Lost Lake

Vilas County, Wisconsin

Aquatic Plant Management Plan

November 2023

Sponsored by:

Lost Lake Protection & Rehabilitation District

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

Onterra, LLC
Lake Management Planning

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Created by: Eddie Heath, Josephine Barlament, & Tim Hoyman
Onterra, LLC
De Pere, WI

Funded by: Lost Lake Protection & Rehabilitation District

Acknowledgements

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

Lost Lake P&R District Commissioners

John Eckerman - Chair	Bob Truppe	Marv Anderson – Vilas County Board
Gary Heeler	Jim Ulett	Ted Ritter – St Germain Town Board
Jim Guckenberg		

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1.0 INTRODUCTION

Lost Lake, Vilas County, is 553-acre lowland drainage lake with a maximum depth of 24 feet and mean depth of approximately 11 feet (Map 1). This lake's outlet (Lost Creek) flows into Big Saint Germain Lake, which drains into the Rainbow Flowage before reaching the Wisconsin River. Lost Lake is impounded by a small dam originally installed in the late 1930s with approximately 1 foot of hydraulic head. The water level is brought down to roughly its pre-dammed level during the winter, offering protection to properties from ice shoves. The lake is raised about 1 foot in the summer, when precipitation allows, to increase depth for recreation and fish spawning habitat.

The Lost Lake Protection & Rehabilitation District (LLPRD) was established in 2012 as a local unit of government authorized to undertake programs of lake protection and rehabilitation for Lost Lake, Vilas County. The goal of the LLPRD is protect and rehabilitate (if necessary) Lost Lake.

Between 2007 and 2009, Eurasian water milfoil (EWM, *Myriophyllum spicatum*) was suspected to be in Lost Lake but its presence was not confirmed until 2013. During the 2013 growing season, a member of the lake association found a suspicious watermilfoil plant which was later confirmed by the Vilas County Land and Water Conservation Department to be EWM. During an early-season AIS survey, Onterra ecologists located a few occurrences of curly-leaf pondweed (CLP, *Potamogeton crispus*). The LLPRD received multiple Wisconsin Department of Natural Resources (WDNR) Aquatic Invasive Species (AIS) Early Detection and Response (EDR) grants to assist in funding monitoring and management of the newly discovered non-native species.

The Town of Saint Germain Lakes Committee most recently sponsored town-wide management plans for lakes in its jurisdiction during 2013; this included Lost Lake. Following the AIS-EDR projects, the LLPRD determined that they required a stand-alone plan with more specific management goals suited for Lost Lake than the town-wide plan. Following a two-year project that included numerous biological and social surveys, planning meetings, agency and tribal involvement, a WDNR-approved *Comprehensive Management Plan* was finalized in 2019.

The *Comprehensive Management Plan* (2019) investigated Lost Lake's water quality condition, analyzed the influence of the watershed on the lake, inventory and assessed the aquatic plant community, and integrated relevant information on the lake's fishery. Further, the *Comprehensive Management Plan* (2019) outlined four management goals and thirteen management actions to help guide the LLPRD in protecting and enhancing Lost Lake.

According to the 2019 *Comprehensive Management Plan*, the Lost Lake watershed (Figure 1.0-1) is approximately 11,602 acres (including the lake's surface area), which yields a watershed to lake area ratio of 20:1. The watershed to lake area ratio is approaching the level where the watershed would be the dominating factor in determining the lake's water quality. The Lost Lake watershed is dominated by forested and wetland areas, which export a minimal amount of phosphorus to the lake compared with other landcover types such as row crop agriculture or urban development. The stained water of Lost Lake is the direct result of having forests and wetlands dominate the watershed's the landscape. The dark color of the water is caused by dissolved organic acids which are the byproduct of the decomposition of leaves and other plant materials. These organic acids are not harmful to the lake and are also responsible for the foam that may appear on the lake's shoreline during windy days that produce choppy conditions on the lake.

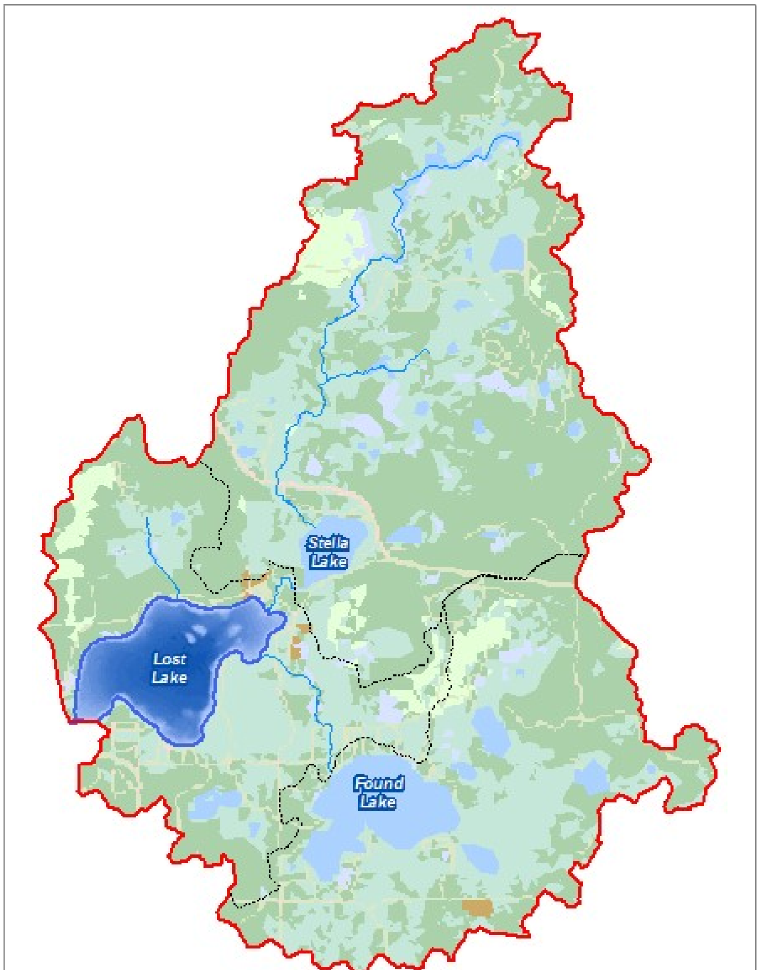


Figure 1.0-1. Lost Lake, Vilas County. Watershed outline in red and land cover types.

The *Comprehensive Management Plan* (2019) indicated the native plant community of Lost Lake is of moderately-high diversity and of high quality, with reduced aquatic plant abundance compared to a decade earlier. The lake contains a healthy population of floating-leaf and emergent plant communities as well, with many riparian concerns about white-water lily populations and their periodic uprooted tubers.

Consistent with their WDNR-approved *Comprehensive Management Plan,* the LLPRD was able to secure WDNR grant funds to partially fund CLP-directed herbicide treatment and monitoring from 2017-2020. These treatments were aggressively monitored to understand 1) pretreatment CLP population (surrogate for measuring turion sprouting), 2) herbicide concentrations at various locations and time periods after treatment, 3) CLP efficacy, 4) native plant impacts.

The annual CLP treatment was successful at killing CLP plants within the targeted area each year, as no CLP was documented in these areas for the remainder of that respective growing season. But some WDNR regulators questioned if the overall management approach could be considered successful as CLP continued to be present each year prior to treatment. Native aquatic plant monitoring indicated that many native aquatic plant species continue to decline during this time period.

The LLPRD applied for a WDNR permit to continue herbicide management towards CLP during spring 2022. The WDNR offered this explanation as to their 2022 herbicide permit denial:

> *"Due to concerns regarding the efficacy of the ongoing CLP treatments, the current condition of the native aquatic plant communities, ongoing tribal concerns over culturally significant wild rice beds and potential impacts to downstream aquatic vegetation the WDNR will not be approving the permit for herbicidal treatment in 2022."*

The WDNR and LLPRD met several times and ultimately decided that an updated Aquatic Plant Management (APM) Plan is warranted even if the traditional 5-year lifespan had not expired. While the APM Plan is technically the LLPRD's plan for managing Lost Lake, it still requires buy-in from other partners. As it applies to certain WDNR codes, there is a formal process for WDNR approval of aspects of a plan. There is not as straight-forward of an approval process from other partners, such as from GLIFWC or sovereign tribal entities such as the Lac du Flambeau Band of Lake Superior Chippewa Indians (LDF Tribe).

While this project is focused on revisiting the LLPRD's aquatic plant management-related Implementation Plan to update its content based on the lessons learned since the last *Plan*, this document also includes discussion on water quality conditions of the lake over this time period.

2.0 STAKEHOLDER PARTICIPATION

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

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

2.1 Strategic Planning Committee Meetings

Planning committee meetings were used to setup the project, gather comments, create management goals and actions, and to deliver study results. Meetings with a quorum of district board members were open to the public.

Front-End Planning Meetings

The LLPRD held a series of meetings at the beginning of this project to make sure it fully understand the rationale of the WDNR's permit denial and to make sure the forthcoming Aquatic Plant Management (APM) Planning project would be designed to succeed. The following bullets document the major meeting events, acknowledging additional discussions took place during this timeframe.

- **May 5, 2022.** This meeting discussed the WDNR permit denial and tribal input that lead to the WDNR's ruling.
    - LLPRD District Board
    - Onterra – Eddie Heath
    - WDNR – James Yach (Northern Wisconsin Secretary's Director), Greg Searle (Water Resources Field Operations Director), Tom Aartila (Northern District Water Resources Supervisor), and Kevin Gauthier (Regional Lakes Biologist)

- **July 7, 2022.** This meeting discussed the future of AIS management and planning on Lost Lake. Following this meeting, the LLPRD requested additional meetings with WDNR.
    - LLPRD District Board
    - Onterra – Eddie Heath
    - WDNR – James Yach, Greg Searle, Tom Aartila

- **July 12, 2022.** This conference call between the LDF tribe and a few LLPRD members focused on the tribal frustration with WDNR process, acknowledgement over difference of perspectives on herbicide management of AIS, and overall willingness to work together in forthcoming APM planning.
  - LLPRD – John Eckerman (Chair), Marv Anderson (Commissioner, Vilas County Representative)
  - LDF Tribe – Celeste Hockings (Water Resource Program Manager), Joe Graveen, (Wild Rice Technician), and Larry Wawronowicz (Natural Resources Director)

- **August 4, 2022.** At this closed-meeting held just prior to a Board of Commissioners Meeting, the LLPRD representatives expressed their concerns about WDNR engagement, absence of a direct WDNR contact, and concern the WDNR will oppose all future herbicide management on Lost Lake. WDNR acknowledged cumbersome nature of Kevin Gauthier's role of regional lake's coordinator but lack of engagement with AIS issues. The conversation led to the development of a written communication plan between the LLPRD and the WDNR.
  - LLPRD – John Eckerman (Chair), Gary Heeler (Secretary), and Ted Ritter (Commissioner, Town of St Germain Lakes Committee Representative)
  - Onterra – Eddie Heath
  - WDNR –Greg Searle, Tom Aartila, Kevin Gauthier, and Carroll Schaal (Lakes & Rivers Section Chief)

- **October 6, 2022.** At this closed-meeting held just prior to a Board of Commissioners Meeting, the LLPRD held a roundtable discussion with the WDNR and LDF Tribe to gain perspective from attending parties before the LLPRD started an updated APM Planning Project. This meeting established core perspectives from each entity on aquatic plant management, planning, and permitting.
  - LLPRD – John Eckerman, Gary Heeler, and Ted Ritter
  - Onterra – Eddie Heath
  - WDNR –James Yach, Tom Aartila, and Al Wirt (Interim Regional AIS Coordinator)
  - LDF Tribe – Celeste Hockings and Andre Virden (Great Lakes Restoration Initiative)

Planning Committee Meeting I

The planning committee meeting attendees were supplied with the draft report sections prior to the meeting and much of the meeting time was utilized to detail the results, discuss the conclusions and initial recommendations, and answer committee questions. The objective of the first meeting was to fortify a solid understanding of their lake among the committee members as well as key project partners.

On April 24, 2023, Eddie Heath met with the seven-member district board and additional public representation from the district during this public meeting. The following WDNR staff were present: Kevin Gauthier (regional lakes biologist), Allan Wirt (regional AIS coordinator), Eric Wegleitner (regional fisheries manager), and James Yach (northern region secretary's director). Adam Ray (inland fish biologist) from GLIFWC attended virtually, and Celeste Hockings (recently promoted to natural resources director) from Lac du Flambeau Tribe also attended virtually for roughly the first half of the meeting. This approximately three hour meeting largely consisted of a presentation of the available data from the system and the latest science and perspective on aquatic plant management activities. Agency partners were invited to provide their perspective on future aquatic plant management preferences and concerns. James Yach relayed a recently adopted policy position of the WDNR, that no aquatic herbicide permits would be approved on waters containing or are upstream of wild rice unless the WDNR has confidence that the activity will not impact the wild rice population.

Planning Committee Meeting II

The second planning committee meeting was held on May 5, 2023 and concentrated on the development of management goals and actions that make up the framework of the implementation plan by the district commissioners.

2.2 Management Plan Review and Adoption Process

On July 19, 2023, the Official First Draft of the LLPRD's Aquatic Plan Management Plan for Lost Lake was supplied to WDNR (lakes and fisheries programs), GLIFWC, Lad du Flambeau Band of Lake Superior Chippewa Indians (LDF Tribe), and Vilas County by Onterra via email.

At that time, the Official First Draft was made available for public review on an Onterra-hosted website and advertised as an official comment period through a combination of district outreach events and meetings. No public comments were received.

The public comment period remained active until the WDNR's comments were received on September 7, 2023, far longer than the minimum 21-day public comment period advised in WDNR guidance. No public comments were received regarding the plan. As discussed above, the WDNR (Kevin Gauthier) provided official comments on September 7, 2023. Adam Ray provided comments on behalf of GLIFWC on August 21, 2023. These comments are addressed in the Comment-Response Document presented here as Appendix E. No comments from other agencies or entities were received.

2.3 LLPRD Riparian Stakeholder Survey

As a part of this project, a stakeholder survey was distributed to district members of Lost Lake Protection & Rehabilitation District around Lost Lake. The survey was designed by Onterra staff and the Lost Lake Protection & Rehabilitation District planning committee and reviewed by a WDNR social scientist. During February and March of 2022, the nine-page, 33-question survey was posted online through Survey Monkey for survey-takers to answer electronically. If requested, a hard copy was sent with a self-addressed stamped envelope for returning the survey anonymously. The returned hardcopy surveys were entered into the online version by a third-party for analysis. Sixty-one (61) percent of the surveys were returned. Since over 60% of the surveys were returned, the results can be used to portray the entire population projections accurately, and make conclusions with statistical validity. The data were analyzed and summarized by Onterra for use at the planning meetings and within the management plan. The full survey and results can be found in Appendix B, while discussion of those results is integrated within the appropriate sections of the management plan and a general summary is discussed below.

Based upon the results of the stakeholder survey, much was learned about the people who use and care for Lost Lake. 45% of respondents indicated that they utilize their residence on weekends, vacation, and/or holidays while 27% utilize their property as a seasonal residence. 69% of respondents have owned their property for over 11 years, and 48% have owned their property for over 25 years (Appendix B).

The following sections (Water Quality, Watershed, Aquatic Plants, and Fisheries Data Integration) discuss the stakeholder survey data with respect these particular topics. Figures 2.0-1 and 2.0-2 highlight several other questions found within this survey. More than half of survey respondents indicate that they use either a canoe/kayak, pontoon boat, larger motor boat (>25hp motor), or a combination of these three vessels on Lost Lake (Appendix B, Question 12). 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 7, several of the top recreational activities on the lake involve boat use. Although unsafe watercraft practices was listed as a factor potentially impacting Lost Lake in a negative manner, it was ranked 6th on a list of stakeholder's top concerns regarding the lake (Question 15).

Question 7: Please rank up to three activities that are important reasons for owning your property on Lost Lake.

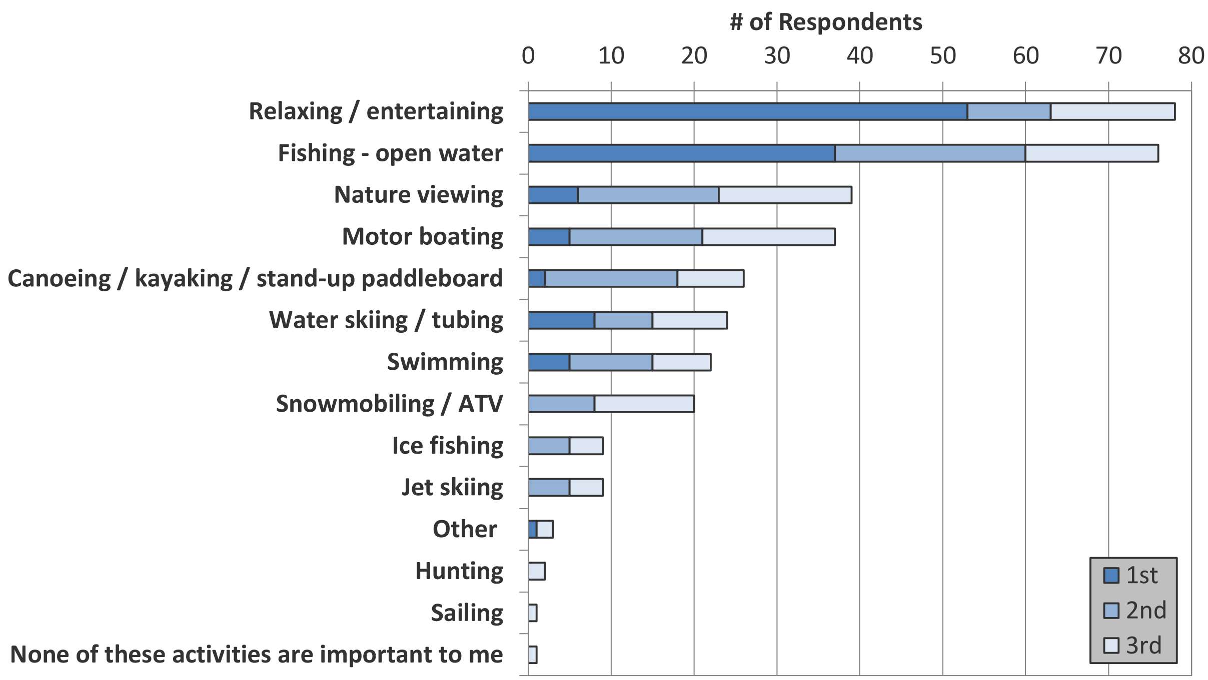
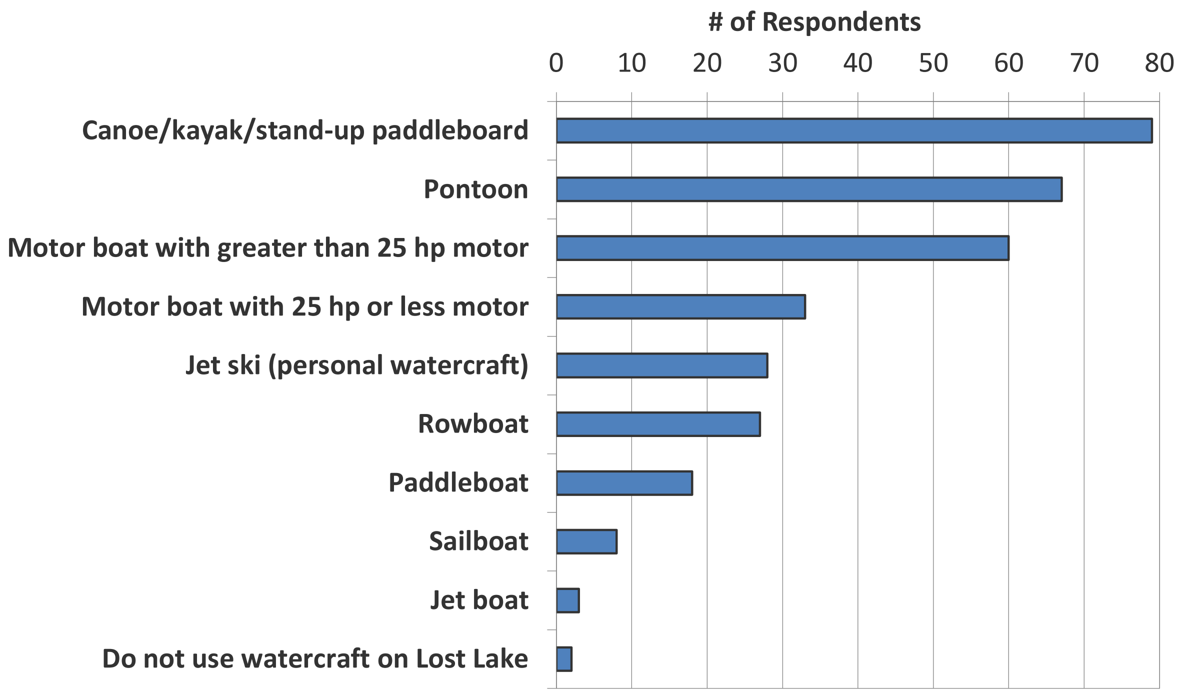


Figure 2.0-1. Select survey responses from the Lost Lake Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

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



Question 15: Please rank your top three concerns regarding Lost Lake.

