in other years, these plants were identified to species level. Two species are considered to be non-native, invasive species: Hybrid/Eurasian water milfoil and reed canary grass. Hybrid Eurasian watermilfoil (HWM), a cross between the non-native Eurasian watermilfoil (*Myriophyllum spicatum*, EWM) and the native northern watermilfoil (*Myriophyllum sibiricum)*, was confirmed through genetical analysis in Crystal Lake in 2004. Without an exhaustive and systematic study of hybridity on Crystal Lake, it cannot be understood if the entire invasive watermilfoil population is comprised of HWM or a mix of EWM and HWM biotypes. Unless specifically indicated, this report will use "HWM" when discussing the invasive watermilfoil (EWM and HWM) population of Crystal Lake.

Lakes in Wisconsin vary in their morphology, water chemistry, substrate composition, and recreational use, and all of these factors influence aquatic plant community composition. Like terrestrial plants, different aquatic plant species are adapted to grow in certain substrate types; some species are only found growing in soft substrates, others only in sandy/rocky areas, and some can be found growing in either. The combination of both soft sediments and areas of harder substrates creates different habitat types for aquatic plants, and generally leads to a higher number of aquatic plant species within the lake.

During the point-intercept surveys, information regarding substrate type were collected at locations sampled with a pole-mounted rake (less than 15 feet). All of the 2018 sampling locations that were 15' or less, were found to have a sandy substrate (Figure 3.4-2). Softer substrates may have been present in deeper portions of the littoral zone; however, substrate composition was not evaluated beyond the reach of the 15-foot survey pole.

Table 3.4-2. Aquatic plant species located on Crystal Lake during 2005-2019 surveys.

Growth Form	Scientific Name	Common Name	Coefficient of Conservatism (C)	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Emergent	*Carex* sp.	Sedge sp.	N/A					I									
	Carex histericina	Porcupine sedge	N/A													I	
	Decodon verticillatus	Water-willow	7	I	I		I	I	I	I	I			X		I	I
	Eleocharis palustris	Creeping spikerush	6					I									
	Equisetum fluviatile	Water horsetail	7					I			I						
	Phalaris arundinaceae	Reed canary grass	Exotic					I								I	
	Sagittaria latifolia	Common arrowhead	3					I								I	
	Sagittaria sp.	Arrowhead sp.	N/A						I	I	I			I			I
	Schoenoplectus tabernaemontani	Softstem bulrush	4													I	
	Typha latifolia	Broad-leaf cattail	1	I													
	Typha sp.	Cattail sp.	1		I			I		I	I					I	
FL	*Nuphar variegata*	Spatterdock	6											I	I	I	I
	Nymphaea odorata	White water lily	6	X	X	X	X	X	X	X	X	X		I	I	I	X
Submergent	*Ceratophyllum demersum*	Coontail	3	X	X	X	X	X	X	X		X	X	X	X		X
	Chara spp.	Muskgrasses	7	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Myriophyllum sibiricum	Northern watermilfoil	7	X										I	I		I
	Myriophyllum spicatum x sibiricum	Hybrid watermilfoil	Exotic	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Najas flexilis	Slender naiad	6	X	X	X	X	X	X	X	X	X	I	X	X	X	X
	Najas guadalupensis	Southern naiad	7												I		
	Nitella spp.	Stoneworts	7														X
	Potamogeton amplifolius	Large-leaf pondweed	7	X													X
	Potamogeton friesii	Frie's pondweed	8	X			X		X		X	X		X	X	X	X
	Potamogeton gramineus	Variable-leaf pondweed	7	X	X	X	X	X	X	X	X	X		X	X	X	X
	Potamogeton illinoensis	Illinois pondweed	6	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Potamogeton natans	Floating-leaf pondweed	5	I	X	I	X	X	X	I	I	I	X	X	X	I	I
	Potamogeton X *scoliophyllus*	Large-leaf X Illinois pondweed	N/A		X												
	Potamogeton zosteriformis	Flat-stem pondweed	6			X								X	X	X	
	Stuckenia pectinata	Sago pondweed	3	X	X	X	X	X	X	X	X	X	X	I	X	X	X
	Utricularia vulgaris	Common bladderwort	7	I										I	I		X
	Vallisneria americana	Wild celery	6	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S/E	*Eleocharis acicularis*	Needle spikerush	5							I				X		X	
FF	*Lemna minor*	Lesser duckweed	5	X	X			I	I	I		X		X	I		I
	Spirodela polyrhiza	Greater duckweed	5						I						I		X

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

Of the 98 point-intercept sampling locations that were shallower than the maximum depth of plant growth in 2018 (the littoral zone), approximately 86% contained aquatic vegetation (Figure 3.4-3). Figure 3.4-3 also displays the locations of all of the sampling points from the 2018 survey including the total rake fullness that was documented at each of the points. Aquatic plant rake fullness data collected in 2018 indicates that 32% of the 98 littoral sampling locations contained vegetation with a total rake fullness rating (TRF) of 1, 17% had a TRF rating of 2, and 37% had a TRF rating of 3 (Figure 3.4-3). A small area on the far western end of the lake was non-navigable at the time of the survey due to a combination of shallow water depths and large floating masses of aquatic vegetation largely comprised of muskgrasses.

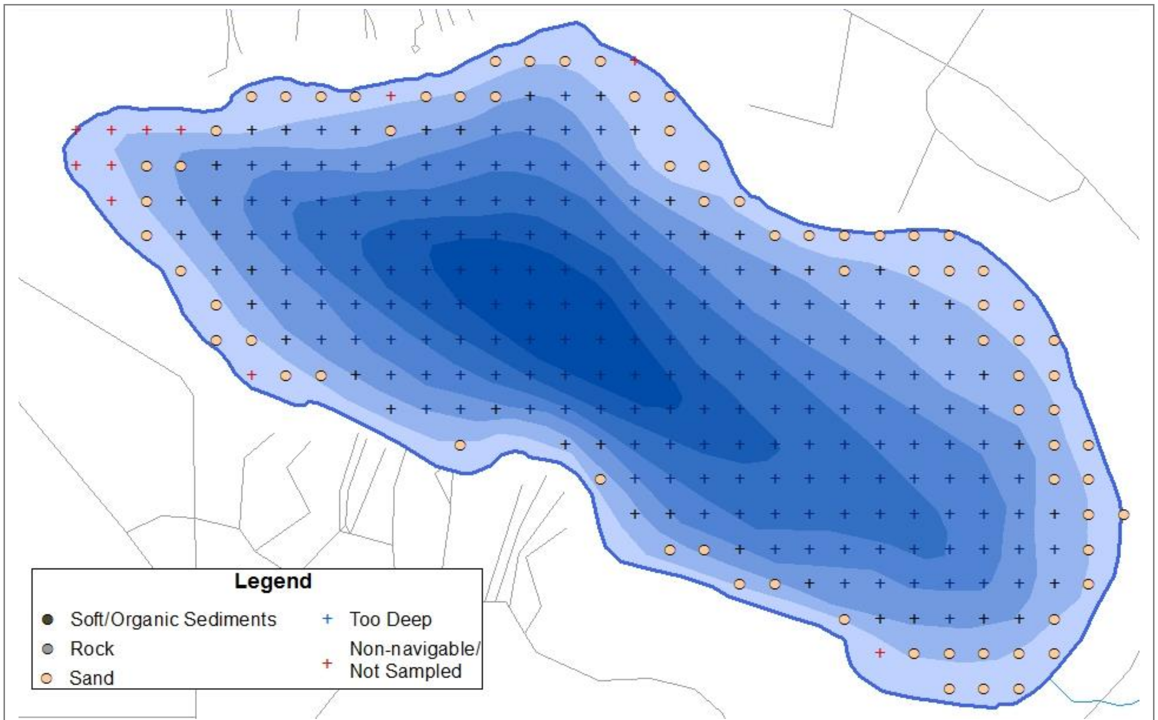


Figure 3.4-2. Crystal Lake 2018 substrate types. Please note sediment data were only recorded at locations ≤ 15 feet. Created using data from 2018 point-intercept survey.

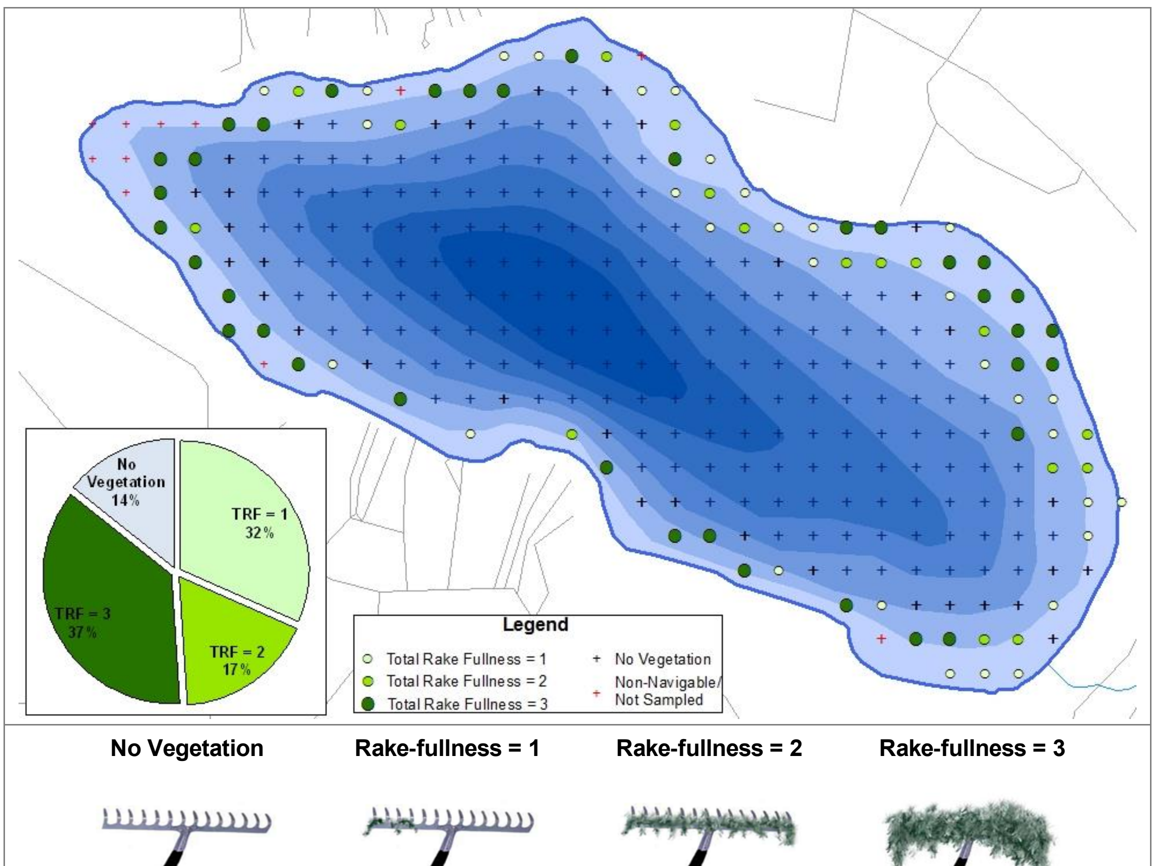


Figure 3.4-3. Crystal Lake 2018 vegetation distribution and total rake fullness ratings. Created using data from 2018 point-intercept survey.

Aquatic plants were found growing to a maximum depth ranging from 24 to 31 feet in past surveys and were found out to 26 feet in the 2018 survey (Figure 3.4-4). As is discussed within the Water Quality Section (3.1), Crystal Lake has high water clarity which allows sunlight to penetrate further into the water column and support aquatic plant growth at deeper depths. The maximum depth of plant growth in 2018 was consistent with previous surveys and there has been little variability in the maximum depth of plant growth dating back to 2007.

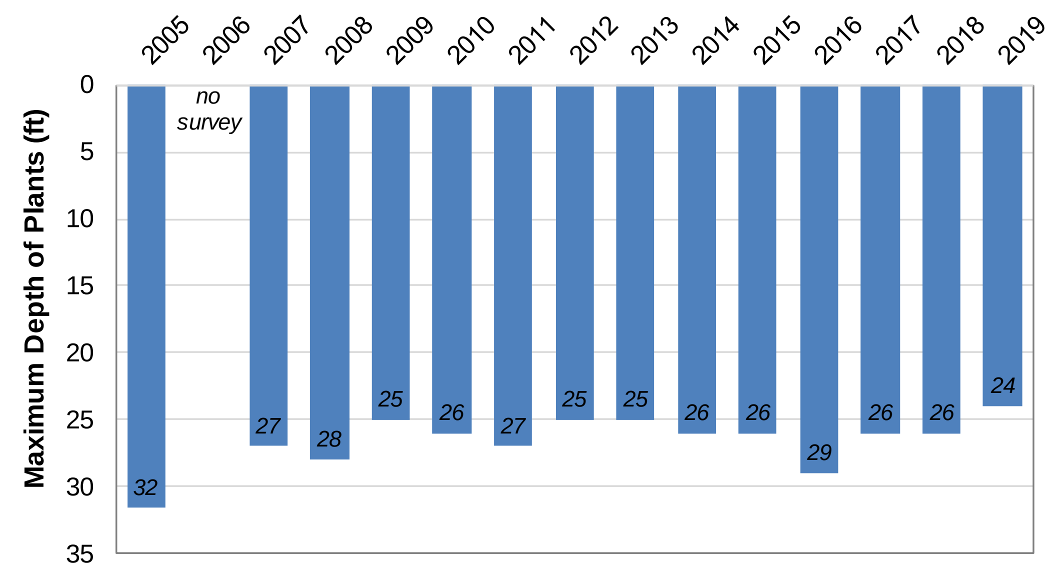


Figure 3.4-4. Crystal Lake maximum depth of plant growth. Created using data from 2005-2019 aquatic plant surveys.

