

Lake Puckaway

Green Lake & Marquette Counties, Wisconsin

Comprehensive Management Plan

September 2017



Sponsored by:

Lake Puckaway Protection & Rehabilitation District

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Onterra, LLC
Lake Management Planning

Lake Puckaway
Green Lake & Marquette Counties, Wisconsin
Comprehensive Management Plan
September 2017

Created by: Tim Hoyman, Paul Garrison, Brenton Butterfield, Todd Hanke, & Emily Henrigillis
Onterra, LLC
De Pere, WI

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Lake Puckaway Protection & Rehabilitation District Planning Committee

Paul Gettelman*
Kurt McCulloch*
Gene Weber*

Jeff Kimber*
Randy Schmidt
Brian Zimmermann

Mick Masters
Roger Swanke*

*LPPRD Board of Commissioners member

Lake Puckaway Protection & Rehabilitation District

Phil Malsack

Adam Malsack

Green Lake County Land Conservation Department

Derek Kavanaugh

Krista Kamke

Wisconsin Dept. of Natural Resources

Ted Johnson

Dave Bartz

Keith Marquardt

Dave Bolha

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EXECUTIVE SUMMARY

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

- 1) Collect current and compile historical information regarding the Lake Puckaway ecosystem.
- 2) Utilize the information to raise the overall understanding of the system among district members, its board of commissioners, and agency staff.
- 3) Develop a comprehensive management plan for Lake Puckaway aimed at increasing the overall health of the lake for future generations.

Lake Puckaway is a very complicated system. Add in the fact that it is a very large lake with a vast watershed draining to it and the complication compounds. This section summarizes the findings of the studies completed on Lake Puckaway and the conclusions drawn from them. While it is a good source of basic information, to fully understand Lake Puckaway, the sections in the main document above should also be read.

The water quality data collected as a part of this project and earlier studies indicate that Lake Puckaway is a hypereutrophic (overly productive) system with high nutrient and algal levels and low water clarity. While there is a high degree of variability between years and within a year with these parameters, on average they are typically considered to be poor when compared to other lakes in the state and ecoregion. Average phosphorus, chlorophyll-*a*, and Secchi disk transparencies in Lake Puckaway are four to 13 times worse than median values for lakes within the ecoregion and the state.

In the majority of Wisconsin lakes, algal growth is controlled by the concentration of phosphorus in the water. However, in some lakes, nitrogen controls algal growth. In those nitrogen-limited lakes, blue-green algae, also known as cyanobacteria, can out compete other algae and produce intense blooms. Some blue-green algae can produce toxins that can reach levels unhealthy to humans and wildlife. Lake Puckaway is at times phosphorus limited and at times it is nitrogen limited. During the times of nitrogen limitation, the lake has the potential to produce blue-green algae blooms, which in some years may be intense.

Poor water quality conditions have resulted in Lake Puckaway's inclusion on the Wisconsin Impaired Waters listing to the Environmental Protection Agency. The lake was first listed in 2010 for excessive total phosphorus, chlorophyll-*a*, and suspended sediment. These levels exceeded thresholds for recreational use and fish and aquatic life use. The lake continued to be listed during reassessments completed in 2012, 2014, and 2016.

Lake Puckaway has a large watershed of over 442,000 acres (watershed to lake area ratio 84:1) consisting of several subwatersheds, including water arriving from Buffalo Lake, the Grand River, Lake Montello, and direct overland flow. The Buffalo Lake subwatershed makes up approximately 44% of the Puckaway's watershed while Lake Montello encompasses 21%, and the remaining 33% is from the Grand River and direct overland flow. Modeling indicates that over 293,000 pounds of phosphorus enters Lake Puckaway from its watershed annually. About 70% of that phosphorus originates from row crop agriculture in the Grand River and direct watershed. This amount of phosphorus being delivered to Lake Puckaway every year definitely has a negative impact on the lake. However, it is not just the agriculture in the watershed that determines the amount of phosphorus entering the lake, the sheer size of the lake's drainage basin must also be

considered because even if it contained substantially less row crop acreage, the lake would still have a great deal of phosphorus loaded to it each year.

As an example, the watershed model was used to develop a scenario where half of the row crop acreage, the acreage that exports the greatest amount of phosphorus, was converted to forested land cover, the cover that exports the least amount of phosphorus. In this scenario, the phosphorus load to Lake Puckaway reduced by nearly 97,000 pounds (~33%) each year. Even utilizing this unrealistic improvement to the watershed, phosphorus concentrations in Lake Puckaway would exceed 77 µg/L and the lake would still be borderline hypereutrophic exhibiting high algae content and low water clarity.

Some of the worst years of water quality in Lake Puckaway are those years with low flows compounded by low levels of plant growth in the lake. During these years, large amounts of phosphorus are released from bottom sediments into the overlying waters. The phosphorus then fuels algae growth and photosynthesis increases greatly. With the increased algal growth, the pH of the lake naturally increases and causing even more phosphorus to be released from the sediment. This positive feed-back loop can allow for so much phosphorus to be added to the system that nitrogen then becomes the limiting plant nutrient, giving blue-green algae, which can utilize nitrogen from the air, an advantage over other algae groups. In Lake Puckaway, these blue-green blooms have been intense and a risk to human health.

In 2011 over a ton of phosphorus was released from Lake Puckaway bottom sediments and during 2012, nearly two tons were released. During those years, Lake Puckaway did not function like a normal lake that intercepts and settles nutrients from in flowing water. In these years, and others in the past, Lake Puckaway was a source of phosphorus for downstream waterbodies. So, Lake Puckaway's current condition is not just unhealthy for the lake itself, but in some years, also the waterways downstream of it. Using equations found in Desortova (1981) and Voros and Padisak (1991) and chlorophyll measured in the eastern basin of Lake Puckaway along with flows measured at the Princeton Dam in 2015, Lake Puckaway exported 0.4 to 1.8 million pounds of algae to downstream waterbodies adversely impacting their water quality tremendously.

The above concept is very important in understanding how Lake Puckaway functions within the Fox River watershed. Most lakes act as sedimentation basins, so as water flows into them biological and physical functions settle pollutants, like nutrients and sediments, to the lake's bottom. Therefore, with most lakes, the water exiting the lake is cleaner than the water entering it. This is not the case with Lake Puckaway because as described above, during some years, the level of nutrient release from the bottom sediments is so great that more phosphorus leaves the lake than enters it, polluting the waterbodies below Puckaway and weakening local, state, and federal efforts to restore them.

Modeling completed to assess the susceptibility of Puckaway bottom sediments to wind-induced waves indicated that over a third of the lake's bottom was prone to resuspension for over a third of the open water season. During times of resuspension, turbidity and phosphorus levels are raised. The increased phosphorus levels can spur algae blooms. Scenario development using the USACE model indicated that by extending the dredge bank by 8,500 feet to the length it was in 1937 would reduce the area available for resuspension a third of the time from 35% to 28%. Further analysis and use of this model would lead to additional in-lake actions that would reduce sediment resuspension.

Aquatic plant studies completed in 2015 indicate Lake Puckaway is sparsely vegetated. Past studies and anecdotal reports indicate aquatic plant abundance in Lake Puckaway began to decline when water levels were regulated with the first lock and dam constructed in 1897. Using historical accounts and aerial photos, Green Lake County Land Conservation Dept. showed the steady decline of emergent plants within Lake Puckaway through 2009. In shallow lakes and flowages that have water level control structures, like the Princeton Dam, it is the unnatural maintenance of near steady water levels that brings about the demise of the plant populations. Decades of research have shown this to be the case (Coops et al. 2003, Leira and Cantonati 2008, and Zhang, et al. 2014). Maintaining higher water levels than would naturally occur during the growing season, year after year, prevents submergent plant survival in deeper water areas by reducing light penetration. Further, many emergent plant species require shallow water and occasional exposed sediments to thrive.

More recent studies have documented a littoral frequency of occurrence within Lake Puckaway of 19%, leaving over 80% of this shallow lake without aquatic plants. Evidence exists that plant population coverage in Lake Puckaway has fluctuated over time. Anecdotal information from reliable sources indicates that plant levels in 2016 were more abundant than in recent history. However, the levels found even at the highest levels in the past several decades do not compare with the levels that existed historically in the lake, especially concerning emergent plant communities.

Shallow lakes in temperate areas such as Wisconsin, are typically dominated by one group of plants - algae, primarily of the free-floating type, or macrophytes, those plants exhibiting leaves, stems, and roots. Lakes dominated by algae are called *turbid-state* lakes and lakes dominated by macrophytes are called *clear-state* lakes. While nutrients and light penetration definitely play a role in which group dominates the lake, interestingly, microscopic animals called ‘zooplankton’, which graze on algae, play a highly important role as well. In lakes with low macrophyte abundance, zooplankton lack cover and are consumed heavily by fish. The reduction in zooplankton, in tandem with high nutrients, leads to dominance by algae. If the macrophytes are present to provide the zooplankton coverage, the zooplankton graze so heavily on algae that the water remains clear. Further, the macrophytes provide substrate for a type of algae called *periphyton*, which attach to the macrophytes and utilize nutrients, but do not cloud the water like free-floating algae. The macrophytes are the key in keeping the lake clear.

Lake Puckaway has transitioned from a historically clear state to its current turbid state, which has resulted in poor water quality conditions and poor fisheries and wildlife habitat. The lake will remain in a turbid state until humans take action to correct it. While shoreland development has resulted in lost habitat on the lake, the most severe habitat loss has occurred with the diminishing aquatic plant population. All forms of aquatic plants – emergent, submergent, and floating-leaf currently occur at low levels in Lake Puckaway. The absence of these populations negatively impact Lake Puckaway in many ways, including:

- Increased sediment resuspension
- Reduced zooplankton refuge
- Decreased water clarity
- Reduced fishery habitat

- Reduced shorebird and waterfowl habitat
- Reduced aesthetics
- Reduced property values
- Increased nutrient availability for algae

As described above, the tremendous scale of the Lake Puckaway watershed limits how changes in that watershed would impact the water quality of the lake. In other words, even unattainable and unrealistic changes to the Lake Puckaway watershed will do little to change the nutrient input to the lake; therefore, to improve the overall health of Lake Puckaway, changes need to be made in the lake itself. The greatest improvement in Lake Puckaway's health would be gained by significantly increasing the plant population within the lake, including submergent, emergent, and floating-leaf species. This concept is not new to the LPPRD because in June 2008, its Board of Directors passed a motion brought forward by the Adaptive Management Committee to establish 1000 acres of emergent and floating-leaf plants.

Increasing emergent and floating-leaf plant abundancies would improve shorebird and waterfowl habitat that has declined in the decades since the construction of the dam. Increases in this type of habitat would also benefit fish species, like northern pike and perch, that utilize these plant communities as spawning grounds. Further, these plant types significantly reduce shoreline erosion in the areas they occupy. Submergent aquatic plants, on the other hand, provide nursery habitat for panfish species, which according to WDNR fisheries biologists, are likely decreasing in Lake Puckaway. Increased panfish habitat would directly benefit anglers that fish for those species and because panfish feed upon young carp, an increase in panfish would also work to reduce Puckaway's unwanted carp population.

Established submergent plants in a shallow system such as Lake Puckaway positively impact water quality in several ways, including the reduction of sediment resuspension by wind-driven waves. As described above, Lake Puckaway's combination of shallow water and large surface area frequently result in large waves which resuspend bottom sediments in portions of the lake. The presence of submergent plants reduces these impacts by reducing wave length and lowering water turbulence. Submergent plants also enhance water quality by competing with algae for light and nutrients. Additionally, the submergent plants increase water clarity by providing refuge for zooplankton which graze heavily on algae. The combination of providing zooplankton refuge and competing with algae for light and nutrients is what keeps many shallow lake ecosystems clear as opposed to turbid like Lake Puckaway's current condition.

Increasing aquatic plant biomass in Lake Puckaway the key in converting the lake from a turbid system to a clear-state system and in raising the overall health of the lake; therefore, it is the primary goal of the Lake Puckaway management plan. The increase in plant growth would include all forms of aquatic plants, including emergent, floating-leaf, and submergent species; however, it is anticipated that the majority of additional growth would occur in the lake's eastern basin, leaving much of the deeper western basin in an open-water state as it is now. While it took decades for the lake to degrade to the point it is now, if aquatic plant abundance in Lake Puckaway can be sufficiently increased, it is expected that improvements to water quality would be realized relatively quickly in terms of lower algae levels and higher water clarity. Positive changes to the fisheries, both in terms of increased gamefish and decreased carp, would likely take a few years.

To restore Lake Puckaway to a healthier condition, the significant establishment of aquatic plants within the lake is required. The required level is above and beyond what has been seen in the lake in recent years and decades and must include emergent, floating-leaf, and submergent species. Within the Implementation Plan, two actions are included, that if both completed, would work together to substantially increase aquatic plant habitat in Lake Puckaway as discussed above.

The Implementation Plan calls for the creation of a Shallow Lake Workgroup comprised of district members, WDNR staff, and other agency representatives. The group will work to complete several in-lake projects aimed at enhancing wildlife and fisheries habitat in Lake Puckaway. These projects will include the reconstruction of at least part of the east dredge bank as well as the reconstruction and stabilization of Pancake Island. Construction of new island habitat will also be considered. These projects will produce in-lake barriers that will reduce resuspension of bottom sediments while providing additional area for floating-leaf and emergent plant habitat.

The actions carried out by the Shallow Lake Workgroup, as outlined above, will increase available area within the lake for aquatic plant growth by providing more shallow and protected areas in the lake. However, those physical improvements alone will not provide for the establishment of additional plant community growth on their own. To promote the enhancement of those communities, Lake Puckaway's management needs to incorporate opportunities for the establishment of additional aquatic plant habitat. To achieve that objective, Lake Puckaway's water levels need to more closely mimic those of a natural system, at least during some years. Lowering water levels during part of the growing season, as seen in natural systems, including the exposure of nearshore bottom sediments, would promote the establishment of emergent and floating-leaf species. Lowering water levels at that time would also increase light penetration in additional areas of the lake and aid in the establishment of submergent species.

Re-establishing aquatic plants through water level management has been accomplished in many systems (Coops and Hosper 2002, Dienst et al. 2004, Havens et al. 2004, and Coops et al. 2004). With funding and technical support from the US Army Corps of Engineers-St. Paul District, researchers conducted experimental water level reductions on three pools of the northern reaches of the Upper Mississippi River (Kenow et al. 2007a, Kenow et al. 2007b, and Kenow 2010). During 2005, water levels were reduced by 1.5 feet in Pool 5 with a second reduction in 2006 being abandoned due to low flows. Pool 6 was reduced by 1.0 foot in 2010. Pool 8 was reduced consecutively by 1.5 feet in 2001 and 2002. All reductions were conducted from roughly mid-June through September and resulted in exposed sediment flats. While all reductions resulted in an increase of aquatic plants of all types, the researchers documented a shift in dominance between annual plant species, like rice-cut grass and bushy pondweed, to perennial species, like common arrowhead, common bur-reed, water stargrass, and softstem bulrush, with the second year of drawdown. Perennial species are those that do not rely on the germination of seeds on an annual basis to sustain the establishment of the community. The latest studies completed on Pool 8 indicated that the newly established aquatic plants persisted for at least six years.

Water level management alone, if conducted properly would increase emergent, floating-leaf, and submergent plants in Lake Puckaway. The in-lake restoration measures proposed as a part of the Shallow Lake Workgroup project list would enhance the increased habitat even further and in some areas, likely extend the longevity of the water level manipulation's affects. The WDNR is pursuing state funding for the reconstruction of the Princeton Dam and have made it clear that without some

semblance of water level management plan in place, an environmental impact statement on the reconstruction of the dam would need to be completed.

That impact statement would include information, as discussed above, that indicates that near-steady state water levels in lakes and flowages leads to aquatic habitat degradation. To offset that damage, the dam operation order for the newly reconstructed dam would include a water level management plan. Further, the Environmental Protection Agency, through the Clean Water Act, is currently completing a Total Maximum Daily Load (TMDL) analysis of the Upper Fox River and will further document that Lake Puckaway, as shown in the studies associated with this project, at times acts as a nutrient source for downstream waters. As a part of the TMDL actions implemented in the Upper Fox River Basin, the EPA would recommend water level management to be used to help correct the Lake Puckaway nutrient export issue.

Completing a sufficient water level reduction from late June through September in two consecutive years will bring about hardships for private and business riparian property owners on Lake Puckaway. That is without a doubt; however, to restore the lake for future generations, many that may inherit property from current property owners, this sacrifice is necessary. Still, it would be unfair to those property owners not to have a realistic method to plan when the reductions would occur. The water level management plan contained within the Implementation Plan accounts for the fact that Lake Puckaway flows are highly variable and as a result of high flows, a reduction may not be feasible during some years. Therefore, a discharge rate has been set in the plan, that if not met on a certain date, would trigger an abandonment of the attempt for that year.

The water level management plan also limits the attempts at water level reductions so district members and other lake users know that year-after-year, reductions will not be attempted. Finally, the plan contains a monitoring strategy to document changes in the lake's water quality and aquatic plant community so future management decisions, such as when another reduction sequence is needed to maintain the plant population enhancements brought on by previous sequences, are based upon real data. Or, to document that the plan is not causing the desired changes and should be rethought or possibly abandoned all together. These considerations for riparians may not be included in a water level management plan created by an outside agency if that agency is forced to create the plan. The water level management plan presented in the Implementation Plan does have some flexibility, but the overarching goal should be to enhance the health of Lake Puckaway and make future management decisions based upon real data.

The Implementation Plan also contains additional goals and actions aimed at increasing the lake management and communications capacity of the district and enhancing the fishery. It also contains an action to spur legislatures on to including the reconstruction of the Princeton Dam in the 2017/2019 Wisconsin biennial budget. If that project is funded, the water levels of the lake would likely need to be lowered for a year during construction. As described in the water level management plan, lowering water levels for a second consecutive year would allow for a portion of the Shallow Lake Workgroup projects to be completed and overall stand as the first water level reduction sequence for Lake Puckaway.

1.0 INTRODUCTION

Lake Puckaway, Green Lake and Marquette counties (Map 1), is a shallow (3 ft average depth), hypereutrophic, 5,039-acre drainage lake that was historically a natural widening of the Fox River. The Village of Marquette is located on the southeast shore of the lake, while towns of Montello and Princeton and the City of Green Lake are all less than 10 miles away. The lake is renowned as a sportsman's paradise, offering diverse waterfowl hunting and fishing opportunities. Lake Puckaway also produced Wisconsin's current record northern pike weighing in at 38 pounds.

The lake is retained by the Princeton Dam, constructed in 1897 by the US Army Corps of Engineers and located approximately 8 miles downstream on the Fox River. For the past decade, the Lake Puckaway Protection & Rehabilitation District (LPPRD) and Wisconsin Department of Natural Resources (WDNR) have been operating the dam in partnership under a Memorandum of Understanding (MOU) which dictates how alterations are made to the dam to control lake water levels. In a typical year, lake levels are high in spring and early summer as a result of spring runoff. When lake levels have dropped, boards are manually placed on the existing dam structure to retain water in Lake Puckaway for recreational purposes. The LPPRD, as alluded to below, aims to have the boards installed on the dam around May 15th of each year; however, since at least 2010, high spring and early summer flows have prevented the boards from being put on until after mid-June. Concerns over safety have been raised regarding the placement and removal of the boards to control water levels.

In June 2004, the LPPRD approved a comprehensive management plan for Lake Puckaway that contained 22 goals overall. The first eight goals were listed as key for having the most long-term effect on the lake's health and included the establishment of a district adaptive management committee, continued monitoring and enhancement of the lake's water quality and aquatic plant habitat, reduction of the lake's carp population, the establishment of a water level management plan with the WDNR, monitoring of the lake's fishery population, the development and implementation of projects to prevent erosion of private and public shorelines, and the implementation of best management practices within Lake Puckaway's watershed.

The adaptive management committee functioned for several years and as a part of their work created the Emergent Plant Stabilization Program (EPSP) that called for the establishment of an additional 500 acres of emergent plants in Lake Puckaway by 2014. The emergent establishment would be facilitated by leaving the boards off the dam an additional 30 days from the original boards-on date of May 15 during 3 of the 5 years from 2010. Emergent plantings would also be completed as well during these years. The district voted in favor of the EPSP in June 2009, but high waters during those years prevented the reduced water levels. However, the plantings did take place over several years, but did not increase the acreage of emergent plants within the lake.

The project discussed here began in the spring of 2015 and included continued assessment of the lake's water quality, modeling of watershed inputs, the completion of multiple surveys to document occurrences of native and non-native plants species within the lake, and a full bathymetric study to develop a new contour map of the lake. The project also included the integration of available fisheries information and data generated by a Green Lake County-sponsored shoreland condition assessment. Further, public participation and opinions were sought through an issues assessment, district-wide stakeholder survey, and the facilitation of seven public meetings held to inform district members and other interested individuals regarding the results of

the studies, the conclusions drawn from those results, and the goals and actions included within the management plan.

Other projects concerning Lake Puckaway are occurring as well, including a Total Maximum Daily Load (TMDL) development project in the Upper Fox and Wolf basins. The TMDL development, as well as the listing of impaired waters by states, is an EPA program regulated by the Clean Water Act of 1972 and amendments added in 1977. Lake Puckaway struggles with water quality issues brought on by its shallow nature, large watershed, carp infestation, and depauperate plant community. The lake has been listed on the WDNR 303(d) impaired list for excessive phosphorus levels, algal growth, turbidity, and degraded habitat since 2012. Because Lake Puckaway is a part of the Upper Fox Basin, the TMDL project does not just look at how Lake Puckaway's watershed impacts Lake Puckaway, it also considers how Lake Puckaway impacts downstream waterbodies. As is discussed in the water quality section, during some years, Lake Puckaway serves as a source of nutrient pollution in the Upper Fox River. Overall, the State of Wisconsin is required by federal law to implement the TMDL and take actions to have waterbodies removed from the 303(d) impaired water list so those waterbodies can be considered as safe for swimming and fishing.

Another project concerning Lake Puckaway, which has been in consideration for over a decade and is just now likely to come to fruition in the next few years, is the reconstruction of the Princeton Dam to include a fixed crest. The new fixed-crest dam will be at the same elevation as the current dam with the boards in place. Final plans for the dam have not been completed, but the WDNR did include the reconstruction project in their proposed budget for the 2017-2019 biennium.

As a part of the planning for the new dam, the WDNR has encouraged the LPPRD to update its 2004 comprehensive management plan. Further, as a part of that updated plan, the WDNR has urged the district to include a water level management plan with other appropriate actions aimed at addressing the water quality and aquatic habitat issues on the lake. By addressing those issues within the district-sponsored plan, the WDNR would be able to avoid completing an environmental impact statement as a part of the dam reconstruction project. If completed, the environmental impact statement would very likely call out the issues brought about by the dam's near-steady water levels, for example loss of aquatic plants and the subsequent issues brought on by that loss. To minimize those issues, the environmental impact statement would call for the development and implementation of a water level management plan. The aim of a water level management plan would be to increase aquatic plant occurrence within Lake Puckaway, which would spur better water quality within the lake. A primary focus of this planning project was to create a water level management plan that was appropriate for Lake Puckaway and take into consideration the needs of the people that use and care for it.

Field Survey Notes

Lake Puckaway is a large, shallow lake with surprisingly very little plant life near much of its shoreline or in deeper waters. Still, there are small areas of the lake with diverse emergent communities. While the invasives, curly-leaf pondweed, brittle naiad, and Eurasian watermilfoil were located, neither seem to be in overabundance. Water quality is characterized by low transparency and high turbidity.



Photograph 1.0-1 Lake Puckaway, Green Lake-Marquette Counties

Lake at a Glance - Lake Puckaway

Morphology	
Acreage	5,013
Maximum Depth (ft)	5
Mean Depth (ft)	3
Shoreline Complexity	9.8
Vegetation	
Curly-leaf Survey Date	June 18-19, 2015
Comprehensive Survey Date	July 10-11, 2015
Number of Native Species	39
Threatened/Special Concern Species	N/A
Exotic Plant Species	Eurasian watermilfoil, Hybrid watermilfoil, Curly-leaf pondweed, Curly-leaf X white-stem pondweed hybrid, Purple loosestrife, Pale-yellow iris, Brittle naiad
Simpson's Diversity	0.92
Average Conservatism	5.5
Water Quality	
Trophic State	Eutrophic – Hypereutrophic
Limiting Nutrient	Transitional Phosphorus/Nitrogen
Water Acidity (pH)	8.4-8.7
Sensitivity to Acid Rain	Not Sensitive
Watershed to Lake Area Ratio	84:1

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 is to accommodate communication between the planners and the stakeholders. The communication is informational in nature, both in terms of the planners informing the stakeholders and vice-versa. The planners inform the stakeholders about the planning process, the functions of the lake ecosystem, their impact on the lake, and what can realistically be expected regarding the management of the aquatic system. The stakeholders inform the planners by describing how they would like the lake to be, how they use the lake, the lake's history, 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, press releases, and postings on the district website and Facebook page.

Lake Puckaway Issues Assessment

As a part of the initial phase of this project, Linda Stoll, L Stoll Consulting, conducted one-on-one interviews with 16 people who are actively involved in the management of Lake Puckaway or are directly impacted by the management decisions. The assessment (Appendix A) was completed to shed light on topics of interest, opinions, and potential issues that may be encountered during the upcoming planning project. As a result of this assessment, the Lake Puckaway management planning project focused on providing information to LPPRD members and the general public through several outlets, including the five planning-information meetings discussed below.

Kick-off Meeting

On June 4, 2016, a project kick-off meeting was held at the Marquette Village Hall to introduce the project to the general public. The meeting was announced through a district mailing, a public notice in local newspapers, on the LPPRD web site, and through personal communications by LPPRD board members. The approximately 60 attendees observed a presentation given by Tim Hoyman, an aquatic ecologist with Onterra, LLC, the lake management planning firm hired by the LPPRD to assist with creating Lake Puckaway's updated management plan. Mr. Hoyman's presentation started with an educational component regarding general lake ecology and ended with a detailed description of the project including opportunities for stakeholders to be involved. The presentation was followed by a question and answer session.

Planning-Information Meetings

The LPPRD created an eight-member Lake Puckaway Planning Committee consisting of current and past district board members and members of the LPPRD that have been involved in district activities. Five planning and informational meetings focusing on different topics were held through the summer and early fall of 2016 (Table 2.0-1). The meetings were primarily directed at the planning committee, but all were open to the general public with the intention of providing an opportunity for all interested individuals to gain a better understanding of the Lake Puckaway ecosystem. Meetings were held at either the Mecan Town Hall or the Marquette Village Hall. The meetings were announced through news releases in the Marquette County Tribune and publications through the Berlin Journal, on Lake Puckaway's Facebook page, and the LPPRD website. The news releases included interviews with each of the meeting presenters as well as a

preview of the information that would be presented at the meeting. A list of meetings and dates were also posted at Lake Puckaway boat launches.

All of the planning-information meetings were professionally facilitated by Linda Stoll, L. Stoll Consulting. Ms. Stoll explained the primary focus of each meeting, introduced presenters, and reviewed the highlights of each presentation with the planning committee members. Questions and comments were also accepted from members of the general public following the discussion with the planning committees. To assure that all public comments were allowed and questions were answered, forms and pens were available at each meeting so attendees could provide written comments. Contact information was required on the form and used by Onterra staff to provide answers to questions and/or responses to comments.

Following each meeting, a meeting summary was created by Ms. Stoll and Onterra staff. The summary also included any comments by the planning committee and general public along with their questions and the answers provided by the presenters. This meeting summary was then posted on the LPPRD web site.

The materials for each of these meetings, including the press release, presentations, and meeting summary, are placed in chronological order in Appendix C.

Table 2.0-1. Lake Puckaway 2016 informational and planning meetings.

Meeting	Topics & Presenters	Location
Aquatic Plant Community and Aquatic Invasive Species June 13, 2016	Brenton Butterfield, Onterra LLC: <i>Lake Puckaway 2015 Aquatic Plant Survey Results</i> Derek Kavanaugh, Green Lake County: <i>Lake Puckaway's Aquatic Plant Trends 1673-2009</i>	Mecan Town Hall
Fisheries & Habitat Workgroup June 28, 2016	Dave Bartz, WDNR: <i>Lake Puckaway Fisheries and Habitat</i> Ted Johnson, WDNR: <i>Shallow Lake Management Workgroup</i>	Marquette Village Hall
Watershed, Water Quality, TMDL and Shoreland Assessment July 18, 2016	Tim Hoyman & Paul Garrison, Onterra LLC: <i>Lake Puckaway Water Quality</i> Keith Marquardt., WDNR: <i>Total Maximum Daily Loads (TMDLs)</i> Krista Kamke, Green Lake County: <i>Puckaway Shoreline Survey</i>	Mecan Town Hall
Fetch Modeling & Sediment Resuspension, Summary/Conclusions, Water Level Management August 8, 2016	Tim Hoyman & Paul Garrison, Onterra LLC: <i>Lake Puckaway Management Plan Update Project – Meeting V</i>	Marquette Village Hall
Conclusions Review, Management Goals and Actions September 26, 2016	Tim Hoyman & Paul Garrison, Onterra LLC: <i>Lake Puckaway Management Plan Update Project – Meeting VI</i>	Marquette Village Hall

Stakeholder Survey

During February 2015, a post card was mailed to the approximately 850 riparian property owners, within in the LPPRD. Each card included a unique code so the recipient could access a 34-question survey on a popular internet website called Survey Monkey. A second postcard was sent out approximately two weeks after the initial postcard to remind stakeholders to complete the online survey. Due to the large nature of Lake Puckaway and its district, if an online response was not completed, paper copies of the survey were sent to those stakeholders who had not yet completed the online survey. Sixty-three percent of the surveys sent out were completed through a combination of the website Survey Monkey and paper copies. The paper copies were entered into Survey Monkey by a LPPRD volunteer and Onterra staff. The data were summarized and analyzed by Onterra for use at the planning meetings and within the management plan. The full survey and results can be found in Appendix D, while discussion of those results is integrated within the appropriate sections of the management plan and a general summary is discussed below.

Due to an error in one of the questions the online survey was shut down briefly in February to correct the mistake. The answers that were already in the system were downloaded and saved to be combined into the complete survey data for analysis.

While Onterra creates the survey, and determines the number of surveys sent out, Onterra does not send out the survey information to allow respondent anonymity can be retained. Due to an error created by the mailing company, stakeholders received two different codes on the post card mailings, plus a hard copy. Some other stakeholders may not have received any piece of mailing. This error was caught by Onterra while in the initial phases of survey analysis. Due to this error, a clarification mailing was sent out to the impacted stakeholders. This clarification piece was either a postcard or a hard copy depending on what that address had received previously. The postcard was used to determine if the property owner had completed an online survey as well as a hard copy of the survey. All of this information was used to reconcile the database and remove duplicate responses.

Once all of the surveys were entered into Survey Monkey, the data was downloaded and analyzed for duplicate entry codes as well as duplicate surveys with different codes. The initial round of paper copies sent out did not include a personalized code so to determine if there was duplicate survey, Onterra used questions with non-opinion based answers, for example: what type of septic system does your property utilize, followed by an open-ended question, for example: how long have you owned or rented your property, to find duplicates. Duplicate responses were deleted. Onterra was able to delete 61 duplicate surveys with confidence from Survey Monkey based upon the clarification postcard as well as looking through all responses and comparing the multitude of codes a single person could have received.

The next step was combining all three datasets to complete the survey analysis. The three datasets were the responses before the survey was shut down in February, the responses completed online, and the surveys that were completed on paper copies, but entered online later. These were all combined and then looked through thoroughly again to check for any duplicate answers as a double check. In the end, there were 533 different surveys recorded of 850 surveys sent, equaling a 63% return rate.

Based upon the results of the Stakeholder Survey, much was learned about the people that use and care for Lake Puckaway. The majority of stakeholders either visit Lake Puckaway on weekends throughout the year (31%) or are year-round residents (31%). Again, 31% of stakeholders have owned their property for over 25 years, and 33% have owned their property for ten years or less.

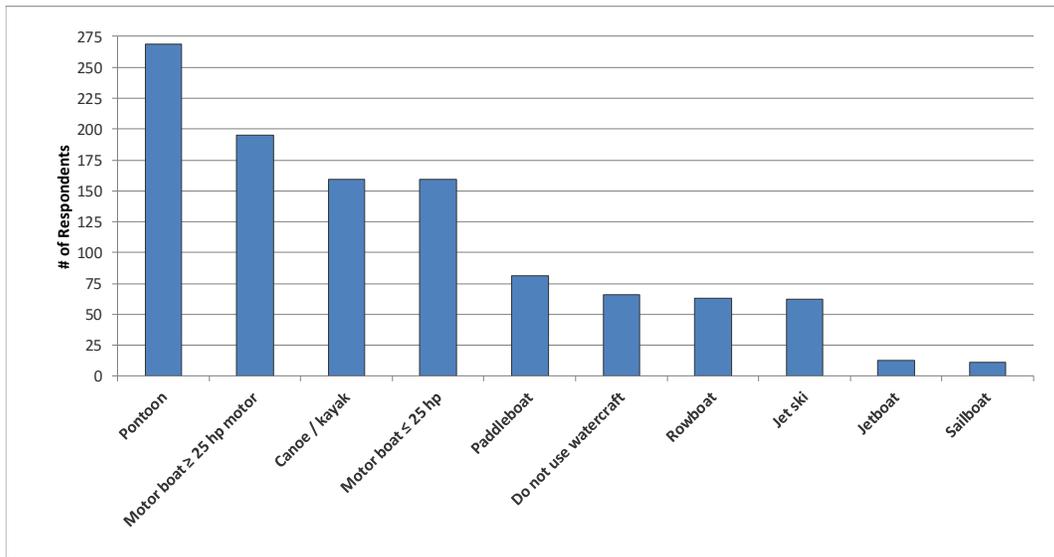
The following sections (Water Quality, Watershed, Aquatic Plants and Fisheries Data Integration) discuss the stakeholder survey data with respect to those particular topics. Figures 2.0-1 and 2.0-2 highlight several other questions found within this survey. More than half of survey respondents indicate that they use either a pontoon boat on Lake Puckaway (Question 12). Motorboats with greater than a 25 hp motor and canoes/kayaks were other popular choices. On a large shallow lake, such as Lake Puckaway, 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. As seen on Question 13, two of the top three recreational activities on the lake involve boat use. Although boat traffic was listed as a factor potentially impacting Lake Puckaway in a negative manner (Question 19), it was ranked 9th on a list of stakeholder's top concerns regarding the lake (Question 20). Low water levels are their number one concern, which also affects boating and recreation.