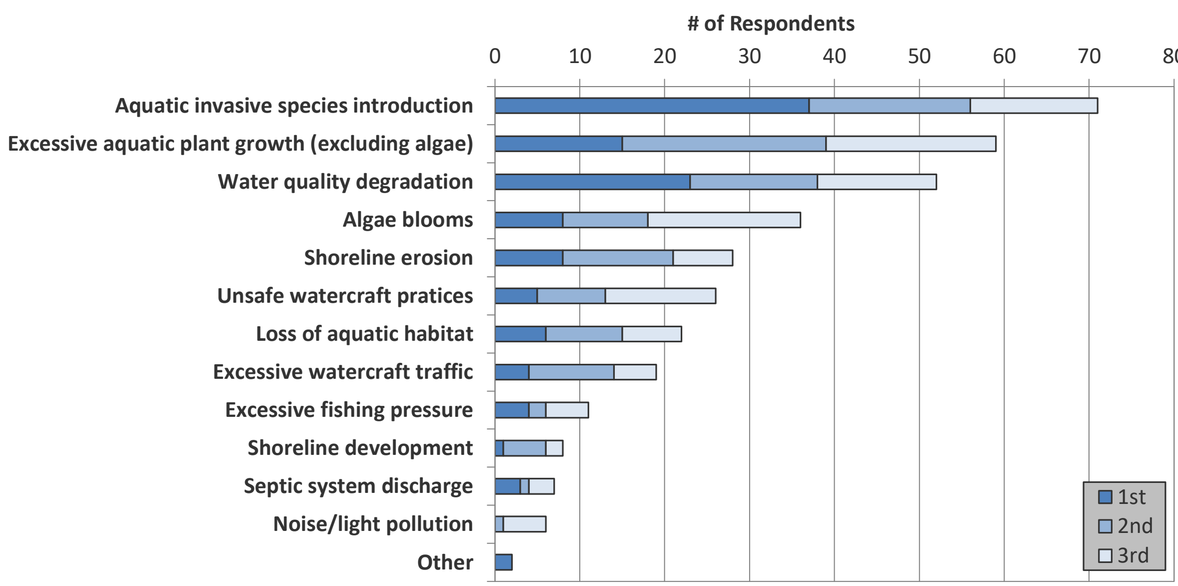


Figure 2.0-2. Select survey responses from the Lost Lake Stakeholder Survey, continued. Additional questions and response charts may be found in Appendix B.

3.0 AQUATIC PLANTS

3.1 Primer on Aquatic Plant Data Analysis & Interpretation

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

The point-intercept method as described Wisconsin Department of Natural Resources Bureau of Science Services, PUB-SS-1068 2010 (Hauxwell et al. 2010) have been conducted on Lost Lake in 2007, 2010, 2014, 2017, 2018, and 2021. The point-intercept survey spacing and total number of sampling points for Lost Lake is 75 meters and 384 points, respectively. At each point-intercept location within the *littoral zone*, information regarding the depth, substrate type (soft sediment, sand, or rock), and the plant species sampled along with their relative abundance on the sampling rake was recorded.

A pole-mounted rake was used to collect the plant samples, depth, and sediment information at point locations of 15 feet or less. A rake head tied to a rope (rope rake) was used at sites greater than 15 feet. Depth information was collected using graduated marks on the pole of the rake (at depths < 15 ft) or using an onboard sonar unit (at depths > 15 feet). Also, when a rope rake was used, information regarding substrate type was not collected due to the inability of the sampler to accurately "feel" the bottom with this sampling device. At each point that is sampled the surveyor records a total rake fullness (TRF) value ranging from 0-3 as a somewhat subjective indication of plant biomass. The point-intercept survey produces a great deal of information about a lake's aquatic vegetation and overall health. These data are analyzed and presented in numerous ways; each is discussed in more detail the following section.

Species List

The species list is simply a list of all of the aquatic plant species, both native and non-native, that were located during the surveys completed in Lost Lake during 2007, 2010, 2014, 2017, 2018, and 2021. The list also contains each species' scientific name, common name, status in Wisconsin, and coefficient of conservatism. The latter is discussed in more detail below. Changes in this list over time, whether it is differences in total species present, gains and losses of individual species, or changes in growth forms that are present, can be an early indicator of changes in the ecosystem.

Frequency of Occurrence

Frequency of occurrence describes how often a certain aquatic plant species is found within a lake. Obviously, all of the plants cannot be counted in a lake, so samples are collected from pre-determined areas. In the case of the whole-lake point-intercept surveys that have been completed; plant samples were collected

Littoral Zone is the area of a lake where sunlight is able to penetrate down to the sediment and support aquatic plant growth.

from plots laid out on a grid that covered the lake. Using the data collected from these plots, an estimate of occurrence of each plant species can be determined. The occurrence of aquatic plant species is displayed as the *littoral frequency of occurrence*. Littoral frequency of occurrence is used to describe how often each species occurred in the plots that are within the maximum depth of plant growth (littoral zone), and is displayed as a percentage.

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.

Floristic Quality Assessment

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

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

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

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

Lost Lake falls within the Northern Lakes and Forests (NLF) *ecoregion* (Figure 3.1-1), and the floristic quality of its aquatic plant community will be compared to other lakes within this ecoregion as well as the entire State of Wisconsin. Ecoregions are areas related by similar climate, physiography, hydrology, vegetation and wildlife potential. Comparing ecosystems within the same ecoregion is sounder than comparing systems within manmade boundaries such as counties, towns, or states. Ecoregional and state-wide medians were calculated from whole-lake point-intercept surveys conducted on 392 lakes throughout Wisconsin by Onterra and WDNR ecologists.

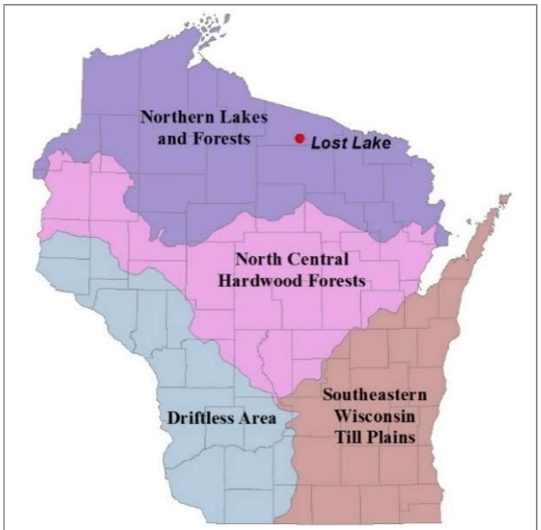


Figure 3.1-1. Location of Lost Lake within the ecoregions of Wisconsin. After (Nichols 1999).

Species Diversity

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

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

The diversity of a lake's aquatic plant community is determined using the Simpson's Diversity Index (1-D):

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

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

If a lake has a diversity index value of 0.90, it means that if two plants were randomly sampled from the lake there is a 90% probability that the two individuals would be of a different species. The Simpson's Diversity Index value from Lost Lake is compared to data collected by Onterra and the WDNR Science Services on 212 lakes within the Northern Lakes and Forests (lakes only, does not include flowages) Ecoregion and on 392 lakes throughout Wisconsin.

3.2 Lost Lake Aquatic Plant Survey Results

The whole-lake point-intercept survey was conducted on Lost Lake on July 29, 2021. During the 2021 survey, a total of 31 aquatic plant species were located (Table 3.2-1). A full matrix of aquatic plant frequencies can be found in Appendix C. Two are considered to be non-native, invasive species: Eurasian watermilfoil and curly-leaf pondweed. These two non-native plant species are discussed in the subsequent *Non-Native Aquatic Plants in Lost Lake* section. Point-intercept surveys were also completed in 2007, 2010, 2014, 2017 and 2018. Three community mapping surveys have also been completed in 2004, 2010, and 2017. Results and comparisons of those community mapping surveys can be found within the 2019 *Comprehensive Lake Management Plan* report. From all six point-intercept surveys and three community mapping surveys, the total number of aquatic plant species located in Lost Lake is 58.

On September 26-27, 2017, Onterra ecologists completed an acoustic survey on Lost Lake. Data regarding substrate hardness collected during the 2017 acoustic survey revealed that Lost Lake's average substrate hardness ranges from hard to moderately hard with deeper areas containing softer sediments (Figure 3.2-1). On average, the hardest substrates (sand/rock/gravel) are found within 1 to 7 feet of water. The greatest transition between hard and softer substrates is found between 7 and 12 feet of water, with hardness declining rapidly with depth. In 12 feet of water and deeper, substrate hardness remains relatively constant. Like terrestrial plants, different aquatic plant species are adapted to grow in certain substrate types; some species are only found growing in soft substrates, others only in sandy areas, and some can be found growing in either. Lakes that have varying substrate types generally support a higher number of plant species because of the different habitat types that are available.

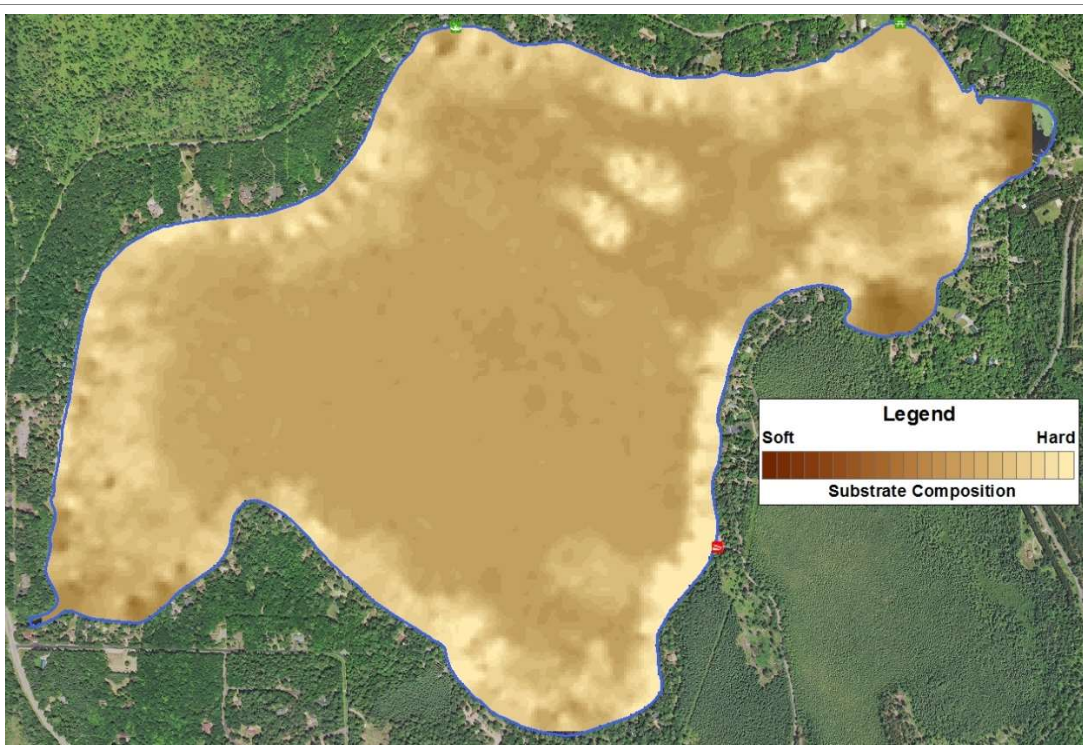


Figure 3.2-1. Lost Lake spatial distribution of substrate hardness. Created using data from September 2017 acoustic survey.

Table 3.2-1. Aquatic plant species located during the 2007, 2010, 2014, 2017, and 2021 surveys.

Growth Form	Scientific Name	Common Name	Status in Wisconsin	Coefficient of Conservatism	2007 (WDNR)	2010 (Onterra)	2014 (WDNR)	2017 (Onterra)	2018 (Onterra)	2021 (Onterra)
Emergent	*Bolboschoenus fluviatilis*	River bulrush	Native	5		I				
	Calla palustris	Water arum	Native	9				I		
	Carex utriculata	Common yellow lake sedge	Native	7		I		I		
	Decodon verticillatus	Water-willow	Native	7				I		
	Eleocharis palustris	Creeping spikerush	Native	6		I	I			
	Eleocharis palustris	Creeping spikerush	Native	6		I	I			
	Iris versicolor	Northern blue flag	Native	5				I		
	Pontederia cordata	Pickerelweed	Native	9	I	X	I	I		
	Sagittaria latifolia	Common arrowhead	Native	3		I		I		
	Schoenoplectus acutus	Hardstem bulrush	Native	5		I	X	I	X	
	Schoenoplectus tabernaemontani	Softstem bulrush	Native	4	I	X				
	Sparganium eurycarpum	Common bur-reed	Native	5		I		I		
	Typha latifolia	Broad-leaved cattail	Native	1		I				
	Typha spp.	Cattail spp.	Unknown (Sterile)	N/A			I	I		
FL	*Nuphar variegata*	Spatterdock	Native	6	X	X	X	X	X	X
	Nymphaea odorata	White water lily	Native	6	X	I		X	X	X
	Sparganium angustifolium	Narrow-leaf bur-reed	Native	9				I		
	Sparganium fluctuans	Floating-leaf bur-reed	Native	10				I		
FL/E	*Sparganium emersum* var. *acaule*	Short-stemmed bur-reed	Native	8			I			
Submergent	*Bidens beckii*	Water marigold	Native	8		X	X	X	X	X
	Callitriche palustris	Common water starwort	Native	8				I		
	Ceratophyllum demersum	Coontail	Native	3	X	X	X	X	X	X
	Ceratophyllum echinatum	Spiny hornwort	Native	10						X
	Chara spp.	Muskgrasses	Native	7	X	X	X	X	X	X
	Elodea canadensis	Common waterweed	Native	3	X	X	X	X	X	X
	Elodea nuttallii	Slender waterweed	Native	7						X
	Eriocaulon aquaticum	Pipewort	Native	9					X	
	Heteranthera dubia	Water stargrass	Native	6	X		X	X	X	X
	Isoetes spp.	Quillwort spp.	Native	8	X	X	X	X	X	X
	Lobelia dortmanna	Water lobelia	Native	10		X				
	Myriophyllum sibiricum	Northern watermilfoil	Native	7	X	X	X	X	X	X
	Myriophyllum spicatum	Eurasian watermilfoil	Non-Native - Invasive	N/A			I	X	X	X
	Myriophyllum tenellum	Dwarf watermilfoil	Native	10					X	X
	Myriophyllum verticillatum	Whorled watermilfoil	Native	8		X				
	Najas flexilis	Slender naiad	Native	6	X	X	X	X	X	X
	Nitella spp.	Stoneworts	Native	7		X				X
	Potamogeton alpinus	Alpine pondweed	Native	9		I				
	Potamogeton amplifolius	Large-leaf pondweed	Native	7	X	X	X	X	X	
	Potamogeton berchtoldii	Slender pondweed	Native	7			X		I	X
	Potamogeton crispus	Curly-leaf pondweed	Non-Native - Invasive	N/A			I	X	X	X
	Potamogeton epihydrus	Ribbon-leaf pondweed	Native	8					I	
	Potamogeton foliosus	Leafy pondweed	Native	6	X					X
	Potamogeton gramineus	Variable-leaf pondweed	Native	7	X	X	X	X		X
	Potamogeton illinoensis	Illinois pondweed	Native	6	X					X
	Potamogeton natans	Floating-leaf pondweed	Native	5		I				
	Potamogeton praelongus	White-stem pondweed	Native	8	X	X	X	X	X	X
	Potamogeton pusillus	Small pondweed	Native	7	X	X	X			
	Potamogeton richardsonii	Clasping-leaf pondweed	Native	5	X	X	X	X	X	X
	Potamogeton robbinsii	Fern-leaf pondweed	Native	8	X	X	X	X	X	X
	Potamogeton spirillus	Spiral-fruited pondweed	Native	8				I		X
	Potamogeton strictifolius	Stiff pondweed	Native	8		X				
	Potamogeton vaseyi	Vasey's pondweed	Native - Special Concern	10		I				
	Potamogeton X haynesii	Haynes' pondweed	Native	N/A		X				
	Potamogeton X spathuliformis	Variable-leaf X Illinois pondweed	Native	N/A		X				
	Potamogeton zosteriformis	Flat-stem pondweed	Native	6	X	X			X	X
	Ranunculus aquatilis	White water crowfoot	Native	8	X					
	Sagittaria sp. (rosette)	Arrowhead sp. (rosette)	Native	N/A	X	X		X	X	X
	Stuckenia pectinata	Sago pondweed	Native	3		X	X	X		
	Utricularia vulgaris	Common bladderwort	Native	7					X	
	Vallisneria americana	Wild celery	Native	6	X	X	X	X	X	X
S/E	*Eleocharis acicularis*	Needle spikerush	Native	5	X	X	X	X	X	X
	Juncus pelocarpus	Brown-fruited rush	Native	8	X	X	X			X
	Sagittaria cristata	Crested arrowhead	Native	9						X
	Sagittaria graminea	Grass-leaved arrowhead	Native	9		I				
FF	*Lemna trisulca*	Forked duckweed	Native	6					X	X
	Lemna turionifera	Turion duckweed	Native	2			I		X	
	Spirodela polyrhiza	Greater duckweed	Native	5		I	I			

FL = Floating-leaf; FL/E = Floating-leaf/Emergent; S/E = Submergent/Emergent; FF = Free-floating
X = Located on rake during point-intercept survey; I = Incidentally located; not located on rake during point-intercept survey

Whole-lake point-intercept surveys are used to quantify the abundance of individual plant species within the lake. Of the 305 point-intercept sampling locations that fell at or shallower than the maximum depth of plant growth (the littoral zone) in Lost Lake in 2021, approximately 50% contained aquatic vegetation. Aquatic plant rake fullness data collected in 2021 indicates that 25% of the 305 sampling locations contained vegetation with a total rake fullness rating (TRF) of 1, 16% had a TRF rating of 2, and 10% had a TRF rating of 3 (Figure 3.2-2). The TRF data indicates that where aquatic plants are present in Lost Lake, they are at a moderate abundance. Total rake fullness levels in 2017, 2018, and 2021 were fairly similar however remain lower than earlier surveys completed in 2007, 2010 & 2014 (Figure 3.2-2).

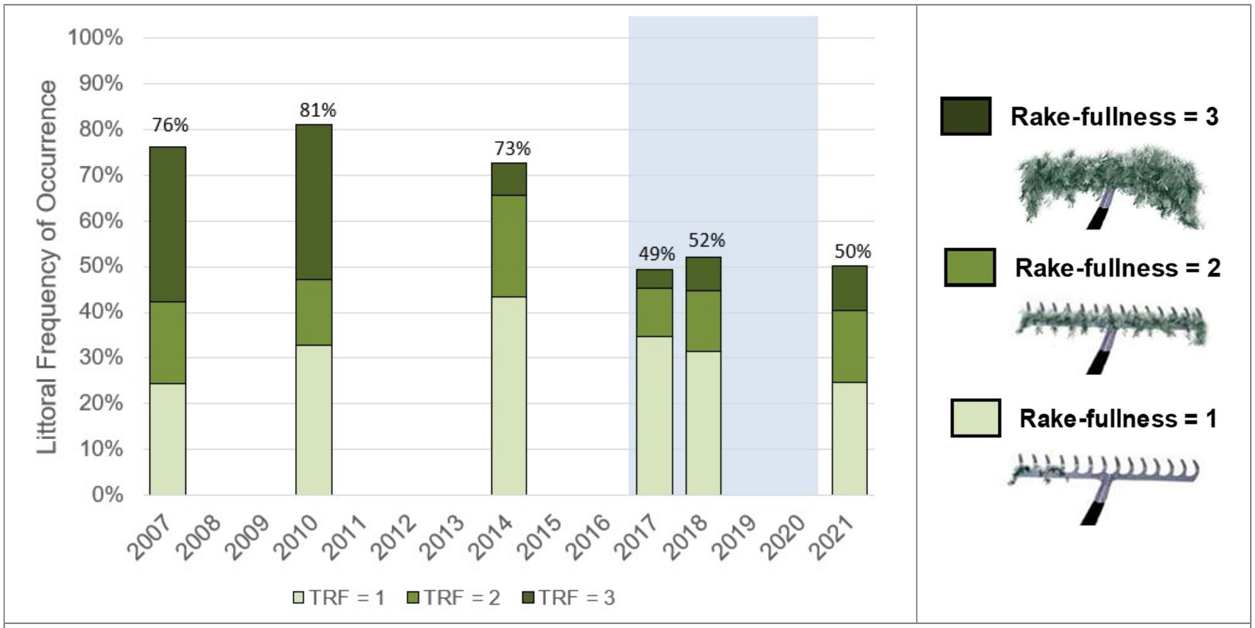


Figure 3.2-2. Lost Lake aquatic vegetation total rake fullness ratings. The shaded blue area signifies spot herbicide treatments in the western basin.