Aquatic plants can be placed in one of two general groups, based upon their form of growth and habitat preferences. These groups include the isoetid growth form and the elodeid growth form. Crystal Lake has both isoetid and elodeid species within its waters. Plants of the isoetid growth form are small, slow growing, and inconspicuous submerged plants. They often have evergreen leaves located in a rosette and are usually found growing in sandy soils within the near-shore areas of a lake (Boston and Adams 1987, Vestergaard and Sand-Jensen 2000). Submersed species of the elodeid growth form have leaves on tall, erect stems which grow upwards into the water column. Examples of common elodeid species that are present in Crystal Lake include slender naiad, wild celery and Fries' pondweed.

Alkalinity is the primary water chemistry factor determining whether a lake is dominated by plant species of the isoetid or elodeid growth form (Vestergaard and Sand-Jensen 2000). Most elodeids are restricted to lakes of relatively higher alkalinity, as their carbon demand for photosynthesis cannot be met solely by the dissolved carbon dioxide (CO_2) present in the water, and they must acquire additional carbon through bicarbonate (HCO_3^-). While isoetids are able to grow in lakes of higher alkalinity, their short stature makes them poor competitors for light, and they are usually outcompeted and displaced by the taller elodeids. Thus, isoetids are most prevalent in lakes of low alkalinity where they can avoid competition from elodeids.

Of the 29 aquatic plant species that have been located in Crystal Lake since 2005, ten species were physically encountered on the survey rake during the 2018 point-intercept survey (Figure 3.4-5). Additional species were located incidentally, meaning they were observed by Onterra ecologists while on the lake but they were not directly sampled on the rake at any of the point-intercept sampling locations. Incidental species typically include emergent and floating-leaf species that are often found growing on the fringes of the lake, and submersed species that are relatively rare within the plant community. Field data collected during the 2018 point-intercept survey can be found in Appendix E.

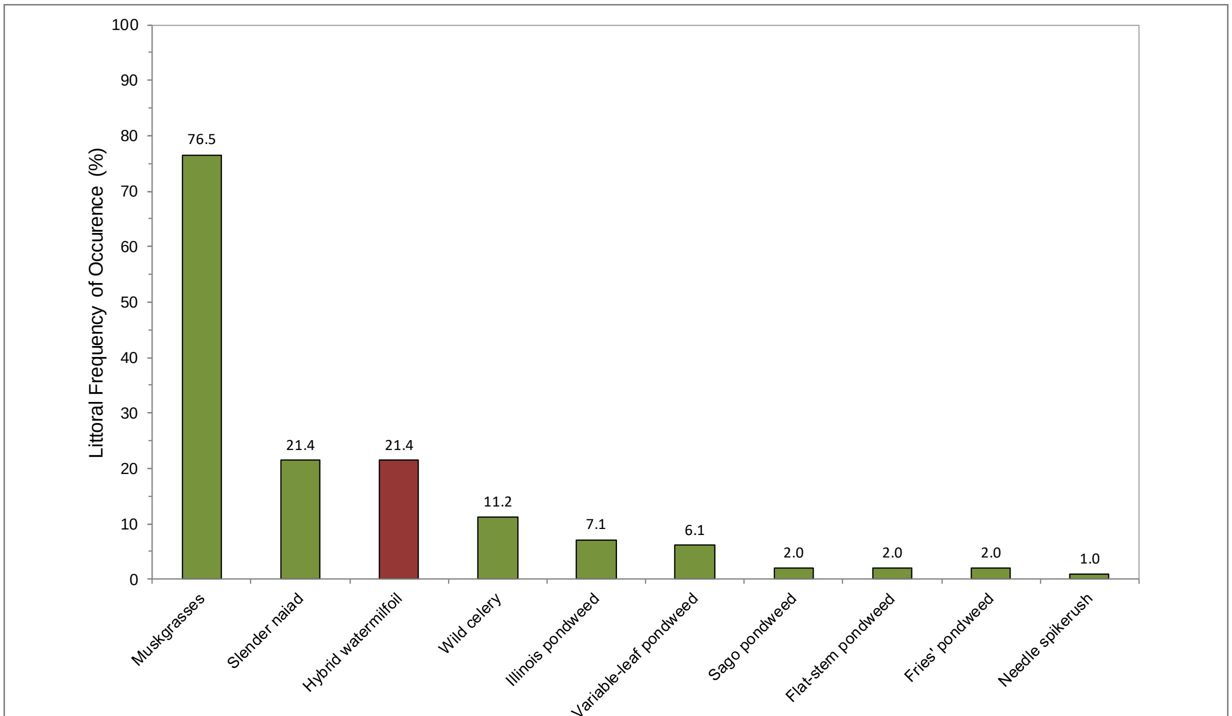


Figure 3.4-5. Crystal Lake aquatic plant littoral frequency of occurrence. Created using data from July 2018 point-intercept survey.

Photograph 3.4-5. A submersed colony of the aquatic macroalgae muskgrasses in Crystal Lake (Chara spp.). Photo credit Onterra.

Muskgrasses are a genus of macroalgae represented by seven species in Wisconsin (Photograph 3.4-5). Muskgrasses are typically common in hardwater lakes like Crystal Lake. These macroalgae have been found to more competitive against vascular plants (e.g. pondweeds, watermilfoils, etc.) in lakes with higher concentrations of calcium carbonate in the sediment (Kufel and Kufel 2002; Wetzel 2001). Muskgrasses require lakes with good water clarity, and their large beds stabilize bottom sediments. They are grey to green colored and grow in large clumps in shallow to deep water. When growing in hard, mineral rich water, muskgrasses sometimes become coated with lime, giving them a rough, “gritty” feel. They are easily identified by their strong skunk-like or garlic odor. As well as providing a food source for waterfowl, muskgrasses often serves as a sanctuary for small fish and other aquatic organisms. Studies have also shown that muskgrasses sequester phosphorus in the calcium carbonate incrustations which from on these plants, aiding in improving water quality by making the phosphorus unavailable to phytoplankton (Coops 2002). In Crystal Lake, muskgrasses were abundant throughout the littoral zone, and were the only species observed at depths beyond 20 feet. Muskgrasses were the most commonly located species in Crystal Lake being present at 75 of the 98 sampling sites below the maximum depth of plant growth resulting in a littoral frequency of occurrence of 76.5% (Figure 3.4-5).

Hybrid watermilfoil was present at 21 of the sampling locations in the 2018 point-intercept survey and was tied for the second most abundant species with a littoral frequency of occurrence of 21.4% (Figure 3.4-5). One native watermilfoil species, northern watermilfoil, was recorded as present in the 2005 point-intercept survey. It is possible that what was identified as northern watermilfoil in 2005 may have actually been HWM, as there is a lot of morphological overlap of these two species. As discussed earlier, DNA testing is necessary to distinguish between EWM, HWM, and northern watermilfoil.

Slender naiad is a submersed, annual plant that may reach lengths of 8 feet and was tied for the second-most encountered species in Crystal Lake in the 2018 survey. It is sometimes called bushy pondweed because its small leaves branch out in numerous directions and become stiff and recurved as it ages. Slender naiad can reproduce through fragmentation, however its primary means of reproduction is by seed. The seeds are a valuable food source for waterfowl.

Wild celery, also known as tape or eel grass, was the fourth-most abundant plant in Crystal Lake in 2018 (Figure 3.4-5), and was most abundant between 8 and 14 feet. The long leaves of wild celery provide excellent habitat for aquatic organisms, while its extensive root systems stabilize bottom sediments. Additionally, the leaves, fruits, and winter buds are food sources for numerous species of waterfowl and other wildlife.

As explained above in the Primer on Data Analysis and Data Interpretation Section, the littoral frequency of occurrence analysis allows for an understanding of how often each of the plants is located during the point-intercept survey. Because each sampling location may contain numerous plant species, relative frequency of occurrence is one tool to evaluate how often each plant species is found in relation to all other species found (composition of population). For instance, while slender naiad was found at 21% of the littoral sampling locations in Crystal Lake, its relative frequency of occurrence is 14%. Explained another way, if 100 plants were randomly sampled from Crystal Lake, 14 of them would be slender naiad. Looking at relative frequency of occurrence, muskgrasses dominate the aquatic plant community in Crystal Lake with a 51% occurrence, with slender naiad and hybrid watermilfoil comprising an additional 14% each (Figure 3.4-6).

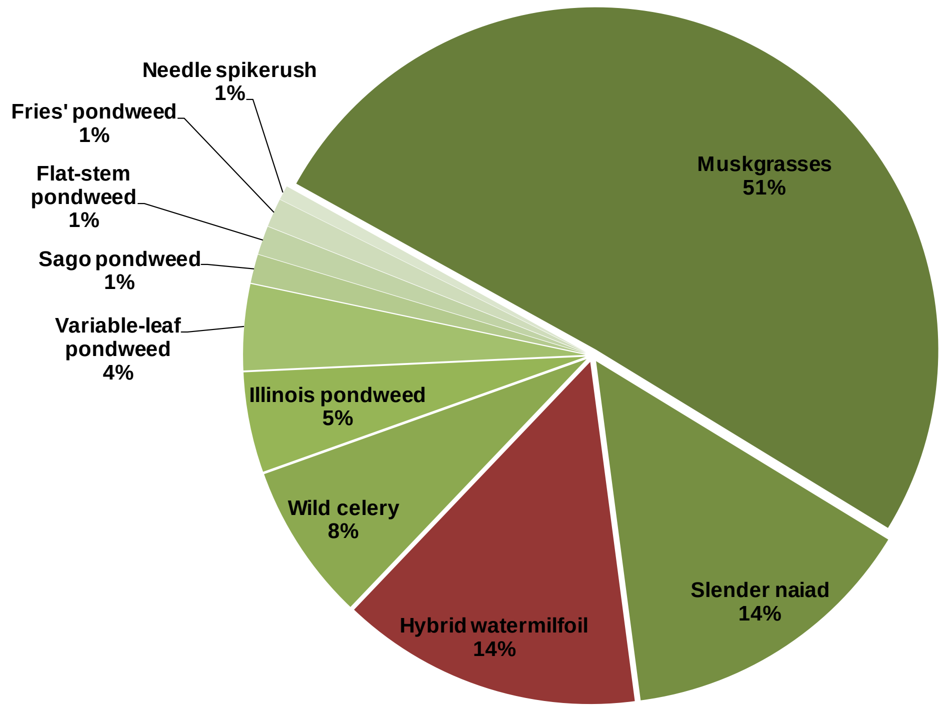


Figure 3.4-6 Crystal Lake relative plant littoral frequency of occurrence. Created using data from July 2018 point-intercept surveys.

As discussed previously, the calculations used for the Floristic Quality Index (FQI) for a lake's aquatic plant community are based on the aquatic plant species that were encountered on the rake during the point-intercept survey and does not include incidental species. For example, while 17 native aquatic plant species were located in Crystal Lake during the 2018 surveys, only nine native species were encountered on the rake during the point-intercept survey. Figure 3.4-7 shows that the native species richness for Crystal Lake is below the North Central Hardwood Forests Ecoregion and Wisconsin State medians.

Data collected from the aquatic plant surveys show that the average conservatism value (5.7) is slightly below the North Central Hardwood Forests Ecoregion and Wisconsin State medians (Figure 3.4-7), indicating that the some of the plant species found in Crystal Lake are considered sensitive to environmental disturbance and their presence signifies good environmental conditions.