A concern of stakeholders noted throughout the stakeholder survey (see Question 20 and survey comments – Appendix B) was water levels within Lake Puckaway and the problems with the Princeton Dam.

Public Comments on Draft Plan

In mid-March 2017, hardcopies of the draft management were placed at the Markesan, Montello, and Princeton public libraries. Electronic copies in Adobe's Portable Document Format (PDF) were also made available on the LPPRD website. The availability of these documents was announced on the district website, its Facebook page, and in a press release (Appendix I). Each document included instructions on providing written comments by April 7, 2017. Six property owners provided comments and questions to the draft plan via email. Onterra responded to each of these submittals along with the comments received by the district board and WDNR (Appendix I)

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



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

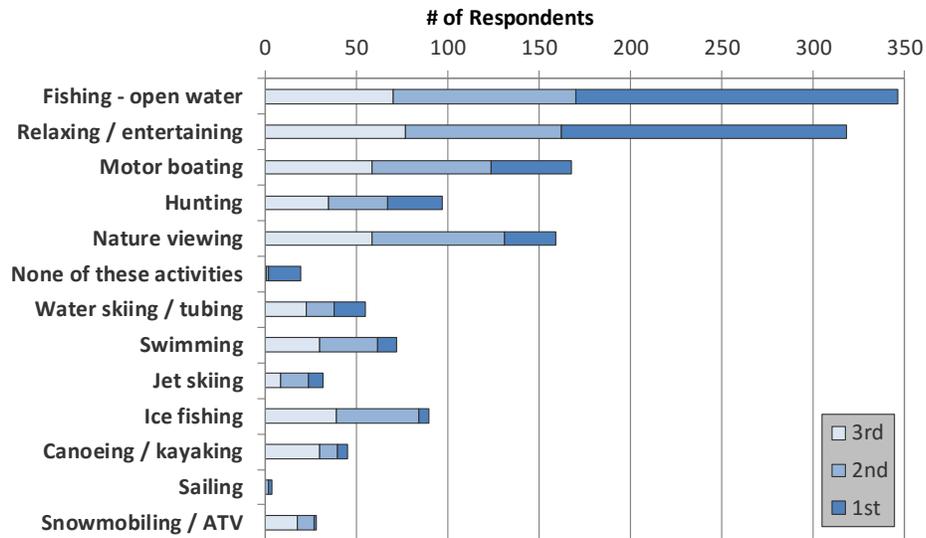
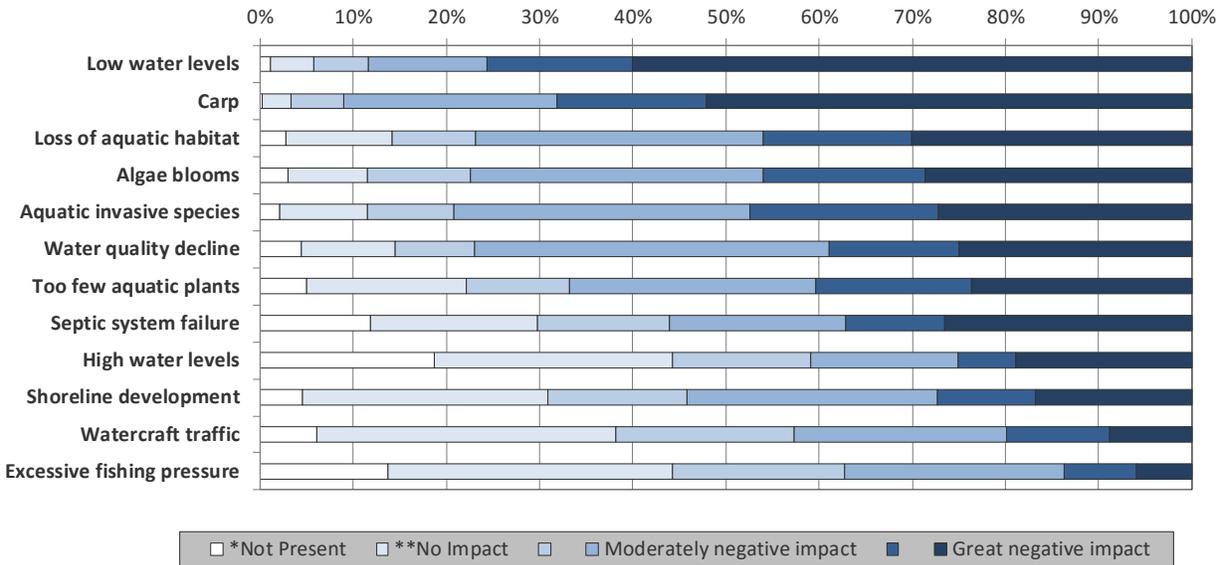


Figure 2.0-1. Select survey responses from the Lake Puckaway Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

Question 19: To what level do you believe these factors may be negatively impacting Lake Puckaway?



Question 20: Please rank your top three concerns regarding Lake Puckaway.

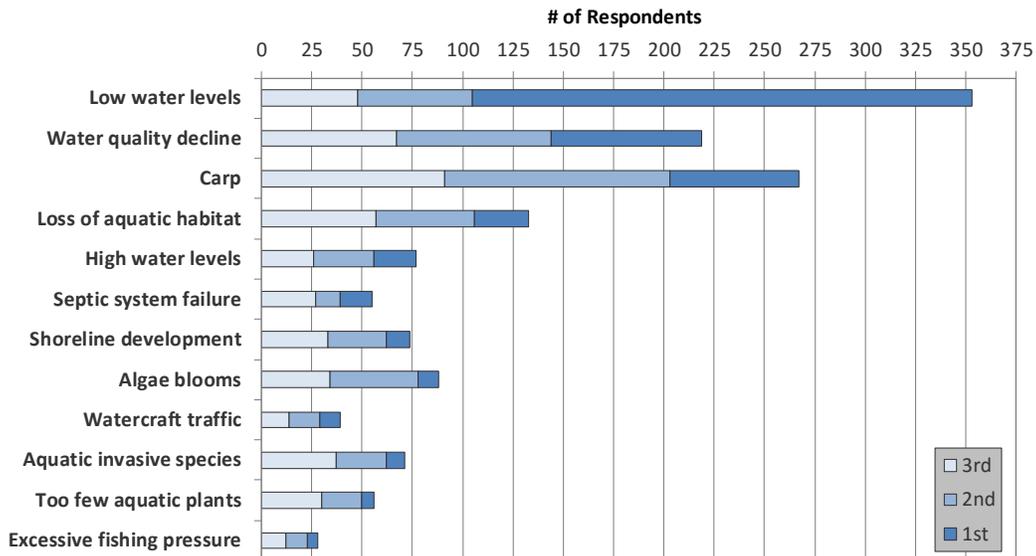


Figure 2.0-2. Select survey responses from the Lake Puckaway Stakeholder Survey, continued. Additional questions and response charts may be found in Appendix B.

Public Comments on Draft Plan

In mid-March 2017, hardcopies of the draft management were placed at the Markesan, Montello, and Princeton public libraries. Electronic copies in Adobe’s Portable Document Format (PDF) were also made available on the LPPRD website. The availability of these documents was announced on the district website, its Facebook page, and in a press release (Appendix H). Each document included instructions on providing written comments by April 7, 2017. Six property owners provided comments and questions to the draft plan via email. Onterra responded to each

of these submittals along with the comments received by the district board and WDNR (Appendix H)

2017 Public Information Meetings

Two identical information meetings were conducted on Thursday, May 4 2017 and Saturday, May 6, 2017. The meetings included a presentation of the primary results of the project, discussion of those results, and a description of the proposed implementation plan, with most time being spent on the water level management plan (Appendix I). All questions and comments were taken during the meetings. Most district board and planning committee members were in attendance at both meetings.

Plan Adoption Process

On Saturday, May 6, 2017, following the final of two public information meetings described above, the Lake Puckaway Planning Committee voted to recommend that the LPPRD Board of Commissioners adopt the March 2017 draft management plan.

During the 2017 Annual LPPRD Meeting, Randy Schmidt made a motion to allow the LPPRD Board of Commissioners to make the decision on adopting or not adopting the management plan as recommended by the Lake Puckaway Planning Committee; the motion was seconded by Deb Flagel. The motion passed with 24 members voting in favor of the motion and 17 members voting against the motion. After a 15-minute recess following the close of the annual meeting, the LPPRD Board of Commissioner reconvened and took action on the motion that was passed in the open session of the earlier portion of the agenda. Commissioner Weber made a motion to accept/adopt the Lake Puckaway Comprehensive Management Plan; seconded by Commissioner Wilson. Motion passed on a vote of 5 to 1.

3.0 RESULTS AND DISCUSSION

3.1 Lake Water Quality

Primer on Water Quality Data Analysis and Interpretation

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

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

As mentioned above, chemistry is a large part of water quality analysis. In most cases, listing the values of specific parameters really does not lead to an understanding of a lake's water quality, especially in the minds of non-professionals. A better way of relating the information is to compare it to lakes with similar physical characteristics and lakes within the same regional area. In this document, a portion of the water quality information collected on Lake Puckaway is compared to other lakes in the state with similar characteristics as well as to lakes within the Southeast Wisconsin Till Plains ecoregion (Appendix C). In addition, the assessment can also be clarified by limiting the primary analysis to parameters that are important in the lake's ecology and trophic state (see below). Three water quality parameters are focused upon in the Lake Puckaway's water quality analysis:

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

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

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

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

Trophic State

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

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

However, through the use of a trophic state index (TSI), an index number can be calculated using phosphorus, chlorophyll-*a*, and clarity values that represent the lake's position within the eutrophication process. This allows for a 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.

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.

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

Internal Nutrient Loading*

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

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

may need to be assessed with further water quality analysis and possibly additional, more intense studies.

Non-Candidate Lakes

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

Candidate Lakes

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

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

Comparisons with Other Datasets

The WDNR document *Wisconsin 2014 Consolidated Assessment and Listing Methodology* (WDNR 2013) 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 Lake Puckaway will be compared to lakes in the state with similar physical characteristics. The WDNR groups Wisconsin's lakes into ten natural communities (Figure 3.1-1).

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

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

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

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

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

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

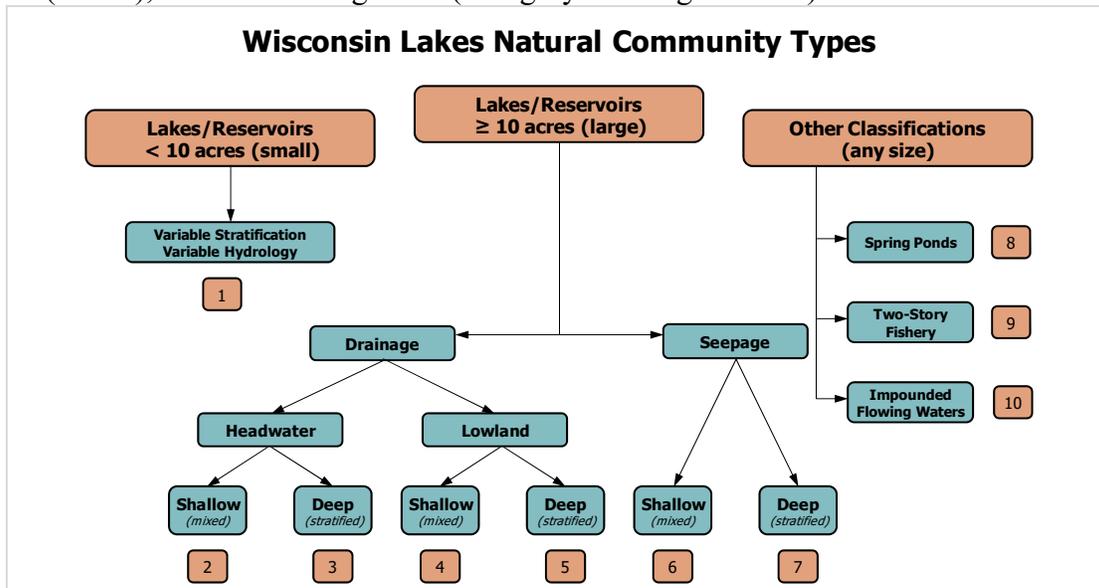


Figure 3.1-1. Wisconsin Lake Natural Communities. Adapted from WDNR 2013A.

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

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

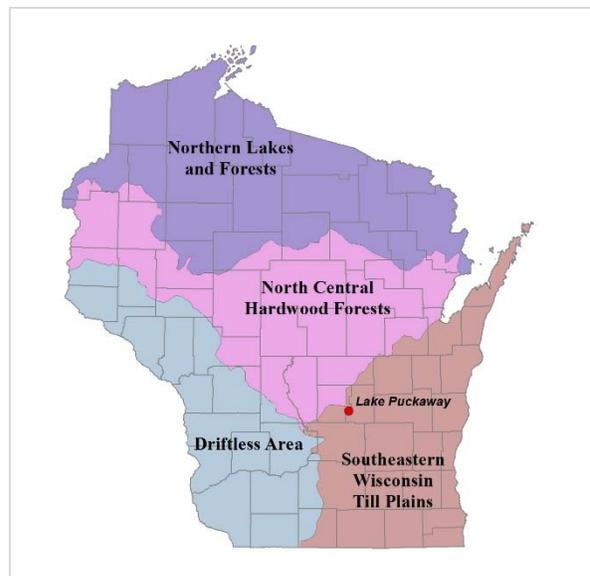


Figure 3.1-2. Location of Lake Puckaway within the ecoregions of Wisconsin. After Nichols 1999.

These data along with data corresponding to statewide natural lake means, historic, current, and average data from Lake Puckaway is displayed in Figures 3.1-3 - 3.1-9. Please note that the data in these graphs represent concentrations and depths taken only during the growing season (April-October) or summer months (June-August). Furthermore, the phosphorus and chlorophyll-*a* data represent only near 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.

Lake Puckaway Water Quality Results

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

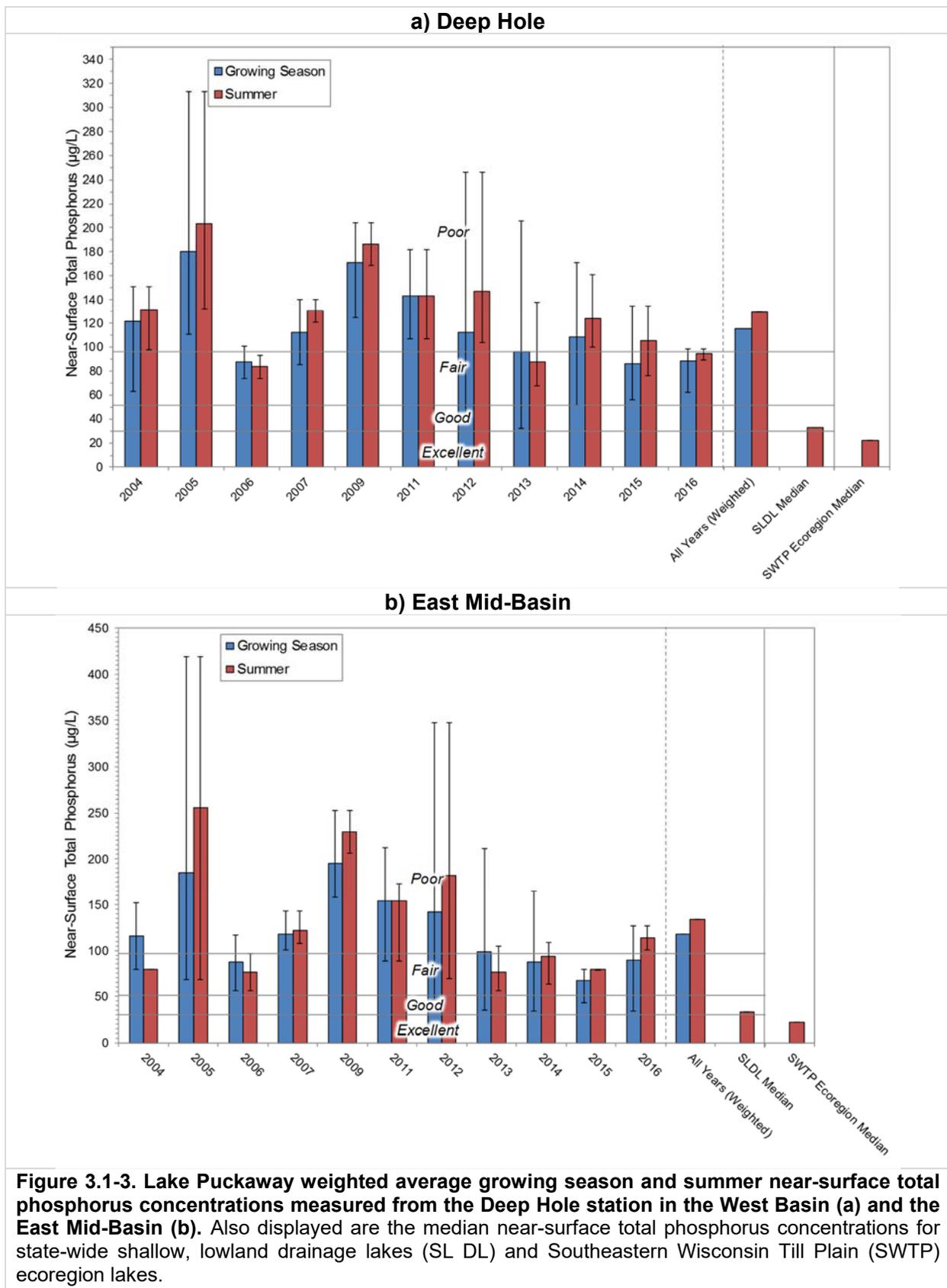
Lake Puckaway contains 12 monitoring stations, and near the inlet there are additional 5 stations in the Fox and Grand rivers (Map 1). There are an additional 2 stations at the outlet. Much of the data collected is for trophic parameters, although a few samples have been collected for mercury, PCBs, sediment characteristics and coliform bacteria. Many of these stations have only been sampled once or twice. The stations in the lake with the longest record are the Deep Hole Station (243039) and the East Mid-Basin Station (243056). For the period from 2011-2014, two stations near the inlet (Fox River near Grand River, 10033617; and Grand River near Fox River, 10033618) were regularly sampled. During this time period, a site near the outlet (Fox River near Wicks Landing, 10033616) was also sampled. It is these frequently sampled stations, in the lake and near the inlet and outlet, that will be discussed in this report.

As previously mentioned, the three primary water quality parameters that are studied in lakes include total phosphorus, chlorophyll-*a*, and Secchi disk transparency. The long-term trends and 2016 data regarding each of these parameters will be discussed in the following sub-sections. The Deep Hole and East Mid-Basin monitoring locations contain the most historical water quality data, and the available water quality data collected at these two locations will be discussed. In addition, within each sub-section, the weighted average value for the respective parameter from the two open water sampling locations will be presented.

Lake Puckaway Long-Term Trends

Total Phosphorus

Data is available from the Deep Hole and East Mid-Basin stations for most years from 2004-2016. Growing season and summer mean concentrations are highly variable. In the Deep Hole, the growing season means range from 62 to 171 µg/L and the summer means range from 84 to 187 µg/L (Figure 3.1-3a). The year with the highest concentration was 2005, while the year with the lowest concentration was the following year, 2006. In 2009, concentrations were nearly as high as 2005, and 2013 was similar to 2006. Most years the mean concentrations were in the poor category. Only in the best years were concentrations in the fair category.



At the East Mid-Basin station, concentration trends were similar as to the Deep Hole Station. Highest concentrations occurred in 2005 and 2009, while the lowest levels were in 2006 (Figure 3.1-3b). Some of the lowest concentrations also occurred from 2013-2015. The growing season means ranged from 68 to 196 $\mu\text{g/L}$ and the summer means ranged from 76 to 256 $\mu\text{g/L}$. Although higher concentrations occurred in the East Mid-Basin compared with the Deep Hole, these generally occurred prior to 2013. From 2013-2015, concentrations have generally been lower in the East Mid-Basin Station. The mean of all the years was similar in both basins with the growing season means being 116 and 119 $\mu\text{g/L}$ in the Deep Hole and East Mid-Basin stations, respectively. The summer means were 132 and 135 $\mu\text{g/L}$ in the Deep Hole and East Mid-Basin stations, respectively.

Weighted averages of summer total phosphorus concentration data are used to compare Lake Puckaway’s total phosphorus concentrations to median values for other shallow, lowland drainage lakes throughout the state and to median values of all lake types within the SWTP ecoregion. The average summer total phosphorus concentrations for the whole lake from all years that data are available 130 $\mu\text{g/L}$ (Figure 3.1-4). This value falls into the *poor* category for shallow, lowland drainage lakes in Wisconsin. While phosphorus concentrations have declined since 2012, summer concentrations are still nearly 10 times higher than the median concentration for shallow, lowland drainage lakes in Wisconsin and approximately 4 times higher than the median value for all lakes within the SWTP ecoregion (Figure 3.1-4).

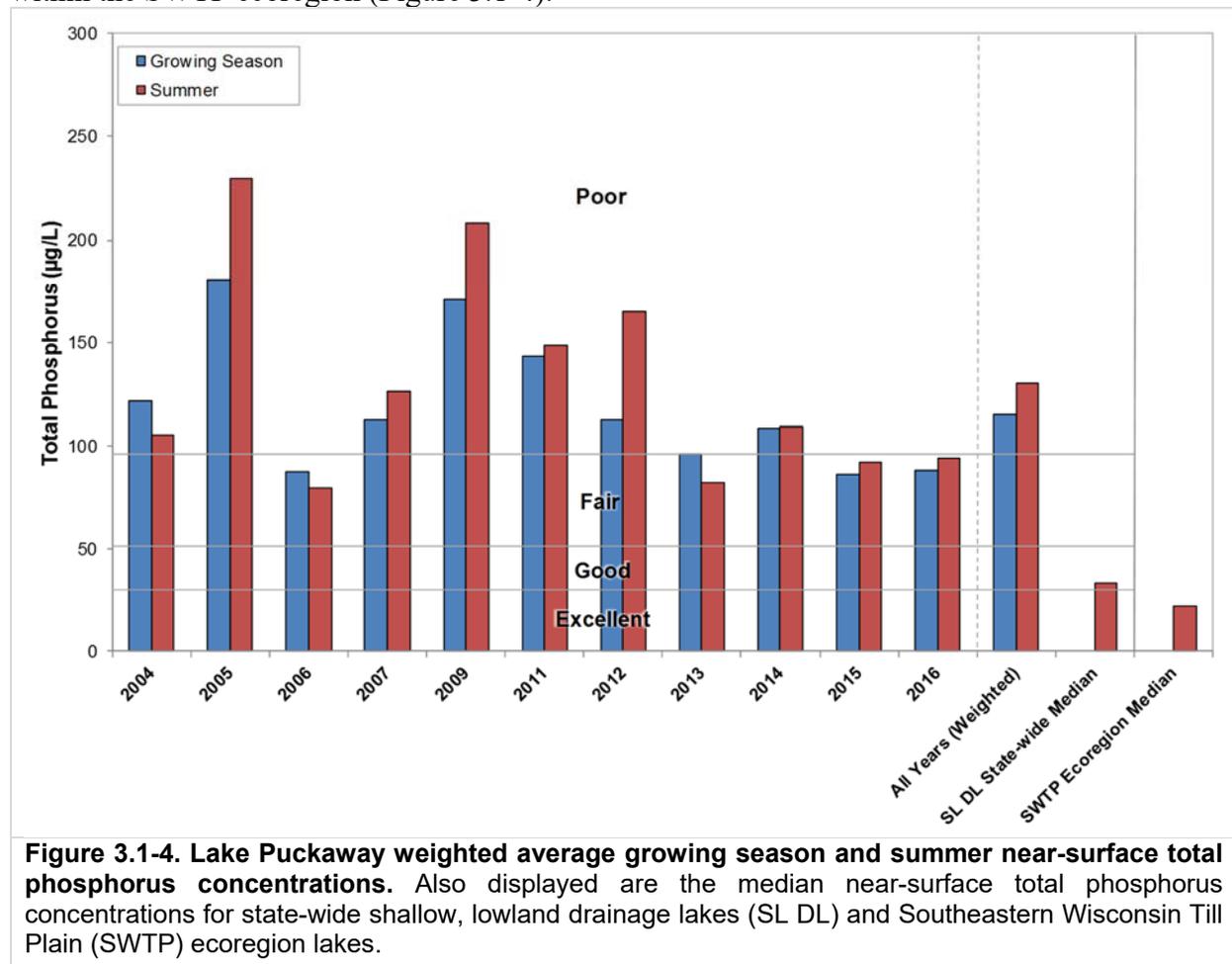


Figure 3.1-4. Lake Puckaway weighted average growing season and summer near-surface total phosphorus concentrations. Also displayed are the median near-surface total phosphorus concentrations for state-wide shallow, lowland drainage lakes (SL DL) and Southeastern Wisconsin Till Plain (SWTP) ecoregion lakes.

Chlorophyll-*a*

As discussed, chlorophyll-*a* is a measure of free-floating algal biomass within a lake and is usually positively correlated with total phosphorus concentrations. Chlorophyll-*a* concentrations in the Deep Hole Station were available for the same period as total phosphorus, 2004-2016. Growing season concentrations ranged from 30 to 113 $\mu\text{g/L}$ (Figure 3.1-5a). For the summer, the concentrations ranged from 30 to 129 $\mu\text{g/L}$. The year with the highest amount of algae was 2005, which was also the year with the highest total phosphorus. The lowest years were 2006 and 2015, which is also similar to total phosphorus trends.

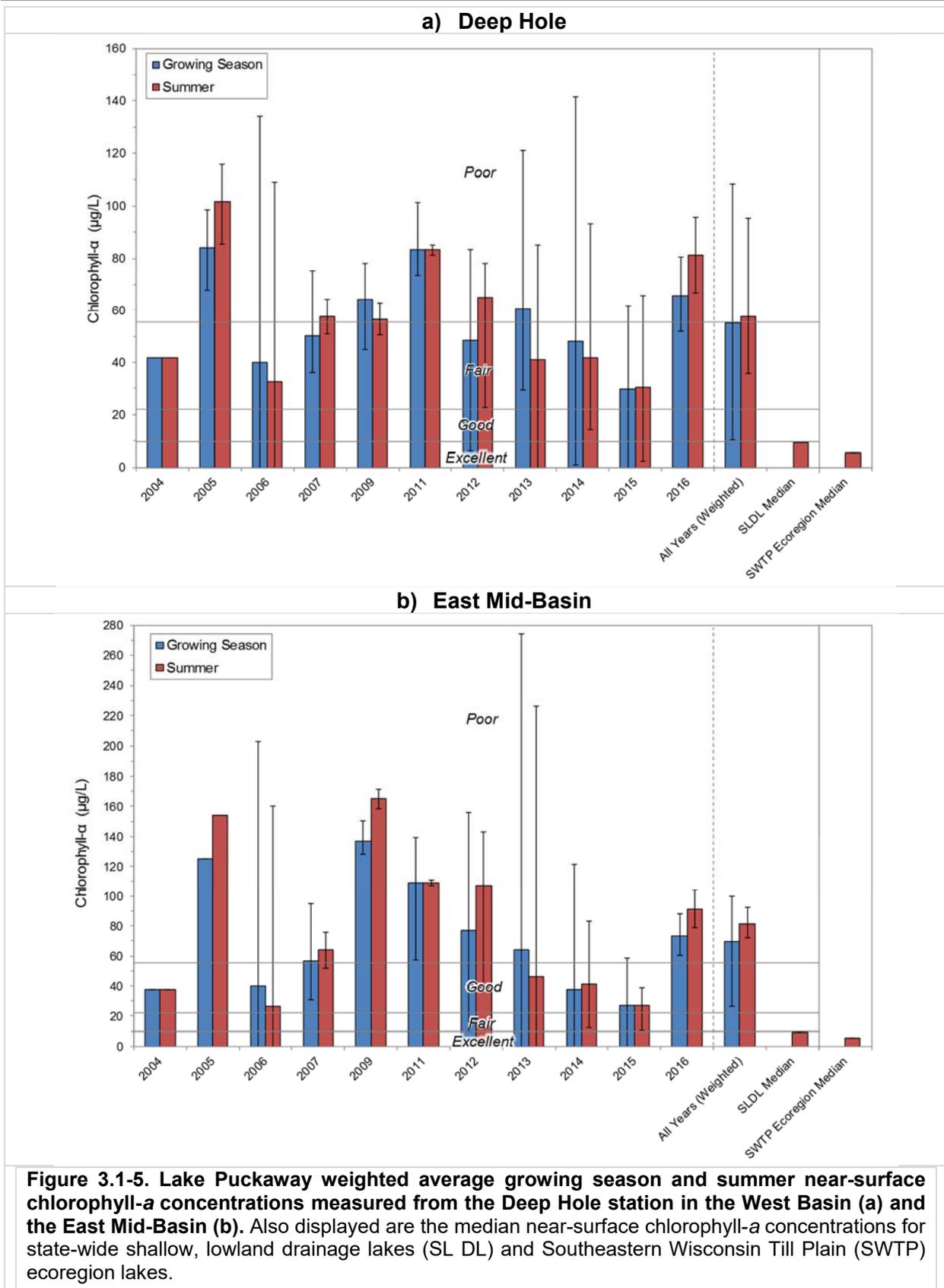
In the East Mid-Basin, chlorophyll-*a* concentrations were sometimes higher than at the Deep Hole Station (Figure 3.1-5b). Growing season values ranged from 27 to 137 $\mu\text{g/L}$. As with the Deep Hole Station, one of the worst years was 2005, although 2009 also had very high levels in the East Mid-Basin Station. The lowest years were 2006 and 2015. Prior to 2014, concentrations tended to be higher in the Deep Hole site, but in 2014-15 concentrations were lower in the East Mid-Basin site.

Weighted averages of summer chlorophyll-*a* concentration data are used to compare Lake Puckaway's chlorophyll-*a* concentrations to median values for other shallow lowland drainage lakes throughout the state and to median values of all lake types within the SWTP ecoregion. The weighted average summer chlorophyll-*a* concentrations from all years that data are available for the lake is 72 $\mu\text{g/L}$ (Figure 3.1-6). This value is in the *poor* category for shallow, lowland drainage lakes in Wisconsin. This value is 7 times higher than the median concentration for shallow, lowland drainage lakes in Wisconsin and approximately 13 times higher than the median value for all lakes within the SWTP ecoregion (Figure 3.1-6). Perceptible algal blooms occur in reservoirs when chlorophyll-*a* concentrations reach approximately 30 $\mu\text{g/L}$, and Lake Puckaway's average concentration is twice this threshold. Fortunately, during the last few years, summer concentrations have been lower than the long-term median and are in the fair category. Values still were generally higher than 30 $\mu\text{g/L}$, indicating algal blooms were occurring.

Secchi Disk Transparency

Secchi disk transparency is a measure of water clarity. In Lake Puckaway, the record for the East Mid-Basin is the same as for total phosphorus and chlorophyll-*a* (2004-2016). For the Deep Hole Station, the record is much longer, sporadically from 1976 to 2016. For the period 1976 through 1991, it is not clear how many readings were taken during the year. These data were obtained from a graph in Congdon (1996). Numerous readings were recorded during the period, 1996-2016. The worse recorded Secchi disk transparency were in 1976 and 2005 (Figure 3.1-7a). Growing season and summer values were the best in 1991, while 2004 and 2015 were not quite as good but better than most years. The Secchi depths ranged from 0.8 to 5.2 feet for both growing season and summer means. The long-term average was 1.8 ft for the growing season and 2.2 ft for the summer.