The maximum depth of aquatic plants found from the point-intercept surveys was 15 feet in each of the 2007, 2010, and 2014 surveys, but decreased to 13 feet in 2017 and 11 feet in 2018 (Figure 3.2-3 and 3.2-4). The 2021 survey found aquatic plants growing to 16 feet, representing the deepest maximum depth of plants in any survey to date. Figure 3.2-5 shows that little vegetation was observed greater than 8 feet deep in 2017 and 2018 whereas, some of the greatest abundance of aquatic plants during 2007, 2010, and 2014 was found in waters of 8 to 14 feet. This indicates that plants that had been growing in the deeper extents of Lost Lake's littoral zone in earlier surveys, were not present in the same depth zones during 2017 and 2018. Changes in Lost Lake's water clarity around are believed to be the driving factor influencing the maximum depth of plant growth.

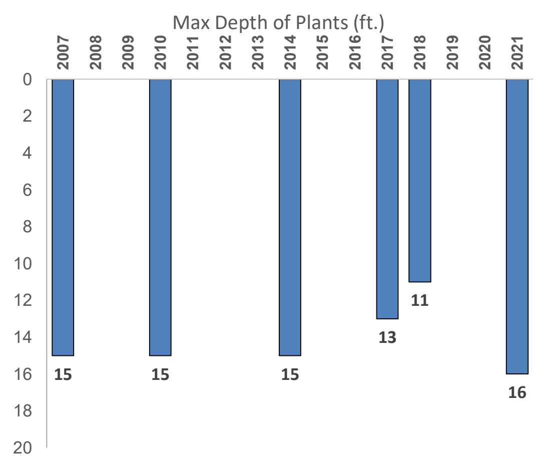


Figure 3.2-3. Maximum depth of plants from point-intercept surveys in Lost Lake.

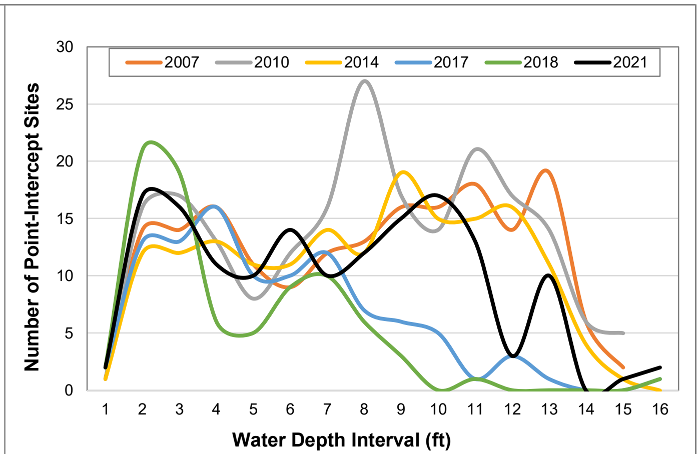


Figure 3.2-4. Depth distribution of aquatic plants from point-intercept surveys in Lost Lake.

In 2021, aquatic plants seemed to be more established within much of the 8-14 foot range of the littoral zone compared to 2017-2018 (Figure 3.2-5). Slightly higher water clarity documented during the early portion of the 2021 growing season may have allowed for aquatic plants to take root within deeper waters of the lake (discussed in Section 3.3, Figure 3.3-4). Depth distribution data from the 2021 whole-lake point-intercept survey show that Eurasian watermilfoil, curly-leaf pondweed, and common waterweed represented the majority of the aquatic plants present at depths of 9-16 feet (Figure 3.2-5).

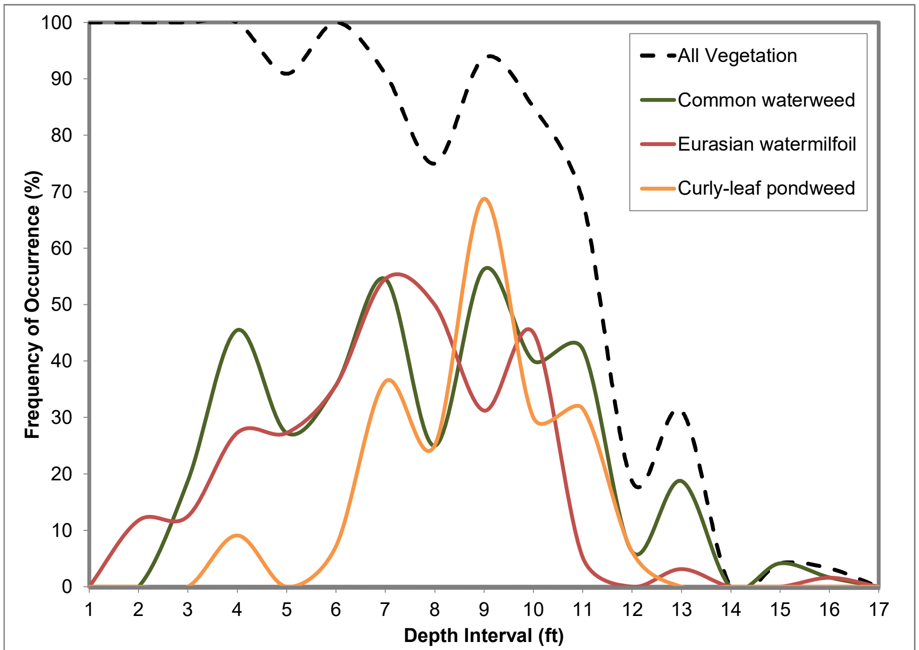


Figure 3.2-5. Depth distribution of aquatic plants in the 2021 whole-lake point-intercept survey.

Using the presence/absence data from each years' point-intercept survey, an interpolation model (kringing) was created that explores the areas of Lost Lake that have a high likelihood of containing vegetation in a given year (Figure 3.2-6).

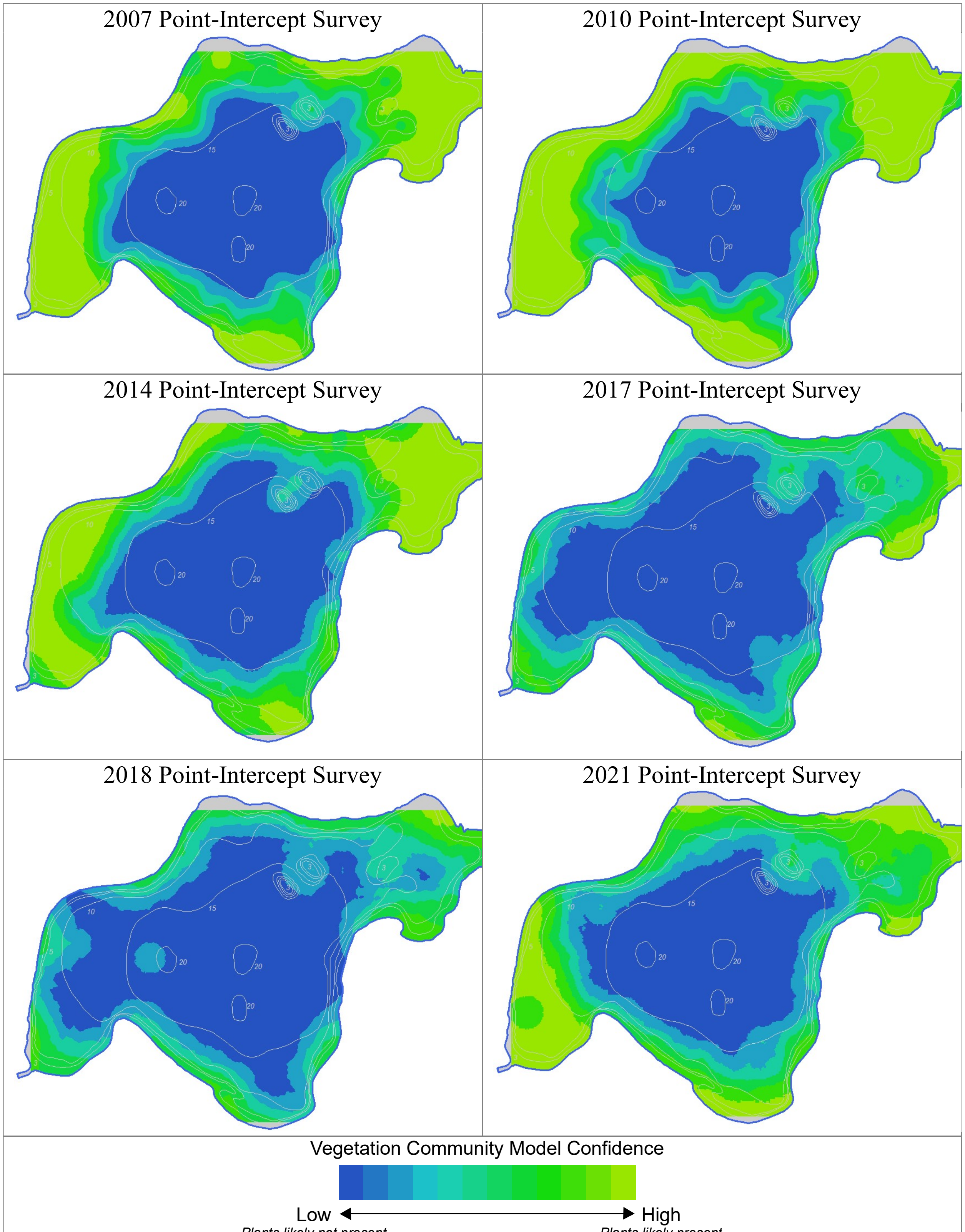


Figure 3.2-6. Distribution model of aquatic vegetation in Lost Lake. Modeled vegetation likelihood based upon interpolation of presence/absence vegetation at point-intercept locations. Grey areas indicate no data.

The model shows the footprint of aquatic vegetation from Lost Lake increased from 2007 to 2010, largely in the lakeward direction. Aquatic vegetation at depth resided in 2014 to an area similar, but perhaps a little smaller, than was observed in 2010. The models from 2017 and 2018 shows less aquatic vegetation in deeper waters, with most of the vegetation being observed in near shore areas. Vegetation reductions were also observed in the far eastern part of the lake during this time period. The model from 2021 demonstrates an expansion in the footprint of aquatic plants compared to 2017-2018 and is more similar to the model from 2014 and prior.

Figure 3.2-7 shows the littoral frequency of occurrence (LFOO) of aquatic plants from the 2021 point-intercept survey. These data indicate that slender naiad, common waterweed, and wild celery are the most frequent native aquatic plant species found in Lost Lake during 2021 (Photograph 3.2-1). Eurasian watermilfoil (15.1%) and curly-leaf pondweed (11.1%) were the third and fourth-most frequently encountered species in the 2021 whole-lake point-intercept survey in Lost Lake. These non-native and invasive species are discussed in greater detail in subsequent sections of this report. It is interesting to note that amount of CLP located during this July 29, 2021 survey, as it is more commonly absent from lakes at this time of year due to natural senesces (die-off).

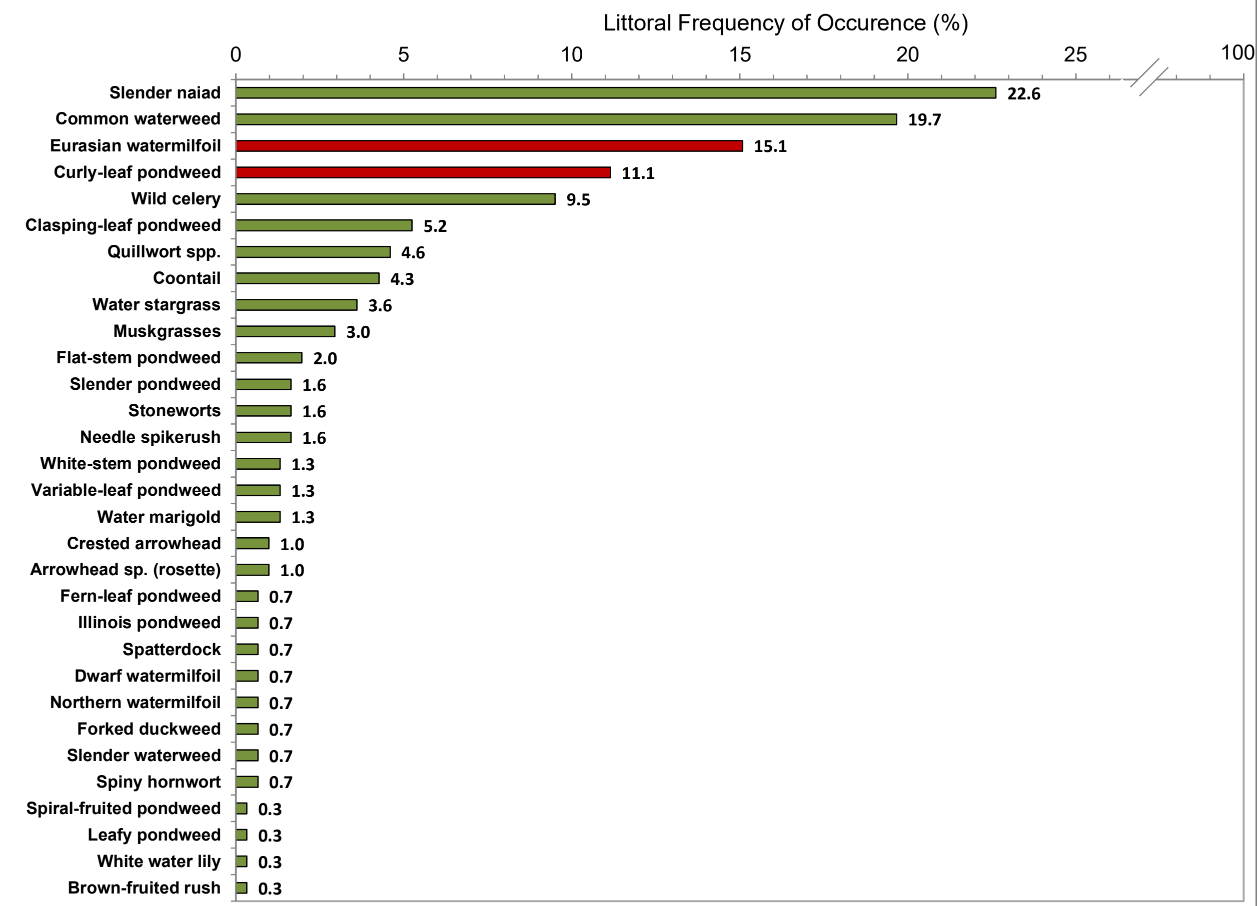


Figure 3.2-7. Lost Lake 2021 LFOO. LFOO = littoral frequency of occurrence.

Photograph 3.2-1. Three-most frequently encountered aquatic plants in Lost Lake in 2021. Photo credit Onterra.

Slender naiad was the most frequently encountered aquatic plant species in the 2021 point-intercept survey with an occurrence of 22.6% (Figure 3.2-7). Slender naiad is one of five naiad species that can be found in Wisconsin. Being an annual, it produces numerous seeds on an annual basis and is considered to be one of the most important food sources for a number of migratory waterfowl species (Borman et al. 1997). In addition, slender naiad's small, condensed network of leaves provide excellent habitat for aquatic invertebrates. In Lost Lake, slender naiad was most prevalent between 1.0 and 5.0 feet of water, with some occurrences growing out to 11 feet. The occurrence of slender naiad has been variable over time with statistically valid changes in occurrence between every survey between 2007 and 2021 (Figure 3.2-8). The 22.6% occurrence of slender naiad in 2021 represented the highest occurrence in any of the six point-intercept surveys.

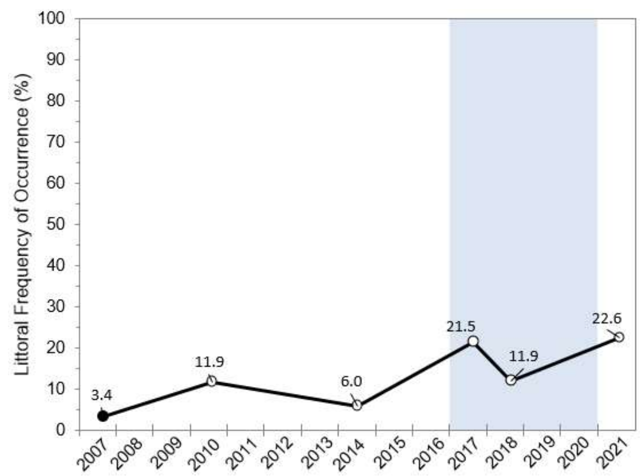


Figure 3.2-8. Slender naiad LFOO in Lost Lake from 2007-2021. Open circle represents statistically valid change from previous survey (Chi-Square α = 0.05). The shaded blue area signifies spot herbicide treatments in the western basin.

Common waterweed was the second-most frequently encountered species in the 2021 survey (Figure 3.2-9). Common waterweed can be found in waterbodies across Wisconsin and throughout North America. It often produces dense beds which provide valuable structural habitat and stabilize bottom sediments. Common waterweed was most prevalent between 4-11 feet in the 2021 survey and was also found to be growing at the maximum depth of plant colonization in the lake at 16 feet (Figure 3.2-9). Slender waterweed (*Elodea nuttallii*) was documented in Lost Lake for the first time in the 2021 point-intercept survey. Due to the morphological similarities to common waterweed and subsequent difficulty in distinguishing between two, these species are combined for analysis purposes. The occurrence of the waterweed species was 16.4% in 2007 and 36.9% in 2010 before exhibiting a statistically valid decrease in occurrence in 2014 to 6.0% (Figure 3.2-9). The occurrence of waterweeds remained relatively stable from 2014, 2017, and 2018 before exhibiting a statistically valid increase in occurrence in 2021 to 20.3%.

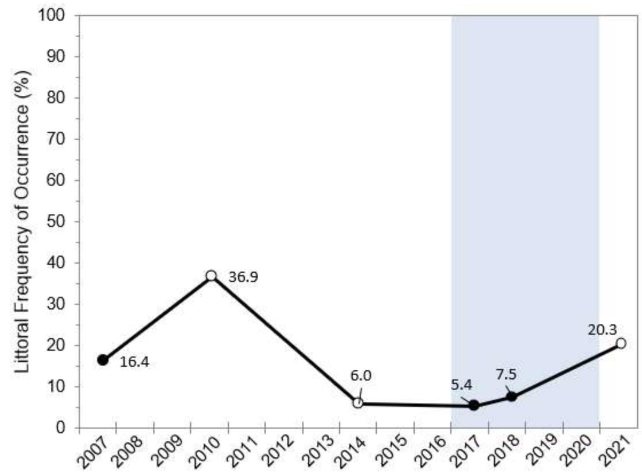


Figure 3.2-9. Common (and slender) waterweed LFOO in Lost Lake from 2007-2021. Open circle represents statistically valid change from previous survey (Chi-Square α = 0.05). The shaded blue area signifies spot herbicide treatments in the western basin.

Wild celery produces long, ribbon-like leaves which emerge from a basal rosette, and it prefers to grow over harder substrates and is tolerant of low-light conditions. Its long leaves provide valuable structural habitat for the aquatic community while its network of roots and rhizomes help to stabilize bottom sediments. In mid- to late-summer, wild celery often produces abundant fruit which are important food sources for wildlife including migratory waterfowl. Wild celery was the third-most frequently encountered native aquatic plant species with a littoral frequency of occurrence of 9.5% during the 2021 point-intercept survey (Figure 3.2-10). In Lost Lake, wild celery was most abundant between 2.0 and 7.0 feet of water. The occurrence of wild celery was 15.5% in 2007 and 14.7% in 2010 before exhibiting a statistically valid decrease in occurrence in 2014 to 4.7%.. The occurrence of wild celery has been variable in recent surveys with the 2021 survey indicating a 9.5% occurrence.