Combining Crystal Lake's aquatic plant species richness and average conservatism values to produce its Floristic Quality Index (FQI) results in a value of 17.5 (equation shown below); which is below the median values for the ecoregion and state (Figure 3.4-7).

$$\text{FQI} = \text{Average Coefficient of Conservatism (5.7)} * \sqrt{\text{Number of Native Species (9.5)}}$$
$$\text{FQI} = 17.5$$

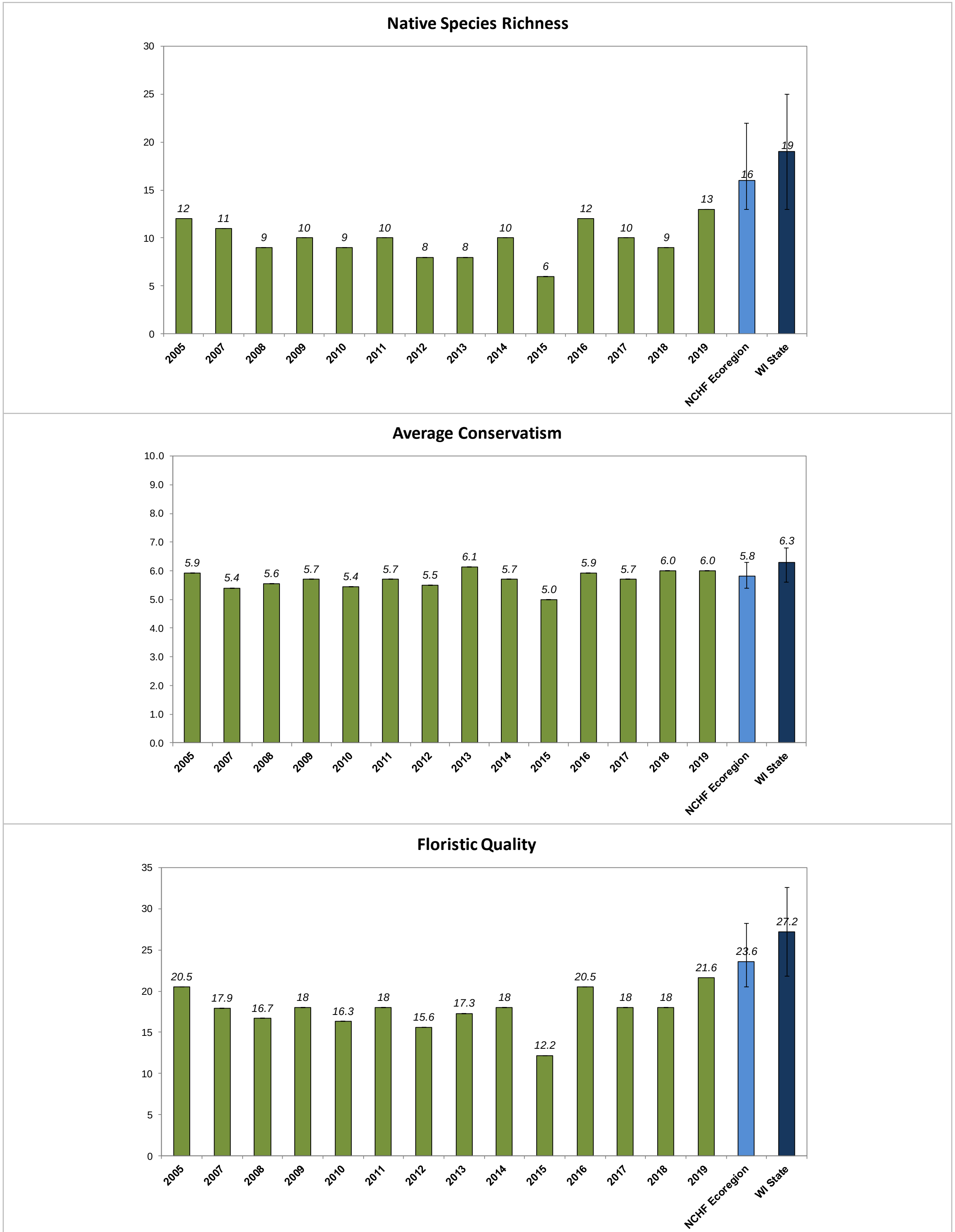


Figure 3.4-7. Crystal Lake Floristic Quality Assessment. Created using data from 2005-2019 whole-lake point-intercept surveys. Regional and state medians calculated with Onterra and WDNR data. Analysis follows Nichols 1999.

Crystal Lake contains a relatively low number of native aquatic plant species, and thus one may assume their aquatic plant communities have low species diversity. However, as discussed earlier, species diversity is also influenced by how evenly the plant species are distributed within the community.

With over half of the plant community being composed of muskgrasses, Crystal Lake does not have an even distribution of plant species and contributes to low diversity. Crystal Lake was found to have a mean Simpson's diversity value of 0.71 from surveys completed between 2005 and 2019 (Figure 3.4-8). This value ranks below state and ecoregion lower quartiles. Lakes with diverse aquatic plant communities are thought to have a higher resilience to environmental disturbances. 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.

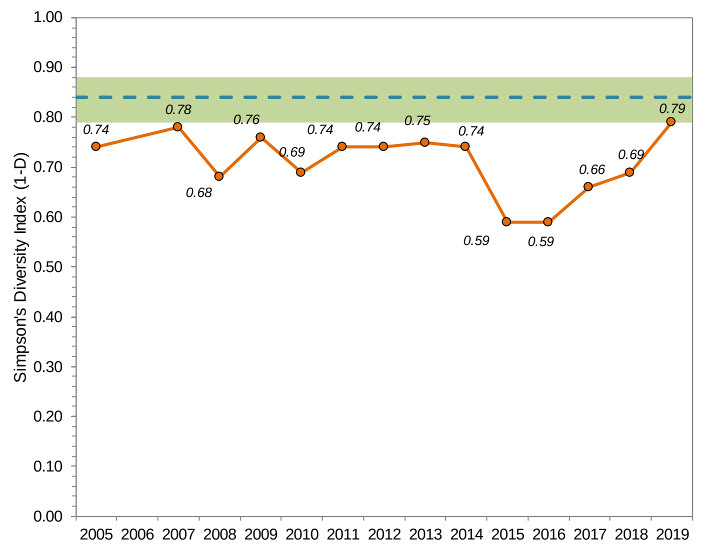


Figure 3.4-8. Crystal Lake species diversity index. Created using data from 2005-2019 aquatic plant surveys. Ecoregion data provided by WDNR Science Services.

The quality of Crystal Lake's plant community is also evaluated by the presence of emergent and floating-leaf plant communities that occur in near-shore areas around the lake. These plant communities are often underrepresented by the point-intercept survey. Therefore, Onterra ecologists conducted an aquatic plant community mapping survey in August 2018 aimed at mapping communities of emergent and floating-leaf vegetation. The 2018 community map indicates that approximately 1.2 acres of the lake's margins contain these types of plant communities (Table 3.4-3 and Map 5). Eight native floating-leaf and emergent species were located on Crystal Lake during the community mapping survey, providing valuable structural habitat for invertebrates, fish, and other wildlife. These communities also stabilize lake substrate and shoreland areas by dampening wave action from wind and watercraft. Reed canary grass, a non-native species was located in two locations on the shores of Crystal Lake. Additional information about reed canary grass is included in later in this section.

Table 3.4-3. Crystal Lake acres of plant community types. Created from August 2018 community mapping survey.

Plant Community	Acres
Emergent	0.2
Floating-leaf	1.0
Mixed Emergent & Floating-leaf	0.0
Total	**1.2**

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

Crystal Lake Aquatic Plant Community Long-Term Trends

Aquatic plant point-intercept datasets from Crystal Lake are available from almost every year between 2005 and 2019. These datasets can be statistically compared to determine if any significant changes in the overall occurrence of vegetation or individual species abundance have occurred over the time period.

Aquatic plant communities are dynamic and the abundance of certain species from year to year can fluctuate depending on climatic conditions, water levels, changes in clarity, herbivory, competition, and disease among other factors. Figure 3.4-9 displays the average number of native aquatic plant species per sampling site from 2005-2019 which has ranged from between 0.8 to 1.7 species per site. Some of the lowest values were observed in 2015-2017.

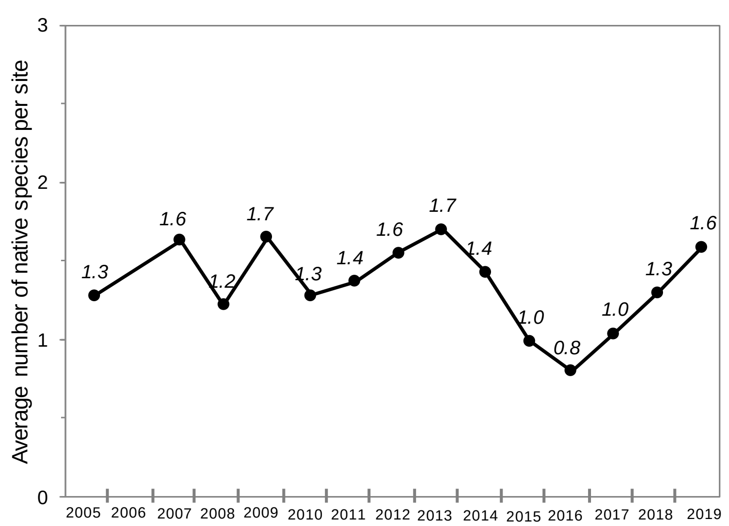


Figure 3.4-9. Average number of native aquatic plant species per sampling site. Created using data from 2005-2019 point-intercept surveys.

In addition to examining changes in the overall occurrence of vegetation in Crystal Lake from 2005 to 2019, changes in the occurrence of individual plant species were also investigated. Submersed aquatic plant species which had a littoral occurrence of at least 5% in one of the 14 surveys were included in this analysis.

Linear regression analysis is a relatively basic way for lake ecologists a way to discover if statistically valid trends (increases or decreases) are occurring. Linear regression analysis generates an equation or line of best fit (regression line) that minimizes the distance between the data points. A statistical measure of how close the measured data are to the regression line is called the r-squared statistic (r^2) and ranges from 0 to 1 (0% to 100%). An r^2 value of 0 indicates that the model does not explain any of the variability in the data (0% of the data), while an r^2 value of 1 indicates that the model explains all of the variability in the data (100% of the data).

In addition to r^2, linear regression analysis also generates a *p*-value, which indicates if time is a significant predictor of change in the plant population (i.e. is a trend occurring). A low *p*-value ($\leq$ 0.05) indicates that a statistically valid change in a parameter has occurred over time, while a larger *p*-value (> 0.05) indicates that a statistically valid change has not occurred.

Of the seven native species that were analyzed for simple linear analysis, four did not exhibit a statistically valid trend over time, one native species exhibited an increasing trend, and two species exhibited a decreasing trend (Figures 3.4-10 and 3.4-11). The littoral occurrences of coontail, muskgrasses, Illinois pondweed, and sago pondweed have fluctuated between years over this time period, but trends in their occurrence over time are not statistically significant (simple linear regression p-value > 0.05).

Two species, slender naiad and variable-leaf pondweed exhibited a statistically valid decreasing trend over this time period (Figure 3.4-10). Slender naiad relies on seed production and propagation and is subject to certain environmental conditions that can favor or inhibit seed viability and growth in any given year. Some environmental factors in Crystal Lake in 2015 resulted in a year in which the littoral occurrence of slender naiad was reduced to 0%. The population remained low in 2016 (1.6%) and was found to be closer to its historical average frequency by 2018 with a 21.4% occurrence. Variable-leaf pondweed also exhibited a decreased occurrence around 2015-2016 and has since rebounded to 8.9% by 2019. Other species in Crystal Lake exhibited statistically valid decreases in occurrence between 2014-2015 as well and it is not known what factors may be responsible for the declines during this time period. Regional climactic conditions in 2015 led to documented declines in aquatic vegetation, including many unmanaged EWM populations, in many lakes in Wisconsin (Nault 2016).

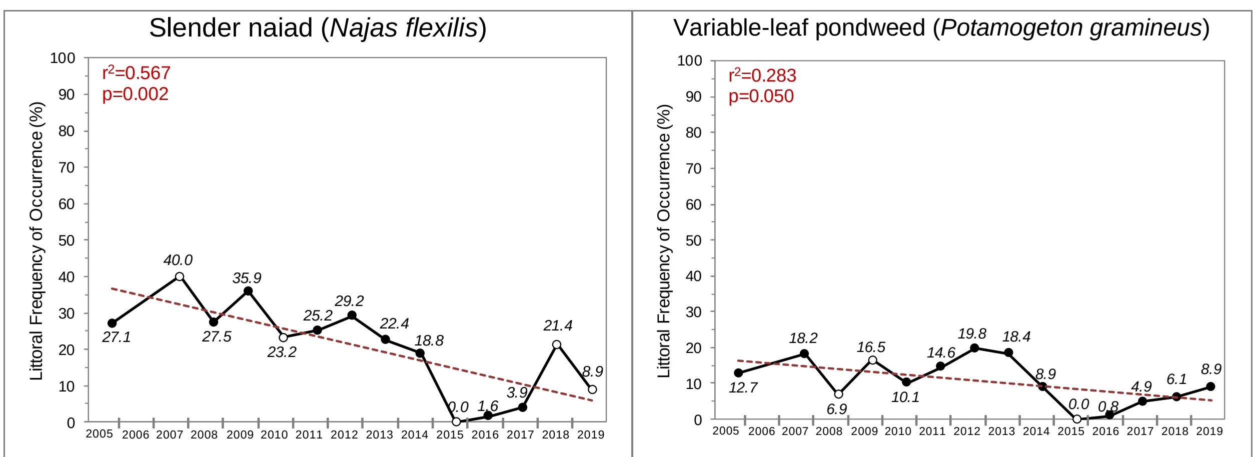


Figure 3.4-10. Littoral frequency of occurrence of native aquatic plant species that exhibited a statistically valid declining trend in occurrence from 2005-2019. Open circle represents statistically valid change from previous survey. (Chi-Square α = 0.05). Species which had an LFOO of at least 5% in one of the surveys are displayed. Red dashed line represents statistically valid trendline based on linear regression analysis.

Wild celery (*Vallisneria americana*), is the only aquatic plant species in Crystal Lake that exhibited a statistically valid increasing trend over this time period. Wild celery exhibited its highest littoral frequency of occurrence in the most recent survey in 2019 at 14.4%.