At the East Mid-Basin Station where data is only available since 2004, the worse years were 2009 and 2011 while the best years were 2004 and the last 3 years (Figure 3.1-7b). The growing season values range from 0.8 to 2.8 feet while the summer values range from 0.6 to 3.5 feet. The average values were the same for growing season and summer at 2.1 feet. For the years when records are



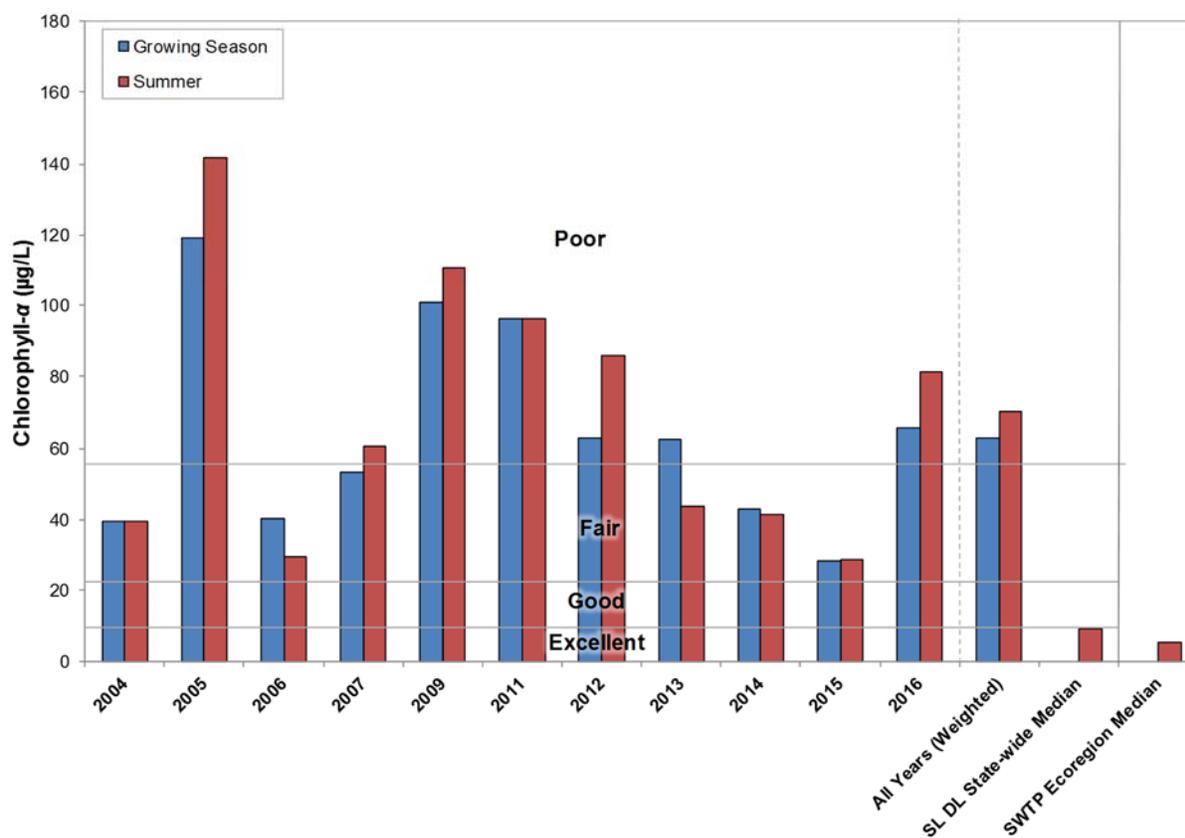
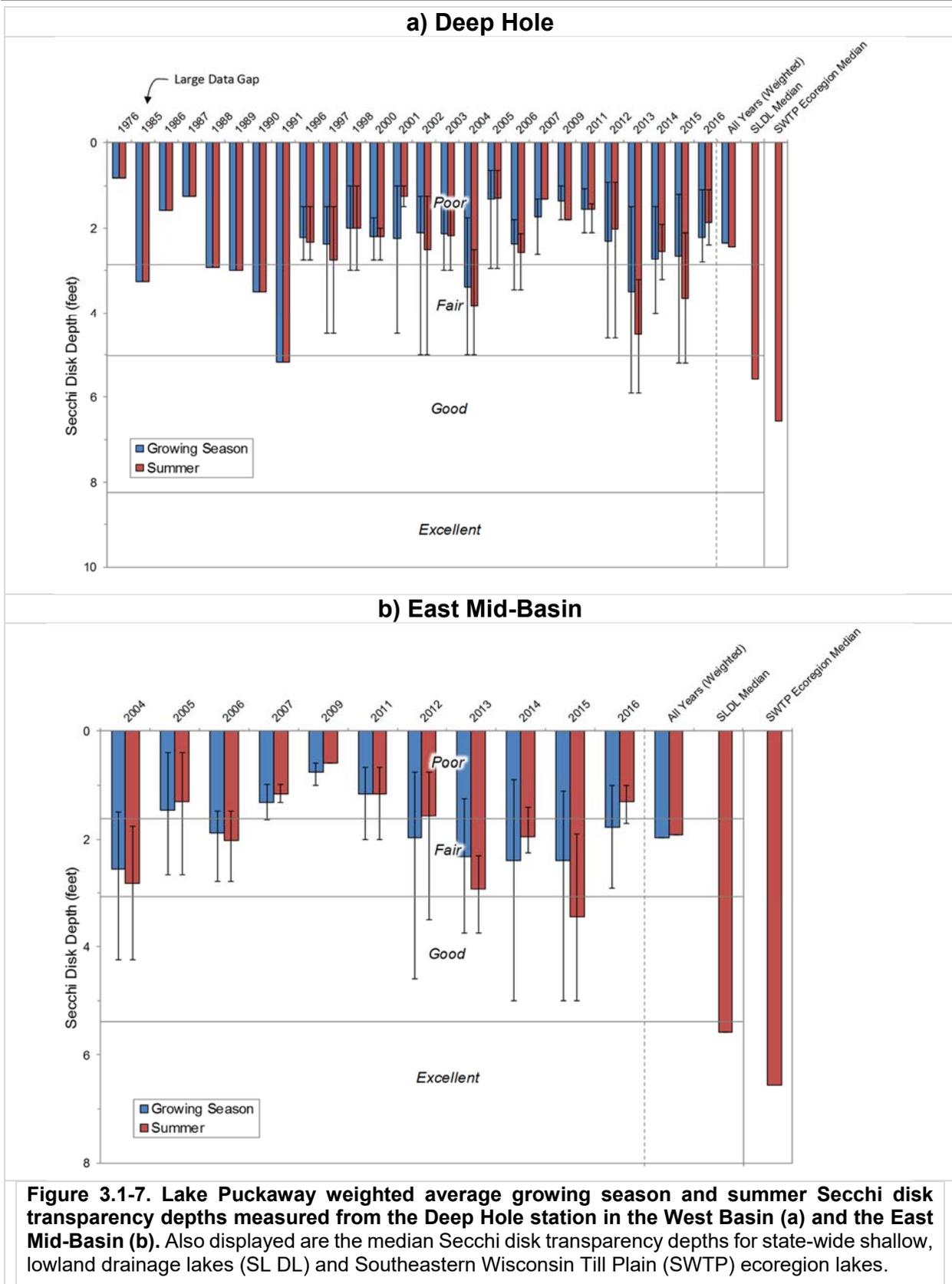


Figure 3.1-6. Lake Puckaway weighted average growing season and summer near-surface chlorophyll-a concentrations. Also displayed are the median near-surface chlorophyll-a concentrations for state-wide shallow, lowland drainage lakes (SL DL) and Southeastern Wisconsin Till Plain (SWTP) ecoregion lakes.

available for both open water stations, the mean growing season and summer values are greater for the Deep Hole Station. The Secchi disk transparency for the East Mid-Basin Station is almost 0.5 feet shallower.

Summer Secchi disk transparency data are used to compare Lake Puckaway's Secchi disk transparency values to median values for other shallow, lowland drainage lakes throughout the state and to median values of all lake types within the SWTP ecoregion. The weighted average summer Secchi disk transparency from all years that data are available from the Deep Hole and East Mid-Basin sampling locations is 2.7 feet and 2.1 feet, respectively (Figure 3.1-7a and 3.1-7b). Both of these values fall into the *fair* category for shallow lowland drainage lakes in Wisconsin. These values are approximately three to four times lower than the median concentration for shallow, lowland drainage lakes in Wisconsin and the median value for all lakes within the SWTP ecoregion (Figure 3.1-7a and 3.1-7b). As with the other trophic parameters, in 2013-15, transparency was better than the long-term median at both stations.



Comparison of Open Water Stations

Mean phosphorus concentrations when data was available for the period 2004-2015 were similar at the Deep Hole and East Mid-Basin stations (Table 3.1-1). Chlorophyll-*a* values were significantly higher in the East Mid-Basin and Secchi depths were lower. This implies that more algal growth is occurring at the shallower eastern end of the lake. In part, the higher algal growth at the eastern end of the lake reflects the fact that at this end of the lake water has resided in the lake longer allowing for more algal growth. In most lakes, this is not an issue, but in Lake Puckaway water residence time during the summer is short, often less than 15 days.

Table 3.1-1. Mean summer values from both open water stations.

Trophic Parameter	Deep Hole	East Mid-Basin
Total Phosphorus (µg/L)	132	135
Chlorophyll- <i>a</i> (µg/L)	61	80
Secchi Disc Depth (ft)	2.7	2.1

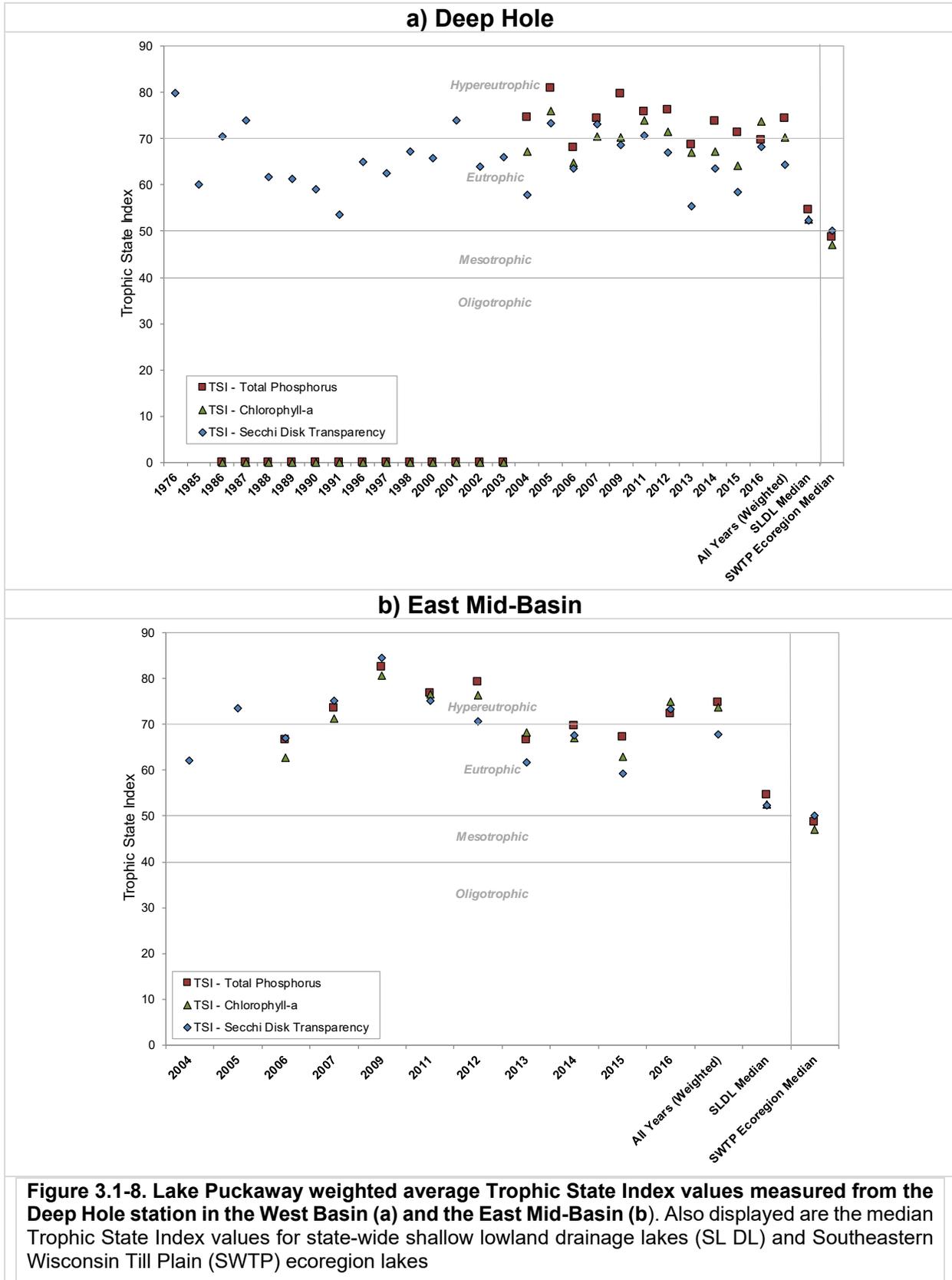
Lake Puckaway Trophic State

Figure 3.1-8a and 3.1-8b contain the weighted average Trophic State Index (TSI) values from each open-water sampling location in Lake Puckaway for which total phosphorus, chlorophyll-*a*, or Secchi disk transparency data are available. The TSI values are calculated with annual average summer month Secchi disk transparency, chlorophyll-*a*, and total phosphorus values. In general, the best values to use in judging a lake's trophic state are chlorophyll-*a* and total phosphorus, as water clarity can be influenced by other factors such as dissolved organic compounds and abiotic suspended materials. The weighted average TSI values for chlorophyll-*a* and total phosphorus indicate Lake Puckaway is *hypereutrophic*. Hypereutrophic lakes are characterized by having excessive levels of nutrients and algae with poor water clarity. Lakes which have total phosphorus concentrations of greater than 100 µg/L fall into the hypereutrophic category. During 2013-16, total phosphorus concentrations were in the hypereutrophic range, but Secchi disk transparency and chlorophyll-*a* were in the eutrophic range.

Fox River Above and Below Lake Puckaway

During the period 2011-2014, samples were collected from the Fox River near the Grand River, the Grand River near the Fox River, and the Fox River where it leaves Lake Puckaway on a regular basis. Although samples were also collected from the Deep Hole and East Mid-Basin stations, this data has been averaged for this discussion.

Total phosphorus concentrations in the Fox River, just above where the Grand River enters, were much lower compared to the Grand River in 2011 and 2012, but this was not the case in 2013 and 2014 (Figure 3.1-9a). In the first two years, concentrations in the lake and outlet were much higher than the lake's inlet. In 2013 and 2014, the total phosphorus concentration in the lake and the Fox River, where it leaves the lake, were similar to inflowing concentrations or lower. Even with the annual variability, the mean concentration in the Fox River, above the Grand River, was lower than the lake or the outlet. The mean concentration in the Grand River was similar to the mean total phosphorus concentration in the lake.



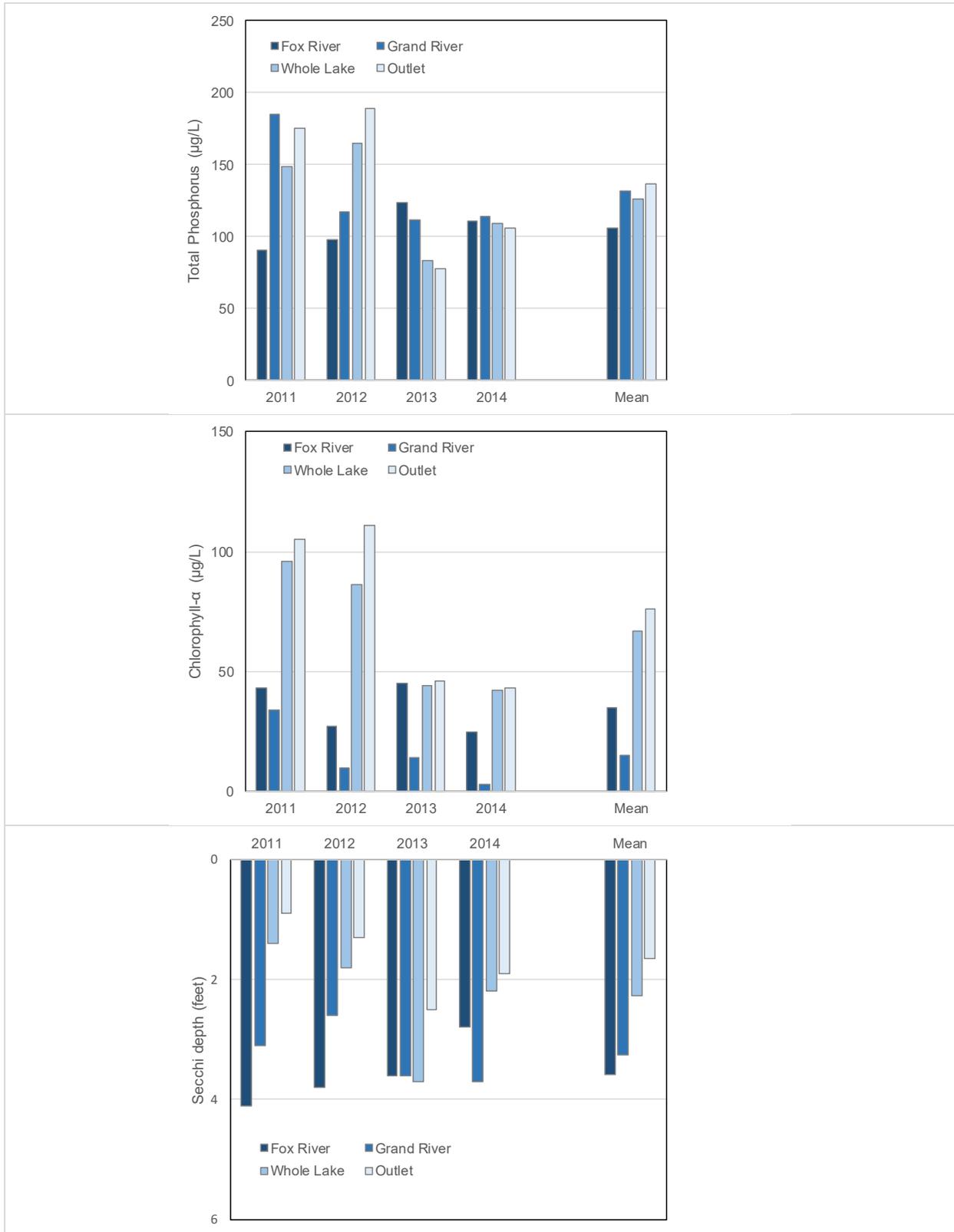


Figure 3.1-9. Comparison of total phosphorus, chlorophyll-a, and Secchi disk transparency in the Fox and Grand rivers above the entrance into Lake Puckaway, the lake itself, and values measured at the lake’s outlet during the period 2011-14.

Chlorophyll-*a* levels were generally lower in the inflowing rivers compared with in-lake concentrations (Figure 3.1-9b). Except for 2011, chlorophyll-*a* levels were lower in the Grand River than they were in the Fox River. In the Grand River, even though total phosphorus levels were only moderately lower in 2012-14 compared with 2011, there was much less chlorophyll-*a* during the latter period. The mean concentration of chlorophyll-*a*, for the period, in the lake and the outlet was much higher than what entered the lake from the rivers. This is because, even with relatively high flows, the water is in the lake long enough for algae to grow. In 2011 and 2012, when internal phosphorus loading was high, chlorophyll *a* was often much higher in the outlet compared with the inlet, but this was because the water remained in the lake longer and there was more phosphorus for algal growth.

During the first two years, water clarity was better in the Fox River compared with the Grand River (Figure 3.1-9c). It was also better than the lake, 3 out of the 4 years. Water clarity in the Grand River was also, generally, better than it was in the lake. Mean values for the 4-year period, in the Fox and Grand rivers, were about 3.5 feet, while it was about 2 feet in the lake and the outlet. With the increased chlorophyll-*a* produced in the lake, there was a decrease in water clarity.

Seasonal changes in phosphorus sometimes increased, compared with what entered the lake, especially in 2011 and 2012 (Figure 3.1-9a), but this was not the case in 2013 and 2014. In 2011 and 2012, there was significant internal loading in July and August. This did not occur in 2013 or 2014 and consequently, concentrations leaving the lake were very similar or less to those entering the lake. In 2013 and 2014, the lake was a sink for phosphorus. This was likely the result of phosphorus associated with sediment particles settling to the lake bottom. In only 2011 and 2012 was there internal loading during the summer with the internal load being greatest in 2012 (Figure 3.1-10).

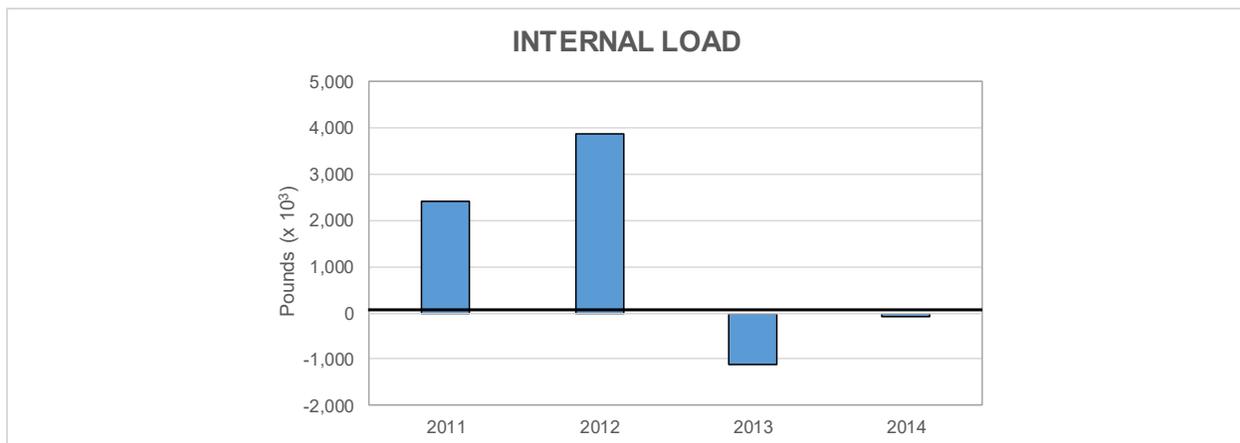


Figure 3.1-10. Internal loading in Lake Puckaway as calculated from the difference between the amount of total phosphorus entering the lake from the Grand and Fox rivers and the amount leaving the lake. Most of the source of this internal load of phosphorus is likely from the sediments. Higher loading occurred in the first two years because flows were less thus water was flushed at a slower rate allowing released phosphorus to be retained in the lake.

There are 3 main reasons why the amount of internal loading could vary between the years:

- Largely dependent upon flow into the lakes - less flow means water stays in the lake longer thus allowing phosphorus to be released from the sediments and algae to accumulate
- With higher pH values associated with high chlorophyll-*a* levels, even more phosphorus is released from the sediments
- Higher water levels result in fewer plants, but less sediment disturbance from wind

Limiting Plant Nutrient of Lake Puckaway

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

There are numerous sources and numerous different forms of nitrogen which are delivered to Wisconsin's lakes. Nitrogen enters waterbodies through precipitation, fixation from the atmosphere by cyanobacteria, surface inflow including fertilizers and animal wastes from agricultural areas, groundwater, and sewage treatment plants or septic systems (Wetzel 2001). The majority of the earth's nitrogen occurs within the atmosphere and is unavailable to most organisms. A bio-available form of nitrogen is created by organisms that have the ability to convert atmospheric nitrogen into a usable form.

In Lake Puckaway, limited nitrogen data has been collected during the summer months. It has been collected only during 2009 (WDNR staff) and 2015-2016 (Onterra ecologists). In 2009, the nitrogen to phosphorus ratio during July and September ranged from 12:1 to 16:1 in the Deep Hole and 9:1 to 14:1 in the East Mid-Basin sites. While nitrogen was likely not limiting in the Deep Hole site at times, it may have been limiting in the East Mid-Basin site. This limitation favors blue-green algae and may partially explain why chlorophyll-*a* concentrations were higher in the East Mid-Basin site, compared with the Deep Hole site. In 2015, nitrogen was only collected in July. Nitrogen may have been the limiting nutrient in the Deep Hole site (11:1), but not at the East Mid-Basin site (22:1). In 2016, nitrogen was also collected in July. The Deep Hole site had a N:P ratio of 13:1, which is very similar to 2015. The East Mid-Basin site had a N:P ratio of 16:1, much lower than in 2015.

Dissolved Oxygen and Temperature in Lake Puckaway

Dissolved oxygen and temperature were measured during water quality sampling visits to Lake Puckaway by Onterra staff in 2015 and 2016. Profiles depicting these data are displayed in Figures 3.1-11 and 3.1-12. These data indicate that given Lake Puckaway's shallow nature, the lake likely remains uniformly mixed throughout the open-water season and does not experience strong thermal stratification. In shallow, productive lakes like Lake Puckaway, dissolved oxygen can often become depleted in the winter with ice cover resulting in fish kills. On February 17, 2016, a profile collected through the ice by Onterra ecologists indicated sufficient levels of oxygen throughout the water column (>8.0 mg/L).

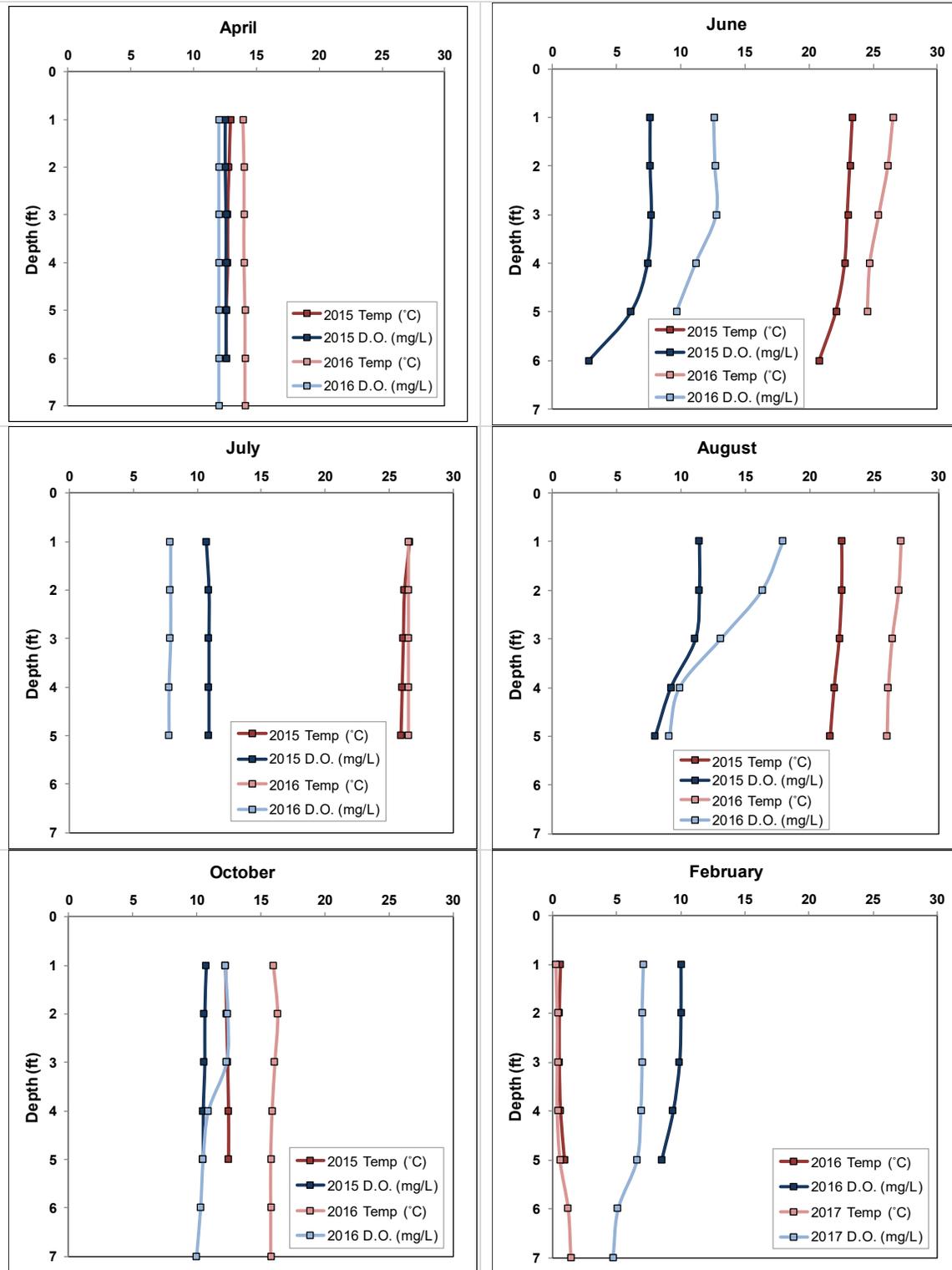


Figure 3.1-11. Lake Puckaway Deep Hole 2015-2017 temperature and dissolved oxygen profiles.

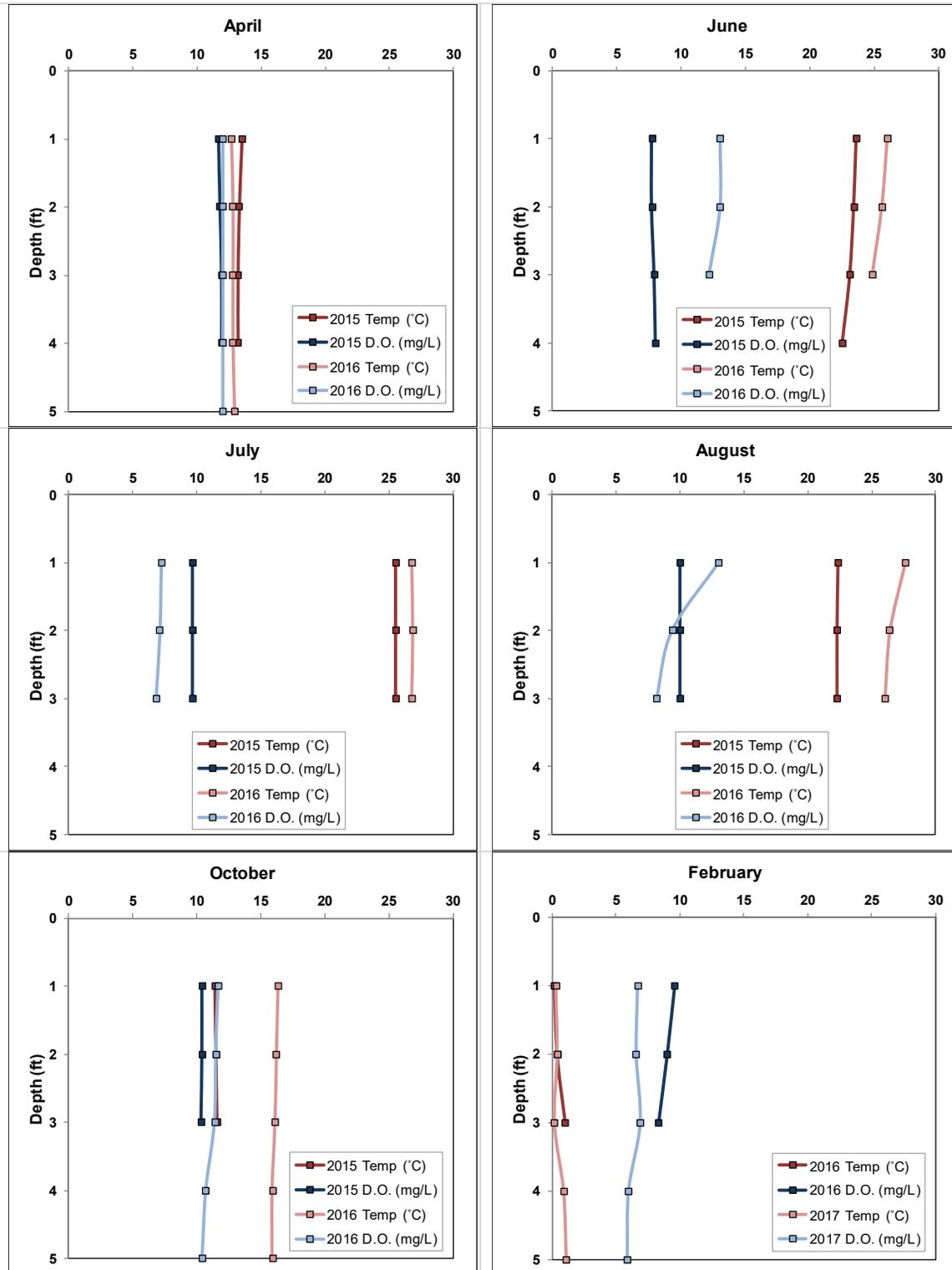


Figure 3.1-12. Lake Puckaway East Mid-Basin 2015-2017 temperature and dissolved oxygen profiles.

Additional Water Quality Data Collected at Lake Puckaway

The previous sections were centered on lake eutrophication. However, parameters other than water clarity, nutrients, and chlorophyll-*a* were collected as part of the project. These other parameters were collected to increase the understanding of Lake Puckaway's water quality and are recommended as a part of the WDNR long-term lake trends monitoring protocol. These parameters include pH, alkalinity, calcium, and total suspended solids. In lakes with a pH of 6.5 and lower, the spawning of certain fish species such as walleye becomes inhibited (Shaw and Nimphius 1985).

The pH scale ranges from 0 to 14 and indicates the concentration of hydrogen ions (H^+) within the lake's water and is an index of the lake's acidity. Water with a pH value of 7 has equal amounts of hydrogen ions and hydroxide ions (OH^-), and is considered to be neutral. Water with a pH of less than 7 has higher concentrations of hydrogen ions and is considered to be acidic, while values greater than 7 have lower hydrogen ion concentrations and are considered basic or alkaline. The pH scale is logarithmic; meaning that for every 1.0 pH unit the hydrogen ion concentration changes tenfold. The normal range for lake water pH in Wisconsin is about 5.2 to 8.4, though values lower than 5.2 can be observed in some acid bog lakes and higher than 8.4 in some marl lakes. In lakes with a pH of 6.5 and lower, the spawning of certain fish species such as walleye becomes inhibited (Shaw and Nimphius 1985). The pH of the water in Lake Puckaway was found to be alkaline with values ranging from 8.4 to 8.5 in 2016 in both basins.

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^{2-}), which neutralize hydrogen ions from acidic inputs. These compounds are present in a lake if the groundwater or stream entering it comes into contact with minerals such as calcite ($CaCO_3$) and/or dolomite ($CaMgCO_3$). A lake's pH is primarily determined by the amount of alkalinity. Rainwater in Wisconsin is slightly acidic naturally due to dissolved carbon dioxide from the atmosphere with a pH of around 5.0. Consequently, lakes with low alkalinity have lower pH due to their inability to buffer against acid inputs. The average near-surface alkalinity in Lake Puckaway was measured at 164 (mg/L) in the Deep Hole and 163 (mg/L as $CaCO_3$) in the East Mid-Basin, indicating that the lake has a substantial capacity to resist fluctuations in pH and has a low sensitivity to acid rain.