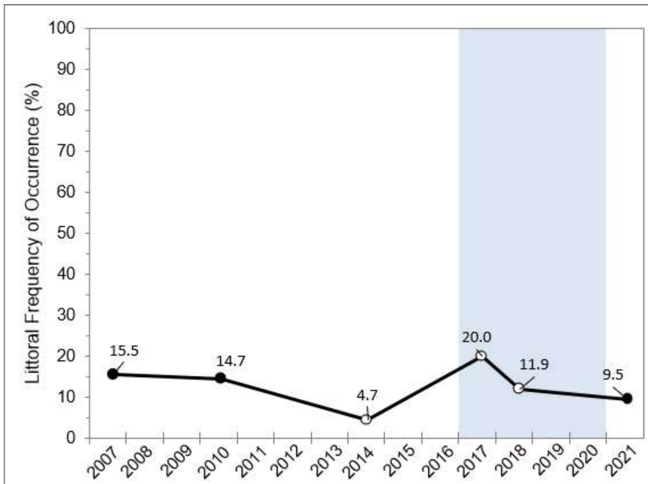


Figure 3.2-10. Wild celery LFOO in Lost Lake from 2007-2021. Open circle represents statistically valid change from previous survey (Chi-Square α = 0.05). The shaded blue area signifies spot herbicide treatments in the western basin.

Figure 3.2-11 investigates the littoral frequency of occurrence of several other native aquatic plant species that have been commonly encountered in point-intercept surveys in Lost Lake.

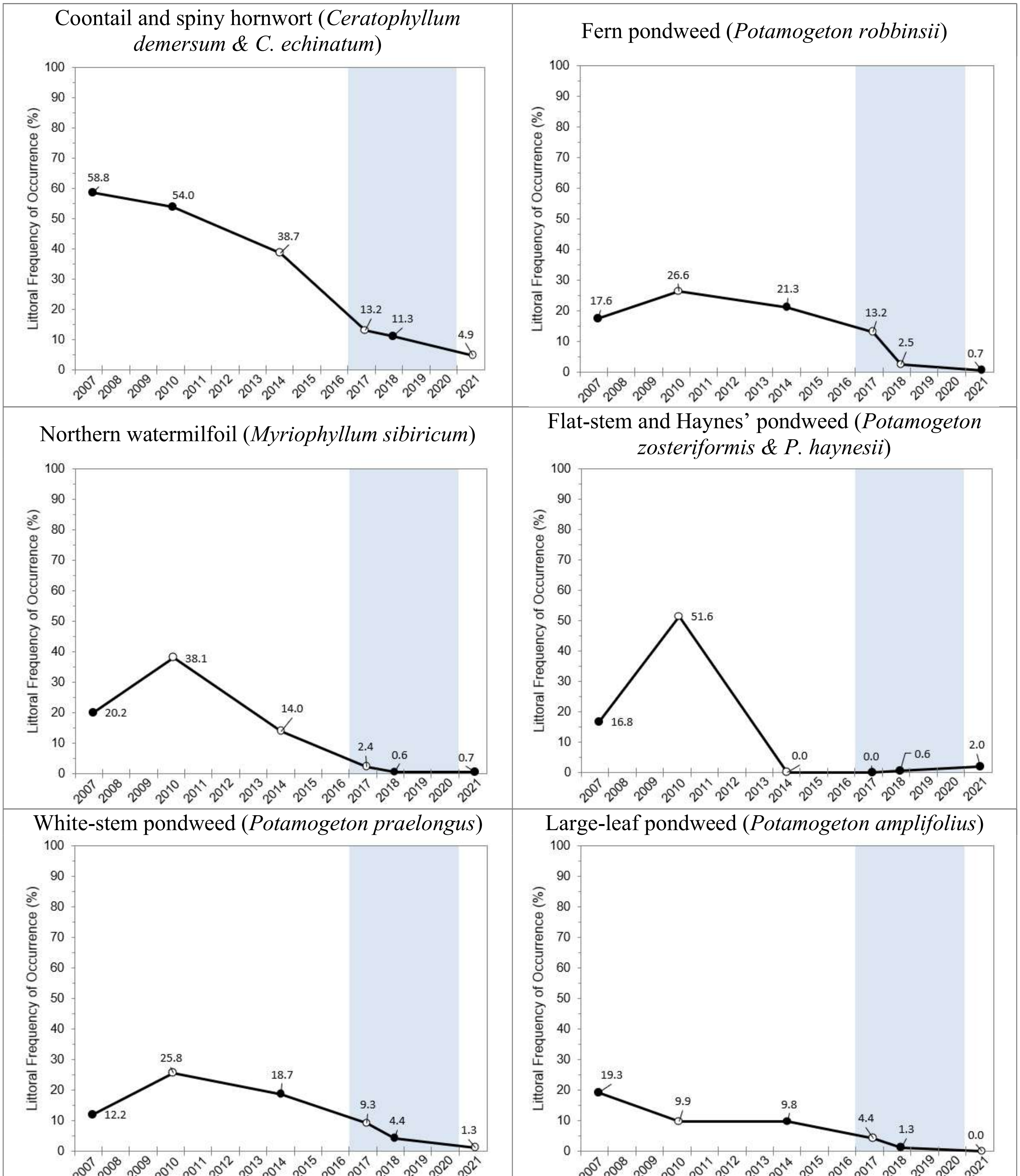


Figure 3.2-11. Common species LFOO in Lost Lake. Open circle represents statistically valid change in occurrence from previous survey (Chi-Square α = 0.05). The shaded blue area signifies spot herbicide treatments in the western basin.

Coontail was one of the most common species in the 2007 and 2010 surveys with occurrences of 58.8% and 54.0% respectively. The occurrence of coontail exhibited statistically valid decreases from 2010-2014, 2014-2017, and again from 2018-2021. The occurrence of coontail of 4.9% in 2021 was the lowest value in any point-intercept survey.

Several pondweed species have exhibited a decreasing trend in occurrence over the course of the monitoring timeframe including fern-leaf pondweed, flat-stem pondweed, white-stem pondweed, and large-leaf pondweed (Figure 3.2-11). Of these species, white-stem pondweed and large-leaf pondweed exhibited statistically valid decreases in occurrence between the 2018 and 2021 surveys. Fern-leaf pondweed was sampled on just two sampling locations in the 2021 point-intercept survey (0.7% occurrence) and Large-leaf pondweed was not sampled on any points in the 2021 survey.

Flat-stem pondweed exhibited an occurrence of 51.6% in 2010 but declined to 0% in 2014. The occurrence of flat-stem pondweed has remained low since 2014 with a 2.0% occurrence in the 2021 survey.

Northern watermilfoil occurrence was 38.1% in 2010 before declining to 14.0% in 2014 and 2.4% in 2017. The occurrence declined further in 2018 to 0.6% and remained low at 0.7% in the 2021 survey.

Because each sampling location may contain numerous plant species, relative frequency of occurrence is one tool to evaluate how often each plant species is found in relation to all other species found (composition of population). For example, while common waterweed was found at 19.7% of the littoral sampling locations in Lost Lake in 2021, its relative frequency of occurrence is 17.0% (Figure 3.2-12). Explained another way, if 100 plants were randomly sampled from Lost Lake, 17 of them would be common waterweed. Figure 3.2-12 displays the relative frequency of occurrence of aquatic plant species from each of the point-intercept surveys in Lost Lake. The figure demonstrates the declining frequency of coontail, northern watermilfoil, fern-leaf pondweed, and white-stem pondweed over time. The figure also displays the increasing frequency of curly-leaf pondweed, Eurasian watermilfoil, and slender naiad over time.

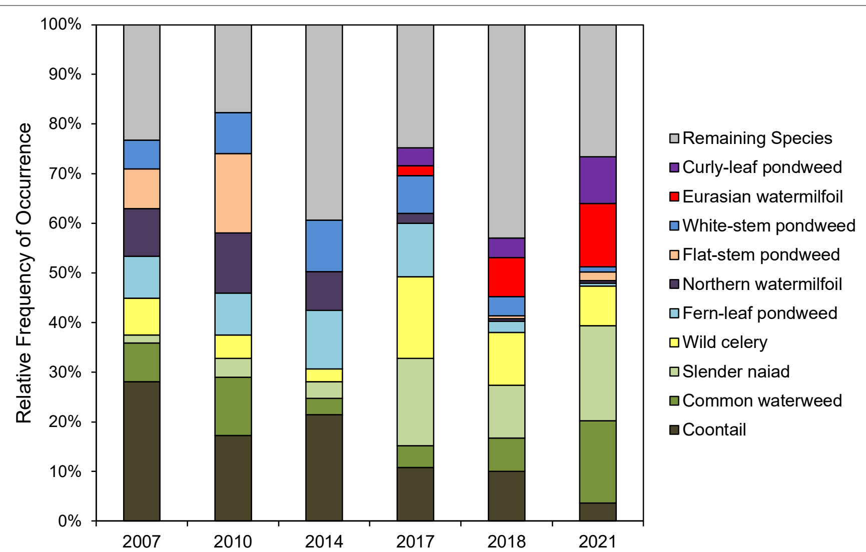


Figure 3.2-12. Relative frequency of occurrence of aquatic plants in Lost Lake.

The native aquatic plant species located on the rake during the point-intercept surveys from 2007-2021 and their conservatism values were used to calculate the Floristic Quality Index (FQI) for each year (Figure 3.0-13). Native species richness, or the number of native plant species recorded on the rake has varied over time in Lost Lake with the lowest values in 2014 (21) and 2017 (19) (Figure 3.2-13). The species richness was highest in the most recent survey completed in 2019 during which 29 species were recorded. In most years, the species richness has been at or above the ecoregion and state median values.

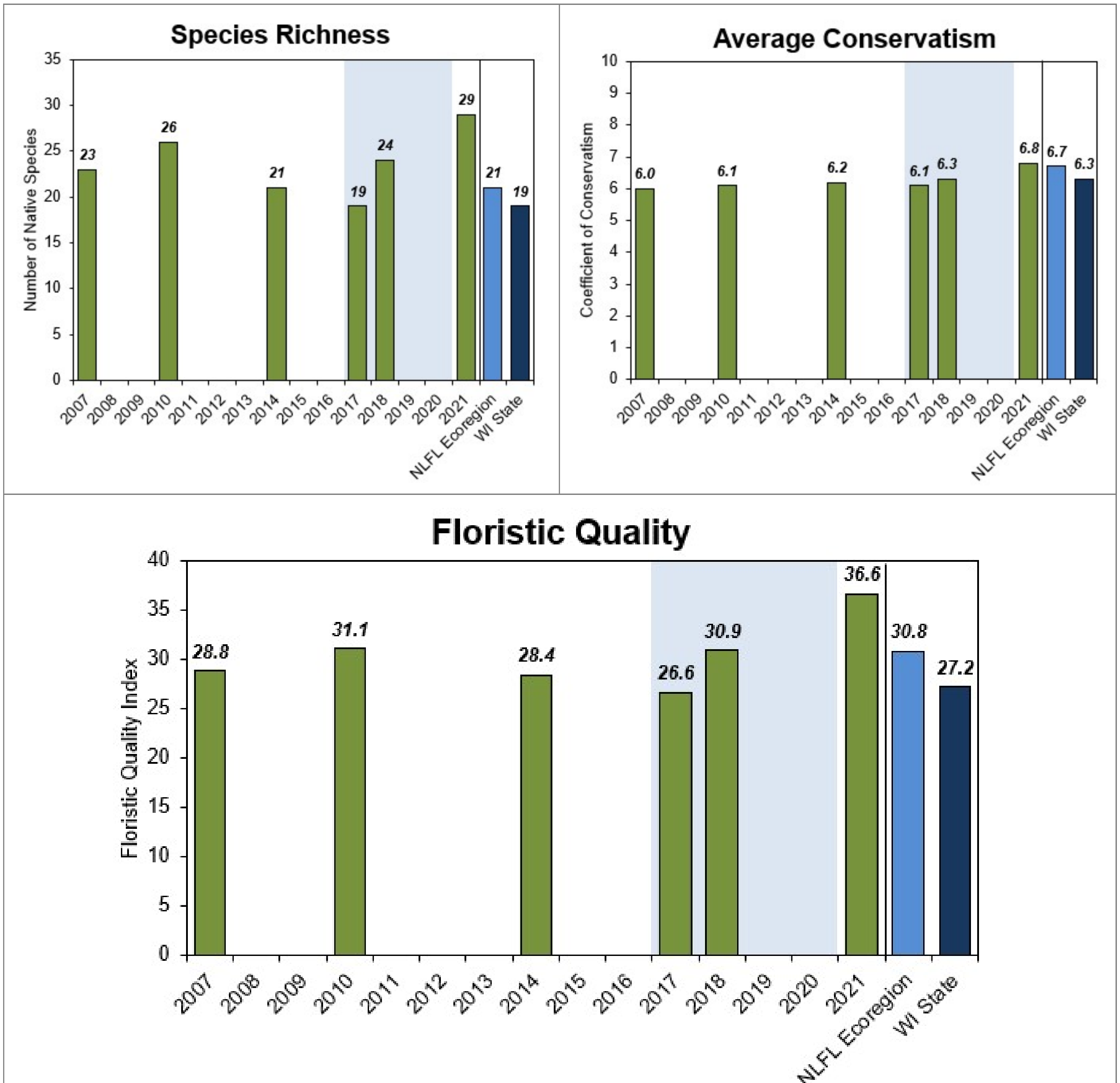


Figure 3.2-13. Native aquatic plant species richness, average conservationism, and floristic quality. The shaded blue area signifies spot herbicide treatments in the western basin.

Average conservatism values were consistently between 6.0-6.3 in surveys conducted between 2007-2018 while the 2021 survey yielded an average conservatism value of 6.8. Part of the reason for the increased average conservatism value in 2021 is a result of the presence of spiny hornwort

(C =10), spiral-fruited pondweed (C=8), and crested arrowhead (C=9) on the survey rake while none of these species had been present on the survey rake in previous surveys. These values are similar to the state median value and with exception of 2021, have been below the ecoregion median.

The floristic quality values were slightly below or above state and ecoregion medians in surveys between 2007-2018. FQI is calculated from values associated with the species richness and average conservatism which were both higher in 2021 compared to past surveys; therefore, the FQI value of 36.6 in 2021 was also higher than any previous year and is well above the state and ecoregion median values.

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 Lost Lake's diversity values rank. Using data collected by Onterra, quartiles were calculated for lakes within the NLFL Ecoregion (Figure 3.2-14). Using the data collected from the whole-lake point-intercept surveys, Lost Lake's aquatic plant species diversity has been relatively consistent over time. In 2021, Simpson's diversity was at the 75th percentile at 0.90.

Figure 3.2-15 investigates the average number of native plant species at each littoral point-intercept sampling location. These data show slightly higher values in 2008-2010, and were relatively stable from 2011-2019. The 2021 survey indicated 0.92 native species per littoral sampling site. This is the lowest value recorded since monitoring began in 2007 and continues the downward trend which began in 2010.

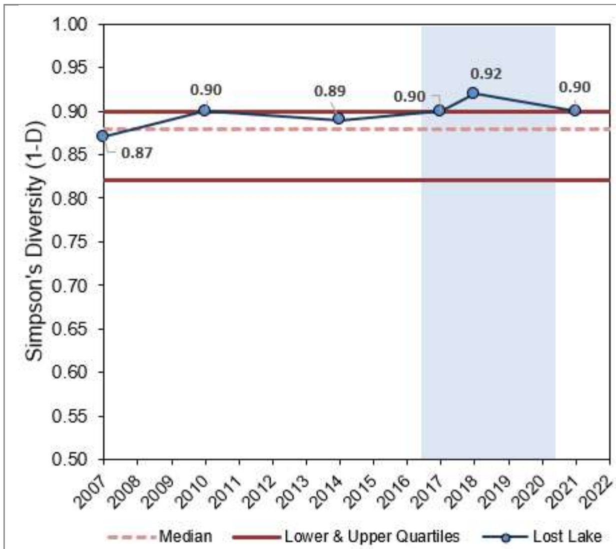


Figure 3.2-14. Lost Lake Simpson's Diversity Index. The shaded blue area signifies spot herbicide treatments in the western basin.

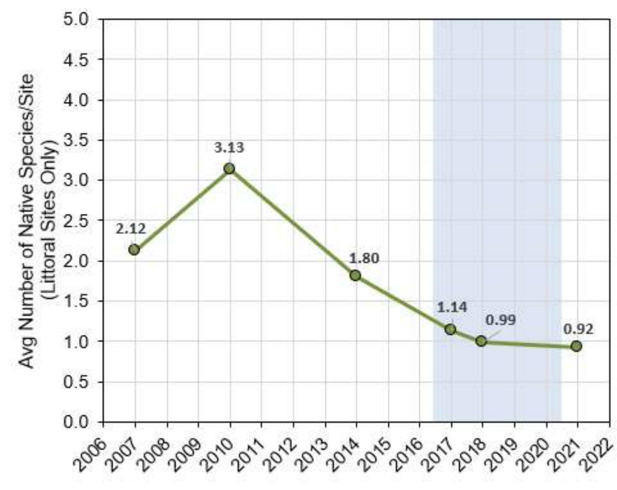


Figure 3.2-15. Average number of native aquatic plant species per littoral sampling site in Lost Lake. The shaded blue area signifies spot herbicide treatments in the western basin.

3.3 Water Quality Summary

The 2019 comprehensive management plan discussed the water quality of Lost Lake in as much detail as possible considering the inconsistency of the dataset. At the time, the water quality data from Lost Lake indicated that the lake is, on average, in good to excellent condition. The data did not reveal any trends over time, but did indicate large swings in values. For instance, water clarity was over 4 feet less than the average in 2017, which is hypothesized to be related to high precipitation, especially earlier in the growing season. Unfortunately, no water quality data exist between 2010 to 2017, a period when aquatic plant populations have been shown to generally decline. Additional information regarding water quality analysis and the relationship between the trophic parameters (phosphorus, chlorophyll-*a*, and Secchi disk transparency) can be found in the 2019 management plan. The general relationship between Lost Lake water quality, especially water clarity, and Lost Lake aquatic plants, are expanded on later in this section.

The last set of data available prior to the completion of the 2019 management plan was from 2017 and was collected as a part of that project. Since the completion of the 2019 project, very little additional water quality has been collected at Lost Lake, and includes several Secchi disk readings and a single sampling visit to the lake in July 2022 completed as a part of this planning project. These additional results are discussed below.

Lost Lake total phosphorus data are displayed in Figure 3.3-1. The July 2022 phosphorus reading from the deep-hole site was 44.1 µg/L, the weighted average from 1979 – 2022 is 34.4 µg/L. The 2022 phosphorus concentration is similar to the 2017 growing season mean and only slightly higher than the 2017 summer month mean. Overall, the 2017 and 2022 data are similar, and both considered to be "Good" for a shallow lowland drainage lake.

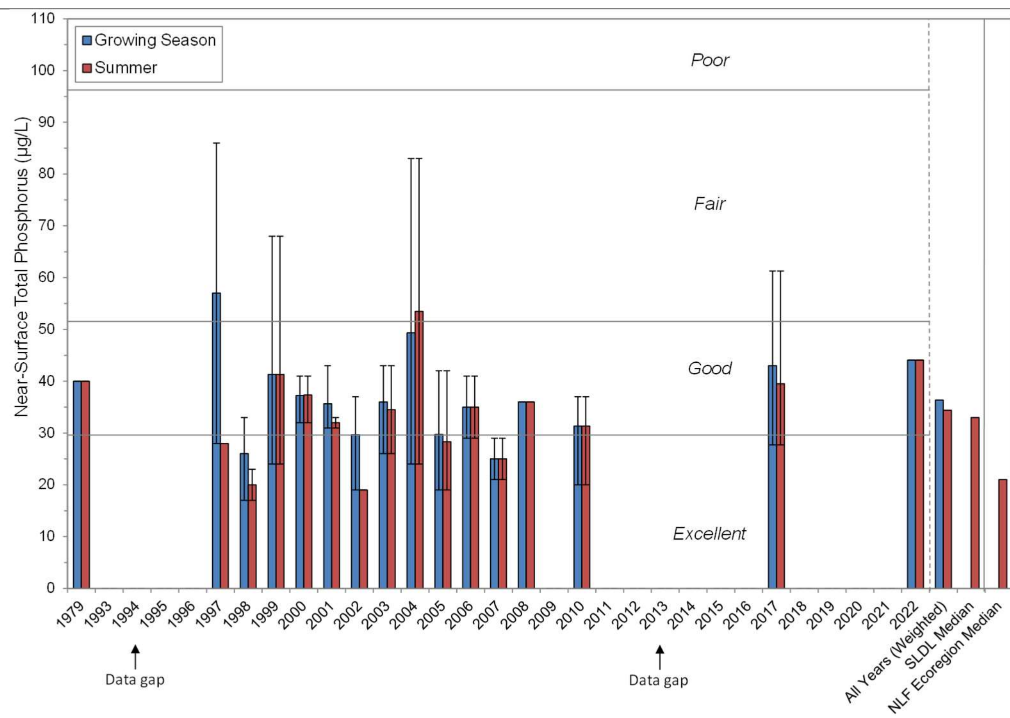


Figure 3.3-1. Lost Lake surface water total phosphorus concentrations. Mean values calculated with summer month surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

A near-bottom water sample was also collected during the July 2022 visit to Lost Lake. During that time, the lake was weakly stratified with anoxic to near-anoxic dissolved oxygen concentrations being recorded at depths 17-feet and below. The near-bottom water sample was collected at a depth of 17-feet and contained an elevated phosphorus concentration of 93.3 µg/L. As discussed in the 2019 management plan, shallow lakes, like Lost Lake, can go through multiple stratification-mixing events in a single growing season. Longer stratification periods can lead to an anoxic bottom layer (hypolimnion) with elevated phosphorus concentrations due to the release of phosphorus that is bound in the sediment during oxic conditions. Typically, the volume of the hypolimnetic layer is relatively small compared to the volume of the layers above it. If the lake stratified during the summer and only mixed once, there would not be much impact because even with the elevated phosphorus concentrations in the hypolimnion, the mass of phosphorus contained in the small volume of water would not lead to a significant addition to the total lake volume when mixed. However, as discussed in the 2019 plan, it appears that Lost Lake, during some growing seasons, goes through several stratification-mixing cycles, that when combined, significantly increase near-surface phosphorus levels. During these years, internal phosphorus loading may be a significant component in Lost Lake's phosphorus budget and may lead to mid- to late-summer algae blooms. Based upon the July 2022 dissolved oxygen-temperature profile and near-bottom phosphorus concentration, it appears that Lost Lake may have been experiencing a growing season with elevated phosphorus concentrations due to internal nutrient loading.