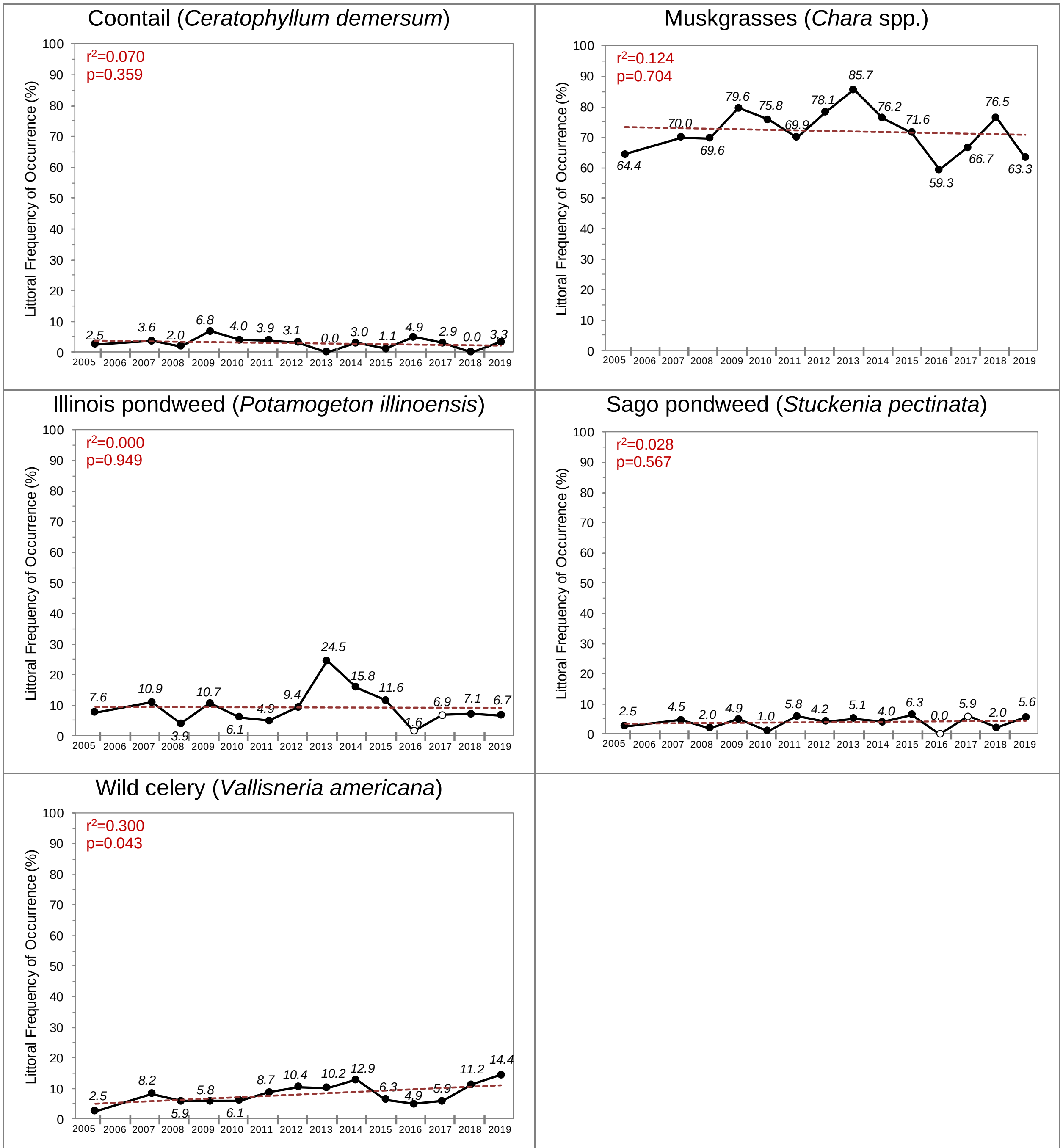


Figure 3.4-11. Littoral frequency of occurrence of select native aquatic plant species from 2005-2018. Open circle represents statistically valid change from previous survey. (Chi-Square α = 0.05). Species which had an LFOO of at least 5% in one of the surveys are displayed. Red dashed line represents trendline based linear regression analysis.

Non-Native Aquatic Plants in Crystal Lake

Hybrid Eurasian Watermilfoil

Hybrid Eurasian watermilfoil, a cross between the non-native Eurasian watermilfoil (*Myriophyllum spicatum*) and the native northern watermilfoil (*Myriophyllum sibiricum)*, was confirmed in Crystal Lake in 2004 through a DNA analysis.

The concept of heterosis, or hybrid vigor, is important in regards to hybrid water milfoil management in Crystal Lake. The root of this concept is that hybrid individuals typically have improved function compared to their pure-strain parents. Hybrid water-milfoil typically has thicker stems, is a prolific flowerer, and grows much faster than pure-strain EWM (LaRue et al. 2012). These conditions likely contribute to this plant being particularly less susceptible to biological (Enviroscience personal comm.) and chemical control strategies (Glomski and Netherland 2010, Poovey et al. 2007). In a recent study of 28 large-scale 2,4-D amine treatments in Wisconsin (Nault et al. 2017), HWM initial control was less and the longevity was shorter than pure-strain EWM control projects. Therefore, it appears that potentially most strains of HWM, but not all, are more tolerant of auxin-mimic herbicide treatments (e.g. 2,4-D, triclopyr) than pure-strain EWM.

The littoral occurrence of HWM from 2005-2019 has ranged from 14.4% to 27.7% (Figure 3.4-12). The lowest occurrence was found during the first point-intercept survey in 2005, while the highest occurrence was found in 2014. Overall, the littoral frequency of occurrence of HWM has been stable over the period of monitoring with an average occurrence of 19.7%. In 2018, the occurrence was 21.4%, or slightly above the average from all previous surveys. Continued monitoring in 2019 found the littoral frequency of EWM to be 26.7%. A linear regression analysis shows that there is not a statistically valid increasing or decreasing trend in the HWM population over the period of monitoring through 2019. This suggests that the HWM population of Crystal Lake has remained almost unchanged since 2005 in a period when no active management has occurred.

Hybrid watermilfoil (*Myriophyllum spicatum X Myriophyllum sibiricum*)

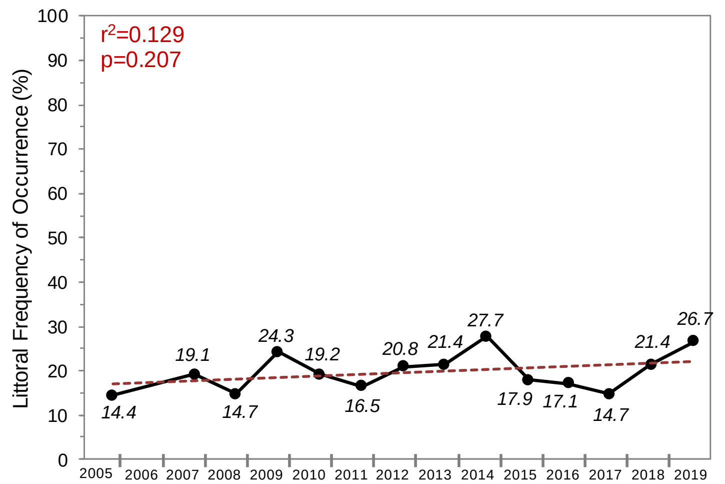


Figure 3.4-12. Littoral frequency of occurrence of Hybrid watermilfoil in Crystal Lake from 2005-2019. Open circle indicates a statistically valid change in occurrence from the previous survey (Chi-Square α = 0.05). Red dashed line represents trendline based on linear regression analysis.

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. Crystal Lake is one of the unmanaged systems within this study.

Like other aquatic plants, EWM populations are 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 3.4-13 shows the EWM populations of three unmanaged EWM lakes in the Northern Central Hardwood Forests ecoregion. To clarify, these lakes have not conducted herbicide treatments or any other forms of strategic EWM management. The EWM population of Montana Lake (Oconto-Marinette counties) has been variable over time, whereas the EWM population of Crystal Lake (Marquette County) has been very stable at around 20% during the timeframe of study. After first being detected in 2005, the EWM population of Crooked Lake (Adams County) was below 3% for at least 10 years, and then increased to 7.4% in 2019 after being in the lake for 14 years.

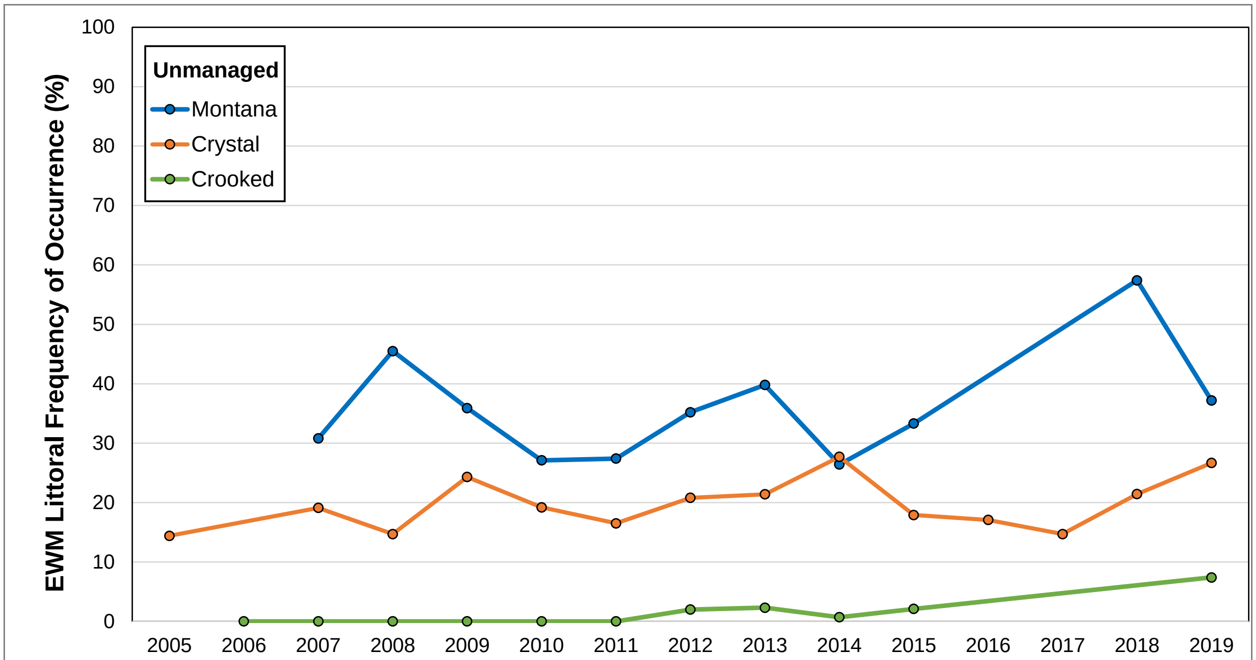


Figure 3.4-13. Littoral frequency of occurrence of Unmanaged EWM populations in the Northern Central Hardwood Forests ecoregion. Data provided by and used with permission from WDNR.

The Science Behind the "So-Called" Super Weed (Nault 2016)

In 2015, the WDNR investigated the most recent point-intercept data from almost 400 Wisconsin Lakes that had confirmed EWM populations. These data show that approximately 65% of these lakes had EWM populations of 10% or less (Figure 3.4-14). At these low population levels, there is not likely to be impacts to recreation and navigation, nor changes in ecological function. At the time of this writing, Crystal Lake's most recent point-intercept survey (2019) yielded EWM at 26.7% of the littoral sampling locations. Only approximately 15% of the lakes in the survey had EWM populations of 30% or higher. This may be due to the fact that the EWM population on some lakes may never reach that level or that management activities may have been enacted to suppress the EWM population to lower levels.

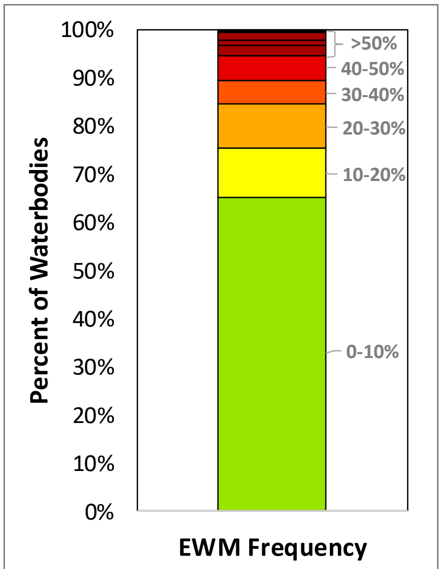


Figure 3.4-14. EWM littoral frequency of occurrence in 397 WI lakes with EWM populations. Data provided by and used with permission from WDNR.

While the point-intercept survey is a valuable tool to understand the overall plant population of a lake, it does not offer a full account (census) of where a particular species exists in the lake. The data is also not at a fine-enough scale to direct management actions (i.e. targeted hand-harvesting and/or herbicide spot treatment). As the name implies, the HWM Peak-Biomass Survey is a meander-based mapping survey conducted when the plant is at its peak growth stage (late-summer), allowing for a true assessment of the amount of this exotic within the lake. HWM occurrences were mapped using either 1) point-based or 2) area-based methodologies. Large colonies >40 feet in diameter were mapped using polygons (areas) and would be qualitatively assigned a density rating based upon a five-tiered scale from *highly scattered* to *surface matting*. Point-based techniques were applied to locations considered as *small plant colonies* (<40 feet in diameter), *clumps of plants*, or *single or few plants*.