Like associated pH and alkalinity, the concentration of calcium within a lake's water depends on the geology of the lake's watershed. Recently, the combination of calcium concentration and pH has been used to determine what lakes can support zebra mussel populations if they are introduced. The commonly accepted pH range for zebra mussels is 7.0 to 9.0, and Lake Puckaway's pH falls inside of this range. Lakes with calcium concentrations of less than 12 mg/L are considered to have very low susceptibility to zebra mussel establishment. In 2016, calcium concentrations were measured in Lake Puckaway in spring and mid-summer, and the average concentration was 36.1 mg/L in the Deep Hole and 36.8 mg/L in the East Mid-Basin sites. The concentration of calcium in Lake Puckaway indicates the lake has *high susceptibility* to zebra mussel establishment if they are introduced. Onterra ecologists conducted plankton tows at three locations in Lake Puckaway in 2015 that underwent analysis for zebra mussel veligers, or the larval stage which is planktonic and their results were negative for the presence of veligers. Onterra ecologists did not observe any adult zebra mussels (alive or dead) during the surveys on Lake Puckaway in 2015.

Total suspended solids (TSS) are a measure of inorganic and organic particles suspended in the water, and include everything from algae to clay particles. High TSS creates low water clarity, and prevents light from penetrating into the water to support aquatic plant growth. Total suspended solids were measured in Lake Puckaway in spring, mid-summer, and fall in 2016. In the Deep Hole, total suspended solids were highest in summer with a value of 14.4 mg/L. This higher value was likely due to the higher amounts of algae growing in the lake at this time of year. The average concentration was 10.0 mg/L in the Deep Hole site. In the East Mid-Basin site, the highest value also occurred during the summer but was much higher than the Deep Hole site at 42.7 mg/L. The average value at the East Mid-Basin was double the Deep Hole site at 20.6 mg/L.

Stakeholder Survey Responses Regarding Lake Puckaway 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 3.1-13 and 3.1-14 display the responses of members of Lake Puckaway stakeholders to questions regarding water quality and how it has changed over their years visiting Lake Puckaway. When asked how they would describe the current water quality of Lake Puckaway, the majority (72%) of respondents answered that they believe the water quality is fair to good (Figure 3.1-13). Another 16% of respondents believe that the water quality is poor with the rest of the stakeholders responding they believe the water quality to be very poor, excellent or that they are unsure.

When asked how water quality in Lake Puckaway has changed since they first visited the lake, 34% indicated that water quality has remained the same, 37% indicated water quality has somewhat to severely degraded, 18% indicated water quality has somewhat or greatly improved and 10% were unsure (Figure 3.1-14). Thirty-one percent of the respondents to the stakeholder survey have owned their property on Lake Puckaway for more than 25 years (Question 3), which means they have had the opportunity to notice changes to the water quality within Lake Puckaway.

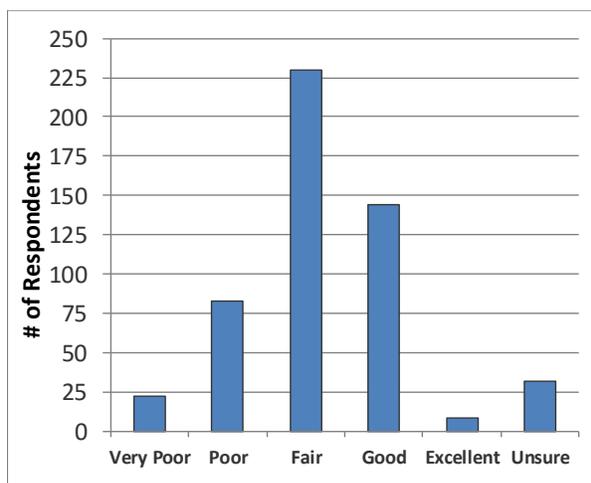


Figure 3.1-13. Stakeholder survey response Question #14. How would you describe the current water quality of Lake Puckaway?

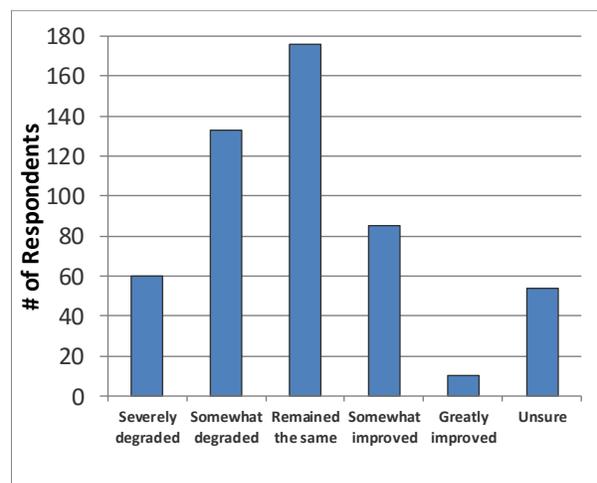


Figure 3.1-14. Stakeholder survey response Question #15. How has the water quality changed in Lake Puckaway since you first visited the lake?

3.2 Watershed Assessment

Primer on Watershed Modeling

Two aspects of a lake's watershed are the key factors in determining the amount of phosphorus the watershed exports to the lake; 1) the size of the watershed, and 2) the land cover (land use) within the watershed. The impact of the watershed size is dependent on how large it is relative to the size of the lake. The watershed to lake area ratio (WS:LA) defines how many acres of watershed 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.

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.

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.

Lake Puckaway Watershed Assessment

The surface water drainage basin, or watershed, for Lake Puckaway encompasses approximately 442,383 acres (691 square miles) across Marquette, Columbia, Adams, Fond du Lac, Dodge, Waushara, and Green Lake counties, yielding a watershed to lake area ratio of 84:1 (Figure 3.2-1; Map 2). In other words, approximately 84 acres of land drains to every one acre of Lake Puckaway. The WiLMS modeling, using average precipitation and base flow values for Green Lake County, indicates that Lake Puckaway's water residence time is approximately 20.7 days, or the water within the lake is completely replaced (flushing rate) every 20.7 days or 18 times per year. However, if recent flow data are used the water residence time for the lake is variable depending upon the flow of the Fox River. The USGS has maintained a monitoring station on the Fox River at Princeton since September 10, 2009. During this time period the average hydraulic residence time was 9.3 days. This means that water within the lake is completely replaced (flushing rate) every 9.3 days or 39 times per year.

Lake Puckaway has four subwatersheds (Figure 3.2-1, Map 2). These are the Buffalo Lake watershed, Lake Montello watershed, Grand River watershed, and direct drainage to Lake Puckaway. Buffalo Lake is the largest subwatershed with 193,770 acres or 44% of the total Lake Puckaway watershed. The Grand River is next with 121,077 acres, followed by Lake Montello with 91,488 acres, and the direct drainage which is 36,047 acres (Table 3.2-1).

Table 3.2-1. Area of subwatersheds to Lake Puckaway.

Subwatershed	Acreage (%)
Buffalo Lake	193,770 (44%)
Grand River	121,077 (27%)
Lake Montello	91,488 (21%)
Lake Puckaway, direct	36,047 (8%)

A detailed description of land cover for the Buffalo and Lake Montello subwatersheds are given in other documents and only the direct drainage to Lake Puckaway and the Grand River will be described in this report. The dominant land cover type is row crops which are 17% of these two subwatersheds (Figure 3.2-2). This land cover type is also dominant in the Buffalo Lake and Lake Montello subwatersheds. In Lake Puckaway and Grand River subwatersheds, the next most common cover type is wetlands, but in both Buffalo Lake and Lake Montello it is forests.



Figure 3.2-1. Map of the subwatersheds of Lake Puckaway. The largest subwatershed is Buffalo Lake.

Residential, whether rural or high and medium density, makes up less than one percent of the Grand River and Lake Puckaway subwatersheds.

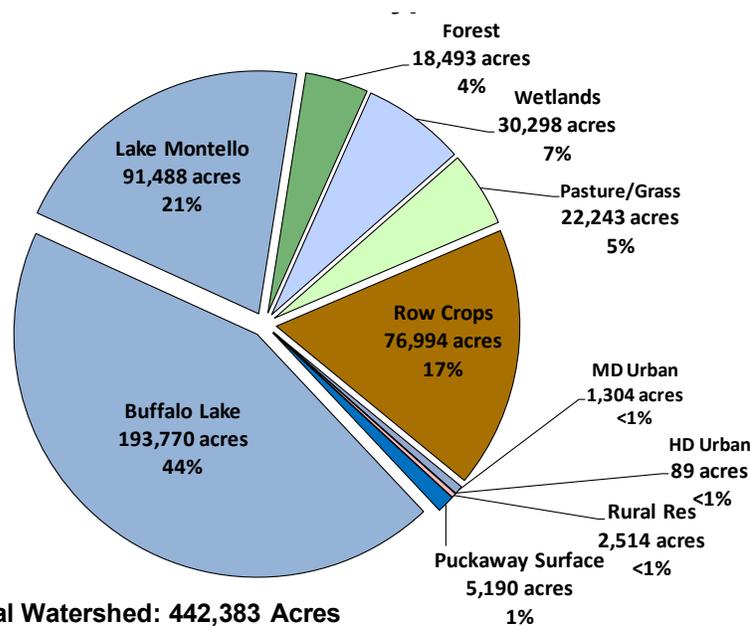
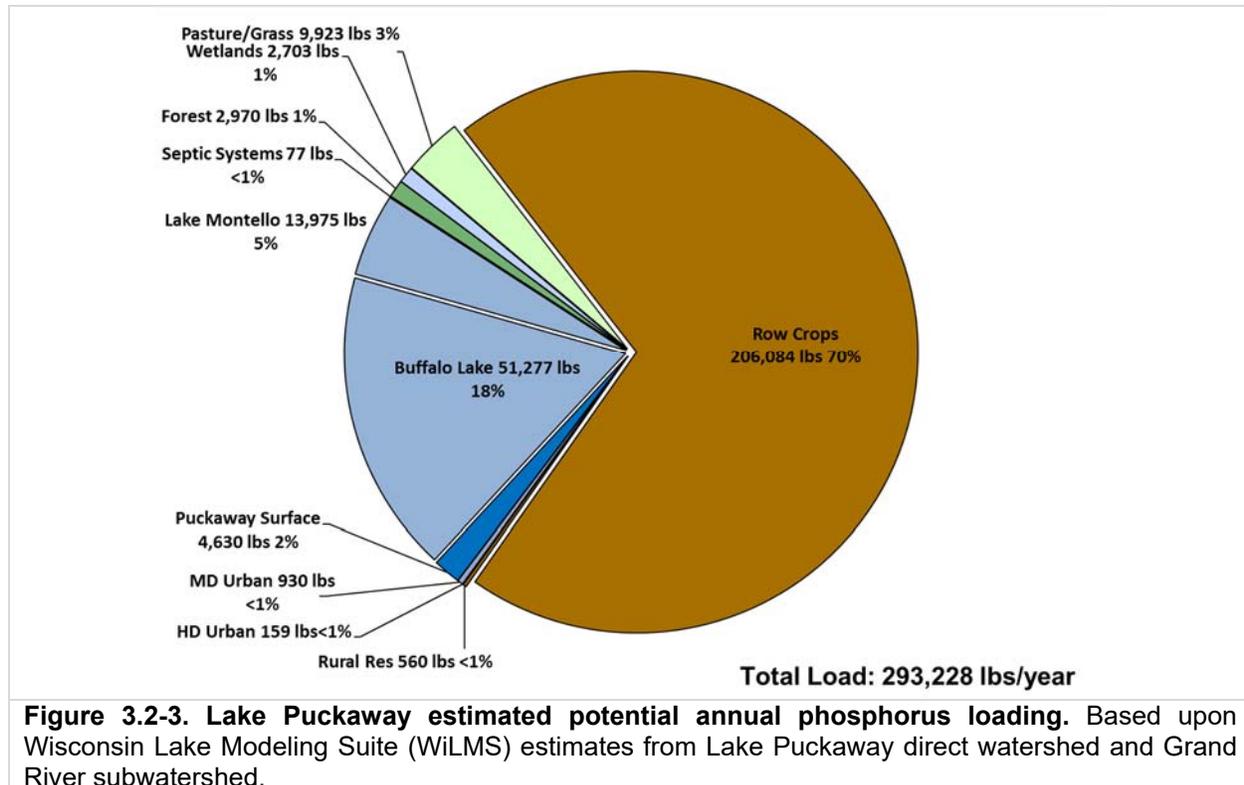


Figure 3.2-2. Lake Puckaway direct watershed and Grand River subwatershed land cover types. Based upon National Land Cover Database (NLCD – Fry et. al 2011). Spatial distribution of land cover types is displayed on Map 2.

Using the land cover types and their acreages within the Grand River watershed and Lake Puckaway’s direct watershed, along with the estimated outflow of phosphorus from the two subwatersheds, WiLMS was utilized to estimate the annual potential phosphorus load delivered to Lake Puckaway from its watershed. In addition, using data obtained from the 2015 stakeholder survey of LPPRD members, an estimate of phosphorus loading to the lake from septic systems

was also incorporated into the model. The model estimated that a total of 293,228 pounds of phosphorus are delivered to Lake Puckaway from its watershed on an annual basis (Figure 3.2-3).

Of the 293,228 estimated pounds of phosphorus being delivered to the lake annually, the majority is estimated to originate from areas of row crop agriculture. This land use was also the major source of phosphorus in the Lake Montello subwatershed (81%) and the Buffalo Lake subwatershed (77%). After row crops, the next largest sources of phosphorus in the Lake Puckaway and Grand River subwatersheds are pasture/grass (3%) and wetlands (1%). Lake Puckaway receives 18% of its phosphorus loading from Buffalo Lake and 5% from Lake Montello.



Using these upper levels of estimated annual potential phosphorus load, WiLMS predicts that Lake Puckaway should have an in-lake growing season mean total phosphorus concentration of 116 $\mu\text{g/L}$. This is virtually the same as the weighted average growing season total phosphorus concentration of 117 $\mu\text{g/L}$, calculated from available data. However, the WiLMS estimated phosphorus loading may be slightly overestimated as a portion of Lake Puckaway's phosphorus originates from the release of phosphorus from bottom sediments (internal phosphorus loading) from processes discussed in the Water Quality Section. As mentioned in the Water Quality Section, internal loading is highly variable among years, but the WiLMS modelling suggests that in the long-term, it is not a significant source of phosphorus to the lake itself on a regular basis. Still, during the years that internal loading is occurring in Lake Puckaway, it is impacting downstream waterbodies. The WiLMS model indicates that the largest fraction of phosphorus originates from agricultural lands within Lake Puckaway's direct watershed and the Grand River subwatershed. The similarity between the WiLMS predicted growing season total phosphorus and

measured growing season total phosphorus concentrations in Lake Puckaway is an indication that there are no significant unaccounted sources of phosphorus.

As described above, row crop agriculture is by far the greatest source of phosphorus to Lake Puckaway. However, the sheer size of the watershed, as demonstrated by the high watershed to lake area ratio of 84:1, is as equally influential on phosphorus loads entering Lake Puckaway. As an example, the watershed model was used to develop a scenario where half of the row crop acreage, the acreage that exports the greatest amount of phosphorus, was converted to forested land cover, the cover that exports the least amount of phosphorus. In this scenario, the phosphorus load to Lake Puckaway reduced by nearly 97,000 pounds (~33%) each year. Even utilizing this unrealistic improvement to the watershed, phosphorus concentrations in Lake Puckaway would exceed 77 µg/L and the lake would still be borderline hypereutrophic exhibiting high algae content and low water clarity.

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

3.3 Shoreland Condition

The Importance of a Lake's Shoreland Zone

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

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

Some forms of development may provide habitat for less than desirable species. Disturbed areas are often overtaken by invasive species, which are sometimes termed "pioneer species" for this reason. Some waterfowl, such as geese, prefer to linger upon open lawns near waterbodies because of the lack of cover for potential predators. The presence of geese on a lake resident's beach may not be an issue; however the feces the geese leave are unsightly and pose a health risk. Geese feces may become a source of fecal coliforms as well as flatworms that can lead to swimmer's itch. Developments such as rip rap, 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 swimmer's itch, because the flatworms that cause this skin reaction utilize snails as a secondary host after waterfowl.

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

Shoreland Zone Regulations

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

Wisconsin-NR 115: Wisconsin's Shoreland Protection Program

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

same, such as lot sizes, shoreland setbacks and buffer sizes. However, several standards changed as a result of efforts to balance public rights to lake use with private property rights. The regulation sets minimum standards for the shoreland zone, and requires all counties in the state to adopt shoreland zoning ordinances. Counties were previously able to set their own, stricter, regulations to NR 115 but as of 2015, all counties have to abide by state regulations. Minimum requirements for each of these categories are described below. Please note that at the time of this writing, changes to NR 115 were last made in October of 2015 (Lutze 2015).

- **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. Ground-water inputs to the lake were found to be significant in terms of water flow and nutrient input. Nitrate plus nitrite nitrogen and total phosphorus yields to the ground-water system from a lawn catchment were three or sometimes four times greater than those from wooded catchments.

A separate USGS study was conducted on the Lauderdale Lakes in southern Wisconsin, looking at nutrient runoff from different types of developed shorelands – regular fertilizer application lawns (fertilizer with phosphorus), non-phosphorus fertilizer application sites, and unfertilized sites (Garn 2002). One of the important findings stemming from this study was that the amount of dissolved phosphorus coming off 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 was 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 with undeveloped lakes than developed lakes (Lindsay et al. 2002). And studies on shoreland development and fish nests show that undeveloped shorelands are preferred as well. In a study conducted on three Minnesota lakes, researchers found that only 74 of 852 black crappie nests were found near shorelines that had any type of dwelling on it (Reed 2001). The remaining nests were all located along undeveloped shoreland.

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



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

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

With development of a lake’s shoreland zone, much of the coarse woody habitat that was once found in Wisconsin lakes has disappeared. Prior to human establishment and development on lakes (mid to late 1800’s), the amount of coarse woody habitat in lakes was likely greater than under completely natural conditions due to logging practices. However, with changes in the logging industry and increasing development along lake shorelands, coarse woody habitat has decreased substantially. Shoreland residents are removing woody debris to improve aesthetics or for recreational opportunities (boating, swimming, and, ironically, fishing).

National Lakes Assessment

Unfortunately, along with Wisconsin’s lakes, waterbodies within the entire United States have shown to have increasing amounts of developed shorelands. The National Lakes Assessment (NLA) is an Environmental Protection Agency sponsored assessment that has successfully pooled together resource managers from all 50 U.S. states in an effort to assess waterbodies, both natural and man-made, from each state. Through this collaborative effort, over 1,000 lakes were sampled in 2007, pooling together the first statistical analysis of the nation’s lakes and reservoirs.

Through the National Lakes Assessment, a number of potential stressors were examined, including nutrient impairment, algal toxins, fish tissue contaminants, physical habitat, and others. The 2007 NLA report states that “*of the stressors examined, poor lakeshore habitat is the biggest problem in the nations lakes; over one-third exhibit poor shoreline habitat condition*” (USEPA 2009).

Furthermore, the report states that “*poor biological health is three times more likely in lakes with poor lakeshore habitat*”.

The results indicate that stronger management of shoreline development is absolutely necessary to preserve, protect and restore lakes. This will become increasingly important as development pressured on lakes continue to steadily grow.

Native Species Enhancement

The development of Wisconsin’s shorelands has increased dramatically over the last century and with this increase in development a decrease in water quality and wildlife habitat has occurred. Many people that move to or build in shoreland areas attempt to replicate the suburban landscapes they are accustomed to by converting natural shoreland areas to the “neat and clean” appearance of manicured lawns and flowerbeds. The conversion of these areas immediately leads to destruction of habitat utilized by birds, mammals, reptiles, amphibians, and insects (Jennings et al. 2003). The maintenance of the newly created area helps to decrease water quality by considerably increasing inputs of phosphorus and sediments into the lake. The negative impact of human development does not stop at the shoreland. Removal of native plants and dead, fallen timbers from shallow, near-shore areas for boating and swimming activities destroys habitat used by fish, mammals, birds, insects, and amphibians, while leaving bottom and shoreland sediments vulnerable to wave action caused by boating and wind (Jennings et al. 2003, Radomski and Goeman 2001, and Elias & Meyer 2003). Many homeowners significantly decrease the number of trees and shrubs along the water’s edge in an effort to increase their view of the lake. However, this has been shown to locally increase water temperatures, and decrease infiltration rates of potentially harmful nutrients and pollutants. Furthermore, the dumping of sand to create beach areas destroys spawning, cover and feeding areas utilized by aquatic wildlife (Scheuerell and Schindler 2004).



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

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

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

Cost

The cost of native, aquatic, and shoreland plant restorations is highly variable and depends on the size of the restoration area, the depth of buffer zone required to be restored, the existing plant density, the planting density required, the species planted, and the type of planting (e.g. seeds, bare-roots, plugs, live-stakes) being conducted. Other sites may require erosion control stabilization measures, which could be as simple as using erosion control blankets and plants and/or seeds or more extensive techniques such as geotextile bags (vegetated retaining walls), geogrids (vegetated soil lifts), or bio-logs (see above picture). Some of these erosion control techniques may reduce the need for rip-rap or seawalls which are sterile environments that do not allow for plant growth or natural shorelines. Questions about rip-rap or seawalls should be directed to the local Wisconsin DNR Water Resources Management Specialist. Other measures possibly required include protective measures used to guard newly planted area from wildlife predation, wave-action, and erosion, such as fencing, erosion control matting, and animal deterrent sprays. One of the most important aspects of planting is maintaining moisture levels. This is done by watering regularly for the first two years until plants establish themselves, using soil amendments (i.e., peat, compost) while planting, and using mulch to help retain moisture.

Most restoration work can be completed by the landowner themselves. To decrease costs further, bare-root form of trees and shrubs should be purchased in early spring. If additional assistance is needed, the lakefront property owner could contact an experienced landscaper. For properties with erosion issues, owners should contact their local county conservation office to discuss cost-share options. In general, a restoration project with the characteristics described below would have an estimated materials and supplies cost of approximately \$1,400. The more native vegetation a site has, the lower the cost. Owners should contact the county's land conservation department for all minimum requirements. The single site used for the estimate indicated above has the following characteristics:

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

- There is no hard-armor (rip-rap or seawall) that would need to be removed.
- The property owner would maintain the site for weed control and watering.

<i>Advantages</i>	<i>Disadvantages</i>
<ul style="list-style-type: none"> ● Improves the aquatic ecosystem through species diversification and habitat enhancement. ● Assists native plant populations to compete with exotic species. ● Increases natural aesthetics sought by many lake users. ● Decreases sediment and nutrient loads entering the lake from developed properties. ● Reduces bottom sediment re-suspension and shoreland erosion. ● Lower cost when compared to rip-rap and seawalls. ● Restoration projects can be completed in phases to spread out costs. ● Once native plants are established, they require less water, maintenance, no fertilizer; provide wildlife food and habitat, and natural aesthetics compared to ornamental (non-native) varieties. ● Many educational and volunteer opportunities are available with each project. 	<ul style="list-style-type: none"> ● Property owners need to be educated on the benefits of native plant restoration before they are willing to participate. ● Stakeholders must be willing to wait 3-4 years for restoration areas to mature and fill-in. ● Monitoring and maintenance are required to assure that newly planted areas will thrive. ● Harsh environmental conditions (e.g., drought, intense storms) may partially or completely destroy project plantings before they become well established.

Lake Puckaway Shoreland Zone Condition

Shoreland Development

The shorelands of Lake Puckaway were surveyed on a parcel by parcel basis in 2015 by the Green Lake County Land Conservation Department (Figure 3.3-1). The results of that survey are referenced within this report. The shoreland survey report, including all results and maps, will be available on the Green Lake County Land Conservation website (<http://www.co.green-lake.wi.us/departments.html?Department=13>). The report was not finalized at the time of this writing. A lake's shoreland zone can be classified based upon the amount of human disturbance (vegetation removal, construction of rip-rap or seawalls, etc.). 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.

Approximately 37% of the shoreline showed little or no human influences and was natural or undeveloped. These shoreland types provide the most benefit to the lake and should be left in their natural state if at all possible. Approximately 57% of the parcels on the lake were found to have less than 10% natural conditions in the shoreland zone (first 35 feet). If restoration of the Lake

Puckaway 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.

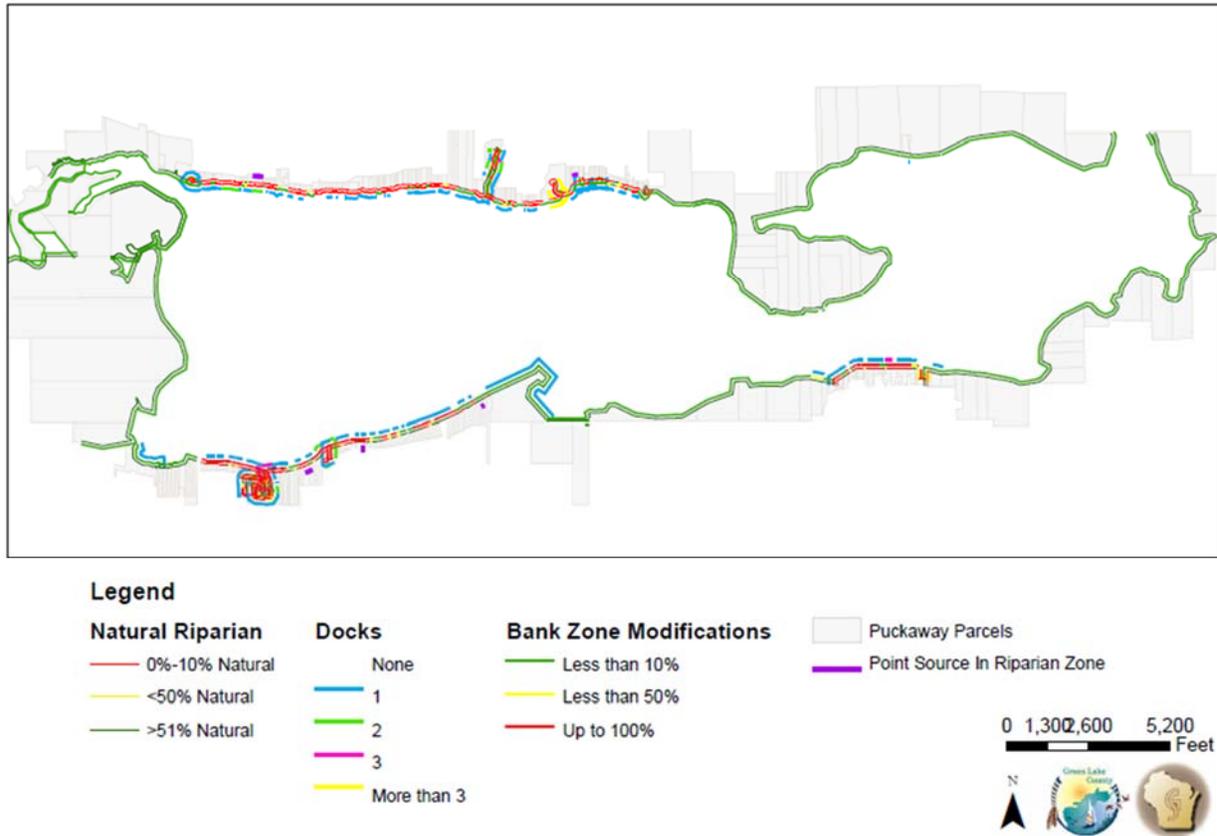


Figure 3.3-1. Lake Puckaway Shoreline Survey. Survey conducted by Green Lake County Land Conservation Department 2015.

While producing a completely natural shoreline is ideal for a lake ecosystem, it is not practical for most lakes, especially considering our natural draw to be near water. However, riparian property owners can take small steps in ensuring their property’s impact upon the lake is minimal. Choosing an appropriate landscape position for lawns is one option to consider. Placing lawns on flat, unsloped areas or in areas that do not terminate at the lake’s edge is one way to reduce the amount of runoff a lake receives from a developed site.

3.4 Aquatic Plants

Introduction

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



Photograph 3.4-1. Example of emergent and floating-leaf communities.

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

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

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

enhance the important plant communities within the lake. Unfortunately, the latter is often neglected and the ecosystem suffers as a result.

Aquatic Plant Management and Protection

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

Important Note:

Even though most of these techniques are not applicable to Lake Puckaway, 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 Lake Puckaway are discussed in Summary and Conclusions section and the Implementation Plan found near the end of this document.

Permits

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

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

Manual Removal

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



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

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

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

Cost

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

<i>Advantages</i>	<i>Disadvantages</i>
<ul style="list-style-type: none"> • Very cost effective for clearing areas around docks, piers, and swimming areas. • Relatively environmentally safe if treatment is conducted after June 15th. • Allows for selective removal of undesirable plant species. • Provides immediate relief in localized area. • Plant biomass is removed from waterbody. 	<ul style="list-style-type: none"> • 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.

<i>Advantages</i>	<i>Disadvantages</i>
<ul style="list-style-type: none">• 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.	<ul style="list-style-type: none">• 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 for Plant Control

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 be increased. This technique to control aquatic plants, should not be confused with water level management to enhance the aquatic plant community of a lake as they are two different actions and have substantially different requirements for success.

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.

<i>Advantages</i>	<i>Disadvantages</i>
<ul style="list-style-type: none"> • 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. 	<ul style="list-style-type: none"> • May be cost prohibitive if pumping is required to lower water levels. • Has the potential to upset the lake ecosystem and have significant effects on fish and other aquatic wildlife. • Adjacent wetlands may be altered due to lower water levels. • Disrupts recreational, hydroelectric, irrigation and water supply uses. • May enhance the spread of certain undesirable species, like common reed and reed canary grass. • Permitting process may require an environmental assessment that may take months to prepare. • Non-selective.

Mechanical Harvesting

Aquatic plant harvesting is frequently used in Wisconsin and involves the cutting and removal of plants much like mowing and bagging a lawn. Harvesters are produced in many sizes that can cut to depths ranging from 3 to 6 feet with cutting widths of 4 to 10 feet. Plant harvesting speeds vary with the size of the harvester, density and types of plants, and the distance to the off-loading area. Equipment



Photograph 3.4-3. Mechanical harvester.

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.

<i>Advantages</i>	<i>Disadvantages</i>
<ul style="list-style-type: none"> • 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. 	<ul style="list-style-type: none"> • 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. The table below provides a general list of commonly used aquatic herbicides in Wisconsin and is synthesized from Netherland (2009).

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

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

	General Mode of Action	Compound	Specific Mode of Action	Most Common Target Species in Wisconsin
Contact		Copper	plant cell toxicant	Algae, including macro-algae (i.e. muskgrasses & stoneworts)
		Endothall	Inhibits respiration & protein synthesis	Submersed species, largely for curly-leaf pondweed; Eurasian water milfoil control when mixed with auxin herbicides
		Diquat	Inhibits photosynthesis & destroys cell membranes	Nuisance natives species including duckweeds, targeted AIS control when exposure times are low
Systemic	Auxin Mimics	2,4-D	auxin mimic, plant growth regulator	Submersed species, largely for Eurasian water milfoil
		Triclopyr	auxin mimic, plant growth regulator	Submersed species, largely for Eurasian water milfoil
	In Water Use Only	Fluridone	Inhibits plant specific enzyme, new growth bleached	Submersed species, largely for Eurasian water milfoil
	Enzyme Specific (ALS)	Penoxsulam	Inhibits plant-specific enzyme (ALS), new growth stunted	New to WI, potential for submergent and floating-leaf species
		Imazamox	Inhibits plant-specific enzyme (ALS), new growth stunted	New to WI, potential for submergent and floating-leaf species
	Enzyme Specific (foliar use only)	Glyphosate	Inhibits plant-specific enzyme (ALS)	Emergent species, including purple loosestrife
		Imazapyr	Inhibits plant-specific enzyme (EPSP)	Hardy emergent species, including common reed

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

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

Spot treatments are a type of control strategy where the herbicide is applied to a specific area (treatment site) such that when it dilutes from that area, its concentrations are insufficient to cause significant effects 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.

<i>Advantages</i>	<i>Disadvantages</i>
<ul style="list-style-type: none"> • 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) 	<ul style="list-style-type: none"> • All herbicide use carries some degree of human health and ecological risk due to toxicity. • Fast-acting herbicides may cause fishkills due to rapid plant decomposition if not applied correctly. • Many people adamantly object to the use of herbicides in the aquatic environment; therefore, all stakeholders should be included in the decision to use them. • Many aquatic herbicides are nonselective. • Some herbicides have a combination of use restrictions that must be followed after their application. • Overuse of same herbicide may lead to plant resistance to that herbicide.

Biological Controls

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

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

Cost

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

<i>Advantages</i>	<i>Disadvantages</i>
<ul style="list-style-type: none"> • Milfoil weevils occur naturally in Wisconsin. • Likely environmentally safe and little risk of unintended consequences. 	<ul style="list-style-type: none"> • 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 californiensis* 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 kiddie 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.

<i>Advantages</i>	<i>Disadvantages</i>
<ul style="list-style-type: none"> • Extremely inexpensive control method. • Once released, considerably less effort than other control methods is required. • Augmenting populations many lead to long-term control. 	<ul style="list-style-type: none"> • 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 Lake Puckaway; the first looked strictly for the exotic plant, curly-leaf pondweed, while the others that followed assessed both native and non-native species. Combined, these surveys produce a great deal of information about the aquatic vegetation of the lake. These data are analyzed and presented in numerous ways; each is discussed in more detail below.

Primer on Data Analysis & Data Interpretation

Species List

The species list is simply a list of all of the species that were found within the lake, both exotic and native. The list also contains the life-form of each plant found, its scientific name, and its coefficient of conservatism. The latter is discussed in more detail below. Changes in this list over time, whether it is differences in total species present, gains and losses of individual species, or changes in life-forms that are present, can be an early indicator of changes in the health of the lake ecosystem.