Lost Lake chlorophyll-*a* data are shown in Figure 3.3-2. As with the phosphorus data, the chlorophyll-*a* concentrations fluctuate widely within the dataset and within individual years. The values range from "Excellent" to "Fair" for shallow lowland drainage lakes. Lost Lake's mean value for the full dataset is in the lower "Good" category and higher than median values from lakes of the same type and all lakes found in the Northern Lakes and Forests ecoregion.

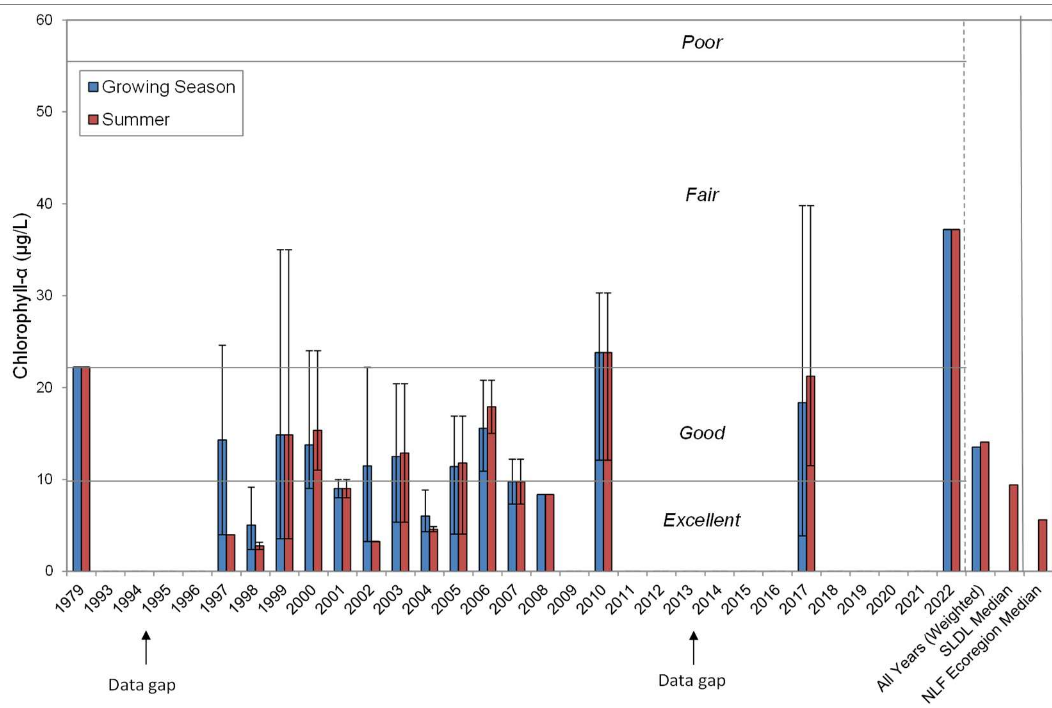
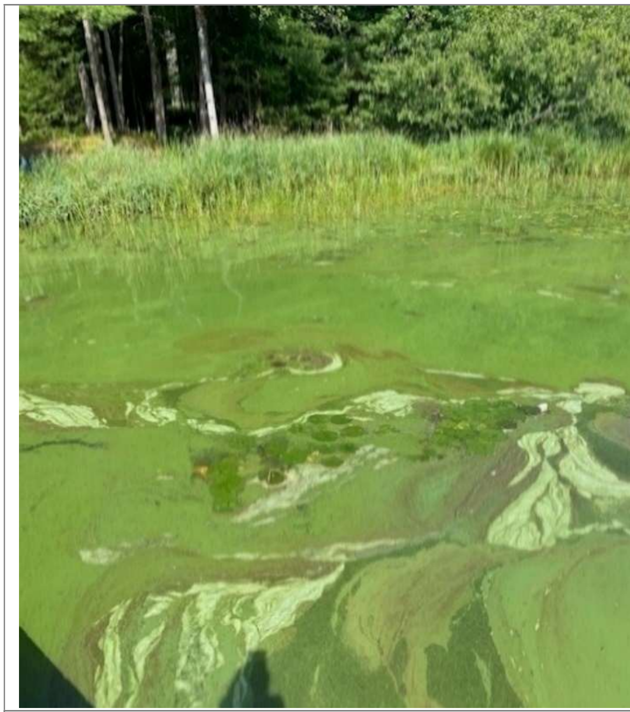


Figure 3.3-2. Lost Lake surface water chlorophyll-*a* concentrations. Mean values calculated with summer month surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

During the 2022 late-season EWM mapping survey, an Onterra crew met with a lake district member who observed an algae-bloom on Lost Lake the week prior (Mid-August). Photos were exchanged between the lake district member and Onterra staff who later confirmed the observation (Photograph 3.3-1).



Photograph 3.3-1. Blue-green algae bloom on Lost Lake summer 2022. Photo credit: Lost Lake Protection & Rehabilitation District. Photo taken 7/15/2022.

The July 2022 chlorophyll-*a* reading from the deep hole site was 37.2 µg/L, one of the highest results in the lake's dataset. The weighted average from 1979 – 2022 is 14.1 µg/L. Nuisance algal blooms typically occur when chlorophyll-*a* concentrations exceed 20 µg/L, so algal blooms were likely common during 2022, as many observed.

In many shallow, mixed lakes, like Lost Lake, the relationship between open water total phosphorus concentrations and that of chlorophyll-*a* can be weak because other factors, like macrophyte biomass, types of algae, water color, and concentrations of other macronutrients can play a significant role in the relationship. To understand the relationship, a large amount of consistently collected water quality must be available. The required level of data is not available for Lost Lake, but in most shallow lakes, with heavily forested watersheds, water color and aquatic plant biomass play a very important role. For instance, high macrophyte levels typically lead to reduced open water algae (phytoplankton) and lowered chlorophyll-*a* concentrations. This is the case because the macrophytes utilize some of the open water phosphorus, but more importantly, they create substrate for attached algae (periphyton) that also utilize open water phosphorus, reducing its availability to phytoplankton. Further, the macrophytes provide cover from fish predation for macroscopic crustaceans called zooplankton. Much like cows graze upon grass, zooplankton graze upon phytoplankton, reducing their abundance. When macrophyte biomass is low, these factors do not impact phytoplankton abundances and their biomass increases.

Unlike phosphorus and chlorophyll-*a* data, Secchi disk data (Figure 3.3-3) were collected in 2020 and 2021 with several readings collected in 2022. As suspected by lake property owners and Onterra ecologists, water clarity in 2022 was less than average for Lost Lake and was nearly half of the weighted mean Secchi disk reading of 6.4 feet. Lost Lake's weighted mean is slightly deeper than the median value from other shallow lowland drainage lakes, and shallower than lakes of all types within the ecoregion. Overall, the average is considered "Excellent" for shallow lowland drainage lakes.

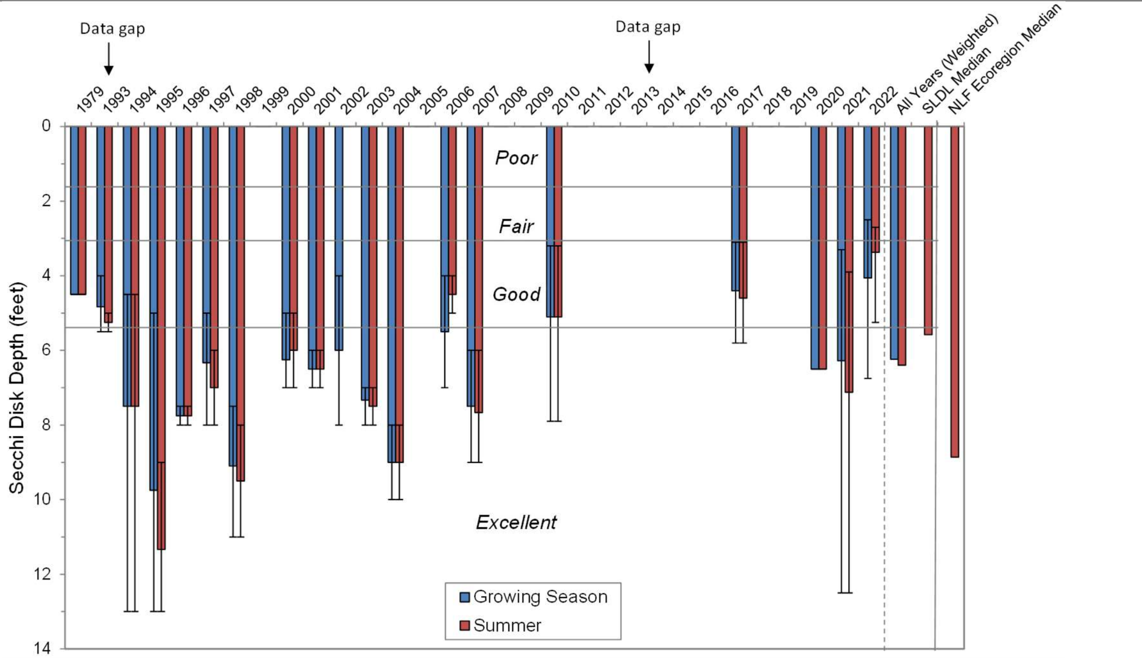


Figure 3.3-2. Lost Lake Secchi disk depths. Mean values calculated with summer month surface sample data. Water Quality Index values adapted from WDNR PUB WT-913.

Monthly Secchi disk data available from 2021 and 2022 can be found on Figure 3.3-4 along with average historical Secchi disk readings from Lost Lake. The 2022 Secchi disk measurements show turbid waters throughout the growing season, with measurements remaining shallower than the historical average readings for each month. During 2021, clarity was greater than average in the first half of the growing season and then became shallower during the second half. As previously discussed, some increases in aquatic plant biomass, especially deeper waters, was documented in 2021.

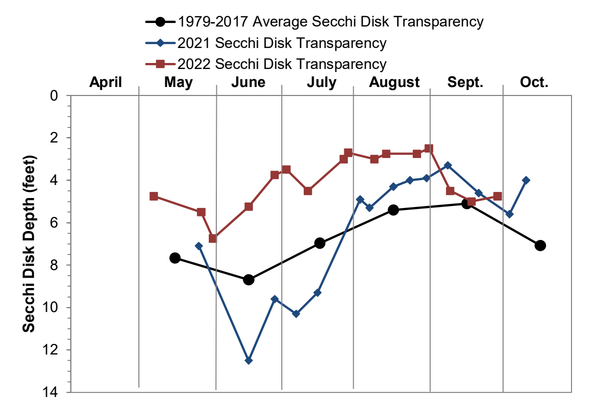


Figure 3.3-4. Secchi disk transparency values by month in Lost Lake.

During the 2019 planning project, 47% of district survey respondents stated that they believe water quality at Lost Lake has degraded to some degree since they first visited the lake. In the past few years, water quality degradation has been discussed at many district meetings and remains a concern among property owners. So little water quality data is available for Lost Lake during the past decade that it is impossible to determine if water quality is truly degrading or if this is just a temporary occurrence. The district is working to collect water quality data as a part of the WDNR Citizen Lake Monitoring Network, Advanced Water Quality Program, but participation is limited, especially in the Northwoods. It is important that data are consistently collected, so the district should consider paying out-of-pocket for analysis of volunteer-collected samples. The district should also consider an expanded, professional monitoring program to determine the extent of internal nutrient loading.

3.4 Non-native Aquatic Plants in Lost Lake

All the aquatic plant data discussed so far was collected as part of point-intercept surveys. The subsequent materials will also incorporate data from AIS mapping surveys. Additional explanation about how these two surveys differ is discussed below.

The point-intercept survey provides a standardized way to gain quantitative information about a lake's aquatic plant population through visiting predetermined locations and using a rake sampler to identify all the plants at each location (Photograph 3.4-1). The point-intercept survey can be applied at various scales. Most commonly, the point-intercept survey is applied at the whole-lake scale to provide a lake-wide assessment of the overall plant community. More focused point-intercept surveys, called sub-sample point-intercept surveys, may be conducted over specific areas to monitor an active management strategy such as herbicide treatments or mechanical harvesting. These types of sub-sample point-intercept surveys have been conducted as part of ongoing herbicide treatment monitoring.

Photograph 3.4-1. Conducting a point-intercept survey. Photo credit Onterra.

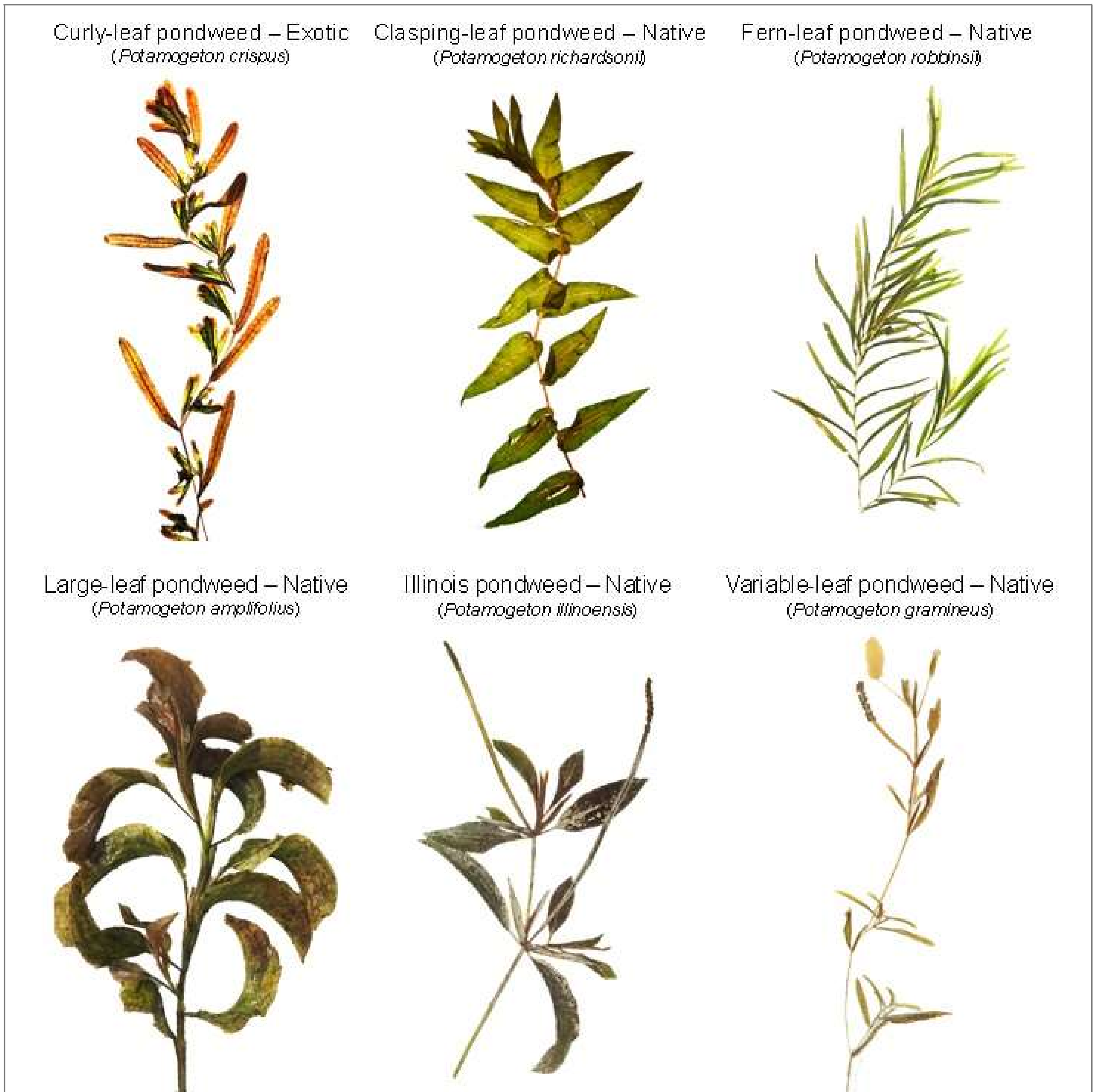
While the point-intercept survey is a valuable tool to understand the overall plant population of a lake, it does not offer a full account (census) of where a particular species exists in the lake. During the EWM or CLP mapping survey, the entire littoral area of the lake is surveyed through visual observations from the boat (Photograph 3.4-2). Field crews supplemented the visual survey by deploying a submersible camera along with periodically doing rake tows. The AIS population is mapped using sub-meter GPS technology by using either 1) point-based or 2) area-based methodologies. Large colonies >40 feet in diameter are mapped using polygons (areas) and are qualitatively attributed a density rating based upon a five-tiered scale from *highly scattered* to *surface matting*. Point-based techniques were applied to AIS locations that were considered as *small plant colonies* (<40 feet in diameter), *clumps of plants*, or *single or few plants*.

Photograph 3.4-2. Conducting an EWM mapping survey. Photo credit Onterra.

Overall, each survey has its strengths and weaknesses, which is why both are utilized in different ways as part of this project.

Curly-leaf Pondweed (Potamogeton crispus)

Curly-leaf pondweed (CLP) is a non-native, invasive submersed aquatic plant native to Eurasia. Like our native pondweeds, CLP produces alternating leaves along a long, slender stem. The leaves are linear in shape with a blunt tip, and the margins are wavy and conspicuously serrated (saw-like). The plants are often brownish/green in color. Lost Lake has a number of native pondweed species, some of which are similar in appearance to and may be mistaken for CLP (Photograph 3.4-3).



Photograph 3.4-3. Curly-leaf pondweed and native pondweed 'look-a-likes.' Featured species found in found in Lost Lake. Photo credit Onterra.

Photograph 3.4-4. Single CLP turion sprouting several new plants. Photo credit Onterra.

Like some of Wisconsin's native pondweeds, CLP's primary method of propagation is through the production of numerous asexual reproductive structures called turions. Once mature, these turions break free from the parent plant and may float for some time before settling and overwintering on the lake bottom. Once favorable growing conditions return (i.e., spring), new plants emerge and grow from these turions (Photograph 3.4-4). Many of the turions produced by CLP begin to sprout in the fall and overwinter as small plants under the ice. Immediately following ice-out, these plants grow rapidly giving them a competitive advantage over native vegetation. Curly-leaf pondweed typically reaches its peak biomass by mid-June, and following the production of turions, most of the CLP will naturally senesce (die back) by mid-July. For unknown reasons, CLP populations tend to persist longer in the growing season than on other WI lakes. As noted earlier CLP had present at 9.5% sampling locations during the July 29, 2021 point-intercept survey. The persistence of CLP throughout the growing season could have future management implications if it is determined that a significant amount of these plants are depositing reproductive turions well after the typical timing of the early-season herbicide control strategy.

The senescence of curly-leaf pondweed populations has been shown to release a significant amount of phosphorus into the water from decomposing plant tissues (Leoni et al. 2016). Modeled using the quantities and densities of curly-leaf pondweed from the 2016 survey, an estimated 51 pounds of phosphorus could be added to the water column. However, the location of the main curly-leaf pondweed population is in front of the Lost Lake outlet. Based on the herbicide concentration data collected in association with the 2017 and 2018 spot treatments, it is likely that the majority of these nutrients are sent downstream as opposed to contributing to the overall phosphorus concentration of the lake. If curly-leaf pondweed populations of similar size and density were located in the eastern part of the lake, its natural mid-summer die-off could be a source of nutrient loading.