During the mapping survey completed in the late-summer of 2018, HWM was present throughout much of the littoral area of the lake, in particular in locations between approximately 5 and 17 feet (Figure 3.4-15). A total of 9.5 acres of HWM were mapped in 2018 of which 2.4 acres consisted of dense colonized populations described as either dominant or highly dominant plants. An additional 7.1 acres of lower density colonies consisting of highly scattered or scattered plants were also mapped in 2018. The majority of the HWM mapped did not extend up to the surface, with many of the colonies being well below the surface. In 2015, the WDNR recorded the locations that HWM was 1) at the surface, 2) within 1 foot of the surface, and 3) greater than 1 foot from the surface during the point-intercept survey. This data indicated that HWM was found below a foot from the water's surface at 14 of the 17 sampling locations that contained HWM.

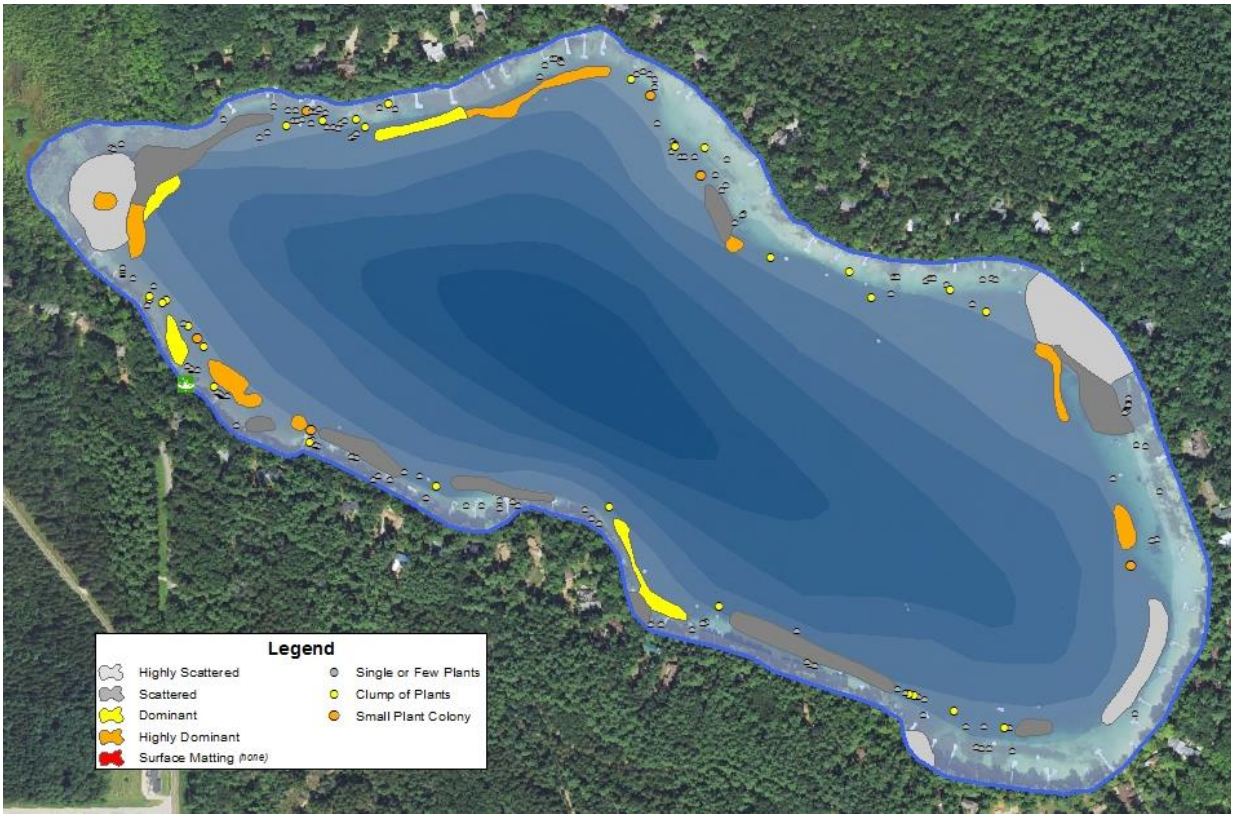


Figure 3.4-15. Crystal Lake Late-Summer 2018 HWM mapping survey results. Survey completed by Onterra, LLC on 10-4-2018.

Possible HWM Management Strategies for Consideration in Crystal Lake

Three potential HWM population goals for consideration including a recommended action plan to help reach each of the goals are outlined below (Figure 3.4-16). Additional details regarding a monitoring and management strategy for HWM are included in the *Implementation Plan* section which was developed through meetings and discussions between Onterra and the Crystal Lake Club planning committee members.

1. **No Coordinated Active Management**
   (Let Nature Take its Course)
   - Focus on education of manual removal by property owners
2. **Minimize navigation and recreation impediment**
   (Nuisance Control)
   - Accomplished through professional hand-harvesting of areas or lanes
   - Hand-harvesting may not be able to accomplish this goal and herbicides or a mechanical harvester may be required
3. **Reduce HWM Population on a lake-wide level**
   (Lake-Wide Population Management)
   - Would likely rely on herbicide treatment strategies (risk assessment)
   - Will not "eradicate" HWM
   - Set triggers (thresholds) of implementation and tolerance

Figure 3.4-16. Potential HWM Management Goals.

Let Nature Take its Course: On some lakes, the EWM/HWM population plateaus or reduces without active management which appears to be the case for Crystal Lake. Some lake groups decide to periodically monitor the HWM population, typically through an annual or semi-annual point-intercept survey, but do not coordinate active management (e.g. hand-harvesting or herbicide treatments). Individual riparians could choose to hand-remove the HWM within their recreational footprint, but the lake group would not assist financially or by securing permits if necessary. In most instances, the lake group may select an HWM population threshold or "trigger" where they would revisit their management goal if the population reached that level.

Nuisance Control: The concept of ecosystem services is that the natural world provides a multitude of services to humans, such as the production of food and water (provisioning), control of climate and disease (regulating), nutrient cycles and pollination (supporting), and spiritual and recreational benefits (cultural). Some lake groups acknowledge that the most pressing issues with their HWM population is the reduced cultural ecosystem services such as recreation, navigation, and aesthetics compared to before HWM became established in their lake. Particularly on lakes with large HWM populations that may be impractical or unpopular to target on a lake-wide basis, the lake group would coordinate (secure permits and financially support the effort) a strategy to improve the navigability within the lake. This is typically accomplished by designing common-use navigation lanes or clearing high use areas that would be managed through hand-harvesting or mechanical harvesting

Lake-Wide Population Management: Some believe that there is an intrinsic responsibility to correct for changes in the environment that are caused by humans. For lakes with HWM populations, that may be to manage the HWM population at a reduced level with the perceived goal to allow the lake to function as it had prior to HWM establishment. Due to the inevitable collateral impacts from most forms of HWM management, lake managers and natural resource regulators question whether that is an achievable goal. The WDNR maintains a cost-share grant funding program for projects that aim to reduced established aquatic invasive species populations.

In early HWM populations, the entire population may be targeted through hand-harvesting or spot herbicide treatments. However, this is a scale-appropriate management action for small areas. On more advanced or established populations, lake-wide HWM population management be accomplished through large-scale control efforts such as water-level drawdowns or whole-lake herbicide treatment strategies. For Crystal Lake, lake-wide population management would almost certainly require a whole-lake herbicide treatment. Whole-lake herbicide treatments have shown to be able to reduce invasive watermilfoil populations for several years, but will not eradicate it from the lake. Typically, lake groups that conduct whole-lake herbicide treatments of EWM/HWM plan on periodically conducting this form of management at 5-7 year intervals when the population rebounds. Efforts to preserve the gains made by a whole-lake treatment such as hand-harvesting have shown success in extending the interval between whole-lake treatments. Herbicide treatments can be impactful of some native plant species as well as carry a risk of environmental toxicity. Some argue that the impacts of the control actions may have greater negative impacts to the ecology of the system than if the HWM population was not managed.

Reed Canary Grass

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

Reed canary grass is difficult to eradicate; at the time of this writing there is no commonly accepted control method. This plant is quite resilient to herbicide applications. Small, discrete patches have been covered by black plastic as an attempt to reduce growth for an entire season. However, the species must be monitored because rhizomes may spread out beyond the plastic. The WDNR's AIS Mapping Tool displays reed canary grass as present on the far western shore of Crystal Lake, and was also located during Onterra's community mapping survey in 2018 (Map 5).

Stakeholder Survey Responses to Aquatic Vegetation within Crystal Lake

As discussed in section 2.0, the stakeholder survey asks many questions pertaining to perception of the lake and how it may have changed over the years. Of the 76 surveys that were distributed, 65 completed the 27-question survey yielding an 86% response rate. In instances where stakeholder survey response rates are 60% or above, the results can be interpreted as being a statistical representation of the population.

When asked to rank the top three concerns regarding Crystal Lake, the survey respondents listed aquatic invasive species introduction as well as excessive aquatic plant growth among their top concerns (Appendix B).

3.5 Aquatic Invasive Species in Crystal Lake

As is discussed in section 2.0 Stakeholder Participation, the lake stakeholders were asked about aquatic invasive species (AIS) and their presence in Crystal Lake within the anonymous stakeholder survey. As of 2018, Onterra and the WDNR have confirmed that the species listed in Table 3.5-1 are present in Crystal Lake or its immediate shoreline.

Table 3.5-1. AIS present within Crystal Lake

Type	Common name	Scientific name	Location within the report
Plants	Eurasian watermilfoil	*Myriophyllum spicatum*	Section 3.4 – Aquatic Plants
	Hybrid watermilfoil	*Myriophyllum spicatum x M. sibiricum*	Section 3.4 – Aquatic Plants
	Reed canary grass	*Phalaris arundinacea*	Section 3.4 – Aquatic Plants
Fish	Common carp	*Cyprinus carpio*	Section 3.5. – Aquatic Invasive Species in Crystal Lake

Figure 3.5-1 displays the 12 aquatic invasive species that some survey respondents believe are in Crystal Lake. Only the species present in Crystal Lake are discussed within their respective locations listed in Table 3.5-1. While it is important to recognize which species stakeholders believe to present within their lake, it is more important to share information on the species present and possible management options. More information on these invasive species or any other AIS can be found at the following links:

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

Common Carp

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

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

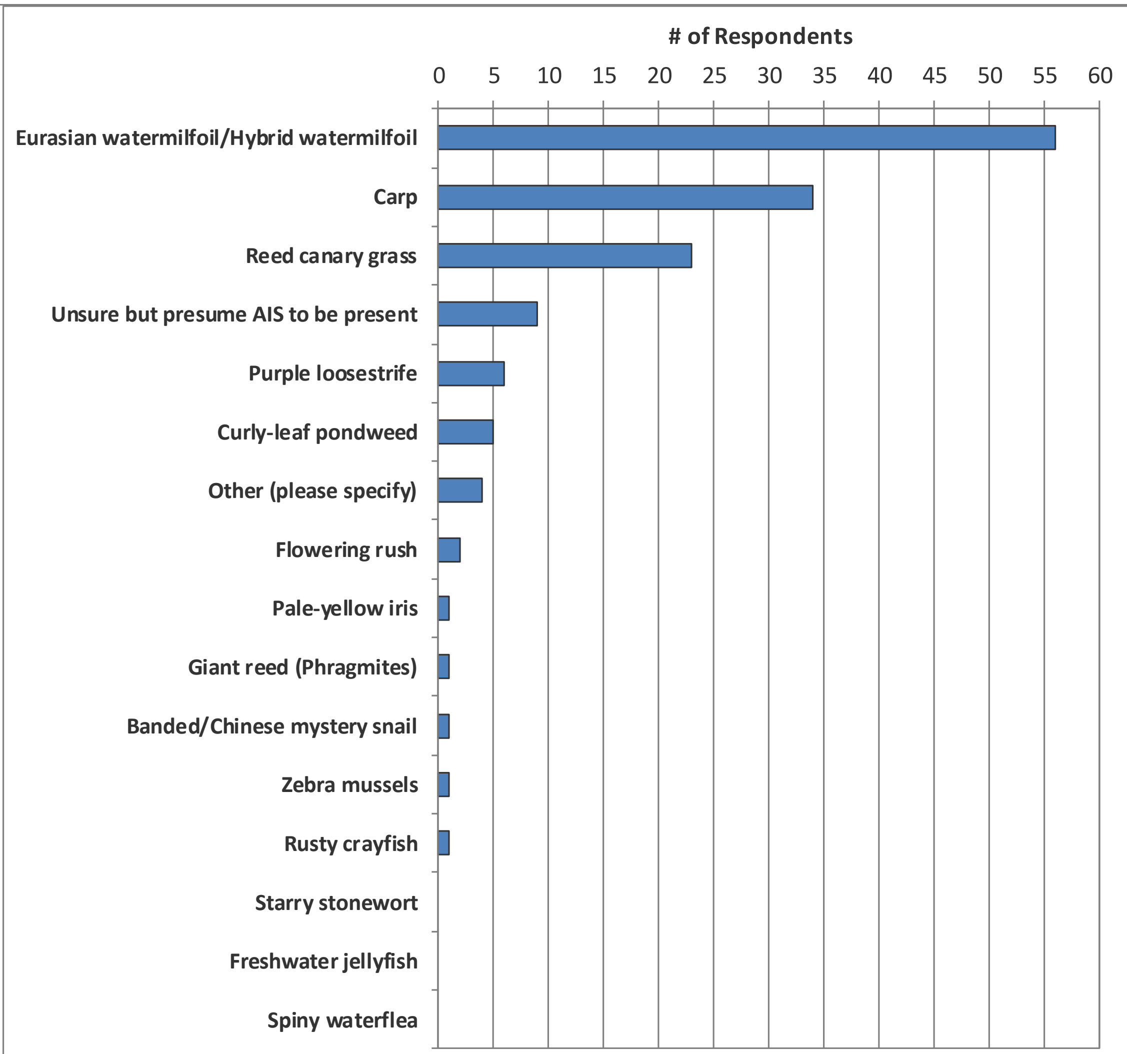


Figure 3.5-1. Stakeholder survey response Question #21. Which aquatic invasive species do you believe are in Crystal Lake?