Frequency of Occurrence

Frequency of occurrence describes how often a certain species is found within a lake. Obviously, all of the plants cannot be counted in a lake, so samples are collected from pre-determined areas. In the case of Lake Puckaway, plant samples were collected from plots laid out on a grid that covered the entire lake. Using the data collected from these plots, an estimate of occurrence of each plant species can be determined. In this section, two types of data are displayed: littoral frequency of occurrence and relative frequency of occurrence. Littoral frequency of occurrence is used to describe how often each species occurred in the plots that are less than the maximum depth of plant growth (littoral zone). Littoral frequency is displayed as a percentage. Relative frequency of occurrence uses the littoral frequency for occurrence for each species compared to the sum of the littoral frequency of occurrence from all species. These values are presented in percentages and if all of the values were added up, they would equal 100%. For example, if water lily had a relative frequency of 0.1 and we described that value as a percentage, it would mean that water lily made up 10% of the population.

In the end, this analysis indicates the species that dominate the plant community within the lake. Shifts in dominant plants over time may indicate disturbances in the ecosystem. For instance, low water levels over several years may increase the occurrence of emergent species while decreasing the occurrence of floating-leaf species. Introductions of invasive exotic species may result in major shifts as they crowd out native plants within the system.

Species Diversity and Richness

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

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

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

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

where:

n = the total number of instances of a particular species

N = the total number of instances of all species and

D is a value between 0 and 1

If a lake has a diversity index value of 0.90, it means that if two plants were randomly sampled from the lake there is a 90% probability that the two individuals would be of a different species. Between 2005 and 2009, WDNR Science Services conducted point-intercept surveys on 252 lakes within the state. In the absence of comparative data from Nichols (1999), the Simpson's Diversity Index values of the lakes within the WDNR Science Services dataset will be compared to Lake Puckaway. Comparisons will be displayed using boxplots that showing median values and upper/lower quartiles of lakes in the same ecoregion (Water Quality section, Figure 3.1-1) and in the state. Please note for this parameter, the Northern Lakes and Forests Ecoregion data includes both natural and flowage lakes.

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

As previously stated, species diversity is not the same as species richness. One factor that influences species richness is the "development factor" of the shoreland. This is not the degree of human development or disturbance, but rather it is a value that attempts to describe the nature of the habitat a particular shoreland may hold. This value is referred to as the shoreland complexity. It specifically analyzes the characteristics of the shoreland and describes to what degree the lake shape deviates from a perfect circle. It is calculated as the ratio of lake perimeter to the circumference of a circle of area equal to that of the lake. A shoreland complexity value of 1.0

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

Floristic Quality Assessment

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

Ecoregions are areas related by similar climate, physiography, hydrology, vegetation and wildlife potential. Comparing ecosystems in the same ecoregion is sounder than comparing systems within manmade boundaries such as counties, towns, or states.

The floristic quality of a lake is calculated using its species richness and average species conservatism. As mentioned above, species richness is simply the number of species that occur in the lake, for this analysis, only native species are utilized. Average species conservatism utilizes the coefficient of conservatism values for each of those species in its calculation. A species coefficient of conservatism value indicates that species likelihood of being found in an undisturbed (pristine) system. The values range from one to ten. Species that are normally found in disturbed systems have lower coefficients, while species frequently found in pristine systems have higher values. For example, cattail, an invasive native species, has a value of 1, while common hard and softstem bulrush have values of 5, and Oakes pondweed, a sensitive and rare species, has a value of 10. On their own, the species richness and average conservatism values for a lake are useful in assessing a lake's plant community; however, the best assessment of the lake's plant community health is determined when the two values are used to calculate the lake's floristic quality. The floristic quality is calculated using the species richness and average conservatism value of the aquatic plant species that were solely encountered on the rake during the point-intercept survey and does not include incidental species or those encountered during other aquatic plan surveys.

Community Mapping

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

Aquatic Plant Survey Results

A number of aquatic plant surveys were completed by Onterra ecologists on Lake Puckaway in 2015. During these surveys, a total of 45 aquatic plant species were located, six of which are considered to be non-native (exotic) species: brittle naiad, curly-leaf pondweed, curly-leaf pondweed hybrid, hybrid watermilfoil, pale-yellow iris, and purple loosestrife (Table 3.4-1). Because of their ecological, sociological, and economical significance, these non-native aquatic plant populations in Lake Puckaway are discussed in detail in the *Non-Native Aquatic Plants* section. Table 3.4-1 also contains the aquatic plant species located during the surveys completed in 2005 (Maxim Technologies) and 2014 (Andrew Sabai). Changes in Lake Puckaway's aquatic plant community over this time period are discussed later in this section.

Lakes in Wisconsin vary in their morphometry, water chemistry, and substrate composition, and all of these factors influence aquatic plant community composition. During the whole-lake point-intercept survey completed on Lake Puckaway by Onterra during July 20 and 21, 2015, substrate data were also recorded at each sampling location in one of three general categories: rock, sand, and soft sediments. These data indicate that the majority (81%) of sampling locations contained soft sediments, 19% contained sand, and 0% were found to contain rock (Figure 3.4-2 and Map 3).

Like terrestrial plants, aquatic plants vary in their preference for a particular substrate type; some species are usually only found growing in soft sediments, others only coarse substrates like sand, while some are more generalists and can be found growing in either. Lakes with varying types of substrates generally support a higher number of aquatic plant species because of the different habitat types that are available.

During the 2015 point-intercept survey, aquatic plants were found growing to a maximum depth of 5.0 feet. Of the 679 sampling locations that fell at or shallower than the maximum depth of the plant growth (littoral zone), 131 or 19% contained aquatic vegetation, indicating the littoral zone of Lake Puckaway is sparsely vegetated (Map 4). Of the 131 sampling locations that contained aquatic vegetation, 86% were located in 3.0 feet of water or less (Figure 3.4-3). Aquatic plant rake fullness data collected in 2015 indicates that 13% of the 679 sampling locations contained vegetation with a total rake fullness rating of 1, 5% had a total rake fullness rating of 2, and 2% had a total rake fullness of 3 (Figure 3.4-4). These total rake fullness ratings indicate that the majority of vegetation that is in Lake Puckaway is of low density.

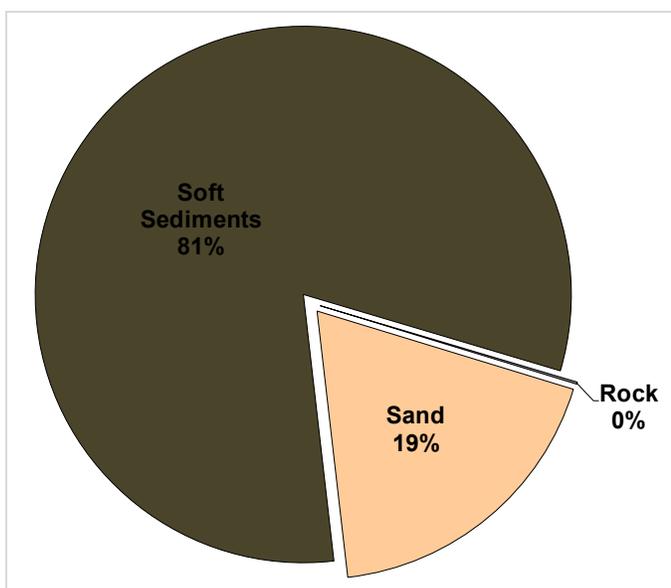


Figure 3.4-2. Lake Puckaway proportion of substrate types. Created from data collected during 2015 whole-lake point-intercept survey (N = 802). Spatial distribution of sediment types in Lake Puckaway are displayed in Map 3.

Table 3.4-1. Aquatic plant species located in Lake Puckaway during 2005, 2014, and 2015 aquatic plant surveys.

Growth Form	Scientific Name	Common Name	Coefficient of Conservatism (C)	2005	2014	2015
Emergent	<i>Bolboschoenus fluviatilis</i>	River bulrush	5		I	I
	<i>Eleocharis erythropoda</i>	Bald spikerush	3			I
	<i>Eleocharis palustris</i>	Creeping spikerush	6		I	
	<i>Iris pseudacorus</i>	Pale-yellow iris	Exotic			I
	<i>Lythrum salicaria</i>	Purple loosestrife	Exotic			I
	<i>Phragmites australis</i> subsp. <i>americanus</i>	Common reed	5	X	X	I
	<i>Sagittaria latifolia</i>	Common arrowhead	3		I	I
	<i>Sagittaria rigida</i>	Stiff arrowhead	8	X	I	X
	<i>Schoenoplectus acutus</i>	Hardstem bulrush	5	X	I	X
	<i>Schoenoplectus pungens</i>	Three-square rush	5		I	I
	<i>Schoenoplectus tabernaemontani</i>	Softstem bulrush	4		I	I
	<i>Sparganium eurycarpum</i>	Common bur-reed	5		I	I
	<i>Typha</i> spp.	Cattail spp.	1	X	I	I
	<i>Zizania aquatica</i>	Southern wild rice	8	X	I	I
FL	<i>Nelumbo lutea</i>	American lotus	8	X	X	X
	<i>Nuphar variegata</i>	Spatterdock	6	X	X	X
	<i>Nymphaea odorata</i>	White water lily	6	X	X	X
	<i>Persicaria amphibia</i>	Water smartweed	5		I	I
Submergent	<i>Ceratophyllum demersum</i>	Coontail	3	X	X	X
	<i>Chara</i> spp.	Muskgrasses	7		I	X
	<i>Elodea canadensis</i>	Common waterweed	3	X	X	X
	<i>Heteranthera dubia</i>	Water stargrass	6		X	X
	<i>Myriophyllum sibiricum</i>	Northern water milfoil	7		X	X
	<i>Myriophyllum sibiricum</i> X <i>spicatum</i> ^a	Hybrid water milfoil	Exotic	X	X	X
	<i>Najas flexilis</i>	Slender naiad	6	X	X	X
	<i>Najas guadalupensis</i>	Southern naiad	7			X
	<i>Najas minor</i>	Brittle naiad	Exotic		X	X
	<i>Potamogeton berchtoldii</i>	Slender pondweed	7		X	X
	<i>Potamogeton crispus</i>	Curly-leaf pondweed	Exotic	X	I	I
	<i>Potamogeton friesii</i>	Fries' pondweed	8			I
	<i>Potamogeton</i> X <i>rectifolius</i> ^b	Clasping-leaf X Long-leaf pondweed	N/A			I
	<i>Potamogeton natans</i>	Floating-leaf pondweed	5	X		X
	<i>Potamogeton nodosus</i>	Long-leaf pondweed	5	X	X	I
	<i>Potamogeton richardsonii</i>	Clasping-leaf pondweed	5	X	I	I
	<i>Potamogeton strictifolius</i>	Stiff pondweed	8			X
	<i>Potamogeton</i> X <i>undulatus</i> ^b	Curly-leaf X White-stem pondweed	Exotic			I
	<i>Potamogeton zosteriformis</i>	Flat-stem pondweed	6	X	I	I
	<i>Stuckenia pectinata</i>	Sago pondweed	3	X	X	X
<i>Utricularia vulgaris</i>	Common bladderwort	7		I	X	
<i>Vallisneria americana</i>	Wild celery	6	X	X	X	
<i>Zannichellia palustris</i>	Horned pondweed	7		X	X	
S/E	<i>Eleocharis acicularis</i>	Needle spikerush	5			X
FF	<i>Lemna minor</i>	Lesser duckweed	5		I	X
	<i>Lemna trisulca</i>	Forked duckweed	6	X	I	X
	<i>Spirodela polyrhiza</i>	Greater duckweed	5		I	X
	<i>Wolffia</i> spp.	Watermeal spp.	N/A		I	X

FL = Floating Leaf; S/E = Submergent and Emergent; FF = Free Floating

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

2005 Maxim Technologies; 2014 Andrew Sabai; 2015 Onterra

^a Hybrid confirmed via DNA (Annis Water Resources Institute at Grand Valley State University 2015)

^b Not confirmed via DNA. Suspected hybrids based on morphology.

Of the 45 aquatic plant species located in Lake Puckaway in 2015, 24 were physically encountered on the rake during the whole-lake point-intercept survey (Figure 3.4-5). The remaining 21 plants were located ‘incidentally’, meaning they were observed and collected while on the lake but they were not recorded on the sampling rake at any of the 802 sampling locations during the point-intercept survey. Of the 24 species encountered on the rake during the point-intercept survey, coontail, common waterweed, wild celery, and American lotus were the four-most frequently encountered (Figure 3.4-5).

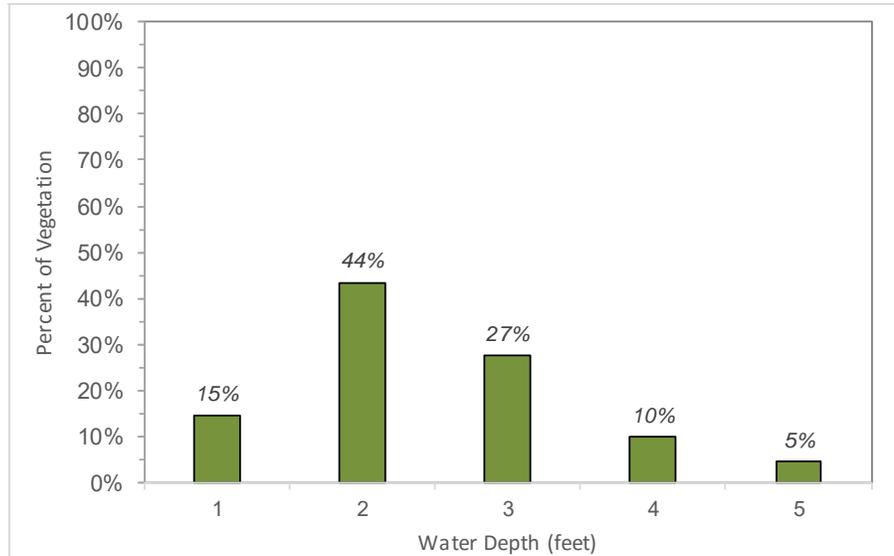


Figure 3.4-3. Lake Puckaway relative frequency of vegetation across water depth. Created from data collected during 2015 whole-lake point-intercept survey (N = 131 locations that contained vegetation). Spatial distribution of vegetation in Lake Puckaway are displayed in Map X

Coontail, arguably the most abundant aquatic plant in Wisconsin, was the most frequently encountered species in Lake Puckaway with a littoral frequency of occurrence of approximately 8% (Figure 3.4-5). Coontail, as its name suggests, possess closely-spaced whorls of stiff leaves that give the plant a raccoon tail-like appearance. Unlike most of the submersed plants found in Wisconsin, coontail does not produce true roots and is often found growing entangled amongst other aquatic plants. Because it lacks true roots, coontail derives most of its nutrients directly from the water (Gross et al. 2003). This ability in combination with a tolerance for low-light conditions

allows coontail to dominate in high-nutrient, eutrophic lakes. Coontail has the capacity to form dense beds which mat on the surface and can hinder recreation; however, this level of growth was not observed in Lake Puckaway.

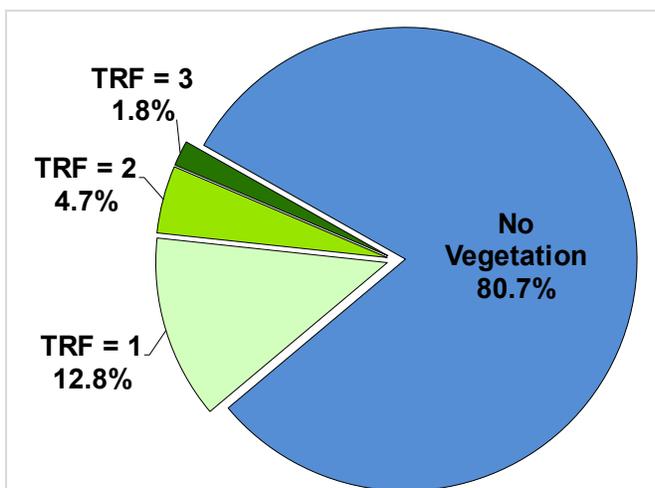
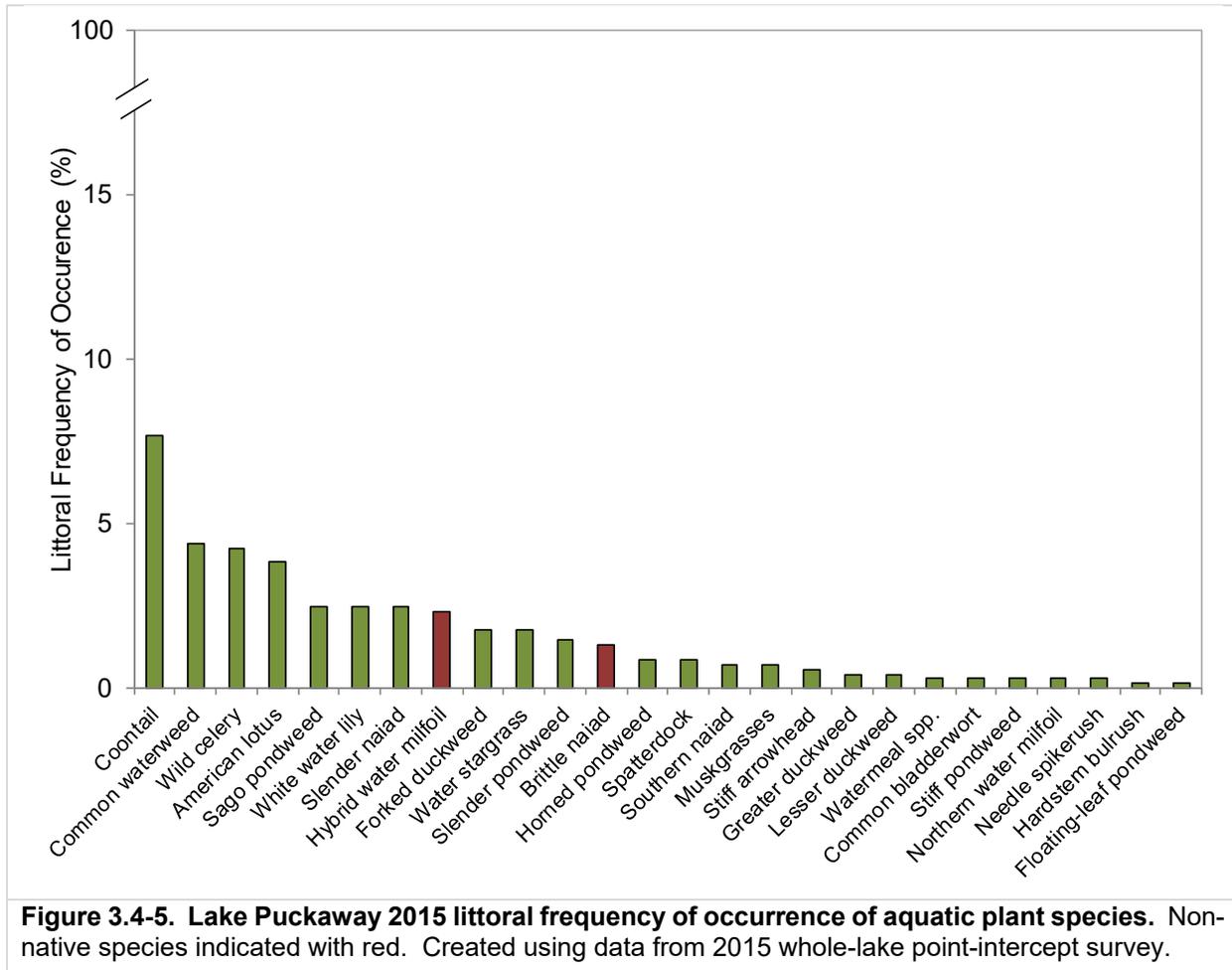


Figure 3.4-4. Lake Puckaway 2015 aquatic vegetation total rake fullness (TRF) ratings. Created from data collected during the 2015 whole-lake point-intercept survey (N = 679).

Common waterweed was the second-most frequently encountered aquatic plant species in Lake Puckaway during the 2015 whole-lake point-intercept survey with a littoral frequency of approximately 4% (Figure 3.4-5). Like coontail, common waterweed is found in waterbodies across Wisconsin and is tolerant of low-light conditions, often making it one of the more abundant plants in eutrophic lakes. It prefers growing in soft sediments, and can often grow in dense beds

that mat at the surface. However, like coontail, common waterweeds dense network of stems and leaves provide excellent habitat for aquatic wildlife.



Wild celery, or tape grass, was the third-most frequently encountered aquatic plant during the 2015 whole-lake point-intercept survey on Lake Puckaway with a littoral frequency of occurrence of 4% (Figure 3.4-5). This plant possesses long, ribbon-like leaves which emerge from a basal rosette, and it produces a deep network of roots and rhizomes which stabilize bottom sediments. Later in the summer, wild celery produces numerous seeds in a banana-shaped seed pod which float at the surface. These seeds have been shown to be an essential component of the diet of certain migratory waterfowl (Borman et al. 2014). Wild celery prefers to grow on firmer substrates, and like the other plants discussed, is tolerant of eutrophic conditions.

The fourth-most frequently encountered aquatic plant in Lake Puckaway in 2015 was American Lotus, with a littoral occurrence of 4% (Figure 3.4-5). American lotus possesses large circular leaves which float on or grow above the water’s surface, and the large lotus communities in Lake Puckaway provide valuable wildlife habitat, stabilize bottom sediments, and reduce non-native plant colonization (Photo 3.4-5). These plants also produce large, fragrant flowers which add aesthetic beauty to Lake Puckaway.

While non-native aquatic plant species in Lake Puckaway are discussed in greater detail in subsequent sections, hybrid watermilfoil was the most frequently encountered non-native species in Lake Puckaway in 2015 with a low littoral frequency of occurrence of 2% (Figure 3.4-5). Brittle naiad also had a low littoral frequency of occurrence of 1% in 2015 (Figure 3.4-5).

Comparisons with Historical Aquatic Plant Data

Prior to 2015, two whole-lake point-intercept surveys have been completed on Lake Puckaway; one in 2005 (Maxim Technologies) and one in 2014 (Andrew Sabai). The placement of the 507 sampling locations in 2005 and 2014 was not done in accordance with WDNR protocol, and the sampling locations were not evenly spaced. However, the sampling methodology did follow WDNR protocol and still allows for a statistical comparison with the data collected in 2015.

The maximum depth of plant growth was 6.0 feet in 2005, 3.5 feet in 2014, and 5.0 feet in 2015. The littoral frequency of occurrence of all aquatic vegetation in Lake Puckaway declined from an occurrence of 32% in 2005, to 22% and 19% in 2014 and 2015, respectively (Figure 3.4-6). The reduction in the occurrence of vegetation from 2005 to 2014 is statistically valid, while the difference in the occurrence of vegetation between 2014 and 2015 is not statistically different (Chi-Square $\alpha = 0.05$). These surveys indicate that the littoral occurrence of aquatic vegetation has declined by approximately 40% between 2005 and 2015 in Lake Puckaway.



Photo 3.4-5. American lotus (*Nelumbo lutea*) colony in Lake Puckaway. Onterra, 2016.

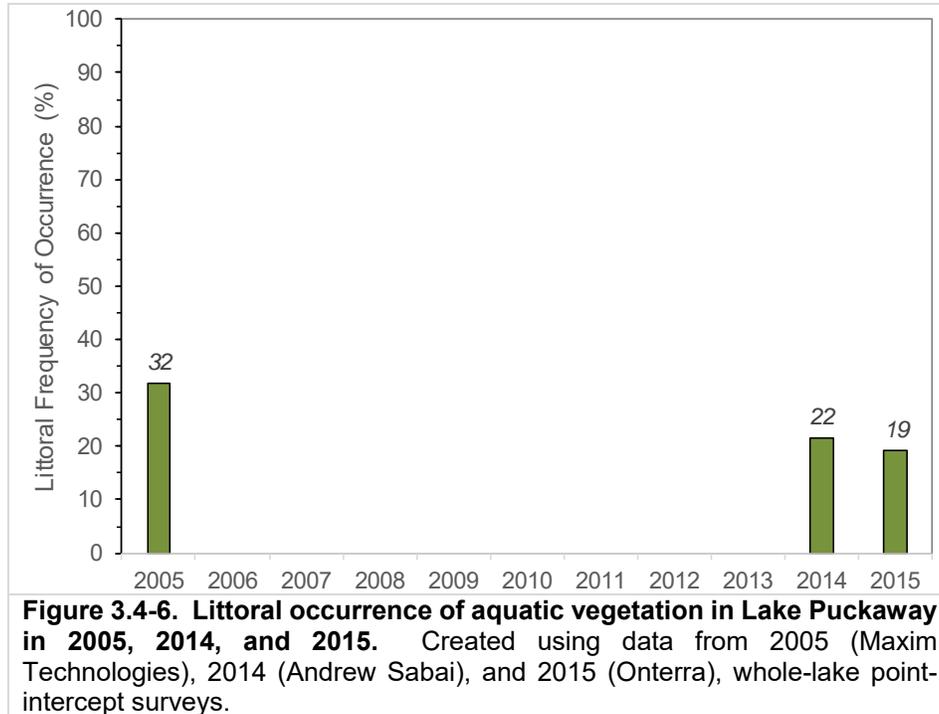


Figure 3.4-7 displays the littoral frequency of occurrence of select aquatic plant species in Lake Puckaway as determined from the 2005, 2014, and 2015 whole-lake point-intercept surveys. It should be noted that the occurrences of slender and southern naiad were combined for this analysis (naiad spp.) as these species are often difficult to separate from one another. As illustrated, six native aquatic plant species exhibited statistically valid reductions in their occurrence from 2005 to 2015, and include common waterweed (67% reduction), naiad spp. (67% reduction), clasping-leaf pondweed (100% reduction), flat-stem pondweed (100% reduction), sago pondweed (82% reduction), and wild celery (76% reduction). The occurrences of coontail, hybrid watermilfoil, American lotus, and white water lily were not statistically different between this same time period. The reduction in vegetation in Lake Puckaway between 2005 and 2015 is an indication of degrading environmental conditions.

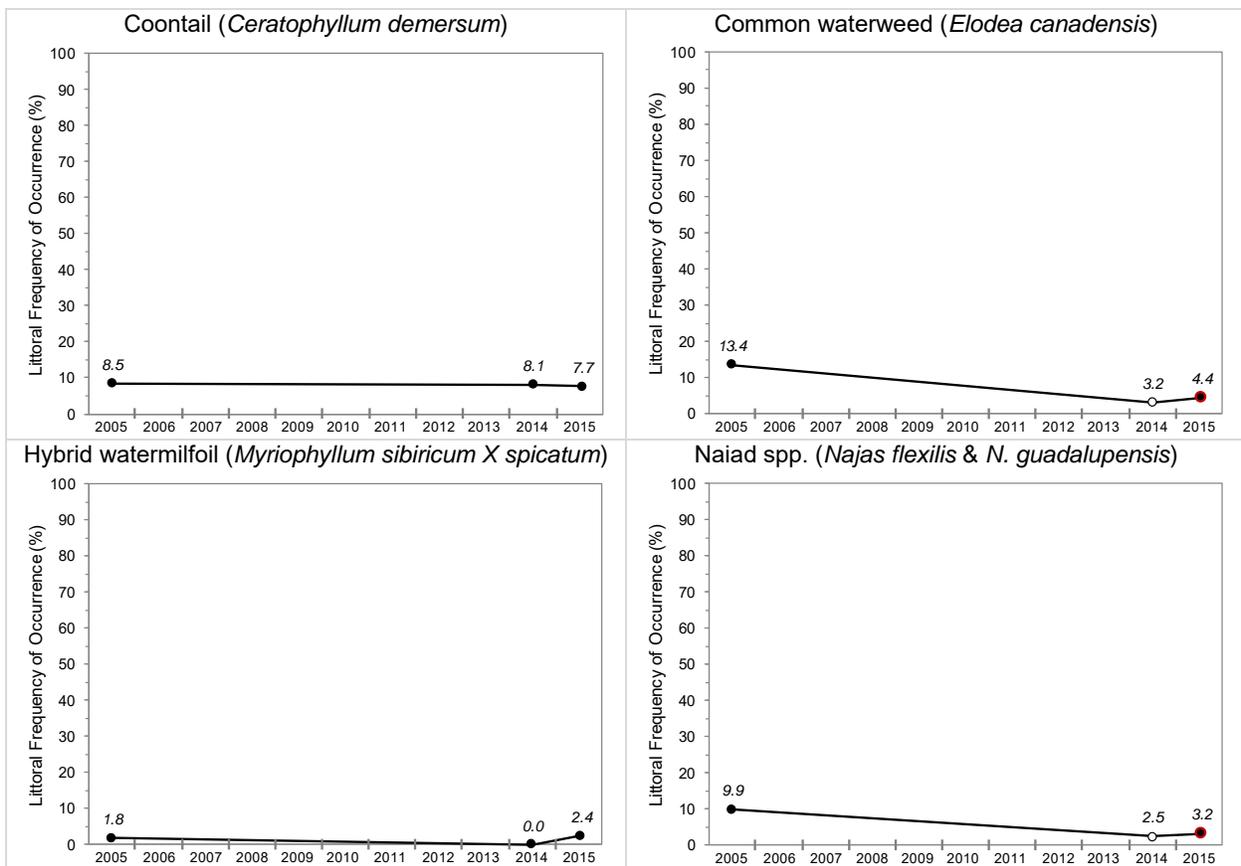


Figure 3.4-7. Littoral frequency of occurrence of select aquatic plant species in Lake Puckaway from 2005, 2014, and 2015. Open circle indicates occurrences is statistically different from previous survey. Red outline indicates 2015 occurrence is statistically different from 2005 (Chi-Square $\alpha = 0.05$). Created using data from 2005 (Maxim Technologies), 2014 (Andrew Sabai), and 2015 (Onterra) whole-lake point-intercept surveys.

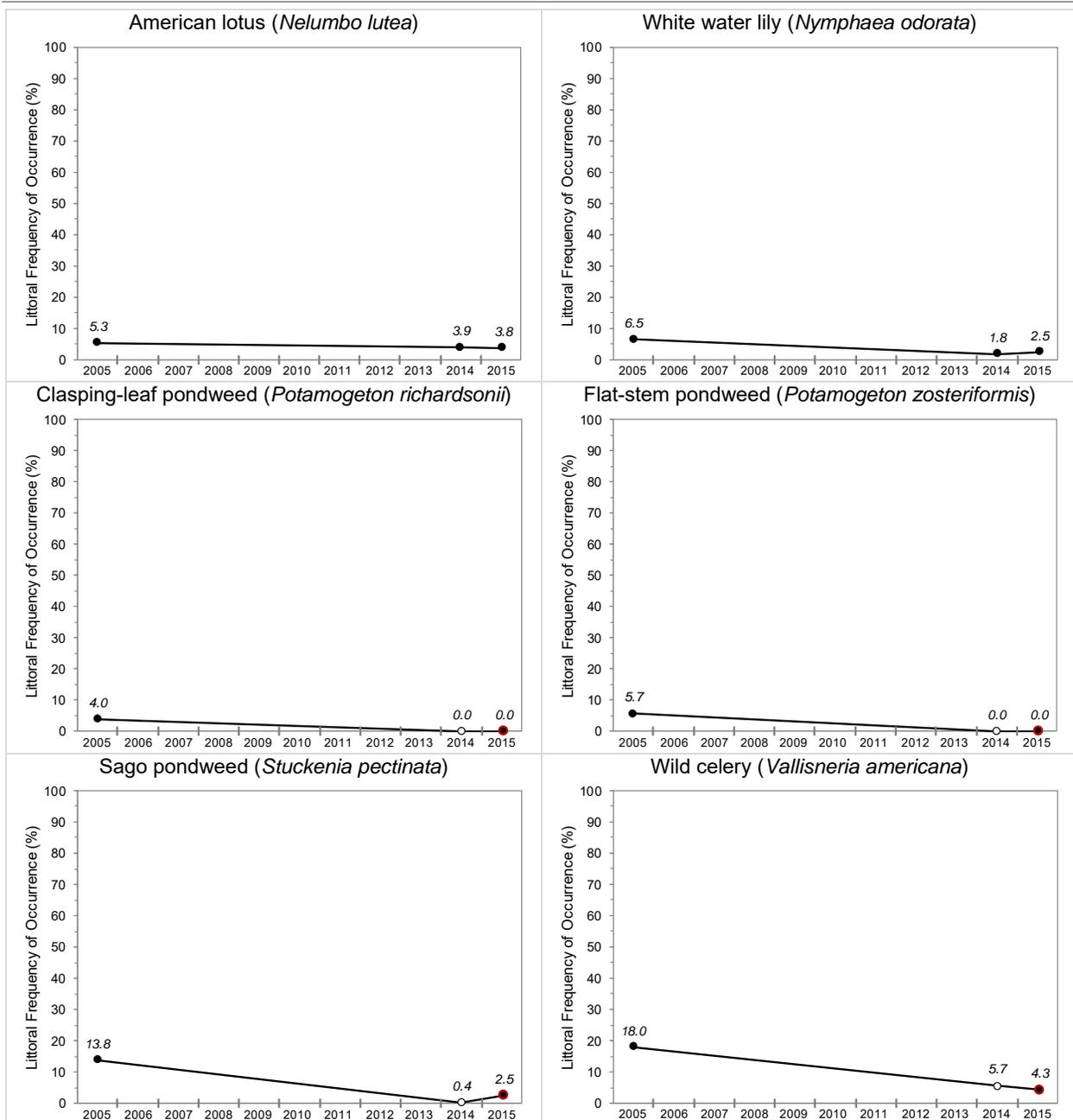


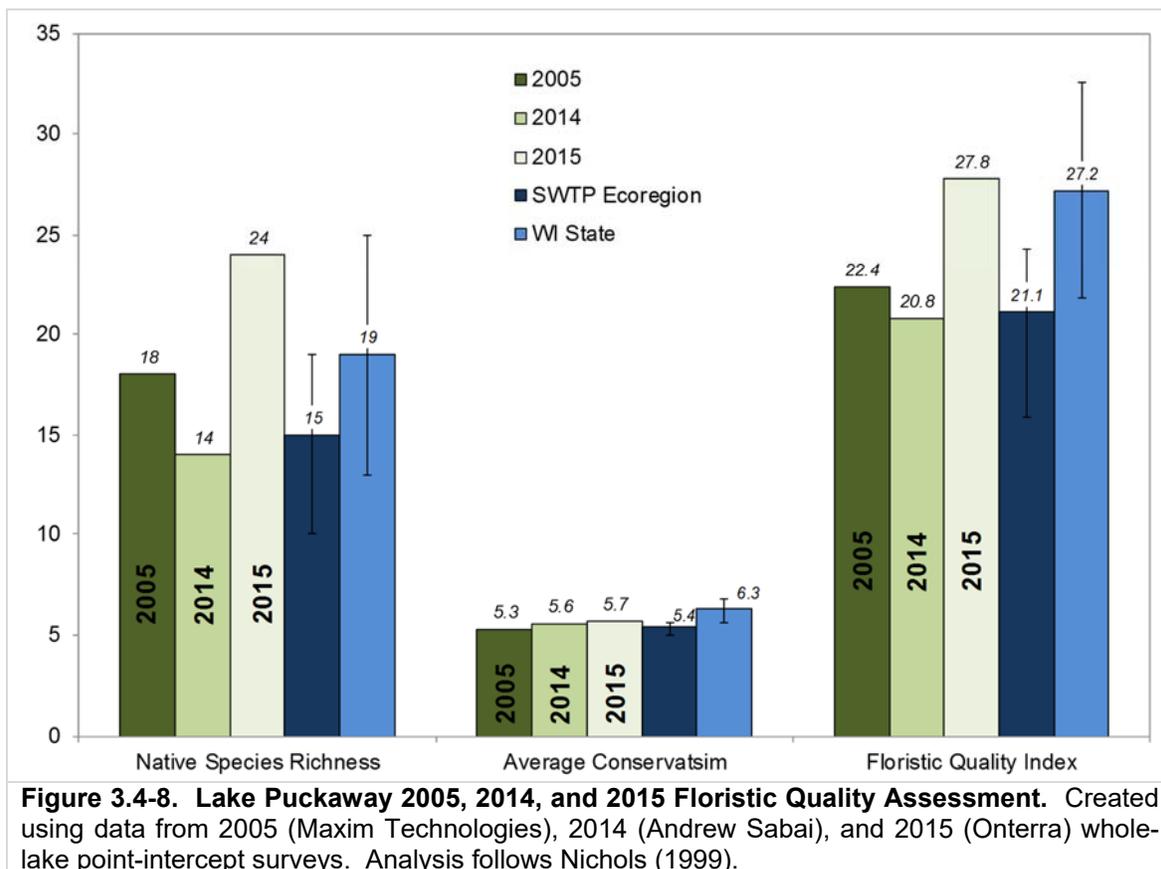
Figure 3.4-7 continued. Littoral frequency of occurrence of select aquatic plant species in Lake Puckaway from 2005, 2014, and 2015. Open circle indicates occurrences is statistically different from previous survey. Red outline indicates 2015 occurrence is statistically different from 2005 (Chi-Square $\alpha = 0.05$). Created using data from 2005 (Maxim Technologies), 2014 (Andrew Sabai), and 2015 (Onterra) whole-lake point-intercept surveys.