In some lakes, CLP can reach growth levels which interfere with navigation and recreational activities. However, in other lakes, CLP appears to integrate itself into the plant community and does not grow to levels which inhibit recreation or have apparent negative impacts to the lake's ecology. plant community without becoming a nuisance or causing measurable impacts to the lake ecosystem. Acknowledging that possibility for Lost Lake, the LLPRD did not reactively conduct active management on the curly-leaf pondweed population in 2014-2016, rather monitored the population dynamics (Figure 3.4-1). In 2016, the CLP population expanded substantially and reductions in navigation and recreation were documented on Lost Lake. During the late-fall/winter of 2016-17, there were a number of correspondences between the district and Onterra discussing the possibility of conducting an herbicide control strategy during the spring of 2017. Factors such as environmentally toxicity of the treatment including likely native plant impacts, the need for multiple subsequent annual treatments, and potential regulatory opposition were weighed heavily. Following these discussions, the LLPRD board of directors supported pursuing an herbicide spot treatment targeting the largest and densest population of CLP during the spring of 2017.

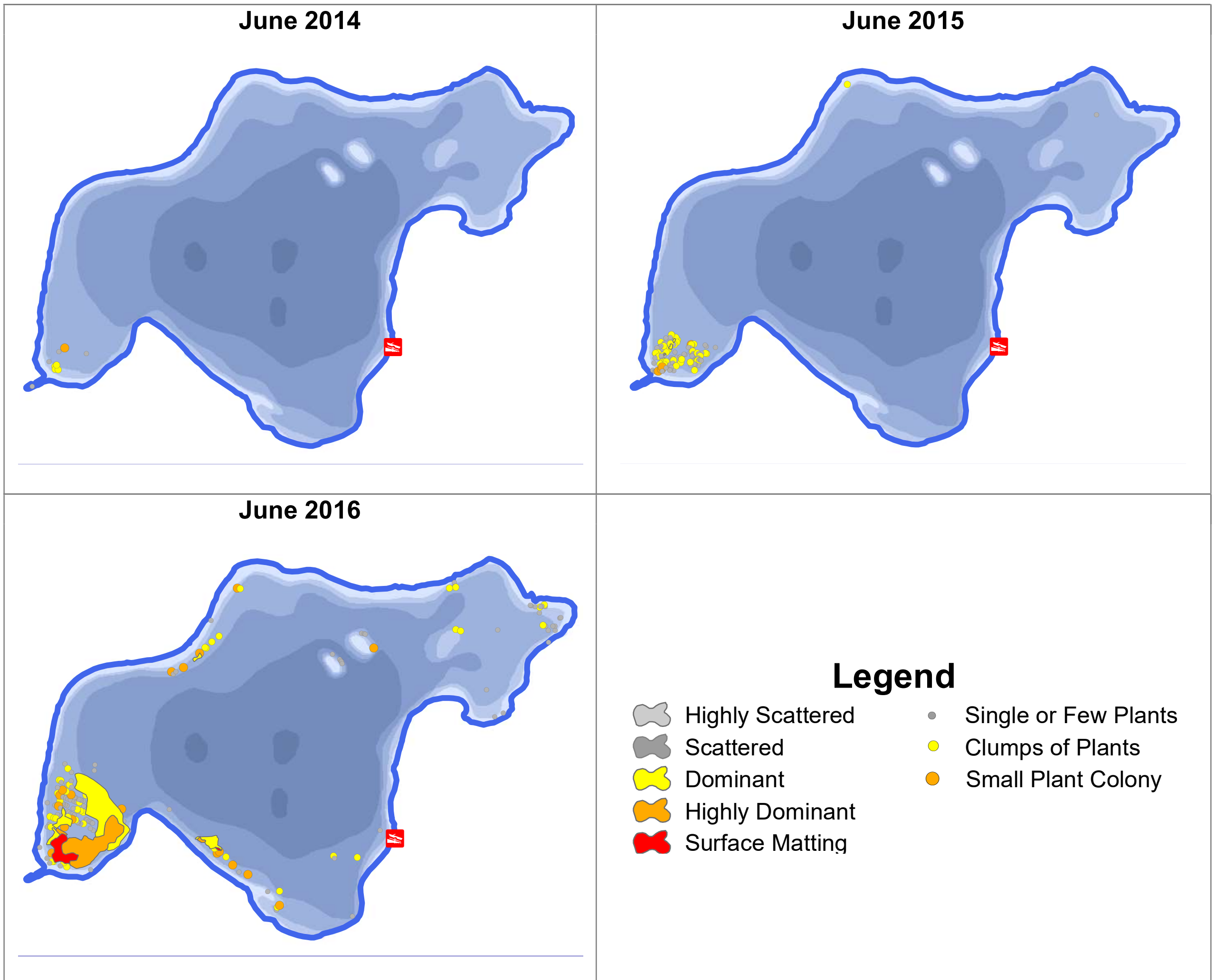


Figure 3.4-1. CLP population progression in Lost Lake from 2014-2016. CLP herbicide control program initiated in spring 2017.

Curly-leaf Pondweed Management Goals

The theoretical goal of CLP management is to kill the plants each year before they are able to produce and deposit new turions. Not all of the turions produced in one year sprout new plants the following year; many lie dormant in the sediment to sprout in subsequent years. This results in a sediment turion bank being developed. Traditionally a control strategy for an established CLP population includes 5-7 years of treatments of the same area to deplete the existing turion bank within the sediment (Johnson et al. 2012) (Skogerboe et al. 2008). In practice, it is unclear how many years CLP turions can remain viable and therefore the number of consecutive years treatments are required is unknown.

Johnson et al. (2012) investigated 9 midwestern lakes with established CLP populations that received five consecutive annual large-scale endothall treatments to control CLP. The greatest reductions in CLP frequency, biomass, and turions was observed in the first 2 years of the control program, but continued reductions were observed following all five years of the project. These lakes contained CLP for numerous years before the herbicide whole-lake treatment program began, likely containing a robust turion bank in the sediment. When treatments ceased after five years, CLP populations continued to be present indicating that five years was insufficient to fully exhaust the sediment turions. In instances where a large turion base may have already built up, lake managers and regulators question whether the repetitive annual herbicide strategies may be imparting more strain on the environment than the existence of the invasive species. Because CLP has only been present in Lost Lake for a few years during 2017, some theorized that the turion base would be small and if a control program was initiated at this time and may not require as many successive treatments as a more established population would.

Consistent with their WDNR-approved *Comprehensive Management Plan,* the LLPRD was able to secure WDNR grant funds to partially fund CLP-directed herbicide treatment and monitoring from 2017-2020. The four herbicide treatments were aggressively monitored to understand 1) pretreatment CLP population (surrogate for measuring turion sprouting), 2) herbicide concentrations at various locations and time periods after treatment, 3) CLP efficacy, 4) native plant impacts. Highlights of these data are discussed in the subsequent sections, with more details available in each years' respective annual *Monitoring & Management Report.*

2017-2020 Herbicide Concentration Monitoring Summary

Endothall is an aquatic herbicide that is applied as either a dipotassium salt or an amine salt. These active ingredients break down following application to endothall acid, the form that acts as an herbicide (Netherland 2009). In association with the 2017-2020 CLP treatments, an herbicide concentration monitoring plan was developed jointly by Onterra and the WDNR, sampling multiple locations at various intervals after treatment. For reference, the Lost Lake treatments used the dipotassium salt at a concentration of 2.0 ppm active ingredient (ai) in 2017-2018, and 1.5 ppm ai in 2019-2020. When broken down into the acid, 1.5 and 2.0 ppm ai equates to 1.065 and 1.42 ppm acid equivalent (ae), respectively.

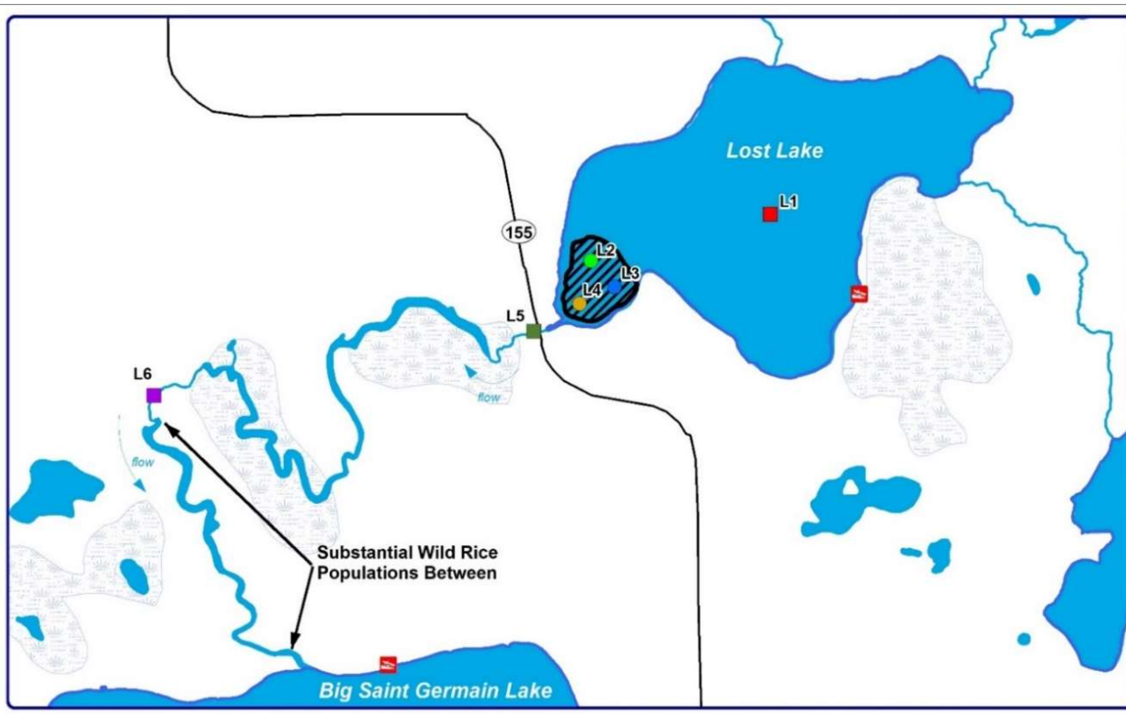


Figure 3.4-2. Herbicide concentration monitoring locations from the 2017-2020 endothall treatments. General location of wild rice population provided by GLIFWC.

Figure 3.4-3 displays the results of the herbicide concentration monitoring from samples collected within the application area during each of the four years spanning 2017-2020. Data in the following section are discussed in regards to hours after treatment (HAT) or days after treatment (DAT).

After 2017, the monitoring period was extended from 72 HAT to 14 DAT. Target concentrations were lowered slightly from 1.42 ppm ae in 2017-2018 to 1.065 ppm ae in 2019-2020 to account for the ability of the local District to manipulate the outlet dam that controls water flow out from Lost Lake thereby maximizing herbicide concentration exposure times. Initial concentrations, collected at 2 HAT or 4 HAT have rarely approached or exceeded the target application rates. By 24 HAT in each year, concentrations were measured at or below 0.25 ppm ae. Endothall concentrations were below detection limits by 14 DAT in each of three years in which samples were collected.

The herbicide concentrations from samples collected at the adjacent outlet (L5) approximately mirror the concentrations from within the application area during each year. Samples collected in the earliest intervals (2 HAT or 4 HAT) tend to be lower than in the treated area as the herbicide takes time to move in the direction of the water flow towards the outlet.

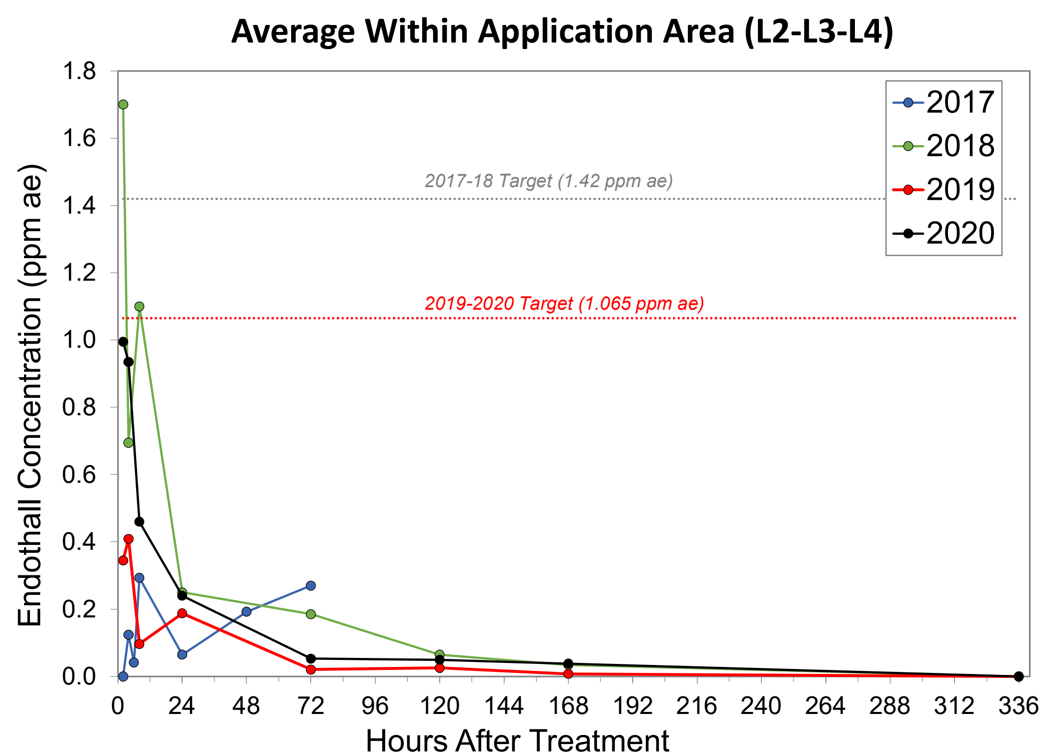


Figure 3.4-3. Average endothall concentrations of the 2017-2020 endothall treatments.

Northern wild rice (*Zizania palustris*) is a valuable emergent grass found downstream of Lost Lake in the Lost Creek. In addition to the ecosystem services this plant provides, it also holds great cultural significance to the Native American communities of this area. The state of Wisconsin works actively with tribal regulatory authorities to review all activities that have the potential to negatively impact wild rice populations. While the use of herbicides to control aquatic invasive species has broad intentions of benefiting the lake ecosystem, the herbicides may have the capacity to impact non-target plants such as wild rice.

Monitoring samples have been collected from a downstream sampling location in Lost Creek (L6) during each year. The collection point is approximately at the start of a wild rice population in the Creek. During all four years, samples collected at 3 DAT (72 HAT) had the highest levels of endothall detected with minimal endothall present in intervals collected immediately before or after at 1, 2, or 5 DAT (Figure 3.4-4). The endothall concentrations that were documented in Lost Creek are lower and for a shorter duration than what the published literature documents as having impacts to wild rice (Nelson et al. 2003) (Madsen et al. 2008). However, even the sub-lethal exposure of tribal food sources to herbicides is concerning.

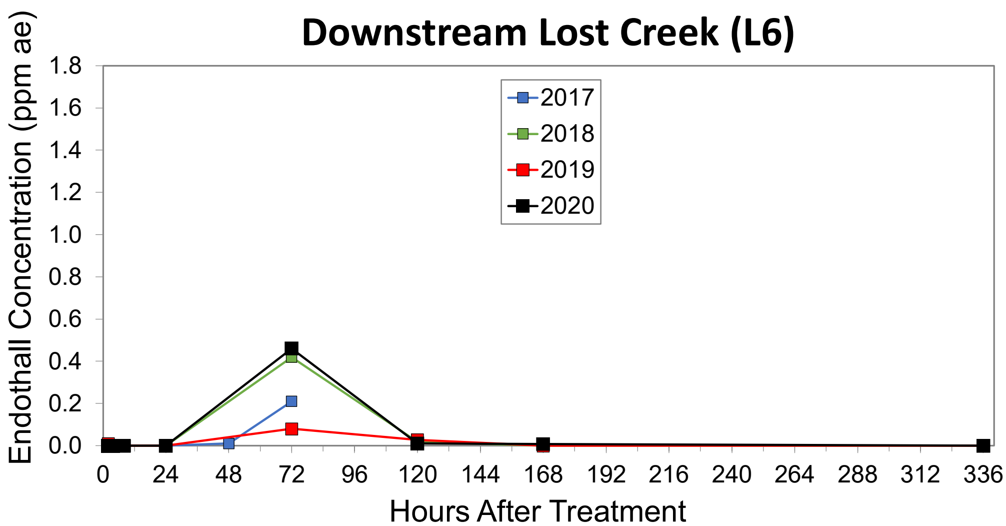


Figure 3.4-4. Downstream (L6) herbicide concentration results from 2017-2020 endothall treatments.

Based on published literature, 3 DAT corresponds roughly with when a lake will reach a whole-lake equilibrium herbicide concentration. In 2017, a single sample was collected at 3 DAT from the center of the lake location. In subsequent years, an earlier (24 HAT) and series of later sampling events were added to the sampling plan. Figure 3.4-6 displays the herbicide concentration monitoring results from samples collected from the center of the lake monitoring site. Note that the y-axis of this figure is 10 times less than the same axis on the previous figures that looked at concentrations within the application area and downstream. Samples collected at 3 DAT were 0.009 in 2017, 0.011 in 2018, 0.058 in 2019, and 0.066 in 2020. Endothall was not detected in any samples collected during any year of monitoring at either 24 HAT or 14 DAT.

For whole-lake CLP treatments, the manufacturers of endothall (UPI) recommend whole-lake target concentrations of 0.53 ppm ae (0.75 ppm ai) to 0.71 ppm ae (1.0 ppm ai). This is approximately an order of magnitude (10X) greater than the measured concentrations from Lost Lake. Based on the measured endothall concentrations observed in the center of the lake, the impacts of the spot treatments are anticipated to be confined to the approximate area of the application area (Figure 3.4-5).

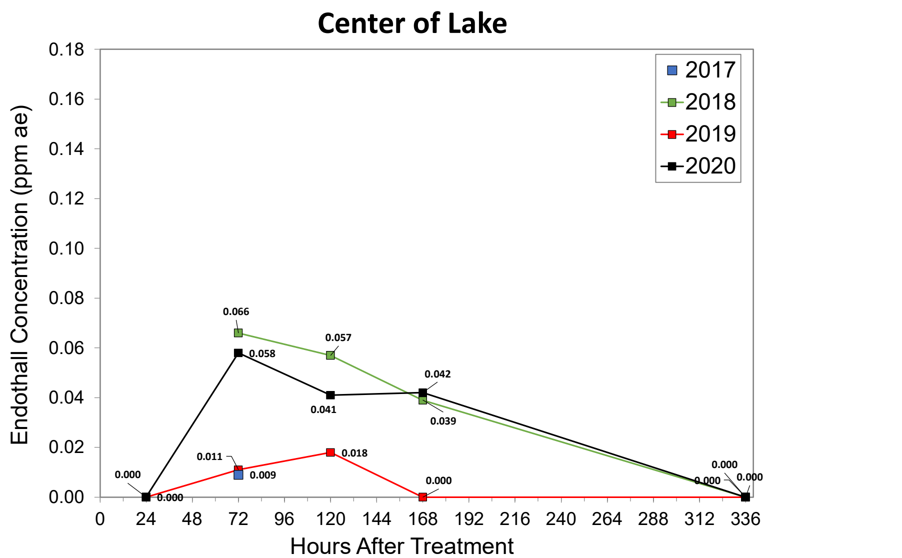
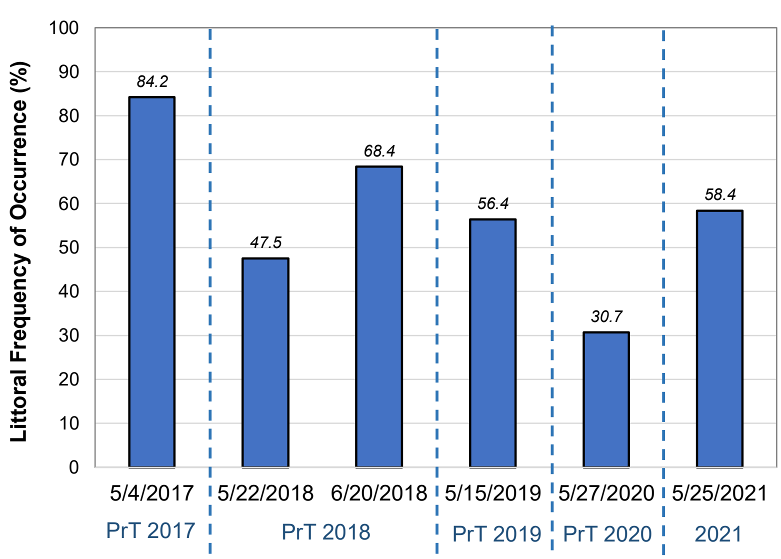


Figure 3.4-5. Center of the lake herbicide concentration results from 2017-2020 endothall treatments.