3.6 Fisheries Data Integration

Fishery management is an important aspect in the comprehensive management of a lake ecosystem; therefore, a brief summary of available data is included here as a reference. The following section is not intended to be a comprehensive plan for the lake's fishery, as those aspects are currently being conducted by the fisheries biologists overseeing Crystal Lake. The goal of this section is to provide an overview of some of the data that exists. Although current fish data were not collected as a part of this project, the following information was compiled based upon data available from the Wisconsin Department of Natural Resources (WDNR) and personal communications with DNR Fisheries Biologist David Bartz (WDNR 2018).

Crystal Lake Fishery

Energy Flow of a Fishery

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

A concept called energy flow describes how the biomass of piscivores is determined within a lake. Because algae and plant matter are generally small in energy content, it takes an incredible amount of this food type to support a sufficient biomass of zooplankton and insects. In turn, it takes a large biomass of zooplankton and insects to support planktivorous fish species. And finally, there must be a large planktivorous fish community to support a modest piscivorous 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.

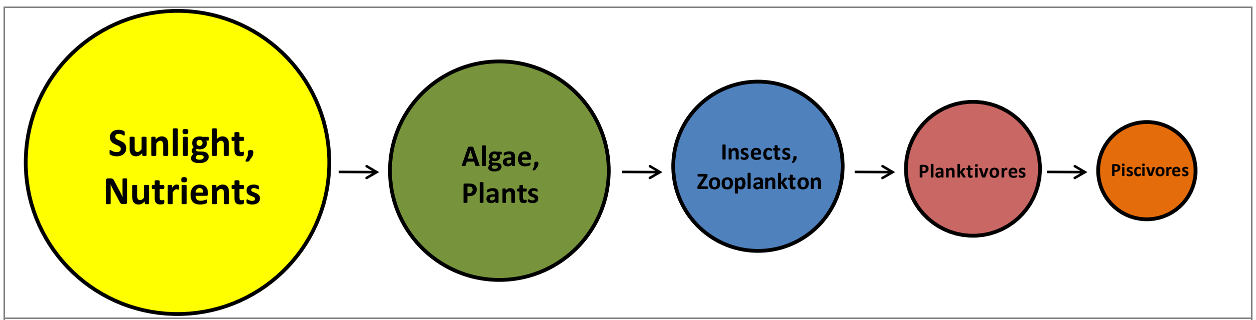


Figure 3.6-1. Aquatic food chain. Adapted from Carpenter et. al 1985.

As discussed in the Water Quality section, Crystal Lake is oligotrophic, meaning it has high water clarity, but a low amount of nutrients and thus low primary productivity. Simply put, this means it is difficult for the lake to support a large population of predatory fish (piscivores) because the supporting food chain is relatively small. Table 3.6-1 shows the popular game fish present in the system. Although not an exhaustive list of fish species in the lake, additional fish species found in Crystal Lake include common carp (*Cyprinus carpio*) and fathead minnow (*Pimephales* *promelas*). Although common carp can cause problems in some lakes, particularly shallow lakes, they are not suspected to be causing issues in Crystal Lake at the current time. Rainbow trout (*Oncorhynchus mykiss*) have been documented for migrating into the lake but were not sampled during WDNR surveys.

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

Common Name (*Scientific Name*)	Max Age (yrs)	Spawning Period	Spawning Habitat Requirements	Food Source
Black Crappie (*Pomoxis nigromaculatus*)	7	May - June	Near *Chara* or other vegetation, over sand or fine gravel	Fish, cladocera, insect larvae, other invertebrates
Bluegill (*Lepomis macrochirus*)	11	Late May - Early August	Shallow water with sand or gravel bottom	Fish, crayfish, aquatic insects and other invertebrates
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
Northern Pike (*Esox lucius*)	25	Late March - Early April	Shallow, flooded marshes with emergent vegetation with fine leaves	Fish including other pike, crayfish, small mammals, water fowl, frogs
Pumpkinseed (*Lepomis gibbosus*)	12	Early May - August	Shallow warm bays 0.3 - 0.8 m, with sand or gravel bottom	Crustaceans, rotifers, mollusks, flatworms, insect larvae (terrestrial and aquatic)
Rock Bass (*Ambloplites rupestris*)	13	Late May - Early June	Bottom of course sand or gravel, 1 cm - 1 m deep	Crustaceans, insect larvae, and other invertebrates
Yellow Perch (*Perca flavescens*)	13	April - Early May	Sheltered areas, emergent and submergent veg	Small fish, aquatic invertebrates

Survey Methods

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

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

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


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

Fish Stocking

To assist in meeting fisheries management goals, the WDNR may permit the stocking of fingerling or adult fish in a waterbody that were raised in permitted hatcheries (Photograph 3.6-2). Stocking 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. Crystal Lake was stocked from 1982 to 2014 with Bluegill, Fathead Minnow and Black Crappie (Table 3.6-2).

Table 3.6-2. Stocking data available for Crystal Lake (1982 - 2014).

Year	Species	Strain (Stock)	Age Class	# Fish Stocked	Avg Fish Length (in)
1982	Bluegill	Unspecified	Adult	2250	-
1984	Panfish	Unspecified	Fingerling	10,000	2
2008	Fathead Minnow	Unspecified	Adult	14000	2
2012	Fathead Minnow	Unspecified	Adult	45000	2
2014	Black Crappie	Unspecified	Large Fingerling	750	4.5

Fishing Activity

Based on data collected from the stakeholder survey (Appendix B), fishing (open-water and ice) was one of the least most important reasons for owning property on or near Crystal Lake (Question #12). Figure 3.6-2 displays the fish that Crystal Lake stakeholders enjoy catching the most, with bluegill/sunfish, largemouth bass and crappie being the most popular. Approximately 74% of these same respondents believed that the quality of fishing on the lake was either good or fair (Figure 3.6-3). Approximately 52% of respondents who fish Crystal Lake believe the quality of fishing has remained the same or is somewhat better since they first started to fish the lake (Figure 3.6-4).

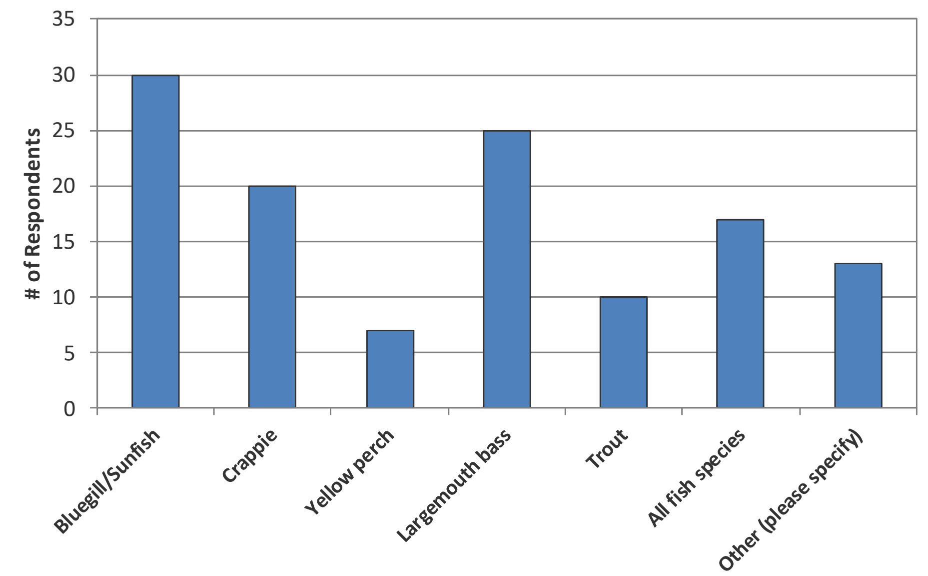


Figure 3.6-2. Stakeholder survey response Question #6. What species of fish do you like to catch on Crystal Lake?

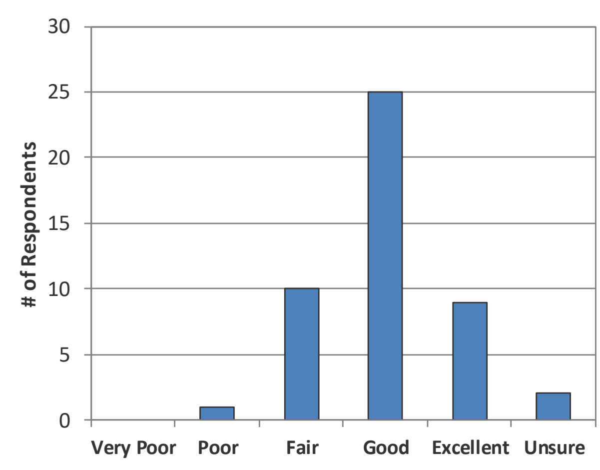


Figure 3.6-3. Stakeholder survey response Question #7. How would you describe the current quality of fishing on Crystal Lake?

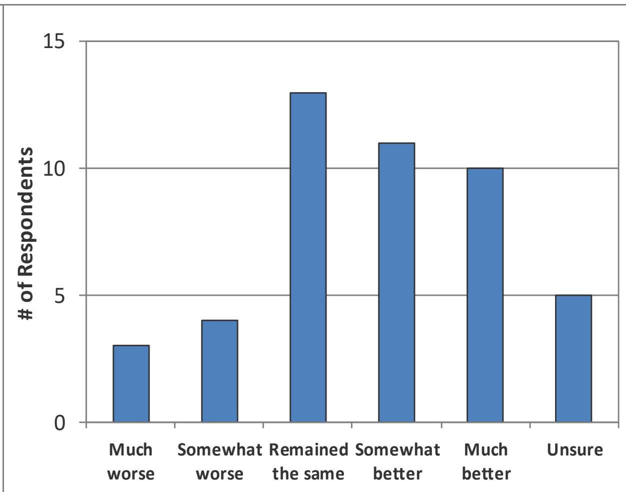


Figure 3.6-4. Stakeholder survey response Question #8. How has the quality of fishing changed on Crystal Lake since you started fishing the lake?

Fish Populations and Trends

Utilizing the fish sampling techniques and specialized formulas mentioned above, WDNR fisheries biologists can estimate populations and determine trends of captured fish species. These numbers provide a standardized way to compare fish caught in different sampling years depending on gear used (fyke net or electrofishing). Data is analyzed by fisheries biologists to better understand the fishery and how it should be managed. The following information is summarized based on communications with Dave Bartz (WDNR Fisheries Biologist).

WDNR Fishery Surveys

Crystal Lake is under an 8-year sampling rotation by the WNDR. Difficult access for a WDNR electrofishing boat may be a partial reason Crystal Lake is on a longer sampling rotation. Surveys have been completed in September 2004, June 2005 and May 2013. Overall the fishery is managed for bluegill and largemouth bass. There is a northern pike component to the fishery as well, however, the WDNR has not sampled the lake with a survey giving an accurate representation of the northern pike population. The bluegill average size has decreased slightly from 3.92 inches to 3.69 inches from 2004 to 2013, respectively (Appendix F). The largemouth average size has increased slightly from 10.05 inches to 10.36 inches from 2004 to 2013, respectively (Appendix F).

Crystal Lake Fish Habitat

Substrate Composition

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

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

According to the point-intercept survey conducted by Onterra in 2018, 100% of the substrate sampled in the littoral zone of Crystal Lake were sand sediments.

Woody Habitat

As discussed in the Shoreland Condition Section, the presence of coarse woody habitat is important for many stages of a fish's life cycle, including nesting or spawning, escaping predation as a juvenile, and hunting insects or smaller fish as an adult. Unfortunately, as development has increased on Wisconsin lake shorelines in the past century, this beneficial habitat has often been the first to be removed from the natural shoreland zone. Leaving these shoreland zones barren of coarse woody habitat can lead to decreased abundances and slower growth rates in fish (Sass 2006). A fall 2018 survey documented 66 pieces of coarse woody along the shores of Crystal Lake, resulting in a ratio of approximately 33 pieces per mile of shoreline. Fisheries biologists do not suggest a specific number of fish sticks for a lake but rather highly encourage their installation wherever possible. To learn how Crystal Lake's coarse woody habitat is compared to other lakes in its region please refer to section 3.3.

Fish Habitat Structures

Some fisheries managers may look to incorporate fish habitat structures on the lakebed or littoral areas extending to shore for the purpose of improving fish habitats and spawning areas. These projects are typically conducted on lakes lacking significant coarse woody habitat in the shoreland zone. 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 (Photograph 3.6-2). 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.