As discussed in the primer section, the calculations used to create the Floristic Quality Index (FQI) for a lake’s aquatic plant community are based on the aquatic plant species that were encountered on the rake during the point-intercept survey and does not include incidentally located species. The native species encountered on the rake during the 2005, 2014, and 2015 point-intercept surveys and their conservatism values were used to calculate the FQI of Lake Puckaway’s aquatic plant community (equation on next page).

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

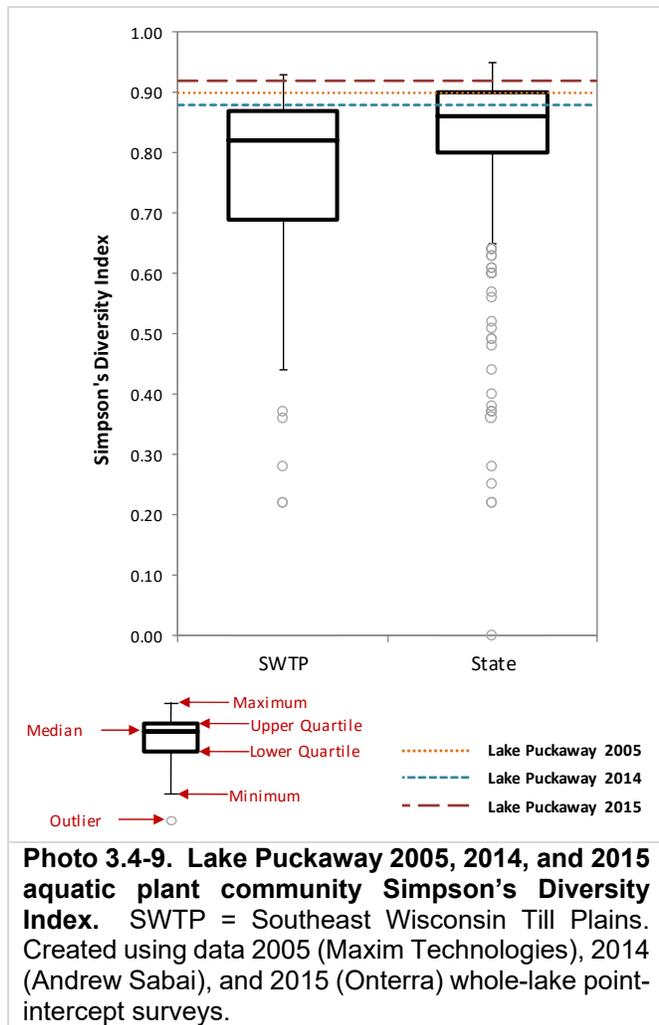
Figure 3.4-8 compares the 2005, 2014, and 2015 FQI components of Lake Puckaway to median values of lakes within the Southeast Wisconsin Till Plains (SWTP) ecoregion and lakes throughout Wisconsin. The number of native aquatic plant species recorded on the rake during the point-intercept surveys, or the native species richness, varied from 18 in 2005, 14 in 2014, and 24 in 2015. The native species richness recorded in 2015 exceeds the upper quartile value for lakes in the SWTP ecoregion and the median value for lakes statewide.

The average conservatism of Lake Puckaway's aquatic plant community ranged from 5.3 in 2005 to 5.7 in 2014 (Figure 3.4-8). Lake Puckaway's 2015 average conservatism exceeds the upper quartile value for lakes in the SWTP ecoregion but falls below the median value for lakes statewide. In other words, Lake Puckaway contains a higher number of environmentally-sensitive aquatic plant species when compared to other lakes within the ecoregion, but contains a lower number of environmentally-sensitive plant species when compared to other lakes throughout Wisconsin. Using Lake Puckaway's native species richness and average conservatism to calculate the FQI (equation above) indicates that the lake's FQI ranged from 20.8 in 2014 to 27.8 in 2015 (Figure 3.4-8). The FQI in 2015 exceeds the upper quartile value for lakes within the SWTP ecoregion and is comparable to the median value for lakes statewide. While the overall occurrence of vegetation has declined in Lake Puckaway since 2005, it appears that the quality in terms of species composition has increased since 2005.



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

While a method for characterizing diversity values of fair, poor, etc. does not exist, lakes within the same ecoregion may be compared to provide an idea of how Lake Puckaway’s diversity value ranks. In addition, this analysis allows for a comparison of aquatic plant diversity in Lake Puckaway from pre- and post-drawdown. Using data collected by Onterra and WDNR Science Services, quartiles were calculated for 77 lakes within the SWTP Ecoregion (Figure 3.4-9). Using the data collected from the 2005, 2014, and 2015 point-intercept surveys shows that aquatic plant diversity in Lake Puckaway has ranged from 0.88 in 2014 to 0.92 in 2015. Simpson’s diversity in all three years from Lake Puckaway exceeded the upper quartile value for lakes within the SWTP ecoregion and the median value for lake’s throughout Wisconsin. In other words, if two individual aquatic plants were randomly samples from Lake Puckaway in 2015, there would be a 92% probability that they would be different species.



Emergent & Floating-leaf Aquatic Plant Communities

The 2015 community mapping survey indicated that approximately 679 acres, or 14% of Lake Puckaway’s 5,013 acres contains emergent and floating-leaf aquatic plant communities (Table 3.4-2 and Maps 5 and 6). These communities were comprised of 17 aquatic plant species. Emergent and floating-leaf aquatic plant communities are an important component of the lake ecosystem as they provide valuable structural habitat, reduce sediment resuspension, and reduce shoreline erosion. Continuing the analogy that the community map represents a ‘snapshot’ of the important emergent and floating-leaf plant communities, a replication of this survey in the future will provide a valuable understanding of the dynamics of these communities within Lake Puckaway. This is important, because these communities are often negatively affected by recreational use and shoreland development. Radomski and Goeman (2001) found a 66% reduction in vegetation

coverage on developed shorelines when compared to undeveloped shorelines in Minnesota Lakes. Furthermore, they also found a significant reduction in abundance and size of northern pike (*Esox lucius*), bluegill (*Lepomis macrochirus*), and pumpkinseed (*Lepomis gibbosus*) associated with these developed shorelines.

Table 3.4-2. Lake Puckaway 2015 acres of emergent and floating-leaf aquatic plant communities. Created using data from 2015 aquatic plant community mapping survey. Locations of these communities are displayed in Maps 5 and 6.

Plant Community	Acres
Emergent	105.4
Floating-leaf	477.9
Mixed Emergent & Floating-leaf	95.7
Total	679.1

Non-native Aquatic Plants in Lake Puckaway

Eurasian/Hybrid watermilfoil

A date for when Eurasian watermilfoil (*Myriophyllum spicatum*; EWM) was first documented in Lake Puckaway is not available; however, it has likely been present in the lake for some time (Photo 3.4-6). In 2015, Onterra ecologists sent specimens of the EWM from Lake Puckaway to the Annis Water Resources Institute at Grand Valley State University in Michigan to undergo DNA analysis. The results indicate that the population in Lake Puckaway is hybrid watermilfoil (HWM), a cross between EWM and the indigenous northern watermilfoil (*M. sibiricum*). Lake Puckaway contains a population of northern watermilfoil, but it is not known if the hybrid originated within Lake Puckaway or was introduced from another waterbody. Knowing whether a milfoil population is pure-strain EWM or HWM is important when considering herbicide application as a method for control as ongoing research is showing that certain strains of HWM are more tolerant to herbicides.

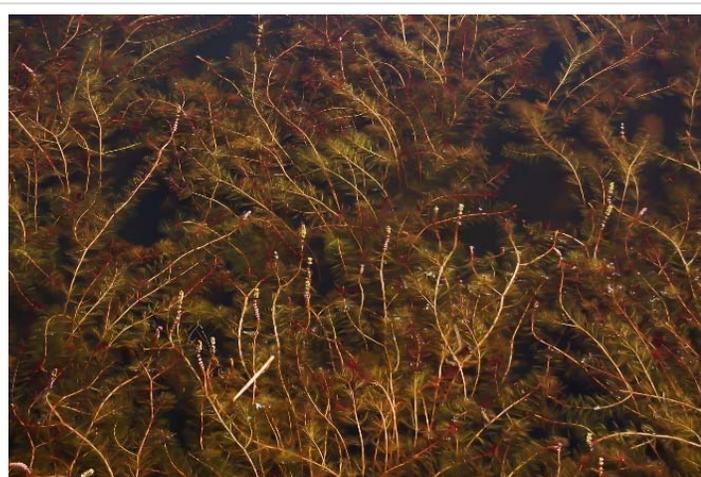


Photo 3.4-6. Eurasian watermilfoil, a non-native, invasive aquatic plant.

As mentioned earlier, the occurrence of HWM in Lake Puckaway in 2015 was low with a littoral frequency of occurrence of approximately 2%. Data from the 2005 and 2014 whole-lake point-intercept surveys indicate that the occurrence of HWM in Lake Puckaway has not changed over this time period. On August 31, 2015, Onterra ecologists completed the HWM Peak-Biomass Survey. This survey revealed Lake Puckaway contains approximately 78 acres of colonized HWM (Figure 3.4-10 and Map 7). However, the majority of this acreage (62%) was delineated a density rating of *scattered* or *highly scattered*, while 29% was delineated as *dominant*, 3% as *highly dominant*, and 6% as *surface matted*. The majority of the colonized HWM was located in the northwestern portion of the lake extending into floating-leaf and emergent plant communities.

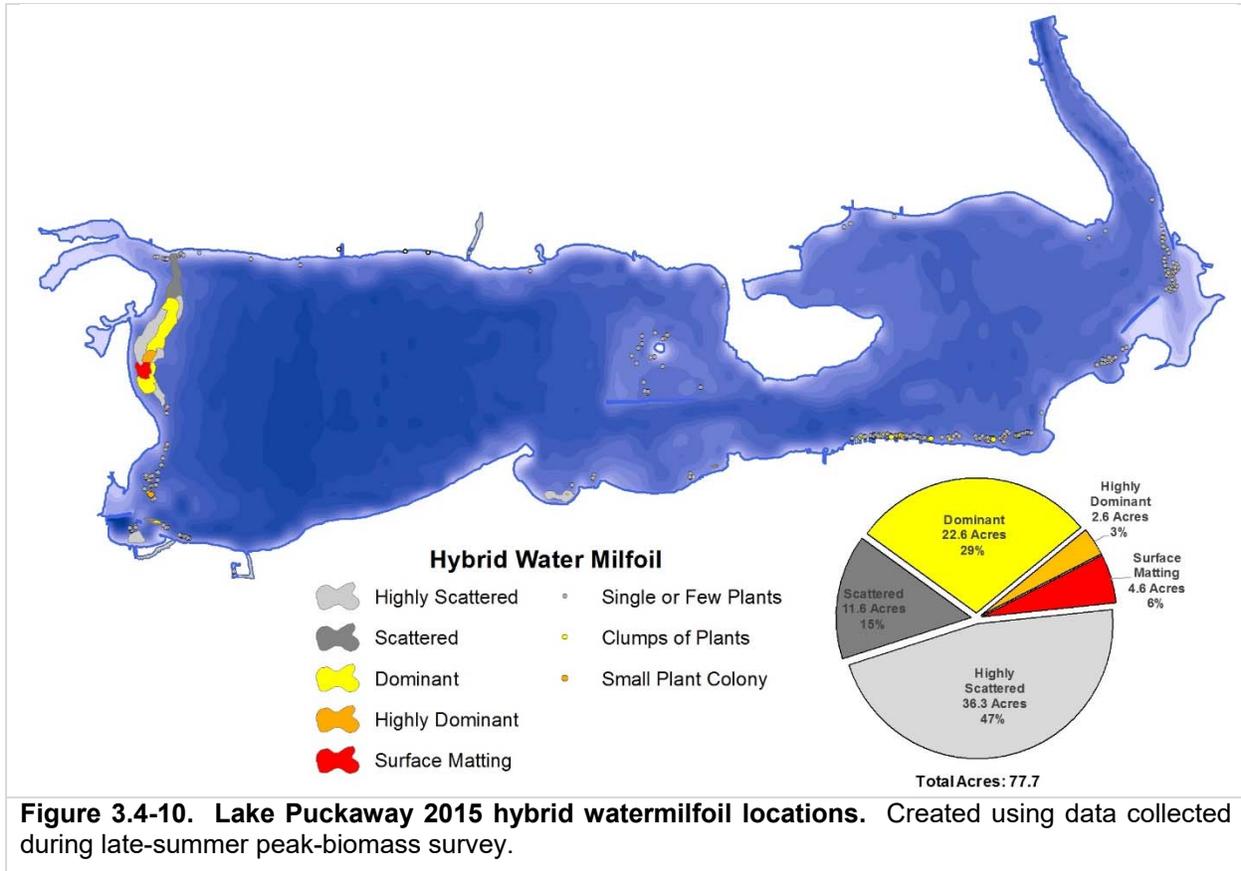


Figure 3.4-10. Lake Puckaway 2015 hybrid watermilfoil locations. Created using data collected during late-summer peak-biomass survey.

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

There is no date available for when curly-leaf pondweed (*Potamogeton crispus*; CLP) was first documented in Lake Puckaway; however, it was recorded in upstream Buffalo Lake in 1982 and has likely been in Lake Puckaway for some time (Figure 3.4-3 and Map 8). Curly-leaf pondweed in Lake Puckaway was mapped by Onterra ecologists during the Early-Season AIS Survey on June 18 and 19, 2015. This survey revealed that the CLP population in Lake Puckaway is small, with approximately six acres of colonized CLP being located, 98% of which was delineated with a density rating of *highly scattered* or *scattered* (Figure 3.4-11). Approximately 0.1 acres (2%) was delineated as having *dominant* CLP. The majority of the CLP located in 2015 was located in the central portion of the lake.

During the surveys completed on Lake Puckaway in 2015, a few occurrences of a presumed hybrid between curly-leaf pondweed and the indigenous white-stem pondweed (*P. praelongus*) were located (Photo 3.4-7). This hybrid has been denoted the name *P. X undulatus*, and genetic analysis is needed to positively identify this plant as such in Lake Puckaway. It is not known how widespread this plant is within Wisconsin, but populations have also been found in upstream Buffalo Lake and some lakes in the Madison area. *P. X undulatus* was only found growing in a few locations in Lake Puckaway in 2015, and it was not observed growing in any large colonies. This plant has not been observed to grow to nuisance conditions in Wisconsin and is currently not a concern in Lake Puckaway.



Photo 3.4-7. Curly-leaf pondweed (*Potamogeton crispus*; left) and presumed curly-leaf X white-stem pondweed hybrid (*P. X undulatus*; right).

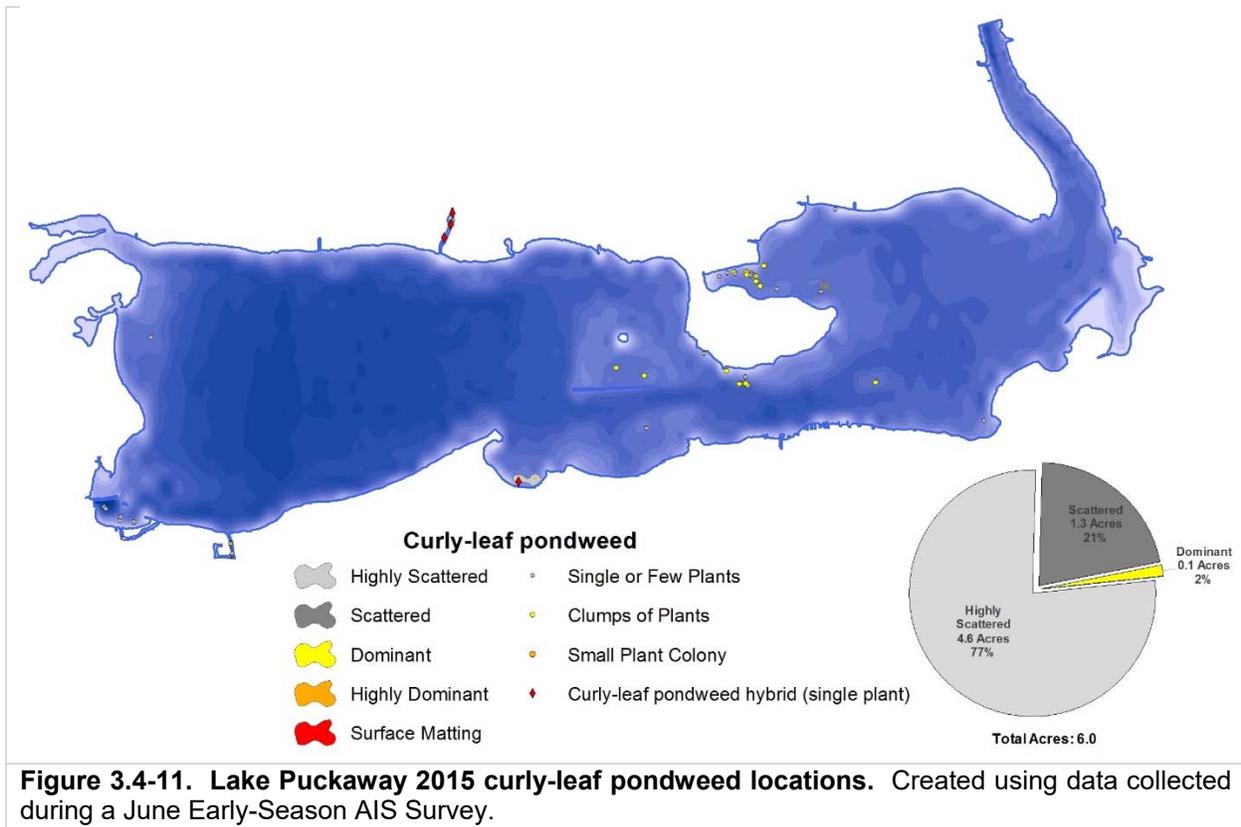


Figure 3.4-11. Lake Puckaway 2015 curly-leaf pondweed locations. Created using data collected during a June Early-Season AIS Survey.

Brittle naiad

Brittle naiad (*Najas minor*; Photo 3.4-8) was first discovered in Lake Puckaway in 2014 and a population is also present in upstream Buffalo Lake. In 2015, brittle naiad had a low littoral occurrence of 1%, indicating a small population in Lake Puckaway. Brittle naiad is similar in appearance to the two native naiads found in Lake Puckaway (*N. flexilis* and *N. guadalupensis*). Brittle naiad grows relatively short and it was not always visible from the surface in Lake Puckaway making mapping of this species difficult. However, using data collected during the 2015 point-intercept survey and during the Late-Summer EWM Peak-Biomass Survey, an idea of the general distribution of brittle naiad in Lake Puckaway could be made (Figure 3.4-12 and Map 9). All of the brittle naiad occurrences in 2015 were located in the eastern portion of the lake, and all occurrences were comprised of *single or few plants*. While brittle naiad has been known to reach high densities, its low occurrence in Lake Puckaway does not warrant control at this time.



Photo 3.4-8. Brittle naiad (*Najas minor*), a non-native, invasive aquatic plant. Photo taken by Alabama Department of Conservation and Natural Resources.

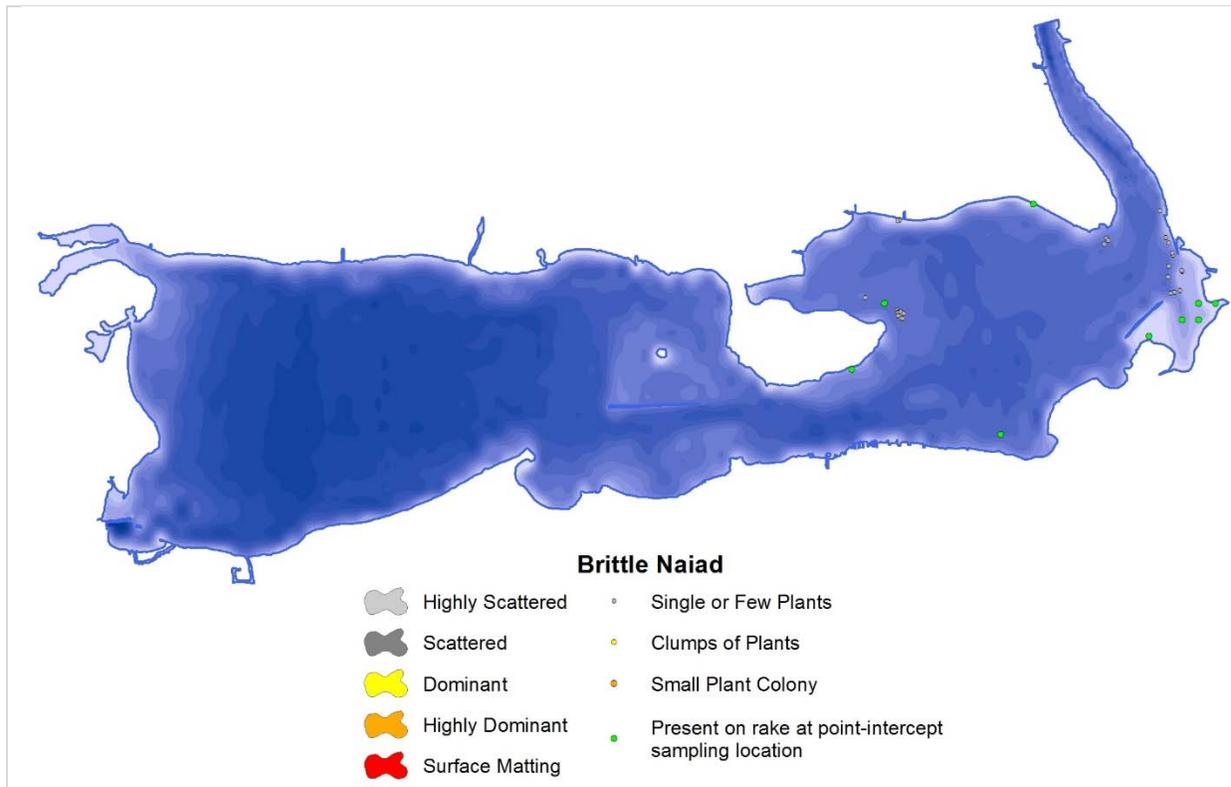


Figure 3.4-12. Lake Puckaway 2015 brittle naiad locations. Created using data collected during 2015 aquatic plant surveys.

Purple loosestrife

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

In Lake Puckaway, purple loosestrife was located in six locations along the northern and southern shorelines of the western basin (Maps 5 and 6). There are a number of effective control strategies for combating this aggressive plant, including herbicide application, biological control by native beetles, and manual hand removal. At this time, hand removal by volunteers is likely the best option as it would decrease costs significantly. Additional purple loosestrife monitoring would be required to ensure the eradication of the plant from the shorelines and wetland areas around Lake Puckaway.

Pale-yellow iris

Pale yellow iris (*Iris pseudacorus*) is a large, showy iris with bright yellow flowers. Native to Europe and Asia, this species was sold commercially in the United States for ornamental use and has since escaped into Wisconsin's wetland areas forming large monotypic colonies and displacing valuable native wetland species. One occurrence of pale-yellow iris was located in the channel along the northern shore of the lake in 2015 (Maps 5 and 6). The optimal time to locate pale-yellow iris is in May and June when the plants are in flower. Hand-pulling or cutting of these plants to below the water line appears to be the most effective method of control for this species at this time.

Stakeholder Survey Responses to Aquatic Vegetation within Lake Puckaway

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 3.4-13 display the response of Lake Puckaway stakeholders to a question regarding aquatic plants and how their decline may or may not have affected the lake. Fifty-five percent of respondents believe that the decline in aquatic plants is a sign of an ecologically unhealthy lake while 35% are unsure of the relationship between aquatic plants and lake ecological health. It is clear that the majority of respondents understand that the lack of aquatic plant habitat in Lake Puckaway is a sign of the lake's poor health. One of the top three factors negatively impacting the lake chosen by Lake Puckaway stakeholders is the loss of aquatic habitat (Figure 2.0-2).

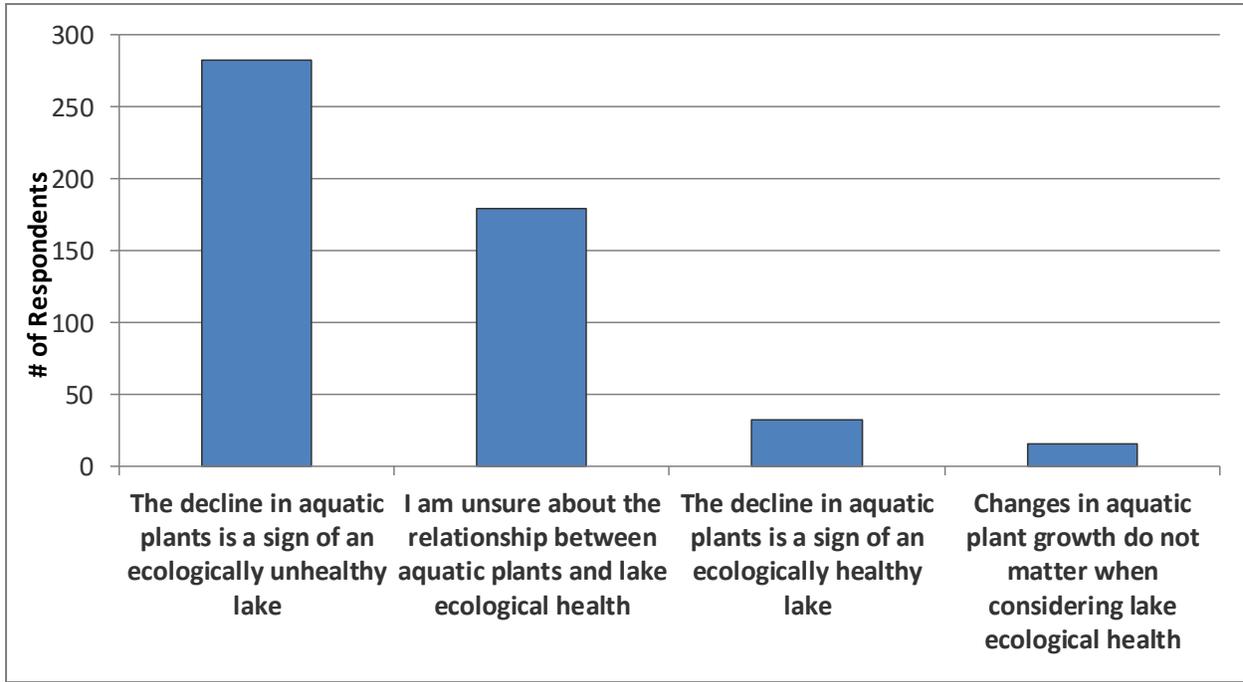


Figure 3.4-13. Stakeholder survey response Question #25. Aquatic plants form the foundation of a lake ecosystem and contribute to healthy lakes by reducing erosion and providing habitat for a number of aquatic animals. It has been noted in past lake management reports that Lake Puckaway currently holds fewer aquatic plants than the lake did prior to the 1960's. Do you believe that the decline in aquatic plant abundance has had a healthy or unhealthy impact on Lake Puckaway?

3.5 Aquatic Invasive Species in Lake Puckaway

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

Table 3.5-1. AIS present within Lake Puckaway

Type	Common name	Scientific name	Location within the report
Plants	Eurasian watermilfoil	<i>Myriophyllum spicatum</i>	Section 3.4 – Aquatic Plants
	Hybrid watermilfoil	<i>Myriophyllum spicatum</i> <i>X M. spicatum</i>	Section 3.4 – Aquatic Plants
	Curly-leaf pondweed	<i>Potamogeton crispus</i>	Section 3.4 – Aquatic Plants
	Curly-leaf x white-stem pondweed	<i>Potamogeton X undulatus</i>	Section 3.4 – Aquatic Plants
	Purple loosestrife	<i>Lythrum salicaria</i>	Section 3.4 – Aquatic Plants
	Pale-yellow iris	<i>Iris pseudacorus</i>	Section 3.4 – Aquatic Plants
Viruses	Viral hemorrhagic septicemia	-	Section 3.5 Aquatic Invasive Species

Figure 3.5-1 displays the 16 aquatic invasive species that Lake Puckaway stakeholders believe are in Lake Puckaway. Only the species present in Lake Puckaway are discussed below or within their respective locations listed in Table 3.5-1. While it is important to recognize which species stakeholders believe to present within their lake, it is more important to share information on the species present and possible management options. More information on these invasive species or any other AIS can be found at the following links:

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

Aquatic Viruses and Parasites

Viral Hemorrhagic Septicemia

Viral hemorrhagic septicemia (VHS) is a deadly fish virus that can affect as many as 25 different fish species. First discovered in Lake Winnebago in 2006, it is unclear how this virus made its way to the Great Lakes. Humans are not susceptible to the virus but should be on the lookout for fish with the following symptoms: bleeding, bulging eyes, unusual behavior, anemia, bloating abdomens, and rapid onset of death. Infected fish spread the virus through their urine and reproductive fluids. Similar to zebra mussels, to help prevent the spread of VHS, boats should be bleached, power washed, and dried after leaving infected waterways and before entering any other waterways.