Spring sub-sample point-intercept surveys

The sub-sample survey was collected from 101 sampling points located directly within the area where herbicide is applied (Figure 3.4-6). This quantitative data allows for an understanding of how many turions sprouted that spring, a surrogate metric to determine if the turion base is reducing over time. If it is, that means that the management program is having an impact. As outlined in the Lost Lake *Comprehensive Management Plan*, the pretreatment sub-sample point-intercept is also part of the mechanism to determine if a treatment is warranted in a given year with 30% CLP occurrence specified as being a threshold for considering herbicide management. The timing of this spring survey is too early in the growing season for use in assessing native aquatic plant species.



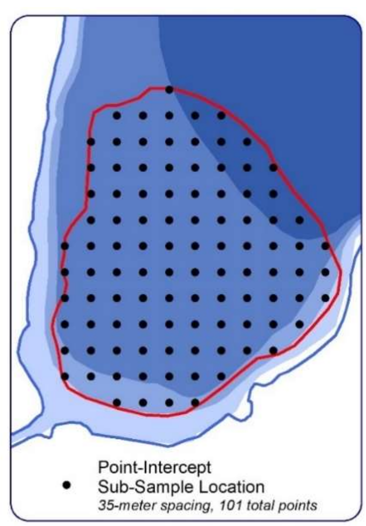


Figure 3.4-6. Pretreatment CLP LFOO in the 2017-2021 sub-sampling survey. (N=101). Blue lines separate pretreatment years.

The pre-treatment occurrence of CLP had decreased each year from 2017 when the occurrence was 84.2%, to 30.7% in 2020 suggesting that fewer viable CLP turions were present as the multi-year control program progressed (Figure 3.4-6). The occurrence of CLP of 58.4% in 2021 was higher than the previous year and indicates that despite four consecutive years of herbicide treatment, a significant population of viable CLP turions remains present in the site.

CLP Mapping Survey Results

Onterra ecologists have completed a CLP mapping surveys in Lost Lake annually during June from 2013-2021. The 2016 survey represents the last time the entire CLP population was assessed prior to the multi-year herbicide control program spanning 2017-2020 (Figure 3.4-7). CLP mapping surveys were conducted annually from 2017-2020 in the main body of the lake, while intentionally omitting the west bay from the survey areas during these years due to the fact that the herbicide treatment had recently taken place. The 2017-2020 mapping surveys have found a relatively modest CLP population outside of west bay with a few areas along the northern shoreline of the lake beginning to consistently harbor colonized populations.

The mid-June 2021 CLP mapping survey was the first time CLP had been mapped in Lost Lake in absence of herbicide management since 2016. Survey crews noted higher water clarity than recent years at the time of the survey and recorded a Secchi disk reading of 10.2 feet on June 15. Figure 3.4-8 compares the CLP population in the west bay of the lake which has been the target of annual herbicide treatments from 2017-2020. The 2021 survey indicated that essentially the entire management site contained *scattered* or *dominant* density CLP with no areas mapped as either *highly dominant* or *surface matted*. The survey results indicate the continued presence of a robust viable turion base in the site.

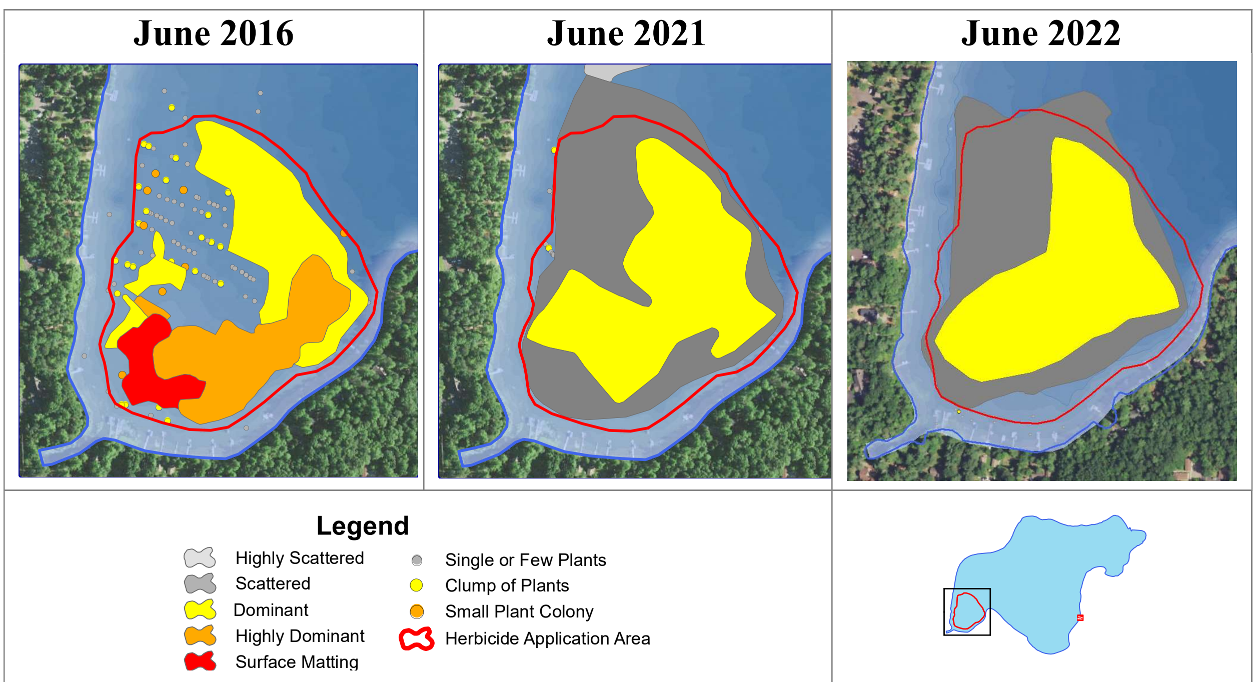


Figure 3.4-7. CLP population in the west bay of Lost Lake during June 2016 and June 2021. Data from Onterra CLP Mapping Surveys. Herbicide management targeting CLP occurred annually from 2017-2020.

The 2021 mapping survey found CLP was present in relatively low densities around many other littoral areas of Lost Lake (Map 2). In total, 41.1 acres of colonized CLP was mapped within Lost Lake during the 2021 survey of which approximately 29 acres was within the west bay of the lake. Outside of the western bay, no other colonies around the lake consisted of *dominant* or greater density ratings.

Onterra ecologists completed an Early-Season EWM Mapping Survey on June 28, 2022. Much of the CLP population in the lake was low growing and difficult to observe visually from the surface. Onterra field crews used rake tows and submersible camera transects to assist in the survey. The largest concentration of CLP in the lake was within the western bay where most of the bay has contained colonized CLP over the past few years (Map 3, Figure 3.4-7). One large dense, *dominant*, colony surrounded by a scattered colony was found in the western bay in 2022 while other smaller *dominant* and *scattered* colonies were discovered in other areas of the lake. The density of the CLP population has remained about the same within the western bay when comparing the 2022 to the 2021 survey results (Figure 3.4-7). Continued monitoring of the lake-wide CLP population of Lost Lake indicate that other areas of the lake continues to hold low-density populations (Map 3).

Riparian Stakeholder Survey Responses to curly-leaf pondweed within Lost Lake

As discussed in section 2.0, the riparian stakeholder survey asks many questions pertaining to perception of the lake and how those that own property on the system believe it may have changed over the years. The return rate of the survey was above 61%. In instances where stakeholder survey response rates are 60% or above, the results can be interpreted as being a statistical representation of the entire population offered the survey. When asked how often CLP aquatic plant growth, during the open water season, natively impacts the enjoyment of Lost Lake (Figure 3.4-8).

23b. Has curly-leaf pondweed (CLP) ever had a negative impact on your enjoyment of Lost Lake?

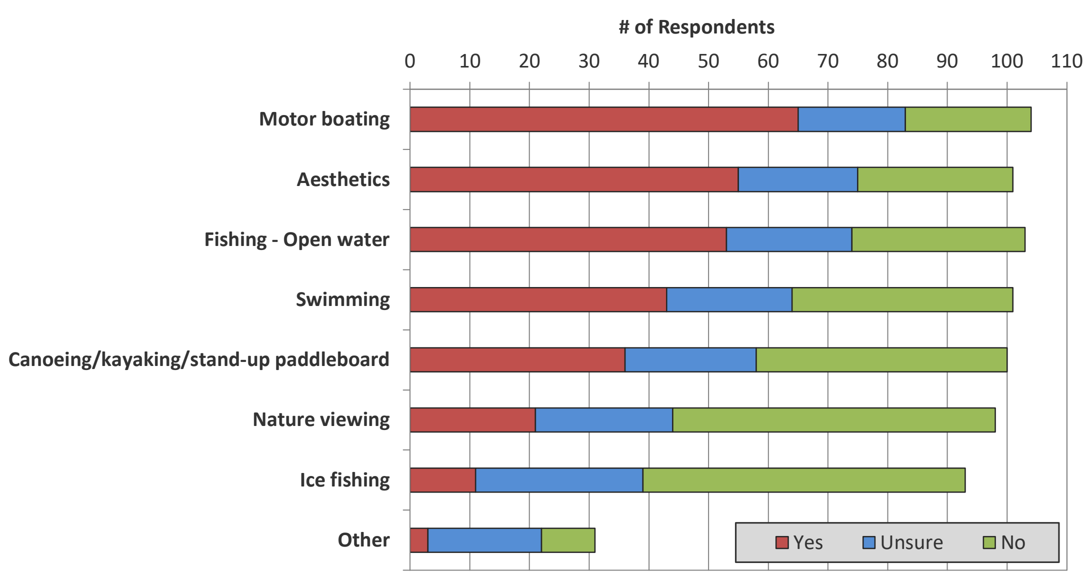


Figure 3.4-8. Select survey responses from the LLPRD Riparian stakeholder survey. Additional questions and response charts may be found in Appendix B.

Curly-leaf pondweed (CLP) was first discovered in Lost Lake in 2014. Following its discovery, the Lost Lake Protection & Rehabilitation District (LLPRD) received a WDNR Early Detection and Response Grant to conduct multiple annual herbicide treatments in 2017, 2018, 2019, and 2020 to manage this pioneering population. Figure 3.4-9 displays the responses of Lost Lake stakeholders and how they felt about the previous herbicide spot treatments.

Question 24: What is your level of support or opposition for the past use of aquatic herbicides to treat CLP in previous years?

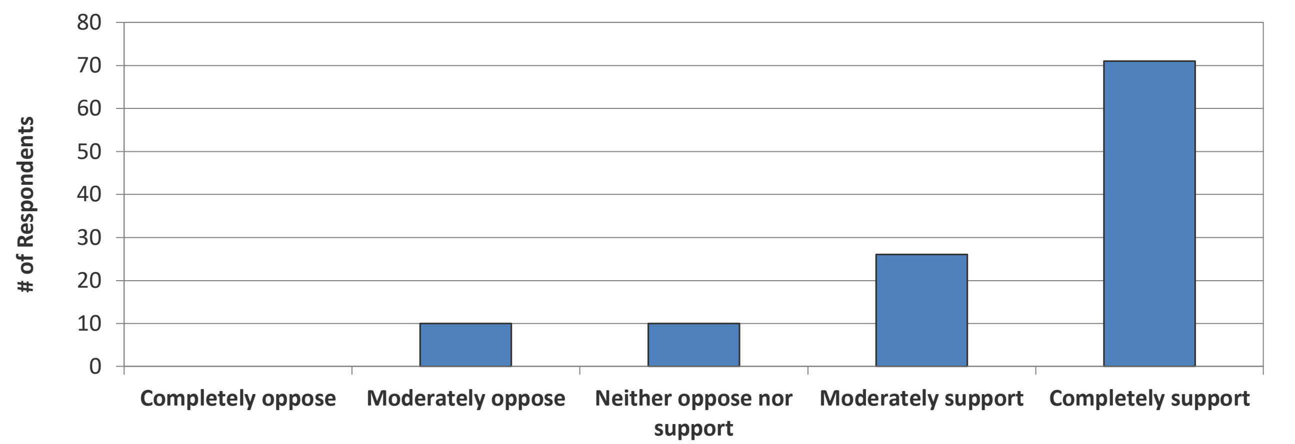
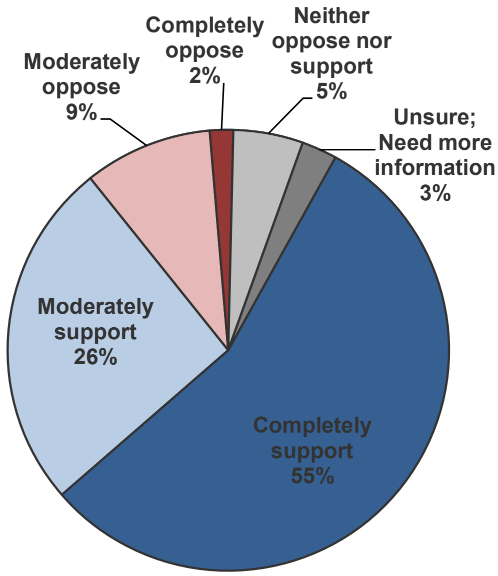


Figure 3.4-9. Select survey responses from the LLPRD Riparian stakeholder survey. Additional questions and response charts may be found in Appendix B.

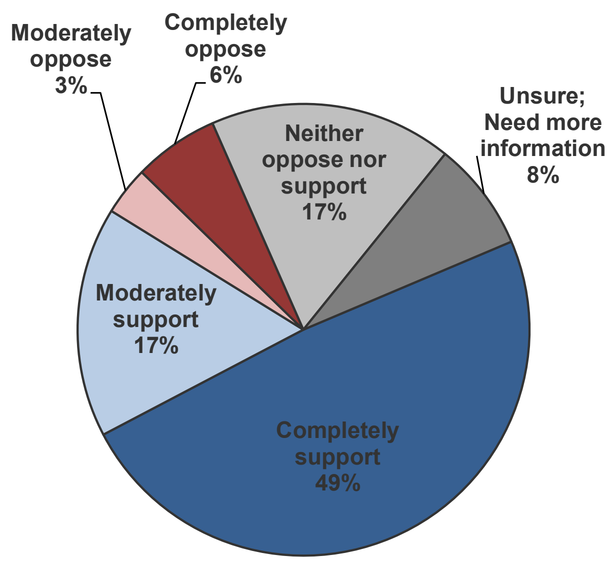
The planning committee wanted to understand the stakeholders' perceptions on the future use of various active management techniques (Figure 3.4-10). Overall, stakeholders overwhelmingly were in favor for supporting mechanical harvesting and herbicide treatments while they were opposed to no active management.

Question 25: Now that the CLP population is past a pioneering stage (the initial time period before an invasive species becomes established), what is your level of support for the future use of the following CLP management techniques in Lost Lake?

Continue chemical treatments



Mechanical harvesting (i.e., weed cutter)



No active management (continue monitoring)

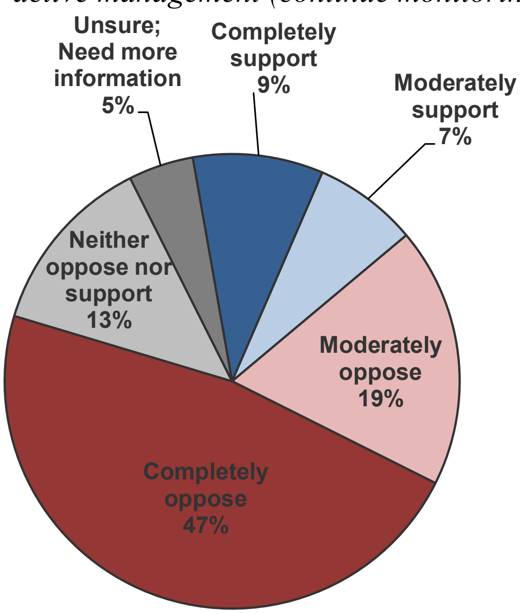


Figure 3.4-10. Select survey responses from the LLPRD Riparian stakeholder survey. Additional questions and response charts may be found in Appendix B.

Eurasian watermilfoil (Myriophyllum spicatum)

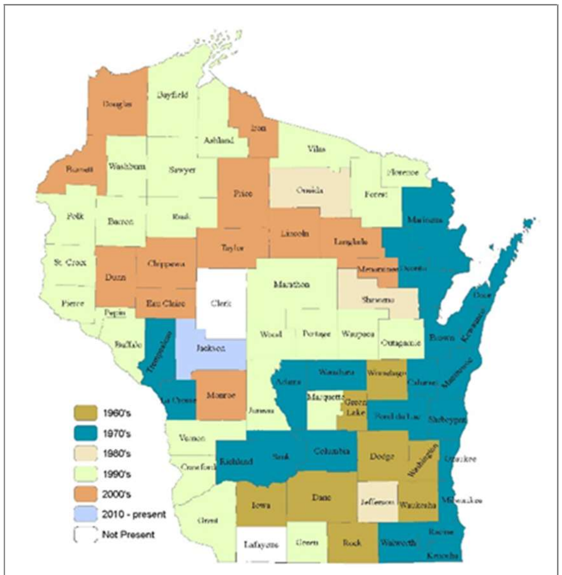


Figure 3.4-11. Spread of EWM within WI counties. WDNR Data 2022 mapped by Onterra.

Eurasian watermilfoil (EWM is an invasive species, native to Europe, Asia and North Africa, that has spread to most Wisconsin counties (Figure 3.4-11). Eurasian watermilfoil is unique in that its primary mode of propagation is not by seed. It actually spreads by shoot fragmentation, which has supported its transport between lakes via boats and other equipment. In addition to its propagation method, Eurasian watermilfoil has two other competitive advantages over native aquatic plants, 1) it starts growing very early in the spring when water temperatures are too cold for most native plants to grow, and 2) once its stems reach the water surface, it does not stop growing like most native plants, instead it continues to grow along the surface creating a canopy that blocks light from reaching native plants. Eurasian watermilfoil can create dense stands and dominate submergent communities, reducing important natural habitat for fish and other wildlife, and impeding recreational activities such as swimming, fishing, and boating. However, in some lakes, EWM appears to integrate itself within the community without becoming a nuisance or having a measurable impact to the ecological function of the lake.

Between 2007 and 2009, Eurasian water milfoil (EWM, *Myriophyllum spicatum*) was suspected to be in Lost Lake but its presence was not confirmed until 2013. During the 2013 growing season, a member of the lake association found a suspicious watermilfoil plant which was later confirmed by the Vilas County Land and Water Conservation Department to be EWM. In 2013, Onterra sent in a single invasive watermilfoil samples from Lost Lake to Grand Valley State University (Dr. Ryan Thum) for genetic testing using a Rapid Assay Method (ITS). This test indicates whether the sample is northern watermilfoil, EWM, or a hybrid of the two (HWM). This sample was confirmed as pure-strain EWM.

The concept of heterosis, or hybrid vigor, is important in regards to EWM management in Lost Lake. The root of this concept is that hybrid individuals typically have improved function compared to their pure-strain parents. In general, hybrid watermilfoil (*M. spicatum* x *sibiricum*) typically has thicker stems, is a prolific flowerer, and grows much faster than pure-strain EWM (LaRue et al. 2012). These conditions may likely contribute to this plant being particularly less susceptible to chemical control strategies (Glomski and Nehterland 2010), (Poovey et al. 2007), (Nault et al. 2018). In lakes that contain both EWM and hybrid watermilfoil (HWM), concern exists that the more-easily controlled EWM component of a lake's invasive milfoil population may be controlled by herbicide treatment, but the slightly less-susceptible HWM component will survive, rebound in a short period of time, and then comprise a larger proportion of the invasive milfoil population.

WDNR Long-Term EWM Trends Monitoring Research Project

Starting in 2005, WDNR Science Services began conducting annual point-intercept aquatic plant surveys on a set of lakes to understand how EWM populations vary over time (M. Nault 2016). This was in response to commonly held beliefs of the time that once EWM becomes established in a lake, its population would continue to increase over time.

Like other aquatic plants, EWM populations are dynamic and annual changes in EWM frequency of occurrence have been documented in many lakes, including those that are not being actively managed for EWM control (no herbicide treatment or hand-harvesting program). The data are clearest for unmanaged lakes in the Northern Lakes and Forests Ecoregion (NLF) and the North Central Hardwood Forests Ecoregion (NCHF) (Figure 3.4-12).