Photograph 3.6-2. Examples of fish sticks (left) and half-log habitat structures (right). (Photos by WDNR)

Fish cribs are a type of fish habitat structure placed on the lakebed. These structures are more commonly utilized when there is not a suitable shoreline location for fish sticks. Installing fish cribs may also be cheaper than fish sticks; however, some concern exists that fish cribs can concentrate fish, which in turn leads to increased predation and angler pressure. Having multiple locations of fish cribs can help mitigate that issue.

Half-logs are another form of fish spawning habitat placed on the bottom of the lakebed (Photograph 3.6-3). Smallmouth bass specifically have shown an affinity for overhead cover when creating spawning nests, which half-logs provide (Wills 2004). If the waterbody is exempt from a permit or a permit has been received, information related to the construction, placement and maintenance of half-log structures are available online.

An additional form of fish habitat structure is spawning reefs. Spawning reefs typically consist of small rubble in a shallow area near the shoreline for mainly walleye habitat. Rock reefs are sometimes utilized by fisheries managers when attempting to enhance spawning habitats for some fish species. However, a 2004 WDNR study of rock habitat projects on 20 northern Wisconsin lakes offers little hope the addition of rock substrate will improve walleye reproduction (WDNR 2004).

Placement of a fish habitat structure in a lake does not require a permit if the project meets certain conditions outlined by the WDNR's checklists available online:

(https://dnr.wi.gov/topic/waterways/Permits/Exemptions.html)

If a project does not meet all of the conditions listed on the checklist, a permit application may be sent in to the WDNR and an exemption requested.

The Crystal Lake Club should work with the local WDNR fisheries biologist to determine if the installation of fish habitat structures should be considered in aiding fisheries management goals for Crystal Lake.

Regulations and Management

Regulations for Crystal Lake gamefish species as of May 2019 are displayed in Table 3.6-3. For specific fishing regulations on all fish species, anglers should visit the WDNR website (*www.http://dnr.wi.gov/topic/fishing/regulations/hookline.html)* or visit their local bait and tackle shop to receive a free fishing pamphlet that contains this information.

Table 3.6-3. WDNR fishing regulations for Crystal Lake (As of May 2019).

Species	Daily bag limit	Length Restrictions	Season
Panfish (bluegill, pumpkinseed, sunfish, crappie and yellow perch)	25	None	Open All Year
Largemouth bass and smallmouth bass	5	14"	May 4, 2019 to March 1, 2020
Muskellunge and hybrids	1	40"	May 4, 2019 to December 31, 2019
Northern pike	2	26"	May 4, 2019 to March 1, 2020
Walleye, sauger, and hybrids	5	15"	May 4, 2019 to March 1, 2020
Bullheads	Unlimited	None	Open All Year

General Waterbody Restrictions: Motor Trolling is allowed with 1 hook, bait, or lure per angler, and 2 hooks, baits, or lures maximum per boat.

Mercury Contamination and Fish Consumption Advisories

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

General fish consumption guidelines for Wisconsin inland waterways are presented in Figure 3.6-5. There is an elevated risk for children as they are in a stage of life where cognitive development is rapidly occurring. As mercury and PCB both locate to and impact the brain, there are greater restrictions on women who may have children or are nursing children, and also for children under 15.

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

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

Figure 3.6-5. Wisconsin statewide safe fish consumption guidelines. Graphic displays consumption guidance for most Wisconsin waterways. Figure adapted from WDNR website graphic (http://dnr.wi.gov/topic/fishing/consumption/)

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 Crystal Lake ecosystem.
2) Collect detailed information regarding invasive plant species within the lake, with the primary emphasis being on Hybrid/Eurasian watermilfoil.
3) Collect sociological information from Crystal Lake riparian stakeholders regarding their use of the lake and their thoughts pertaining to the past and current condition of the lake and its management.

The three objectives were fulfilled during the project and have led to an understanding of the Crystal Lake ecosystem, the folks that care about the lake, and what needs to be completed to protect and enhance them.

A volunteer group of CLC members formed a planning committee for this project and were instrumental in the development of the Implementation Plan for this management project. The planning committee served to provide the local sociological perspective related to Crystal Lake's use and in developing the CLC's role in protecting, enhancing, and managing Crystal Lake for the years to come. Pairing the understanding of the technical data that has been collected over time as well as the CLC's sociological needs through this planning project has led to the creation of a realistic management plan for the CLC to implement in managing Crystal Lake.

Historical data, as well as data collected during the management planning project, indicate Crystal Lake has excellent water quality. Crystal Lake is considered to be in an oligotrophic state with low productivity characterized by low nutrient and chlorophyll levels and high water clarity. Crystal Lake can be described as a marl lake based on its high levels of calcium carbonate. The lake's relatively small watershed consists mostly of wetland and forested landcovers that contribute less nutrients to the lake than other land uses such as agricultural or urbanized landcovers.

The shoreland condition assessment identified areas of the lake's shoreland that are important to protect and maintain in their natural state and also identified areas where restoration actions would have the most benefit.

Crystal Lake is fortunate to have a robust collection of aquatic plant survey data in the form of point-intercept surveys dating back to 2005. These data allow for comparisons of aquatic plant populations over time and show whether any given species is increasing or decreasing over time. The aquatic plant population in Crystal Lake is characterized as exhibiting relatively low species richness which is consistent other hardwater lakes in the ecoregion.

Crystal Lake's water quality conditions are conducive to supporting the growth of muskgrasses, a type of native macroalgae. Muskgrasses have consistently been the most frequently encountered species encountered during the point-intercept surveys in Crystal Lake. Muskgrasses provide beneficial qualities in the aquatic environment; however, they have been documented to cause some localized nuisance conditions in Crystal Lake characterized by plants matting on the water surface. The CLC investigated methods to mitigate nuisance conditions brought on by muskgrasses as a part of the Implementation Plan (Section 5.0) of this management plan.

Hybrid/Eurasian watermilfoil (HWM) was first confirmed in Crystal Lake in 2004; however, was likely present in the lake for a number of years prior. The population of HWM has been quantitatively monitored nearly every year since 2004 through annual point-intercept surveys. Analysis of these data show the population fluctuates on a year to year basis but overall has been relatively stable during this time period with no statistically valid increasing or decreasing trend. The HWM population was qualitatively mapped in 2018 as a part of this management planning project and showed HWM to be present in nearly all littoral areas of the lake. At current levels, HWM is not believed to be contributing a great negative impact to the ecological function of the lake. Continued monitoring of the HWM population is important in documenting the population dynamics and the distribution within the lake. Monitoring will be instrumental in determining whether considerations for actively managing the species become warranted in future years, particularly if the species expands to levels that significantly impede recreational activities in the lake.

Crystal Lake's fishery is managed by the WDNR for bass and panfish, with northern pike also present. Many of the stakeholder survey respondents described the quality of the fishery to be good or excellent as of 2018. The CLC will work with the local WDNR fisheries biologist in managing and enhancing the fishery.

The collection of historical data from Crystal Lake shows natural year-to-year variability that is largely driven by environmental factors. In order to evaluate whether changes are occurring in the lake, continued water quality and aquatic vegetation monitoring is paramount.

5.0 IMPLEMENTATION PLAN

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

Management Goal 1: Maintain Current Water Quality Conditions in Crystal Lake

Management Action:	Monitor water quality through WDNR Citizens Lake Monitoring Network.
Timeframe:	As soon as possible.
Facilitator:	CLC Water Quality Committee
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 the lake by building a database that can be used for long-term trend analysis. Early discovery of negative trends may lead to the reason of why the trend is occurring. Volunteers from the CLC have been monitoring water quality as a part of the UW-Stevens Point Center for Watershed Science program since the late 1980s. This club-paid program includes the collection of water samples for phosphorus analysis during the spring and fall overturn events. This essentially measures the 'whole lake' phosphorus content, but does not align with data used in the Wisconsin 2018 Consolidated Assessment and Listing Methodology (WDNR 2017) and what most water quality monitoring models require. The Citizen Lake Monitoring Network (CLMN) is a WDNR program in which volunteers are trained to collect water quality information on their lake. The CLC volunteers would be trained to monitor the deep hole site as a part of the advanced CLMN program. This includes collecting Secchi disk transparency and sending in water chemistry samples (chlorophyll-a, and total phosphorus) to the Wisconsin State Laboratory of Hygiene for analysis. The samples are collected once during the spring and three times during the summer. It is important to note that as a part of this program, the data collected are automatically added to the WDNR database and available through their Surface Water Integrated Monitoring System (SWIMS).

		It will be the Water Quality Committee's responsibility to ensure that a volunteer is prepared to communicate with WDNR representatives and collect water quality samples each year.
Action Steps:		
	1.	CLC contacts Ted Johnson (920.424.2104) to acquire necessary materials and training for new volunteer(s)
	2.	Trained CLMN volunteer(s) collects data and report results to WDNR and to district members during annual meeting.
	3.	CLMN volunteer and/or CLC Water Quality Committee facilitate new volunteer(s) as needed

Management Action:		Conduct hydrologic and chemical study of groundwater inputs to Crystal Lake.
Timeframe:		2020 or 2021
Facilitator:		CLC Water Quality Committee
Prospective Grant:		Lake Planning Grant
Description:		There is concern among Crystal Lake property owners regarding increased amounts of filamentous algae in the lake. Filamentous algae begin growing on bottom where it draws nutrients out of the sediment. As the algal mat grows denser, gases build up underneath it and eventually it floats to the top and get caught on vascular plants or washes up on shore. The CLC would like to discover if the filamentous algae blooms are being fueled by unnatural sources of nutrients arriving via ground water. The first step in this process would be determination of near-shore ground water inputs and outputs in Crystal Lake. Input areas would be sampled for phosphorus and nitrogen. Comparisons with in-lake concentrations would determine if the input is adding nutrients to the lake or diluting them. If extremely high inputs are located, further investigations may be necessary to determine the source. Further, filamentous algae locations would also be mapped during the study to determine if they occur more frequently in specific areas of the lake. The UW-Stevens Point Center for Watershed Science has completed several studies of this type. They may be willing to assist the CLC in completing the work and analysis for Crystal Lake.
Action Steps:		
	1.	Representative from CLC Water Quality Committee contacts Dr. Paul McGinley, Director (715.346.4501) to begin discussions and create project design.
	2.	Apply for WDNR Surface Water Grant to fund project.
	3.	Utilize grant award to complete the project, CLC local share not to exceed $1,000.

Management Goal 2: Protect and Enhance Ecological Health of Crystal Lake

Management Action:	Continue no-motor lake status and investigate establishing slow-no-wake ordinance on Crystal Lake.
Timeframe:	2020
Facilitator:	CLC Water Quality Committee
Description:	In 1976, the Town of Crystal Lake enacted an ordinance banning the use of combustion motors on Crystal Lake. This ordinance has been and will be continued to be supported by the CLC. Recent developments in electric motor and lithium battery technology have led to higher thrust trolling motors and electric personal watercraft. Use of these developing technologies could allow boats and personal watercraft to reach sufficient speeds to cause large wakes. On small lakes like Crystal, frequent occurrence of these wakes can bring about shoreland erosion. Further, the use of these watercraft in and near floating-leaf and emergent plants can disrupt this important habitat. To counteract these negative effects and to assure the continued tranquility on the lake, the CLC will investigate the development of a slow-no-wake ordinance for Crystal Lake. The first step in this process will be to establish the level of support among club members. If majority support exists of the action, the CLC will petition Crystal Lake Township and the Township of Newton to create the ordinance.
Action Steps:	
1.	CLC Water Quality Committee prepare a presentation in support of slow-no-wake ordinance to CLC Board of Directors.
2.	If approved by CLC Board, presentation to be shared at CLC annual meeting.
3.	If approved at CLC annual meeting, CLC Board add to township ordinances of Crystal Lake and Newton Townships.

Management Action:	Conduct periodic quantitative vegetation monitoring on Crystal Lake.
Timeframe:	Point-Intercept Survey every 3-5 years, Community Mapping every 7-10 years
Possible Grant:	Small-Scale Lake Planning Grant or AIS-Education, Prevention, and Planning in <$10,000 category.
Facilitator:	CLC Water Quality Committee
Description:	As of 2019, Crystal Lake is on an annual point-intercept monitoring regimen being completed by Golden Sands Resource Conservation & Development Council as a part of a continuation of a long-term trends study that was originally started by the WDNR. In the event that the annual monitoring by Golden Sands comes to an end, then the survey will be completed approximately every 3-5 years. The survey would be initiated sooner if perceived changes in the aquatic plant community are

	believed to be occurring or if the lake enters a period of significant active aquatic plant management. This will allow a continued understanding of the submergent aquatic plant community dynamics within Crystal Lake. In order to understand the dynamics of the emergent and floating-leaf aquatic plant community in Crystal Lake, a community mapping survey would be conducted every 7-10 years. A community mapping survey was conducted on Crystal Lake in 2017 as a part of this management planning effort. The next community mapping survey will be completed between 2025 and 2028.
Action Steps:	
	See description above.