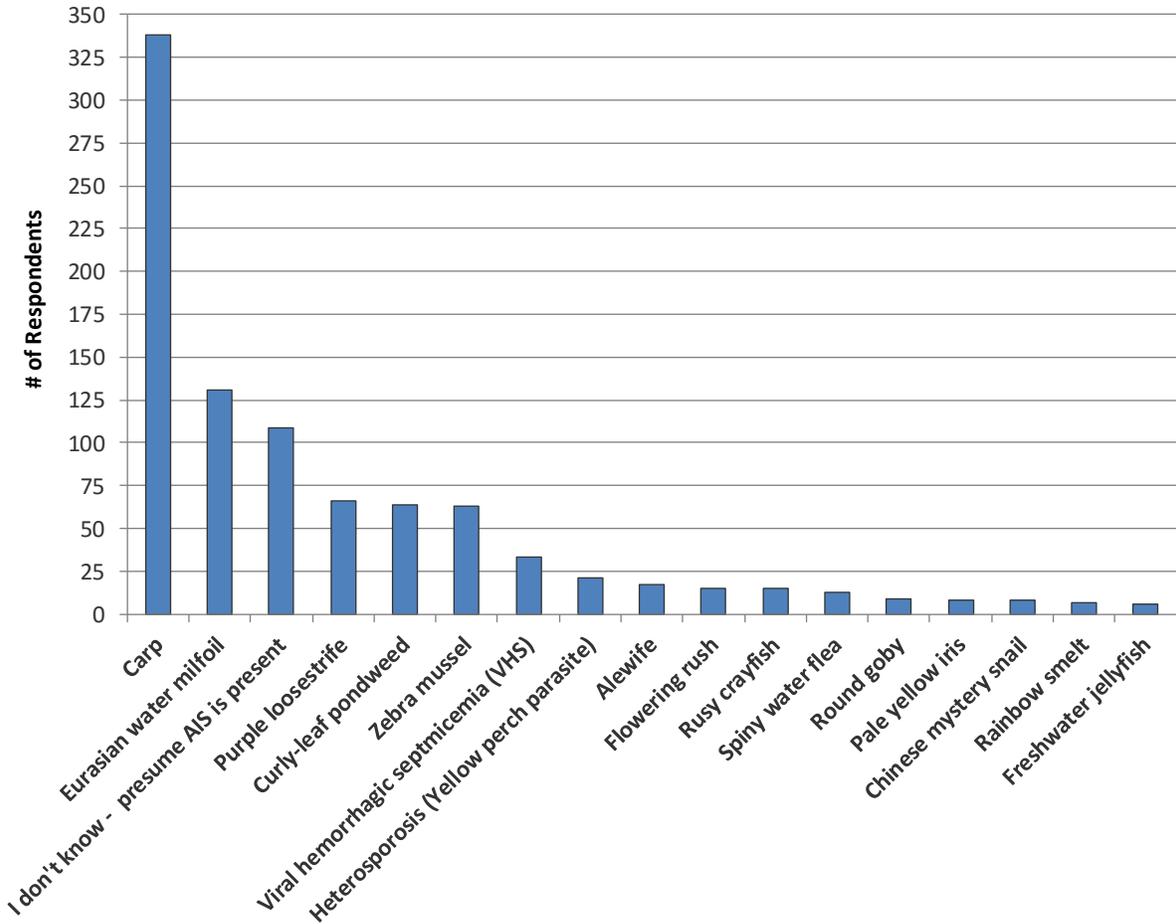


Figure 3.5-1. Stakeholder survey response Question #20. Which aquatic invasive species do you believe are in Puckaway?

3.6 Fisheries Data Integration

Fishery management is an important aspect in the comprehensive management of a lake ecosystem; therefore, a brief summary of available data is included here as reference. The following section is not intended to be a comprehensive plan for the lake's fishery, as those aspects are currently being conducted by the numerous fisheries biologists overseeing Lake Puckaway. The goal of this section is to provide an overview of some of the data that exists, particularly in regards to specific issues (fish stocking, angling regulations, etc.) that were brought forth by the LPPRD stakeholders within the stakeholder survey and other planning activities. Although current fish data were not collected, the following information was compiled based upon data available from available sources including the WDNR. The department is completing a comprehensive fishery survey on Lake Puckaway during 2017 with results available over the winter of 2018. Comparisons will be made with data collected on Lake Puckaway during 2011.

Lake Puckaway Fishery

Lake Puckaway Fishing Activity

Based on data collected from the stakeholder survey (Appendix D), fishing was the highest ranked important or enjoyable activity on Lake Puckaway (Figure 2.0-1). Approximately 70% of these same respondents believed that the quality of fishing on the lake was either fair or good (Figure 3.6-1) and approximately 56% believe that the quality of fishing has gotten worse or much worse since they have obtained their property (Figure 3.6-2).

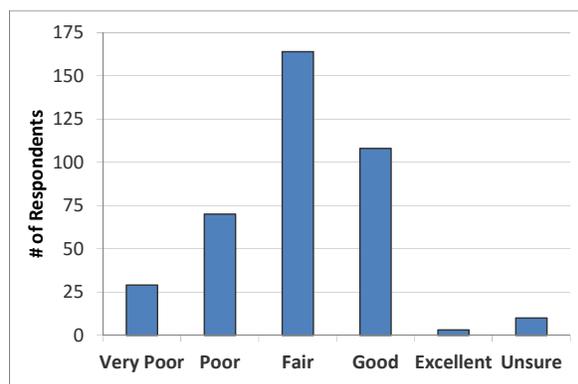


Figure 3.6-1. Stakeholder survey response Question #10. How would you describe the current quality of fishing on Lake Puckaway?

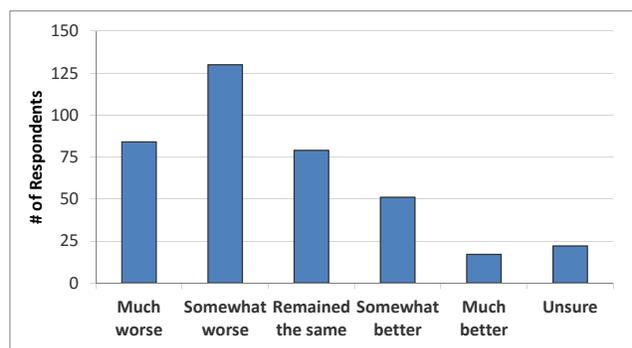


Figure 3.6-2. Stakeholder survey response Question #11. How has the quality of fishing changed on Lake Puckaway since you started fishing the lake?

Table 3.6-1 shows the popular game fish that are present in the system. 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 Lake Puckaway 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 3.6-3.

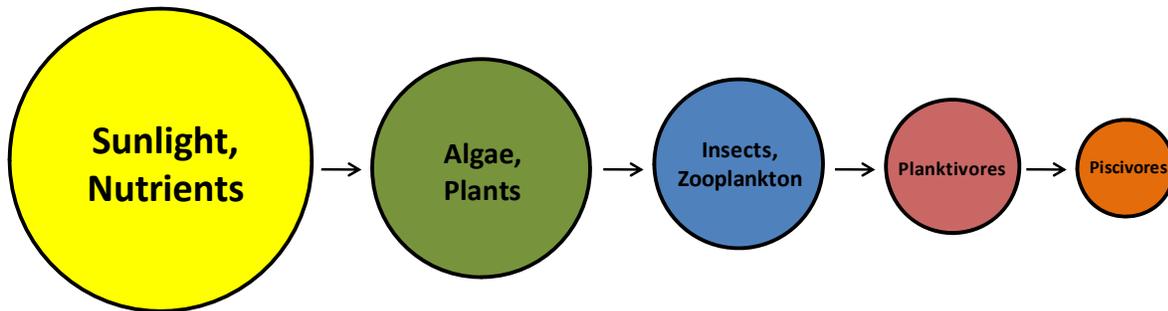


Figure 3.6-3. Aquatic food chain. Adapted from Carpenter et. al 1985.

As discussed in the Water Quality section, Lake Puckaway is an overly productive system, meaning it has high nutrient content and thus very high primary productivity. Simply put, this means Lake Puckaway should be able to support sizable populations of predatory fish (piscivores) because the supporting food chain is relatively robust.

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

Common Name	Max Age (yrs)	Spawning Period	Spawning Habitat Requirements	Food Source
Northern Pike	25	Late March - Early April	Shallow, flooded marshes with emergent vegetation with fine leaves	Fish including other pike, crayfish, small mammals, water fowl, frogs
Muskellunge	30	Mid April - Mid May	Shallow bays over muck bottom with dead vegetation, 6 - 30 in.	Fish including other muskies, small mammals, shore birds, frogs
Walleye	18	Mid April - Early May	Rocky, wavewashed shallows, inlet streams on gravel bottoms	Fish, fly and other insect larvae, crayfish
Yellow Perch	13	April - Early May	Sheltered areas, emergent and submergent veg	Small fish, aquatic invertebrates
Largemouth Bass	13	Late April - Early July	Shallow, quiet bays with emergent vegetation	Fish, amphipods, algae, crayfish and other invertebrates
Smallmouth Bass	13	Mid May - June	Nests more common on north and west shorelines over gravel	Small fish including other bass, crayfish, insects (aquatic and terrestrial)
Black Bullhead	5	April - June	Matted vegetation, woody debris, overhanging banks	Amphipods, insect larvae and adults, fish, detritus, algae
Yellow Bullhead	7	May - July	Heavy weeded banks, beneath logs or tree roots	Crustaceans, insect larvae, small fish, some algae
Brown Bullhead	5	Late Spring - August	Sand or gravel bottom, with shelter rocks, logs, or vegetation	Insects, fish, fish eggs, mollusks and plants
Flathead Catfish	14	June - July	Secluded, dark places, usually banks	Fish, crayfish
Channel Catfish	15	May - July	Dark cavities or crevices, rock ledges, beneath tree roots	Fish, insects, other invertebrates, seeds, plant materials
Lake Sturgeon	100	Late April - Early June	Shallow, rocky shoreline with moderate current	Benthic Invertebrates
Black Crappie	7	May - June	Near <i>Chara</i> or other vegetation, over sand or fine gravel	Fish, cladocera, insect larvae, other invertebrates
White Crappie	13	May - June	Within 10 m from shore, over hard clay, gravel, or roots	Crustaceans, insects, small fish
Bluegill	11	Late May - Early August	Shallow water with sand or gravel bottom	Fish, crayfish, aquatic insects and other invertebrates
Green Sunfish	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
Rock Bass	13	Late May - Early June	Bottom of coarse sand or gravel, 1 cm - 1 m deep	Crustaceans, insect larvae, and other invertebrates
Pumpkinseed	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)
White Bass	8	Late April - June	Running water of streams, windswept shorelines, sand, gravel, or rock	Crustaceans, insect larvae and other invertebrates, and fish
Longnose Gar	27	May - Late June	Shallow water weed beds with emergent plants	Small fish
Bowfin	30	Late April - Early June	Vegetated areas from 2 - 5 ft with soft rootlets, sand or gravel	Fish, crayfish, small rodents, snakes, frogs, turtles
Common Carp	47	April - August	Shallow, weedy areas from 3 - 6 ft	Insect larvae, crustaceans, mollusks, some fish and fish eggs

Lake Puckaway Fish Stocking

To assist in meeting fisheries management goals, the WDNR may stock fish in a waterbody that were raised in nearby permitted hatcheries. Stocking of a lake is sometimes done to assist the population of a species due to a lack of natural reproduction in the system, or to otherwise enhance angling opportunities.

The LPPRD Walleye Hatchery has stocked walleye fry for several years in which eggs from walleye netted in Lake Puckaway are used. The hatchery is completely funded by the LPPRD and with some funds from the Lake Puckaway Improvement Association. In 2016, approximately

756,000 fry were released and since 2010, approximately 9,313,000 fry have been released into Lake Puckaway (Table 3.6-2).

Table 3.6-2. LPPRD Walleye Hatchery summary 2010-2016.

Year	Walleye Fry Stocked
2010	640,000
2011	2,000,400
2012	518,000
2013	1,216,000
2014	1,970,000
2015	2,212,800
2016	756,000
Total	9,313,200

Additional historic stocking data available from the WDNR is shown in Tables 3.6-3 and 3.6-4. Walleye have been stocked nearly every year from 1980 to present. Other species that have been stocked historically in Lake Puckaway include northern pike, muskellunge, largemouth bass and bluegill.

Table 3.6-3. Stocking data available from the WDNR from 1983 to 2015 (WDNR 2017).

Year	Species	Strain (Stock)	Age Class	# Fish Stocked
1983	Bluegill	Unspecified	Fingerling	52,440
1983	Undetermined Centrarchid Hybrid	Unspecified	Fingerling	28,450
1996	Largemouth Bass	Unspecified	Fingerling	18,200
1989	Largemouth Bass	Unspecified	Fingerling	50,000
1988	Largemouth Bass	Unspecified	Fingerling	54,280
1985	Largemouth Bass	Unspecified	Fingerling	24,150
1987	Muskellunge	Unspecified	Fingerling	399
1986	Muskellunge	Unspecified	Fingerling	11
1990	Northern Pike X Muskellunge	Unspecified	Fingerling	500
1989	Northern Pike X Muskellunge	Unspecified	Fingerling	956
1988	Northern Pike X Muskellunge	Unspecified	Fingerling	1,761
1987	Northern Pike X Muskellunge	Unspecified	Fingerling	915
1986	Northern Pike X Muskellunge	Unspecified	Fingerling	725
1985	Northern Pike X Muskellunge	Unspecified	Fingerling	4,500
2007	Northern Pike	Puckaway	Fry	136,000
2006	Northern Pike	Puckaway	Fry	78,000
2005	Northern Pike	Puckaway	Fry	350,000
2003	Northern Pike	Puckaway	Fry	498,049
2002	Northern Pike	Puckaway	Fry	1,067,998
2001	Northern Pike	Unspecified	Fry	1,131,958
2000	Northern Pike	Lake Puckaway	Fry	2,306,160
1999	Northern Pike	Lake Puckaway	Fry	384,000
1998	Northern Pike	Lake Puckaway	Fry	660,000
1998	Northern Pike	Unspecified	Fry	542,767
1997	Northern Pike	Unspecified	Fry	329,014
1996	Northern Pike	Unspecified	Fry	1,357,800
1994	Northern Pike	Unspecified	Fry	398,300
1990	Northern Pike	Unspecified	Fry	5,000,000
1989	Northern Pike	Unspecified	Fry	5,000,000
1988	Northern Pike	Unspecified	Fry	5,207,000
1986	Northern Pike	Unspecified	Fry	2,277,000
1984	Northern Pike	Unspecified	Fry	5,275,000
1983	Northern Pike	Unspecified	Fry	1,092,500

Table 3.6-4. Walleye stocking data available from the WDNR from 1980 to 2015 (WDNR 2017).

Year	Species	Strain (Stock)	Age Class	# Fish Stocked
2015	Walleye	Lake Michigan	Fry	2,212,800
2014	Walleye	Lake Michigan	Fry	1,720,000
2013	Walleye	Lake Michigan	Fry	1,216,000
2012	Walleye	Lake Michigan	Fry	518,000
2011	Walleye	Lake Michigan	Fry	1,851,800
2010	Walleye	Unspecified	Fry	640,000
2007	Walleye	Lake Michigan	Fry	1,724,799
2006	Walleye	Lake Michigan	Fry	2,600,000
2005	Walleye	Lake Michigan	Fry	924,500
2004	Walleye	Lake Michigan	Fry	1,500,000
2003	Walleye	Lake Michigan	Large Fingerling	6,084
2003	Walleye	Lake Michigan	Small Fingerling	69,360
2002	Walleye	Lake Michigan	Fry	900,000
2001	Walleye	Unspecified	Small Fingerling	1,000,000
1999	Walleye	Lake Puckaway	Fry	821,900
1998	Walleye	Puckaway	Fry	391,686
1998	Walleye	Unspecified	Fry	2,929,933
1997	Walleye	Unspecified	Fry	500,000
1996	Walleye	Unspecified	Fry	2,150,000
1995	Walleye	Unspecified	Fry	2,000,000
1993	Walleye	Unspecified	Fry	506,600
1992	Walleye	Unspecified	Fingerling	18,210
1991	Walleye	Unspecified	Fry	5,000,000
1990	Walleye	Unspecified	Fry	5,000,000
1989	Walleye	Unspecified	Fry	5,000,000
1988	Walleye	Unspecified	Fry	9,000,000
1987	Walleye	Unspecified	Fry	15,000,000
1986	Walleye	Unspecified	Fry	5,000,000
1985	Walleye	Unspecified	Fry	5,000,000
1984	Walleye	Unspecified	Fry	5,000,000
1983	Walleye	Unspecified	Fry	5,000,000
1982	Walleye	Unspecified	Fry	5,000,000
1981	Walleye	Unspecified	Fry	5,000,000
1980	Walleye	Unspecified	Fry	5,200,000

Lake Puckaway Substrate and Near Shore Habitat

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

According to the point-intercept survey conducted by Onterra, 81% of the substrate sampled in the littoral zone on Lake Puckaway consisted of soft sediments, with the remaining 19% being composed of sand (Map 4). Substrate and habitat are critical to fish species that do not provide parental care to their eggs, in other words, the eggs are left after spawning and not tended to by the parent fish. Muskellunge is one species that does not provide parental care to its eggs (Becker 1983). Muskellunge broadcast their eggs over woody debris and detritus, which can be found above sand or muck. This organic material suspends the eggs above the substrate, so the eggs are not buried in sediment and suffocate as a result. Walleye is another species that does not provide parental care to its eggs. Walleye preferentially spawn in areas with gravel or rock in places with moving water or wave action, which oxygenates the eggs and prevents them from getting buried in sediment. Fish that provide parental care are less selective of spawning substrates. Species such as bluegill tend to prefer a harder substrate such as rock, gravel or sandy areas if available, but have been found to spawn in muck as well.

As discussed in the Shoreland Condition Section, the presence of coarse woody habitat is important for many stages of a fish's life cycle, including nesting or spawning, escaping predation as a juvenile, and hunting insects or smaller fish as an adult. Unfortunately, as development has increased on Wisconsin lake shorelines in the past century, this beneficial habitat has often been the first to be removed from the natural shoreland zone.

Lake Puckaway Regulations and Management

Walleye must be at least 15" in length and the daily limit is five fish. Northern pike must be 32" in length and the daily limit is one fish. Muskellunge and hybrids must be 40" and the daily limit is one fish. Statewide regulations apply for all other fish species.

To review specific regulations on Wisconsin waters, including Lake Puckaway, anglers should visit the WDNR website (<http://dnr.wi.gov/topic/fishing/regulations/hookline.html>) for specific fishing regulations or visit their local bait and tackle shop to receive a free fishing pamphlet that would contain this information.

Mercury Contamination and Fish Consumption Advisories

Freshwater fish are amongst the healthiest of choices you can make for a home-cooked meal. Unfortunately, fish in some regions of Wisconsin are known to hold levels of contaminants that are harmful to human health when consumed in great abundance. The two most common contaminants are polychlorinated biphenyls (PCBs) and mercury. These contaminants may be found in very small amounts within a single fish, but their concentration may build up in your body over time if you consume many fish. Health concerns linked to these contaminants range from poor balance and problems with memory to more serious conditions such as diabetes or cancer. These contaminants, particularly mercury, may be found naturally to some degree. However the majority of fish contamination has come from industrial practices such as coal-burning facilities,

waste incinerators, paper industry effluent and others. Though environmental regulations have reduced emissions over the past few decades, these contaminants are greatly resistant to breakdown and may persist in the environment for a long time. Fortunately, the human body is able to eliminate contaminants that are consumed however this can take a long time depending upon the type of contaminant, rate of consumption, and overall diet. Therefore, guidelines are set upon the consumption of fish as a means of regulating how much contaminant could be consumed over time.

General fish consumption guidelines for Wisconsin inland waterways are presented in Figure 3.6-4. There is an elevated risk for children as they are in a stage of life where cognitive development is rapidly occurring. As mercury and PCB both locate to and impact the brain, there are greater restrictions on women who may have children or are nursing children, and also for children under age 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 3.6-4. 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/>)

Fishery Management

Lake Puckaway has a long and well documented history of fisheries management. The lake is heavily utilized during the open water season and for ice fishing. The fishery has been subject to large population shifts and changes stemming from the variable aquatic plant compositions, water level fluctuations, environmental factors and a disruptive carp population. An extensive effort was undertaken in the late 1970’s to restore the fishery through water level drawdowns, aggressive carp removal efforts and intensive stocking. The carp removal program has had a positive impact on the fishery as well as on plant populations and erosion reduction.

Recent fisheries surveys on Lake Puckaway show northern pike are naturally reproducing in the lake and the majority of the walleye population is natural with added contributions from the walleye fry stocking program in recent years. The panfish populations, (including bluegill, crappie

and yellow perch) exhibits healthy growth rates and size structure although anglers have reported low catch rates indicating lowered fish densities. Factors limiting the panfish populations in the lake may include high predation and limited vegetative cover.

Common carp were stocked in many Wisconsin waterbodies in the late 1800's as a potential food source for anglers. By the early 1900's, extensive carp control and removal efforts were undertaken on many lakes due to the unforeseen negative impacts carp were causing to many lakes. On Lake Puckaway, carp were likely contributors in the loss of vegetation in much of the lake and inhibit the establishment of newly planted vegetation by uprooting and disturbing the sediment. The carp population likely impacted the water quality in a negative way through frequent sediment disruptions and re-suspending sediment into the water column resulting in a reduction in water clarity and thus a reduction in aquatic plant growth. Historical efforts to control and remove carp from Lake Puckaway included the use of fish toxicants, netting, and commercial fishing of the species.

3.7 Lake Puckaway Wave and Sediment Resuspension

As wind moves across open water, shear force along the water surface creates waves. The distance that the wind moves over open water, without impediments like islands, points, or dense plant growth, is called effective fetch. With greater effective fetch, the same wind speed develops larger waves. Larger waves are represented by longer wavelengths, which is the measured distance between the waves troughs or crests. As effective fetch increases, so does wavelength. When a wave of a certain length moves into water that is half of its wavelength or shallower, the wave has sufficient energy to resuspend bottom sediments. For example, if a wave with a wavelength of 10 feet moves into water of 5 feet or shallower, the wave will stir up bottom sediments.

Wind speed and direction data from 2015 and water depths from the 2015 bathymetric study completed by Onterra, were used in a GIS (Geographic Information System) model developed by the US Army Corps of Engineers (USACE). The USACE model is used to understand how often and where wind-induced waves can resuspend bottom sediments. Resuspended bottom sediments can increase in-lake phosphorus levels and turbidity, reduce water clarity, and prevent the reestablishment of submersed aquatic plants.

As described above, effective fetch along with wind speed determines wavelength. Effective fetch depends on the size and shape of the lake as well as the wind direction. Figure 3.7-1 shows how frequent the winds blew from cardinal and intercardinal directions during the open water season of 2015. The most frequent directions were winds coming from the northeast, southeast, and south. Figure 3.7-2 shows how wavelength is determined on Lake Puckaway by different wind speeds coming from the northeast, one of the more prominent directions. Very little resuspension would be expected with a 5 mph wind, but at 10 and especially 15 mph, there would be areas on the southern side of the lake, in both basins, that would likely have bottom sediments being resuspended by wave action. Figure 3.7-3 utilizes wind data during the open water season of 2015 to model the percentage of days that areas of the Lake Puckaway bottom would be susceptible to sediment resuspension with lake levels at approximately the height they would be in mid-June. In 2015, approximately 35% of the lake bottom would be susceptible to wind-induced wave resuspension of sediments. About 9% of the lake bottom is susceptible to resuspension 50% of the time.

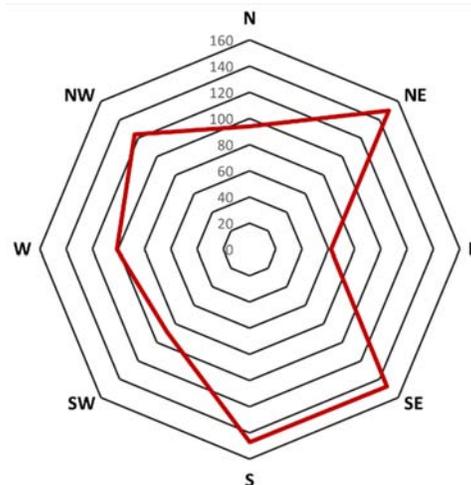


Figure 3.7-1. Wind direction count near Lake Puckaway during open water season from 2011 to 2015. Data obtained from NOAA station at Fond du Lac, WI Airport.

In February 2017, the LPPRD was awarded a WDNR Small-Scale Planning Grant to partially fund additional studies by the US Army Corps of Engineers aimed at refining the fetch modeling further and to propose designs of in-lake modifications, possibly including the rebuilding of the east dredge bank and Pancake Island. This work would be facilitated by the Puckaway Shallow Lake Workgroup discussed in the implementation plan.

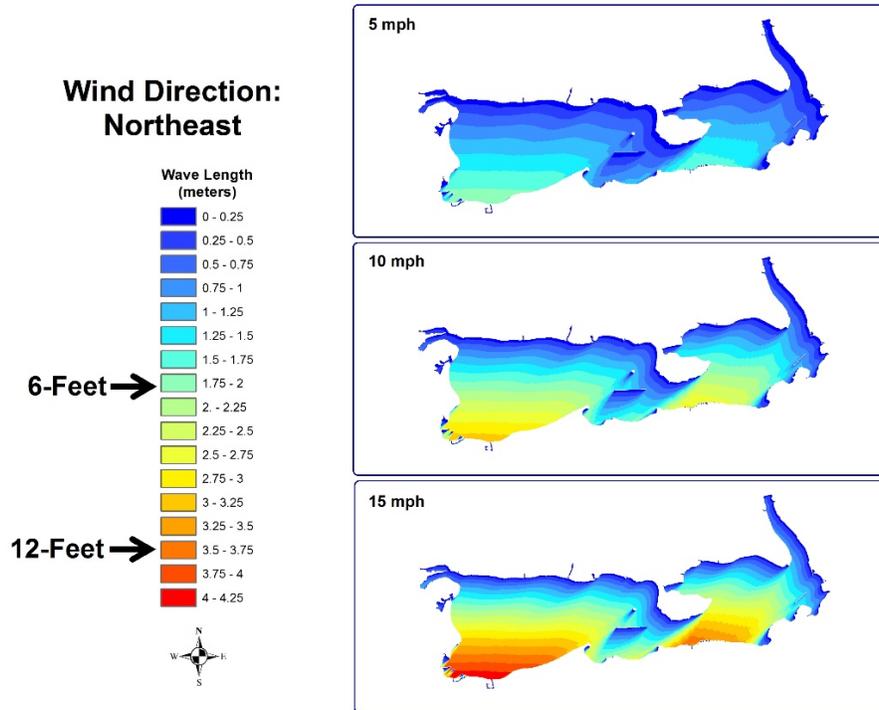


Figure 3.7-2. Modeled wavelength on Lake Puckaway based upon northeast wind at 5, 10, and 15 mph. Results from US Army Corps of Engineers Wind and Wave Model.

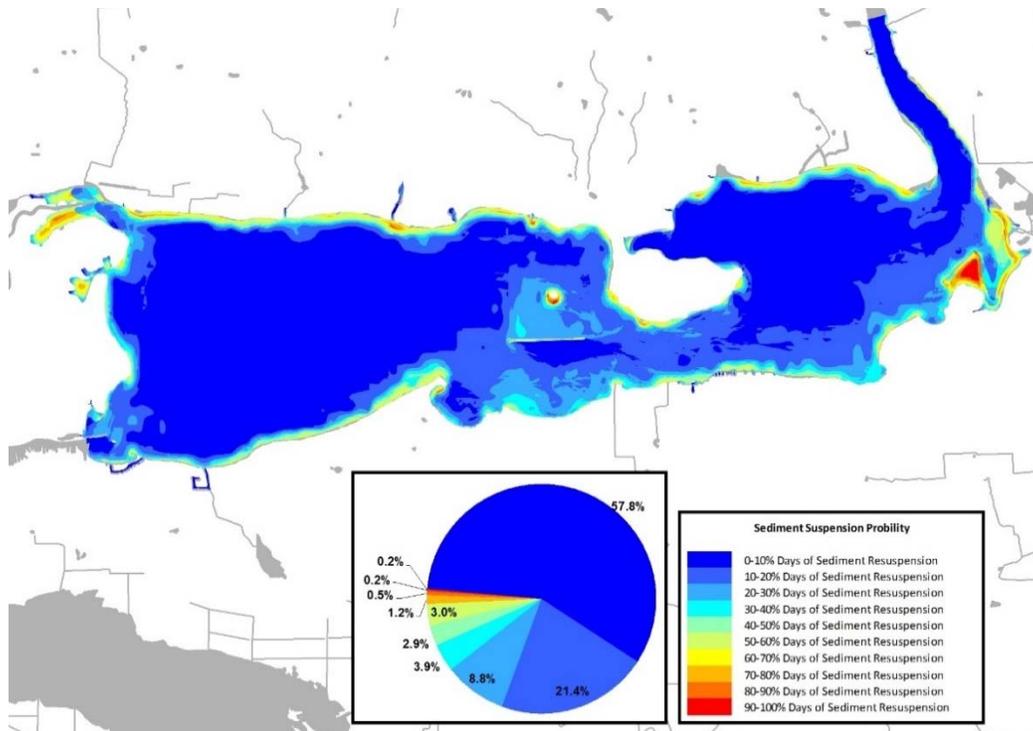


Figure 3.7-3. Sediment resuspension probability in Lake Puckaway during the 2015 open water season. Results derived with 2015 wind data collected at Fond du Lac, WI Airport and modeled with US Army Corps of Engineers Wind and Wave Model.

4.0 IMPLEMENTATION PLAN

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

Management Goal 1: Improve Overall Ecological Condition of Lake Puckaway

Management Action: Initiate volunteer-based annual water quality monitoring of Lake Puckaway through the WDNR Citizen Lake Monitoring Network.

Timeframe: Initiate 2017

Facilitator: LPPRD Board of Commissioners

Description: Long-term trend analysis included in the Water Quality Section indicates that total phosphorus, chlorophyll-*a*, and water clarity fluctuate greatly in Lake Puckaway. Tracking changes in these parameters while this management plan is implemented is important in understanding if the management actions are having the desired effect on the lake or if they need to be refined or abandoned all together. Developing a consistent and long-term database is the best method of having the information needed to make effective management decisions.

The Citizen Lake Monitoring Network (CLMN) is a WDNR program in which volunteers are trained to collect water quality information on their lake. It is the responsibility of the LPPRD Board of Commissioners to recruit and coordinate a volunteer(s) to regularly collect these data. According to the stakeholder survey sent to district members in 2015, 118 individuals indicated they would be willing to participate in water quality monitoring if called upon by the district. When a volunteer or group of volunteers have been selected, Ted Johnson (920-424-2104) or the appropriate WDNR/UW-Extension staff should be contacted so that the volunteers receive the appropriate training and equipment. Volunteers would start collecting solely water clarity data using a Secchi disk from the two water quality monitoring sites used during this project and earlier efforts four times each year (May, June, July, and August). A couple years into the CLMN program, volunteers would likely start collecting water samples that would be analyzed for total phosphorus and chlorophyll-*a*. It is also important to note that as a part of this program, the data collected are

automatically added to the WDNR database and available through their Surface Water Integrated Monitoring System (SWIMS) by the volunteer.

Action Steps:

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

Management Action: Form Puckaway Shallow Lake Management Workgroup.

Timeframe: Initiate 2016

Facilitator: LPPRD Board of Commissioners, Lake Puckaway Planning Committee, Ted Johnson (WDNR)

Funding Source: Lake Protection Grant for design and implementation of restoration actions

Description: Lake Puckaway's issues are complicated and have developed over the decades. Solutions to the lake's issues are complicated as well and no silver bullets exist to solve them quickly. Further, this lake management plan is a living document that will be refined as its effectiveness is monitored, management goals/actions are added, additional information is gained, and new lake management techniques are developed.

The Puckaway Shallow Lake Management Workgroup (PSLMW) would be made up of at least one district commissioner, several district members, and agency professionals. Agency professionals would include Ted Johnson, WDNR Regional Water Resource Management Specialist, Green Lake County Land Conservation Dept. staff, and ad-hock members as needed for specific projects. The intent of the PSLMW is not just to meet and discuss the management of Lake Puckaway, but to actually complete the tasks needed to implement this plan. The PSLMW would work to develop project designs for in-lake projects like the restorations of the east dredge bank and Pancake Island, and work to fund and implement those projects.

Action Steps:

1. Recruit members for committee.
2. Elect chair and secretary and define their responsibilities.
3. Develop meeting schedule.
4. Develop mission statement to define group's purpose and guide its actions.

5. Develop list of projects and associated timeline.
6. Identify and secure project funding.
7. Conduct necessary planning studies, such as geotechnical analysis of current bottom sediments to determine structure support capacities.
8. Create project designs
9. Develop project-specific monitoring plans.
10. Implement and/or construct projects.

Management Action: Implement Lake Puckaway Water Level Management Plan

Timeframe: Initiate 2017

Facilitator: LPPRD Board of Commissioners

Funding Source: Lake Protection Grant for monitoring plan

Description: **Basis for Water Level Management on Lake Puckaway**

Maintaining unnaturally high water levels in lakes and flowages leads to decreased aquatic plant populations, especially submergent and emergent forms (Coops et al. 2003, Leira and Cantonati 2008, and Zhang, et al. 2014). Maintaining higher water levels than would naturally occur during the growing season, year after year, prevents submergent plant establishment in deeper water areas by reducing light penetration. Many emergent plant species require shallow water and occasional exposed sediments to thrive. As discussed in the report sections above, flows and water levels in Lake Puckaway vary greatly during the year and among years. Utilizing data over the past 30 years, water levels start just above 763 feet MSL in early May and slowly decrease by a foot by the end of the month, increase by less than a half of a foot in early to mid-June when the LPPRD has set the dam boards, then after a brief fall back to pre-board placement levels, slowly rises over the course of July and by the middle of August fall to the levels found in the beginning of May. It is this predominant pattern of maintaining high water levels late in the growing season over the course of the past many decades, whether for navigation in the early part of the 20th Century or for recreation as the case more recently, that has brought about the documented decline in aquatic plant abundances in Lake Puckaway. The lack of plants in Lake Puckaway leads to poor fisheries habitat for panfish and bass thus allowing carp to flourish, and reducing cover for algae-grazing zooplankton. It also promotes internal loading of phosphorus, which not only impacts Puckaway itself by spurring on algae blooms, but also impacts downstream waterbodies because Lake Puckaway is acting as a point-source of nutrients for those systems during some years.

Re-establishing aquatic plants through water level management has been accomplished in many systems (Coops and Hosper 2002, Dienst et al. 2004, Havens et al. 2004, and Coops et al. 2004). Studies, most

recently on the Mississippi backwaters (not the main channel), have shown that periodically lowering water levels during the growing season aids in the establishment of submergent aquatic plants in deeper waters (Kenow et al. 2007a, Kenow et al. 2007b, and Kenow 2010). The studies indicated that lowering water levels which exposes sediments, leads to the establishment of emergent plants in near-shore areas. Further, completing two consecutive water level reductions leads to better aquatic plant establishment because annual species primarily establish during the first year and perennial species during the second year. Populations were shown to thrive for at least 6 years following consecutive actions. An excellent summary of some of these studies can be found by navigating to the US Army Corps of Engineers website (<http://www.mvp.usace.army.mil>) and entering “Summary of Results - Pools 5 & 8 DDs” in the search box at the top of the page.

Increasing plant growth, in all forms, including submergent, emergent, and floating-leaf, will reverse the negative impacts brought on by their absence in Puckaway. Periodic reductions in water levels during the growing season, as described above, in conjunction with the other elements of this management plan, is the best path for increasing aquatic plants in Lake Puckaway and bettering the overall health of the Lake Puckaway ecosystem. Bettering the overall ecological health of Lake Puckaway means clear water, better wildlife habitat, and a stronger and more stable fishery.

Specifications and Definitions

Objective - At the starting lake level described below, rooted, submergent aquatic plants grow to a depth of approximately 3.5 feet with the bulk of those plants existing in depths 2 feet and under (Map 4, Figure 3.4-3). The objective of the Water Level Management Plan (WLMP) is to promote significant plant growth within Lake Puckaway by temporarily extending the littoral zone (area in which aquatic plants grow) to allow submergent and floating-leaf plant establishment and to temporarily expose bottom sediments in near-shore areas to allow for the establishment of emergent species.

Starting Lake Level – Lake Puckaway average water levels fluctuate greatly during the growing season and no ordinary high water mark has been officially established for the lake (Pers. Comm. Matthew Kirkman, Code Enforcement Officer, Green Lake County Land Use Planning Department); therefore based upon the bathymetry collected during June and July 2015 and verified with data collected by LPPRD level-loggers at Fish Camp, the starting lake level for the purpose of this WLMP is **764.375** feet MSL. This elevation aligns well with the reference water level used by MWH in their January 2016 Lake Puckaway study of 764.44 for an average summer flow of 571 CFS at the Princeton Dam USGS (Highway 23) site. The elevation is about 2

feet higher than the 30-year average on June 15 and about 0.74 feet higher than levels since 2006. This means that based upon the 10-year average, the Lake Puckaway would be lowered 1.76 feet and based upon the 30-year average, it would be lowered only 0.5 feet.

Suitable Water Level Reduction – Based upon the aquatic plant studies completed in 2015, aquatic plant growth in Lake Puckaway occurs in less than 38% of the lake area with the majority of those plants occurring in less than 13% of the lake area. Further, the littoral frequency of plants within the lake is less than 20% (Figure 4.0-1). A sufficient water level reduction would expand the area available to plant growth to 75% of the lake area and expose sediments in nearshore areas. To accomplish this, a water level reduction of 2.5 feet or greater would be needed (Figure 4.0-2); however, it is anticipated that the newly encompassed deeper depths would not maintain high occurrences of aquatic plants just as they do not now. Still, the target would be to establish more plants into depths reaching 4-feet or more, which does not occur currently.

Successful Reduction Sequence – The probability of reducing water levels in Lake Puckaway to 761.875 feet MSL (2.5 feet below starting lake level) in two consecutive growing seasons is low; however, if the first year does reach a reduction 762.375 feet MSL (2.0 feet below starting lake level) and the second only to 762.875 feet MSL (1.5 feet below starting lake level), some benefits would likely emerge. Therefore, a successful reduction sequence would include the first year's reduction reaching 762.375 feet MSL or lower and the second year's reduction reaching 762.875 feet MSL or lower.

Duration of Water Level Reduction – To meet the objective of the WLMP, the water levels would need to be reduced by early to mid-July and remain at the reduced level through September.

Flow Rates – Unless stated otherwise, all flow rates utilized within the WLMP are recorded at the USGS stream site on the Fox River at Princeton, WI (USGS 04073365). Current and historical flow rates from this monitoring site are available at:
http://waterdata.usgs.gov/wi/nwis/inventory/?site_no=04073365.

Lake Puckaway Water Level – Unless stated otherwise, all water levels utilized within the WLMP are from the staff gauge or water level sensor installed at Fish Camp on the west end of Lake Puckaway at the Fox River inlet. Please note, as of this writing, to convert levels recorded at these sites to feet above Mean Sea Level (MSL), the following conversions must be utilized:

- Fish Camp Staff Gauge: Add 761.21 for Mean Sea Level (feet)
- Fish Camp Level Sensor: Add 760.275 for Mean Sea Level (feet)

Generic Timeline

Year 1 – begin reducing water levels on June 15th by opening lock gates. From this point forward, opening of the lock gates would mean completely or as far as practically and safely possible.

Lock gates remain open through September

2-3' reduction in water levels from June 15 level expected

Year 2 – begin reducing water levels on June 15 by opening lock gates

Lock gates remain open through September

2-3' reduction in water levels from June 15 level expected

Specific Conditions on Attempts at Reductions

As described above and in the report sections, water levels and flows on and through Lake Puckaway vary greatly interannually and within a given year; therefore, during certain years, specifically, those with high flows, a useful water level reduction meeting the WLMP objective may not be attainable. Further, growing season reductions in water levels will upset summer recreation on Lake Puckaway and impact many of the business that rely on the lake to bring in customers. Having the opportunity to anticipate and plan for the summers with low water levels will ease some of the impacts brought on by this management action. Therefore, the following conditions will be used to plan future water level management on Lake Puckaway.

Reduction Attempts - Reductions will be attempted in two consecutive years. If a sufficient water level reduction is not anticipated to occur (see abandonment below) in either of those two years, then during the next two years, no reductions would be attempted. If during either of the two years in which a water level reduction is attempted, a reduction of 2.0 feet or more is achieved, on June 15 of the following year, the lock gates will be opened and remain open through September and the water levels reduced as far as possible.

Abandonment - If discharge at the USGS Princeton site is greater than 1,200 cfs on June 15 OR greater than 1,000 cfs on June 30 of either the first attempt or second attempt year, the attempt will be abandoned. The 2016 MWH report states that a flow of 1,000 cfs can yield a 1.85' reduction in about 24 days. If flows are greater than 1,200, a much lower reduction would be reached in a greater time period, (e.g. less than 1.5 feet in 30 days) which would not meet the WLMP objective. The second qualifier of June 30th will account for rains after or around June 15th that would increase flows and prevent the WLMP objective from being met. If the flows are greater than 1,000 cfs at the end of June, a 1.85' reduction in late July would not help the district achieve the benefits to the lake.

Early Start of Water Level Reduction – Water flow through Lake Puckaway determines the water elevation in the lake whether or not the flashboards are placed on the dam. During dry springs, water levels on Lake Puckaway may be naturally low causing navigation issues on the lake; therefore, during those low-flow springs that occur during a water level reduction attempt, the lock gates would be opened early to allow for the maximum benefit of the water level reduction. If water flows at the USGS Princeton site are at 600 cfs or less on June 1, the lock gates would be opened immediately.

Frequency of Water Level Reductions – If a successful reduction sequence is achieved, a second set of reductions would not be attempted for 10 years. It is important that this specification remain flexible to assure that the ecological benefits gained by completing a successful reduction sequence are not lost. The frequency of reductions should be determined by the results of the studies completed as outlined in the monitoring plan below.

Anticipated Results – Predicting the level of aquatic plant establishment is impossible because so many factors come into play. However, as described above, the target would be to establish more plants into depths reaching 4-feet or more, which occurs infrequently now as less than 9% of the area contains plants. Even with the target levels discussed below, it is anticipated that the eastern basin of the lake would provide the bulk of the habitat and provide the passive recreation area in the lake, while the western basin would be largely plant free and provide the motorsport recreation area (Figure 4.0-3).

WLMP Modification or Abandonment – The overarching goal of the WLMP, along with other management actions, is to improve the overall ecological health of Lake Puckaway, which will benefit the lake itself along with downstream waterbodies. Enhancements to the aquatic plant community will be the foundation and the greatest indicator of improving ecological health of the lake. However, implementing water level reductions, as mentioned above, will have negative impacts on recreation while water levels are low; therefore, if certain predetermined thresholds are not met by a successful reduction sequence, then the WLMP should be modified or abandoned all together.

Aquatic plant species, as well as entire communities of aquatic plants, fluctuate over the course of years, so anticipating the exact level of change brought on by a management action is impossible. Still, a certain level of improvement does need to be set to gauge if the action was successful at providing the desired results. The following two thresholds would be used to determine the success of a suitable water level reduction sequence:

The 2015 point-intercept survey indicated a littoral frequency of occurrence of only 19.3%. The threshold for positive change in this matrix would be an increase of 50% leading to a littoral frequency of occurrence to about 29%.

The 2015 aquatic plant community mapping survey documented 679 acres of floating-leaf and emergent species within Lake Puckaway (~13% of lake area). The threshold for positive change in this matrix would be a 25% increase to 848 acres (~16% of lake area).

Monitoring Plan

Documenting changes in water quality, aquatic plant populations, and fisheries would be important in determining the correct frequency of water level actions on Lake Puckaway and would lead to a better understanding of the water level management plan's true impacts to the lake.

Pre-water level reduction aquatic plant studies would be completed within 3 years prior to the first year of a water level reduction attempt and include a point-intercept survey using the WDNR grid created in 2015 and an emergent and floating-leaf species mapping survey. Fishery studies should be completed within 5 years prior to the first year of a water level reduction attempt. Water quality data, specifically total phosphorus, chlorophyll-*a*, and Secchi disk transparency, should be collected each year, including during the reductions if possible as a part of the Citizen Lake Monitoring Program described in the action above.

Post water level reduction aquatic plant surveys, as described above, should be completed for three consecutive years following a successful reduction sequence and also 5 and 8 years post reduction. Fishery studies should be completed 3-5 years following the successful reduction sequence.

Princeton Dam Reconstruction

If the Princeton Dam Reconstruction project, which is currently included in the WDNR proposed 2017-19 biennial budget request is funded in the State biennial budget (goal and action below), it is anticipated that the reconstruction of the Princeton Dam will begin between 2018 and 2020. As an example, if the project were to begin in 2019, water levels would begin to be reduced in fall 2018 and remain at the lowest level possible through the construction of the dam in 2019, the winter of 2019/2020, and through the growing season of 2020. The water levels would remain low during 2020 to allow for additional dam work as required, in-lake habitat construction, and to allow for additional establishment of aquatic plants within Lake Puckaway.

Because the reconstruction project has not been officially funded by the State of Wisconsin, construction details, including water level requirements, have not been determined. The best-case scenario would be to have the reductions associated with the reconstruction project meet the successful reduction requirements discussed above. If that is the case, the post reduction studies would be initiated. If the dam reconstruction reductions do not meet the successful reduction requirements outlined above, water level reduction would not be attempted until fifth year following the completion of the reconstruction. This would facilitate recreational activities on the lake while allowing the ecosystem to stabilize after the construction project. It would also provide time for the pre-studies to be completed before the next reduction attempt.

Again, the best-case scenario would be for the reductions anticipated to occur as a part of the dam reconstruction project to act as the first successful reduction sequence. However, if the project is not funded in either the 2017-19 or the 2020-21 biennial state budget, water level reductions would be attempted following the guidelines in the WLMP in 2021.

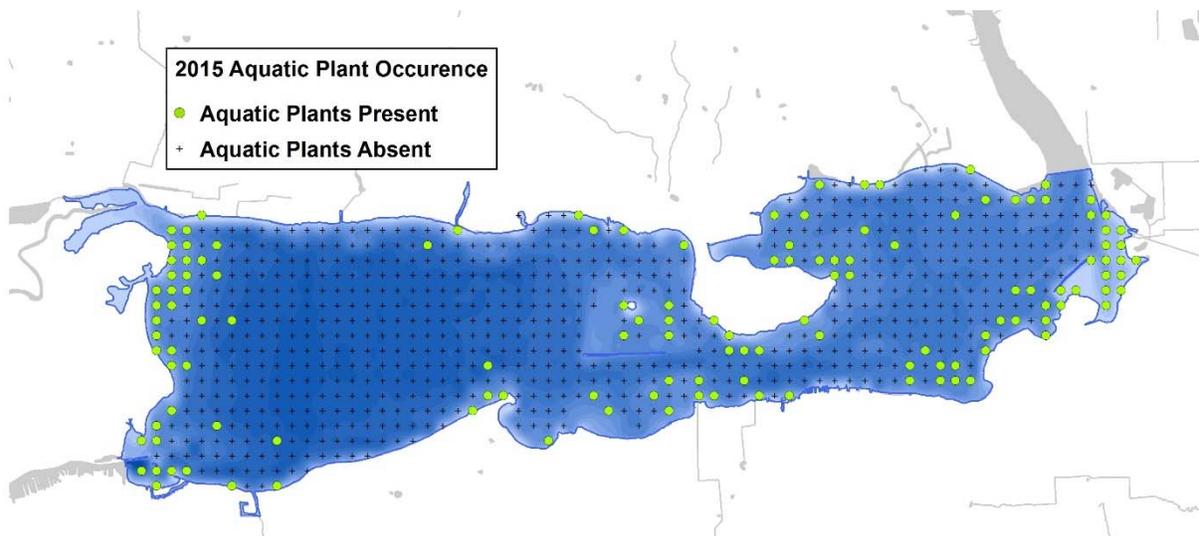


Figure 4.0-1. Aquatic plant occurrences in Lake Puckaway during 2015 point-intercept survey. The frequency of plants during 2015 was less than 20% of the lake's littoral zone including depths 5.0 feet and under. These data are also displayed based upon total rake fullness in Map 4.

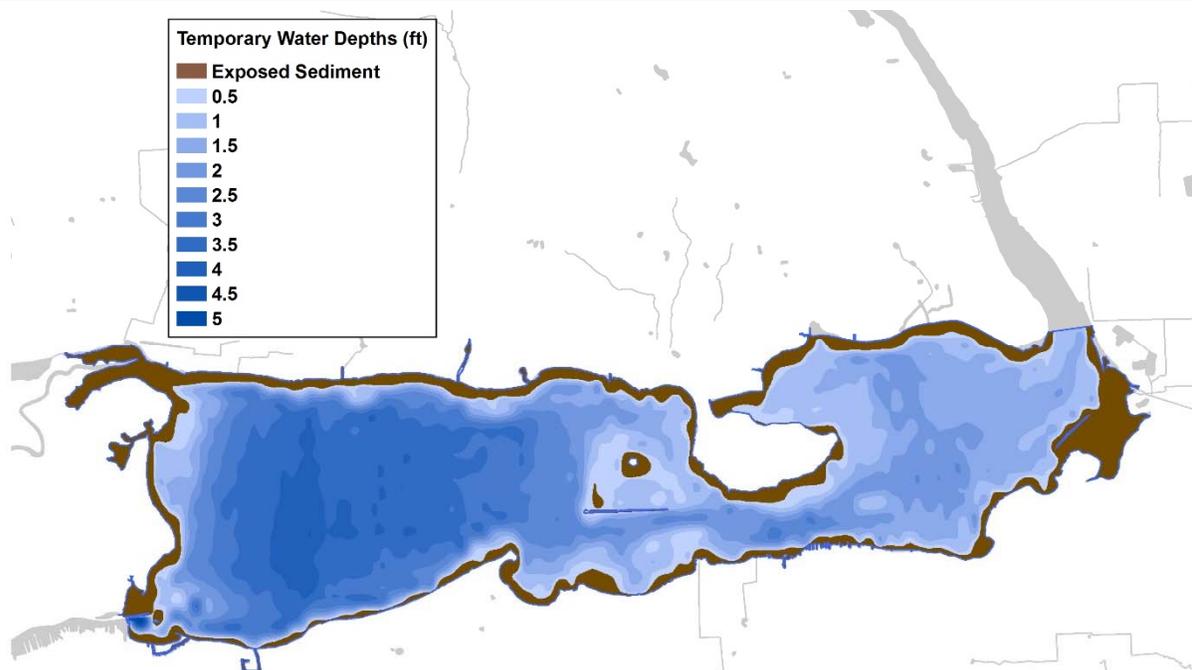


Figure 4.0-2. Estimated bottom sediment exposure and remaining water depths during a 2.5-ft water level reduction on Lake Puckaway. Map produced utilizing bathymetric data collected during 2015 by Onterra, LLC.

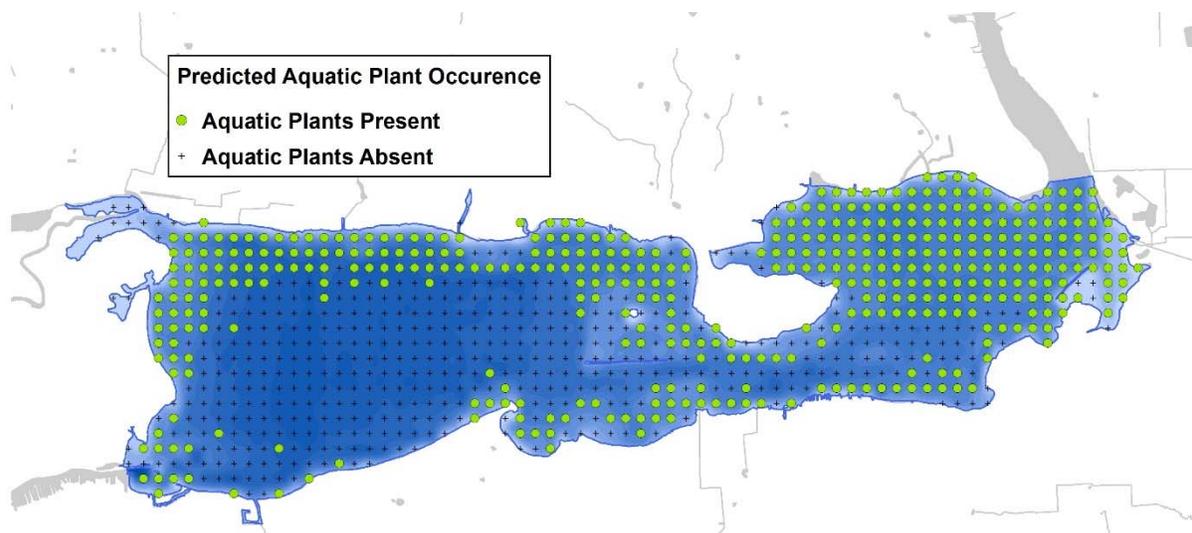


Figure 4.0-3. Predicted plant occurrences following a successful water level reduction sequence in Lake Puckaway.

Management Goal 2: Improve Dam Operation Safety at Princeton Dam

Management Action: Urge State of Wisconsin to reconstruct Princeton Dam as a fixed-crest dam.

Timeframe: Initiate 2016

Facilitator: Board of Commissioners

Description: Current operations involve installing flashboards in the late spring or early summer to raise Lake Puckaway summer recreational water levels and removing the flashboards in late summer or early fall to lower lake levels for the winter season. The current flashboard system consists of placement of three levels of 2x6- in (nominal) wooden boards totaling 16.5 inches in height against steel pins inserted in the crest 4-foot on centers. The flashboard installation and removal often occurs with flow passing over the dam which subjects workers to difficult and potentially dangerous working conditions. Placement of the flashboards is dangerous work and requires sufficient planning to achieve the manpower needed to mount the boards and have local fire department staff on the water for a rescue if required.

In 2015, the WDNR proposed the reconstruction of the Princeton Dam to a fixed-crest at the height of the current dam with the flashboards placed. The WDNR currently has the reconstruction project proposed in their 2017-19 biennial budget package; however, for the project to be funded at the state level, there are several steps that need to be successfully completed. In general, the following entities must approve the item for inclusion in the state budget:

1. WDNR Budget Development
 - a. Management & Budget (M & B)
 - b. Natural Resources Board
2. Department of Administration (DOA)
3. Governor
4. Joint Committee on Finance (JCF)
5. House/Senate
6. Senate/House
7. Governor

Gaining support of the local legislatures and the governor will be critical in having the Princeton Dam Reconstruction Project included in the 2017-19 Wisconsin Biennial Budget.

To create the best opportunity to have the reconstruction project included in the 2017-2019 budget, district board members will meet with current legislators to discuss need for Princeton Dam Reconstruction Project.

Senator (District 14): Luther S. Olsen
Vice-Chair, Joint Committee of Finance
Room 313 South
State Capitol
Madison, WI 53707-7882
sen.olsen@legis.wisconsin.gov
608.266.0751

**Representative
(District 41): Joan Ballweg**
Assembly District 41
Room 210 North
State Capitol
PO Box 8952
Madison, WI 53708
rep.ballweg@legis.wisconsin.gov
608.266.8077

UPDATE District representatives garnered the support of Senator Luther Olsen during a meeting held on February 3, 2017. As of March 2017, the Princeton Dam Reconstruction Project has been included in the Governor's Budget for 2017-2019.

Goal 3: Enhance Lake Puckaway Fishery

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

Timeframe: Continuation of current effort

Facilitator: Board of Commissioners

Description: Non-native common carp impose negative impacts on lake ecosystems by increasing nutrients and turbidity, decreasing aquatic macrophyte abundance, and altering native fish communities.

Commercial harvesting of common carp in Lake Puckaway has been occurring annually since the mid-1960s. While the commercial harvesters contract with the WDNR to harvest common carp on Lake Puckaway to sell to fish markets around the world, the removal of common carp also benefits the health of the lake. Understanding this, the LPPRD has subsidized the fishermen in the past to ensure maximum harvesting levels.

Weber et al. (2011) found that common carp abundance substantially declined with commercial exploitation of up to 40% of the population. Beyond 40% exploitation, effects on carp abundance were limited; however, with exploitation from 40-60%, carp abundance and recruitment were reduced. They concluded that to maximize reductions to the common carp population, commercial harvesting should target 40-60% of population annually. No specific carp population study has been completed on Lake Puckaway; therefore, the LPPRD has used 300,000 to 500,000 lbs. as the target annually. In recent years, possibly due to reduced carp population, commercial fishing catch rates have fallen well below this level or no harvest has been made altogether.

Continued harvesting of carp from Lake Puckaway will be important in maintaining aquatic habitat gained by implementing this plan.

Action Steps:

1. The LPPRD and WDNR fisheries biologists will work together on the continued aggressive, annual harvesting of common carp by commercial fishermen from Lake Puckaway.
2. If warranted the LPPRD will offer an incentive to the commercial harvester to achieve the recommended exploitation level. The incentive program will be reviewed annually by the LPPRD Board of Commissioners and adjusted accordingly at their discretion

Management Action: Continue annual operation of the LPPRD Walleye Hatchery**Timeframe:** Continuation of existing effort**Facilitator:** Board of Commissioners**Description:** Since 2010 LPPRD volunteers have worked with WDNR fisheries personal to supplement natural walleye reproduction by raising walleye fry in a volunteer-built and operated rearing facility on the southwest end of the lake. WDNR staff loan equipment to the LPPRD for use by volunteers for netting ripe females for milking and males for sperm harvest. District volunteers then tend to the eggs until hatching and release the fry into Lake Puckaway. Over 9.2 million walleye fry have been released in Lake Puckaway since the start of the hatchery.

This action will be reviewed annually by the LPPRD Board of Commissioners and funded and operated as the board believes appropriate.

Goal 4: Increase Communication Capacity of Lake Puckaway Protection & Rehabilitation District

Management Action: Create LPPRD Communication & Education Committee

Timeframe: Initiate 2017

Facilitator: Board of Commissioners

Funding Source: Small-Scale Planning Grant for initial start-up costs

Description: Currently, the LPPRD maintains a district website, Facebook page, and sends out an annual newsletter letter with the annual meeting announcement. Fifty-five percent of those who responded to the question believe that the district keeps them fairly well informed or highly informed, while 27% believe the district does not keep them well informed or informed at all. Eighteen percent of respondents were unsure. While this is evidence that the district is doing a sufficient job of informing its members, it would like to do more to assure that important and interesting information regarding Lake Puckaway and its management are made readily available to district members and other interested individuals.

All of the communications being released by the district are currently being created by members of the board of commissioners. The website is being maintained voluntarily by a member of the district. To ease the burden on these individuals and to increase the overall capacity of district communications, the LPPRD board of commissioners will create a standing committee made up of a single commissioner and district members. Once formed, the LPPRD Communication and Education Committee will formulate a communication strategy for the district. Likely elements in the strategy will include:

- Multiple newsletters per year containing district news, announcements, and informational articles.
- Enhanced website design to optimize loading and access to content.
- Assembly of LPPRD email list for newsletter and special announcement broadcasting.
- Possible hiring of professionals to assist with start-up and/or continued implementation of communication strategy.

Action Steps:

1. LPPRD Board of Commissioners recruits volunteers for LPPRD Communication & Education Committee.
2. Committee members meet to set meeting schedule, develop expectations, and begin work on communication strategy.
3. Once communication strategy is drafted, committee meets with board to discuss implementation and funding.

5.0 METHODS

Lake Water Quality

Baseline water quality conditions were studied to assist in identifying potential water quality problems in Lake Puckaway (e.g., elevated phosphorus levels, anaerobic conditions, etc.). Water quality was monitored at two locations on the lake that would most accurately depict the conditions of the lake (Map 1). Water quality was monitored at the two locations in Lake Puckaway by Onterra staff. Samples were collected only at subsurface (S) depths and occurred once in spring, winter and fall, and three times during the summer for two years. All samples requiring laboratory analysis were processed through the Wisconsin State Laboratory of Hygiene. The parameters measured and sample collection timing are in the following table.

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

● indicates samples collected by consultant under proposed project.

Watershed Analysis

The watershed analysis began with an accurate delineation of Lake Puckaway'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

Early-Season AIS Survey

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

Point-Intercept Survey

The point-intercept method as described in the Wisconsin Department of Natural Resource document, Recommended Baseline Monitoring of Aquatic Plants in Wisconsin: Sampling Design, Field and Laboratory Procedures, Data Entry, and Analysis, and Applications (WDNR PUB-SS-1068 2010) was used to complete this study. A point spacing of 155 meters was used resulting in approximately 872 points.

Community Mapping

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

Water Levels and Flow

Acoustic Survey

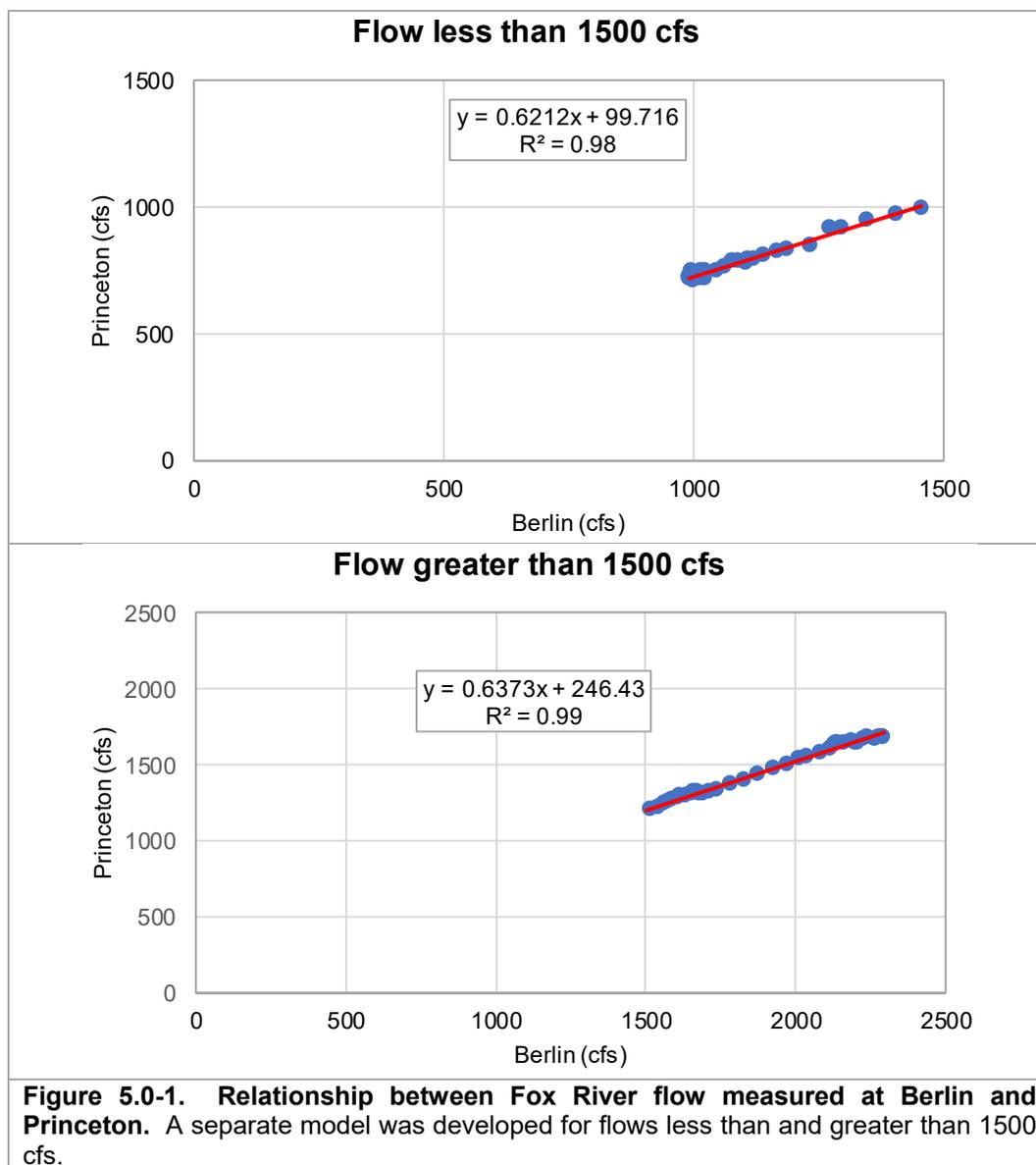
During the mid- to late-summer of 2015 and spring of 2016, Onterra systematically collected continuous, advanced sonar data across Lake Puckaway. The resulting data was sent to a Minnesota-based firm (ciBiobase) for processing and was analyzed for bathymetry, submersed aquatic vegetation bio-volumes, and substrate analysis. The processed data was used in conjunction with the aquatic plant results and used in the fetch, wave, and sediment resuspension modeling. Please note that these surveys are conducted during the mid/end of summer when native plant growth has reached its full potential; however, data was also collected in the Fox River channel in spring of 2016 for bathymetry purposes only.

Wave and Sediment Resuspension

Fetch, wave, and sediment resuspension modeling was completed using the USGS Wind Fetch and Wave Model. The Wind Fetch and Wave Model utilized ArcMap version 10.3.1 and the Spatial Analyst license. Fetch was calculated using lake area and 2015 open water season (April 1 through September 30) wind speed and direction data from NOAA's Climate Data Online database. The fetch model results were used with lake depth (bathymetry data gathered by Onterra bio-acoustic surveys) to model wavelength and sediment resuspension.

Flow Estimates

The USGS has been measuring flows of the Fox River at Berlin since 1898. At Princeton, they have been measuring flows of the Fox River since September 2009. To estimate the flows of the Fox River at Princeton for years prior to 2009 the relationship between flows at Berlin and Princeton was determined. The best relationship was developing separate models for flows at Berlin for flows less than and greater than 1500 cfs (Figure 5.0-1).



There is not a sufficient record of measured lake levels in Lake Puckaway; therefore, a relationship was established between flow of the Fox River at Princeton and the lake level as recorded by district volunteers at the Fish Camp gauge. Two models were developed. One with the boards in place on the Princeton Dam and another model for when the boards are not in place (Figure 5.0-2).

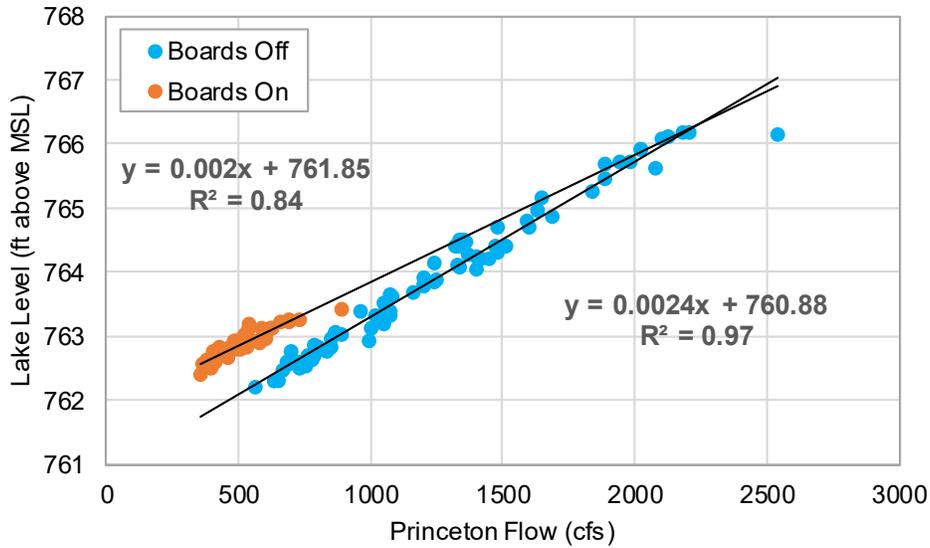


Figure 5.0-2. Relationship between Fox River flow at Princeton and lake level in Lake Puckaway at Fish Camp. A separate model was developed for when the boards were in place on the Princeton Dam and with the boards off.

All of the models have very good correlations, at least 0.97 except for the relationship between flows at Princeton and lake level when the boards were in place. This means that the lake level of Lake Puckaway can be estimated from the flow of the Fox River at Princeton with a high degree of confidence. Measured and calculated lake levels for 2014 and 2015 are shown in Figure 3.

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