<u>Management Action:</u>	Educate stakeholders on the importance of shoreland condition, shoreland restoration, and proper shoreland stewardship on Crystal Lake.
Timeframe:	Initiate 2020
Possible Grant:	Healthy Lakes Initiative Grant
Facilitator:	CLC Water Quality Committee
Description:	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. As discussed in the Shoreland Condition Section (3.3), the Healthy Lakes & Rivers Grant program provides cost share for implementing the following best practices: • Rain Garden • Rock Infiltration • Diversion • Native Plantings • Fish Sticks The cost share allows $1,000 per practice, up to $25,000 per annual grant application. More details and resources for the program are included within the Shoreland Condition Section (3.3) and can be found at: <u>https://healthylakeswi.com</u> Approximately 18% of Crystal Lake's shoreline is considered completely urbanized or developed unnatural (Figure 3.3-3). This limits shoreland habitat, but it also reduces natural buffering of

	shoreland runoff and allows nutrients to enter the lake. Approximately 44% of Crystal Lake's shoreline is undeveloped and in a natural condition. These areas provide important habitat and pollutant buffering benefits to the lake. Many riparian property owners do not understand the importance of shoreland condition and maintenance in the ecological health of their lake. The initial objective of this action will be to provide information to CLC members through a variety of educational opportunities, including newsletter articles, direct emailing of informational material, presentations at the club's annual meeting, and sponsoring a booth at the Fall Festival. Informational topics will include shoreland restoration resources, like the WDNR Healthy Lake Initiative grants, the importance of private, onsite septic system maintenance, and general good-neighbor practices like reducing litter in the lake and minimizing light and sound pollution. Marquette County and the UW-Extension Lakes Program (see Table 5.0-1) are excellent sources of information and articles. If shoreland property owners are interested in restoring all or a portion of their shoreline, the WDNR's Healthy Lakes Initiative Grant program allows partial cost coverage for native plantings in transition areas. This reimbursable grant program is intended for relatively straightforward and simple projects. More advanced projects that require advanced engineering design may seek alternative funding opportunities, potentially through Marquette County.
Action Steps:	
	See description above.

<u>Management Action:</u>	Coordinate with WDNR and private landowners to expand coarse woody habitat in Crystal Lake
Timeframe:	Initiate 2020
Possible Grant:	Healthy Lakes Initiative Grant
Facilitator:	CLC Water Quality Committee
Description:	CLC stakeholders realize the complexities and capabilities of the Crystal Lake ecosystem with respect to the fishery it can produce. With this, an opportunity for education and habitat enhancement is present in order to help the ecosystem reach its maximum fishery potential. Often, property owners will remove downed trees, stumps, etc. from a shoreland area because these items may impede watercraft navigation, shore-fishing, or swimming. However, these naturally occurring woody pieces serve as crucial habitat for a variety of aquatic organisms, particularly fish. The Shoreland

	Condition Section (3.3) and Fisheries Data Integration Section (3.6) discuss the benefits of coarse woody habitat in detail.
	
	The WDNR's Healthy Lakes Initiative Grant allows partial cost coverage for coarse woody habitat improvements (referred to as "fish sticks"). This reimbursable grant program is intended for relatively straightforward and simple projects. More advanced projects that require advanced engineering design may seek alternative funding opportunities, potentially through the county.
	• 75% state share grant with maximum award of $25,000; up to 10% state share for technical assistance
	• Maximum of $1,000 per cluster of 3-5 trees (best practice cap)
	• Implemented according to approved technical requirements (WDNR Fisheries Biologist) and complies with local shoreland zoning ordinances
	• Buffer area (350 ft^2) at base of coarse woody habitat cluster must comply with local shoreland zoning or:
	    ○ The landowner would need to commit to leaving the area un-mowed
	    ○ The landowner would need to implement a native planting (also cost share through this grant program available)
	• Coarse woody habitat improvement projects require a general permit from the WDNR
	• Landowner must sign Conservation Commitment pledge to leave project in place and provide continued maintenance for 10 years

Action Steps:	
1.	CLC member to contact WDNR Lakes Coordinator and WDNR Fisheries Biologist to gather information on initiating and conducting coarse woody habitat projects.
2.	The CLC will encourage property owners that have enhanced coarse woody habitat to serve as demonstration sites.

Management Goal 3: Manage Current Aquatic Invasive Species in Crystal Lake and Prevent Further Introductions

Management Action:	Coordinate annual volunteer monitoring of aquatic invasive species on Crystal Lake.
Timeframe:	Continuation of current effort.
Facilitator:	CLC Water Quality Committee
Description:	While EWM/HWM already inhabits many parts of Crystal Lake and small amounts of reed canary grass also exist, other AIS plants, do not occur, including purple loosestrife, pale-yellow iris, and curly-leaf pondweed. Monitoring for these species is important because early detection will lead to better control and possibly eradication. This action will include monitoring for all AIS plant species, including reed canary grass, but not for EWM/HWM. AIS animal species, like zebra mussels, rusty crawfish, and mystery snails can also be included, although control options do not exist. The CLC will solicit assistance from Golden Sands Resource Conservation and Development Commission (see table 5.0-1) for training on methods and identification of species. Surveys would be completed at least twice during each summer to increase chances in finding AIS.
Action Steps:	
	See description above.

Management Action:	Initiate rapid response plan following detection of new AIS.
Timeframe:	If/When Necessary
Possible Grant:	AIS-Early Detection and Response Grant
Facilitator:	CLC Water Quality Committee
Description:	CLC members will be trained to bring any suspected new invasive species to the attention of the CLC Water Quality Committee. If volunteer or professional surveys locate a suspected new AIS within Crystal Lake, the location would be marked (e.g. GPS, marker buoy) and a specimen would be taken to the WDNR Lake Coordinator (Ted Johnson), to Golden Sands RC&D, or to the Marquette County Land Conservation Department for verification. If the suspected specimen is indeed a non-native species, the WDNR will fill out an incident form and develop a strategy to determine the population level within the lake. The lake would be professionally surveyed, either by agency personnel or a private consulting firm during that species' peak growth phase.

	If the AIS is a NR40 prohibited species (i.e. red swamp crayfish, starry stonewort, hydrilla, etc.), the WDNR may take an active role in the response. If the AIS is a NR40 restricted species (i.e. purple loosestrife, curly-leaf pondweed, etc.), the CLC would need to reach out to a consultant to develop a formal monitoring and/or control strategy. The WDNR would be able to help financially through the AIS Grant Program's Early Detection and Response program. This grant program is non-competitive and does not have a specific application deadline, but is offered on a first-come-basis to the sponsor of project waters that contain new infestations (found within less than 5% of the lake and officially documented less than 5 years from grant application date). Currently this program will fund up to 75% percent of monitoring and control costs, up to $20,000.
Action Steps:	See description above.

<u>Management Action:</u>	Continue HWM monitoring and consider control actions based upon those results.
Timeframe:	Continuation of current action.
Facilitator:	CLC Water Quality Committee
Description:	As described near the end of Section 3.4, the littoral occurrence of HWM from 2005-2019 has ranged from 14.4% to 27.7% (Figure 3.4-12). The lowest occurrence was found during the first point-intercept survey in 2005, while the highest occurrence was found in 2014. Overall, the littoral frequency of occurrence of HWM has been stable over the period of monitoring with an average occurrence of 19.7%. The population is considered stable because there is not statistical trend, up or down, over the course of the dataset. During the planning meeting, committee members expressed that the primary issue with the current HWM population is localized navigation issues brought on by dense stands of HWM near piers. This issue is addressed in the next goal. The committee also expressed that there would likely be very little support of herbicide use in the lake at current HWM levels; however, if the HWM occurrence increase dramatically, the CLC may consider other forms of more aggressive HWM management that align with current best management practices. The second action of Goal 2 calls for the continued monitoring of the Crystal Lake aquatic plant community via periodic point-intercept surveys. The point-intercept surveys will be completed every 3-5 years if the HWM population is perceived to be remaining stable, as has been for the last 14 years. If the HWM population appears to be increasing, the CLC will initiate the surveys more frequently to document changes. If the HWM population increases to 30% or greater littoral frequency of

	occurrence for two successive years, the CLC will begin discussions regarding the completion of more aggressive HWM management efforts that utilize best management practices which may include a coordinated hand harvesting/DASH program. The WDNR would be brought into the discussions early-on so they may provide guidance.
Action Steps:	
	See description above

<u>Management Action:</u>	Educate local boat transport companies regarding the spread of AIS.
Timeframe:	2020
Facilitator:	CLC Water Quality Committee
Description:	Many Crystal Lake property owners utilize the services of local companies to pick-up, winterize, store, and return their boats to the lake. The companies use the same trailer to retrieve and launch boats from many lakes, including Crystal Lake; therefore, there is a serious risk of transporting AIS between the area lakes. To reduce the risk of spread, the CLC Board of Directors will send a letter to each of the companies used by CLC members asking that they power wash their equipment between uses so the risk of spreading AIS is decreased.
Action Steps:	
1.	Ask CLC members to advise which local firms are used to launch boats on Crystal Lake.
2.	Contact each contractor to determine what their cleaning and decontamination protocol is.
3.	Educate CLC boaters that use these contractors to ask to have the trailering equipment cleaned between launches.

Management Goal 4: Assure Navigation to Open Water Areas of Crystal Lake from Riparian Properties

Management Action:	Support hand-harvesting of submergent vegetation to provide navigation lanes to riparian properties.
Timeframe:	Begin in 2020
Facilitator:	CLC Water Quality Committee
	Navigation issues exist in several areas of Crystal Lake due to dense HWM and Chara beds. 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 a mechanical device, 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. State regulations require that all plant material be removed from the lake and disposed of on land. The CLC Water Quality Committee will educate members about available aquatic plant removal options and will support riparian property owners by supplying tools to remove aquatic vegetation. The CLC will provide contact information for firms that provide aquatic plant removal services for the individual riparian owners to solicit services at their own expense if they so choose. The Water Quality Committee would request funding from the CLC to address trouble spots of HWM, however would not seek funding for removal of native vegetation including Chara.
Action Steps:	See description above.

Management Goal 5: Develop and Maintain Partnerships with Other Management Entities of Crystal Lake

Management Action:	Continue the CLC's involvement with other entities that have responsibilities in managing (management units) Crystal Lake
Timeframe:	Continuation of current efforts
Facilitator:	CLC Board of Directors & Water Quality Committee
Description:	The waters of Wisconsin belong to everyone and therefore this goal of protecting and enhancing these shared resources is also held by other entities. Some of these entities are governmental while others organizations rely on voluntary participation. It is important that the CLC actively engage with all management entities to enhance the club'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 below:
Action Steps:	
	See guidelines in Table 5.0-1.

Partner	Contact Person	Role	Contact Frequency	Contact Basis
Town of Crystal Lake	Crystal Lake Town Clerk (920.293.4252)	Crystal Lake falls within this township.	Once a year, or more as issues arise.	Town staff may be contacted regarding ordinance reviews or questions, and for information on community events
Town of Newton	Newton Town Clerk (920-787-44561)	Crystal Lake falls within this township.	Once a year, or more as issues arise.	Town staff may be contacted regarding ordinance reviews or questions, and for information on community events
Golden Sands Resource Conservation & Development Council	Staff (715.343.6215)	Nonprofit organization that covers central WI	Once a year, or more as issues arise.	Provide information on conservation and natural resource preservation
Marquette County Land & Water Conservation Department	County Conservationist (Patrick Kilbey - patrick.kilbey@wi.nacdnet.net)	Oversees conservation efforts for land and water projects.	Continuous as it relates to lake and watershed activities	Can aid with shoreland buffers/restorations, shoreland erosion and habitat improvements. Healthy Lakes contact.
Wisconsin Department of Natural Resources	Fisheries Biologist (David Bartz – 920.787.3016)	Manages the fishery of Crystal Lake.	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 (Ted Johnson – 920.424.2104)	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.
University of Wisconsin – Extension Lakes Program	Eric Olson, Director and Lakes Specialist (715.346.2192) Paul Skawinski, Citizens Lake Monitoring Network Educator (715.346.4853)	Provide general information regarding lakes and lake districts. Assist in CLMN training and education.	As needed.	The UW-Ext Lakes Program is a resource for educational materials and guidance regarding lakes, lake monitoring, and the operations of lake management districts.
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.	Members may attend WL's annual conference to keep up-to-date on lake issues.

6.0 METHODS

Lake Water Quality

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

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

In addition, during each sampling event Secchi disk transparency was recorded and a temperature and dissolved oxygen profile was completed using a HQ30d with a LDO probe.

Watershed Analysis

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

Aquatic Vegetation

Curly-leaf Pondweed Survey

Surveys of curly-leaf pondweed were completed on Crystal Lake during a June 21, 2018 field visit, in order to correspond with the anticipated peak growth of the plant. Visual inspections were completed throughout the lake by completing a meander survey by boat.

Comprehensive Macrophyte Surveys

Comprehensive surveys of aquatic macrophytes were conducted on Crystal Lake to characterize the existing communities within the lake and include inventories of emergent, submergent, and floating-leaved aquatic plants within them. The point-intercept method as described in the Wisconsin Department of Natural Resource document, Recommended Baseline Monitoring of Aquatic Plants in Wisconsin: Sampling Design, Field and Laboratory Procedures, Data Entry, and Analysis, and Applications (WDNR PUB-SS-1068 2010) was used to complete this study on July 31, 2018. A point spacing of 40 meters was used resulting in approximately 302 points.

Community Mapping

On August 28, 2018, the aquatic vegetation community types within Crystal Lake (emergent and floating-leaved vegetation) were mapped using a Trimble Pro6T Global Positioning System (GPS) with sub-meter accuracy. Furthermore, all species found during the point-intercept surveys and the community mapping surveys were recorded to provide a complete species list for the lake.

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

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