The results of the study clearly indicate that EWM populations in unmanaged lakes can fluctuate greatly between years (Figure 3.4-12). Following initial infestation, EWM expansion was rapid on some lakes, but overall was variable and unpredictable (Nault, 2016). On some lakes, the EWM populations reached a relatively stable equilibrium whereas other lakes had more moderate year-to-year variation. Regional climatic factors also seem to be a driver in EWM populations, as many EWM populations declined in 2015 even though the lakes were at vastly different points in time following initial detection within the lake. 2019 also experienced record rainfall which may have had an impact on the EWM population indirectly through a decrease in water clarity.

Eurasian watermilfoil (Photograph 3.4-5) was first documented in Lost Lake in 2013. Eurasian watermilfoil populations on Lost Lake were initially targeted through professional hand-harvesting activities (2013-2015). The hand-harvesting provided modest reductions in the areas where the hand-harvesting occurred, but the Eurasian watermilfoil population increase was greater than the amount of Eurasian watermilfoil that was being removed each year (Figure 3.4-14). Specific information regarding the hand-harvesting program is included within each years' *AIS Monitoring & Control Strategy Assessment Report.* Once the population exceeded a threshold where these activities were thought to no longer be feasible, the LLPRD opted to discontinue further active management until it understands if the Eurasian watermilfoil population will continue to increase or if it will plateau at a level where the ecosystem function and navigation, recreation, and aesthetics are not impeded. The decision to cease active management of the Eurasian watermilfoil population was partially based on the WDNR Eurasian watermilfoil Long-Term Trends Monitoring Program.

Photograph 3.4-5. Eurasian watermilfoil, a non-native, invasive aquatic plant. Photo credit Onterra.

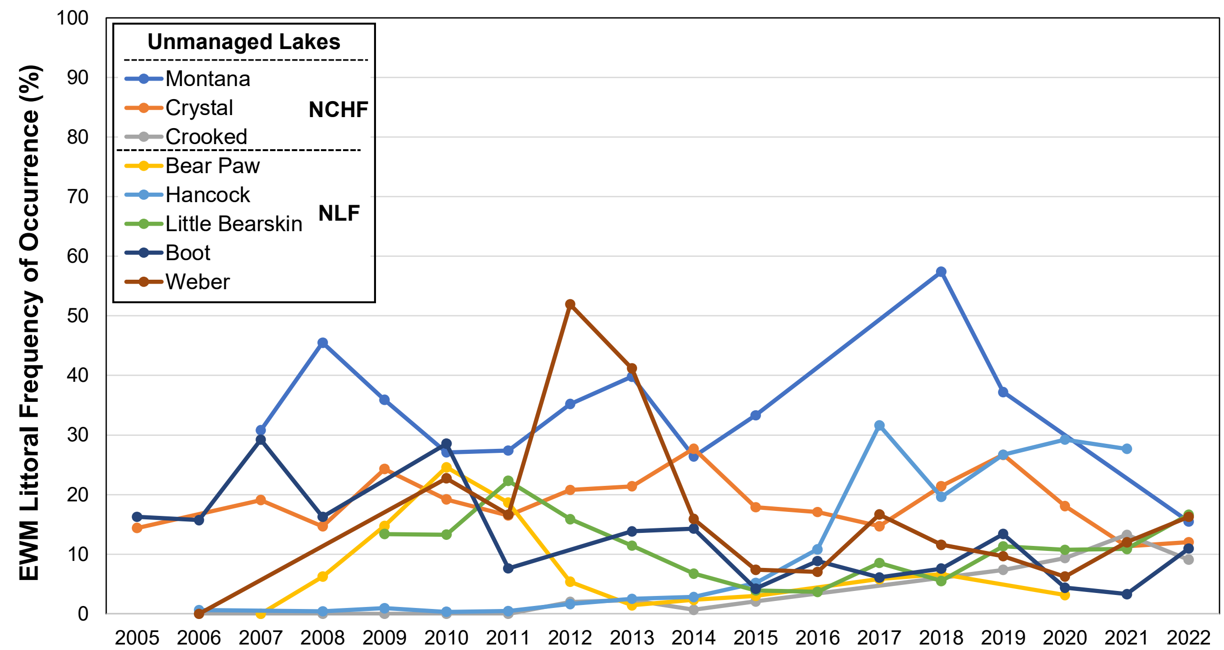


Figure 3.4-12. LFOO of EWM in the NLF and NCHF Ecoregions without management. Data provided by and used with permission from WDNR.

EWM population of Lost Lake

Eurasian watermilfoil populations on Lost Lake were initially targeted through professional hand-harvesting activities (2013-2015). The hand-harvesting provided modest reductions in the areas where the hand-harvesting occurred, but the EWM population expansion quickly out-paced the removal efforts. Once the population exceeded a scale where these activities were thought to be applicable, the LLPRD opted to discontinue further active management until it understands if the EWM population will continue to increase or if the population will plateau at a level where the ecosystem function is not altered and navigation, recreation, and aesthetics are not impeded.

Onterra ecologists completed a Late-Season EWM Mapping Survey on August 23, 2022. Survey crews has talked to a lake association member who mentioned there was a blue-green algae bloom on the lake a week prior. Field crews looked at photos of the bloom and verified the members observation. Much of the EWM population in the lake was either approaching the water's surface making for easy identification or low growing and difficult to observe visually from the surface. The largest concentration of EWM in the lake was within the eastern bay where most of the bay contained colonized EWM over the past few years (Map 4, Figure 3.4-13). Multiple dense, *dominant* and *highly dominant*, colonies surrounded a shallow submersed rocky area and other areas on the eastern side of the lake which corresponds to the approximate area where EWM was initially discovered in the lake. The density of the EWM population decreased within areas of the eastern bay with more colonies consisting of either *dominant* or lower densities outside of the eastern bay compared to the 2021 survey results/

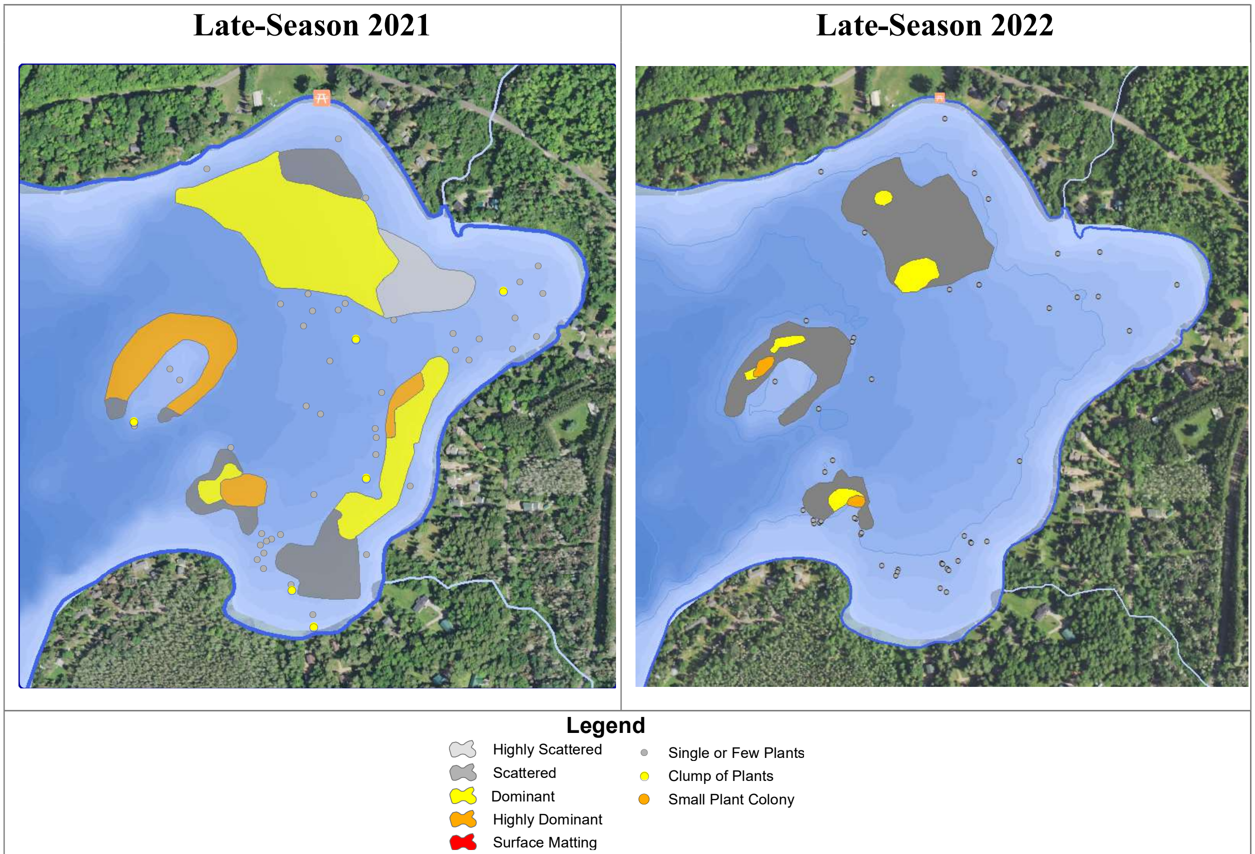


Figure 3.4-13. Late-Season EWM locations in the eastern bay of Lost Lake from 2021-2022. Data from annual Onterra Late-Season EWM Mapping Surveys.

The LLPRD has expressed concerns over the increasing EWM population and have begun to observe localized impacts to navigability where EWM has grown densest. Annual mapping surveys over the past several years indicated the EWM population has shown some signs of expansion around Lost Lake, with the largest concentration of plants residing in portions of the eastern bay and southern shore of the lake. The 2022 Late-Summer EWM Mapping Survey indicated 31.2 acres of EWM within Lost Lake, representing a decrease in population from the 2021 survey (Figure 3.4-14). Of the EWM colonies mapped during 2022, 3.4 acres consisted of a *dominant* density rating with another 0.3 acres of *highly dominant* densities. It is important to note that the acreages reflected on Figure 5.0-2 only account for EWM mapped with area-based methodologies (polygons) and any point-based mapping occurrences (points) do not contribute to the acreage totals. The littoral frequency of occurrence of Eurasian watermilfoil in 2021 whole-lake point-intercept survey resulted in a 15.1% occurrence compared to 8.8% in 2018 and 2.4% in 2017 (Figure 3.4-15).

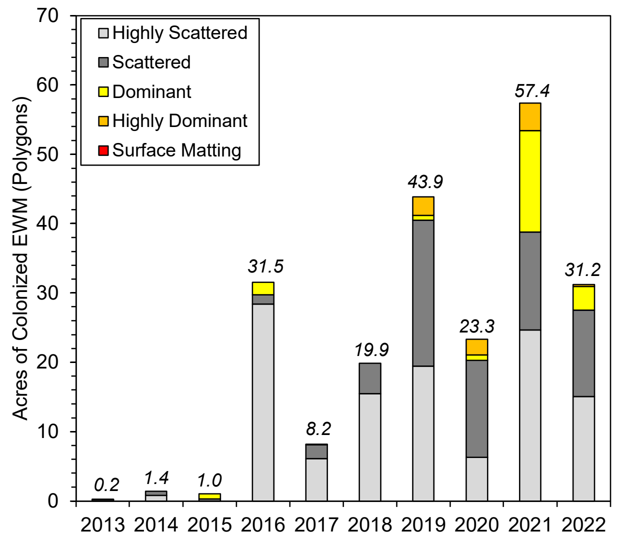


Figure 3.4-14. Acres of EWM colonies in Lost Lake from 2013-2021. Data from annual Onterra Late-Season EWM Mapping Surveys.

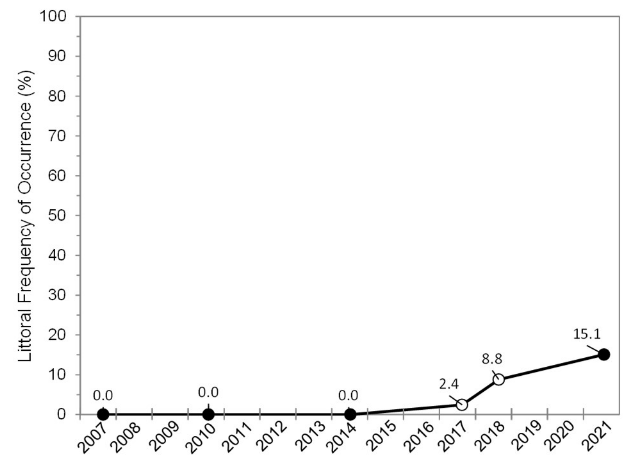


Figure 3.4-15. Littoral frequency of occurrence of EWM in Lost Lake. Open circle represents statistically valid change from previous survey (Chi-Square α = 0.05).

Riparian Stakeholder Survey Responses to Eurasian watermilfoil within Lost Lake

As discussed in section 2.0, the riparian stakeholder survey asks many questions pertaining to perception of the lake and how those that own property on the system believe it may have changed over the years. When asked how often EWM aquatic plant growth, during the open water season, natively impacts the enjoyment of Lost Lake (Figure 3.4-16).

23a. Has Eurasian watermilfoil (EWM) ever had a negative impact on your enjoyment of Lost Lake?

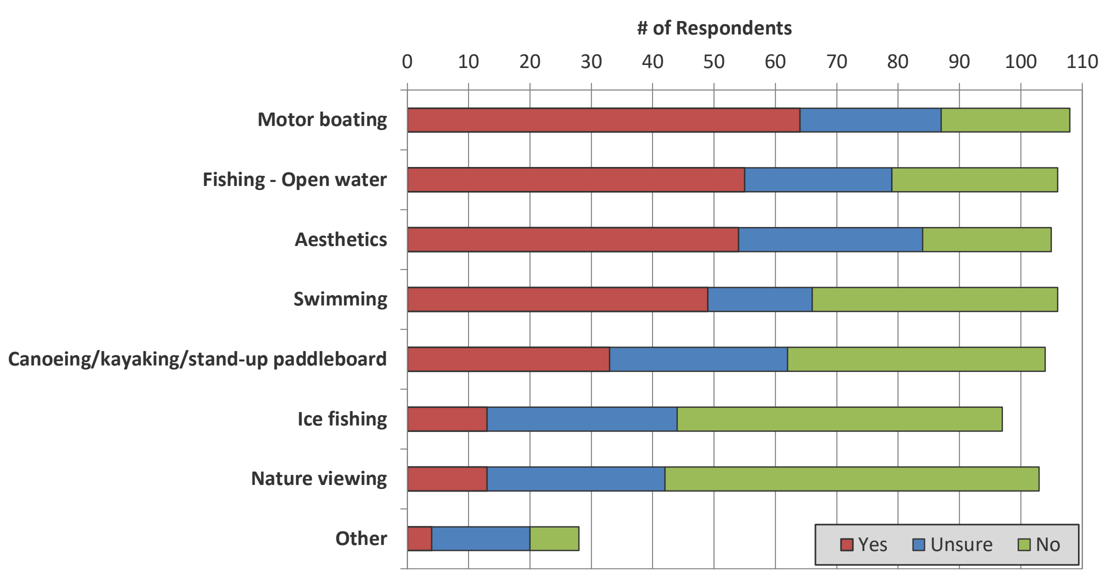


Figure 3.4-16. Select survey responses from the LLPRD Riparian stakeholder survey. Additional questions and response charts may be found in Appendix B.

Eurasian watermilfoil (EWM) was first discovered in Lost Lake in 2013. Originally the LLPRD used hand-harvesting for EWM management (2014-2015) until the population expanded to a point where it was no longer feasible. The LLPRD has monitored the population in absence of active management in recent years (2016 – current) but are now considering active management again. Figure 3.4-17 displays the responses of the Lost Lake stakeholders and how they feel about the use of various management techniques in Lost Lake. In general, district members were supportive of all active management options presented to them, with the most support for herbicide spot treatment, followed by mechanical harvesting.

27. What is your level of support for the use of the following EWM management techniques in Lost Lake?

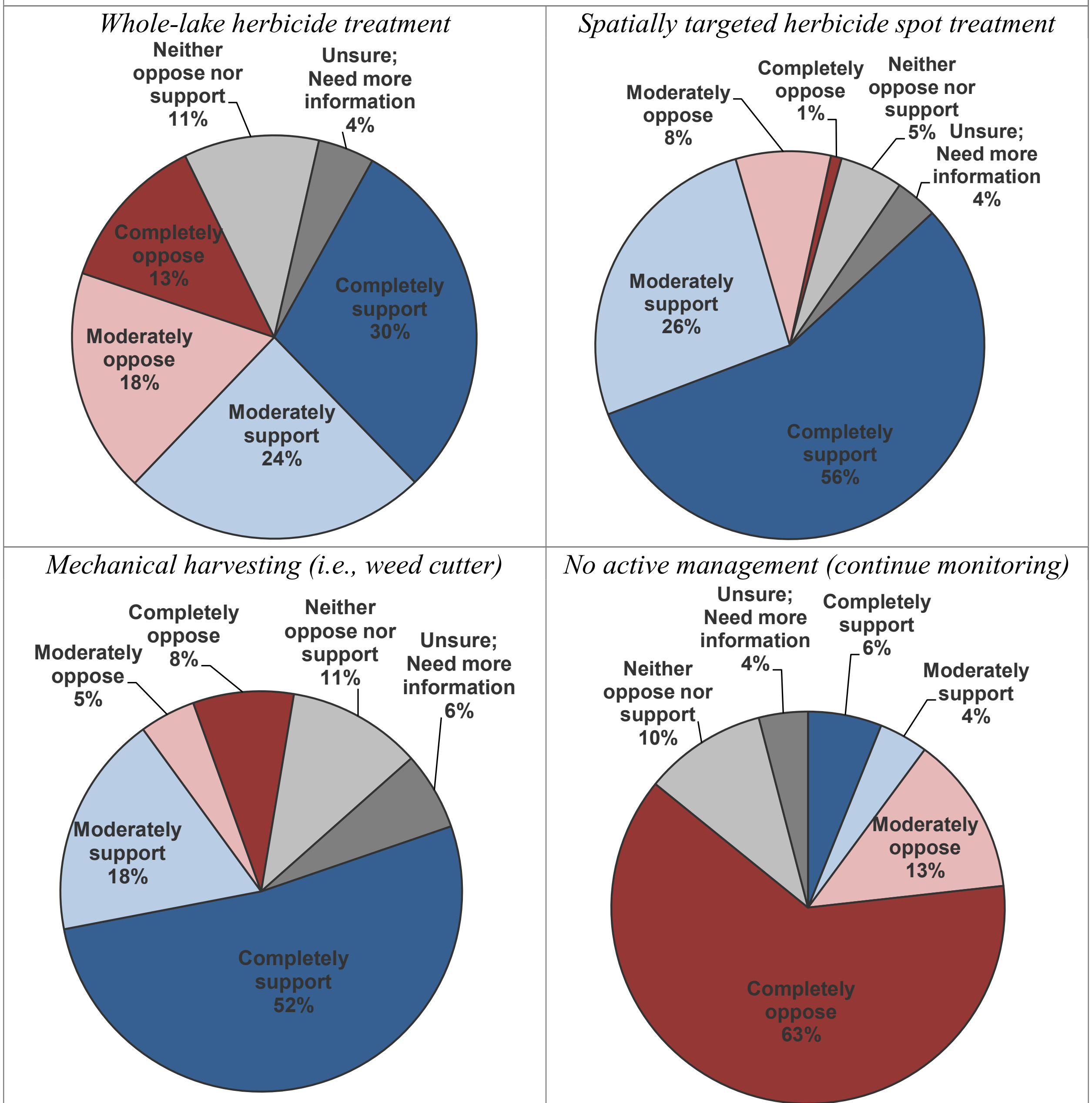


Figure 3.4-17. Select survey responses from the LLPRD Riparian stakeholder survey. Additional questions and response charts may be found in Appendix B.

Future AIS Management Philosophy

During the Planning Committee meetings held as part of this project, three broad Eurasian watermilfoil and curly-leaf pondweed management goals were discussed including a generic potential action plan to help reach each of the goals. During these discussions, conversation regarding risk assessment of the various management actions was also discussed. Onterra provided extracted relevant chapters from the WDNR's *APM Strategic Analysis Document* to serve as an objective baseline for the LLPRD to weigh the benefits of the management strategy with the collateral impacts each management action may have on Lost Lake ecosystem. These chapters are included as Appendix D. The LLPRD Planning Committee also reviewed these management perspectives in the context of perceived riparian stakeholder support.

1. Let Nature Take its Course: On some lakes, invasive plant populations plateau or reduce without active management. Some lake groups decide to periodically monitor the AIS population, either through mappings survey or a whole-lake point-intercept survey, but may not coordinate active management (e.g., hand-harvesting or herbicide treatments). Individual riparians could choose to hand-remove the AIS, particularly EWM, within their recreational footprint, but the lake group would not assist financially or by securing permits if necessary. In most instances, the lake group may select an AIS population threshold or trigger where they would revisit their management goal if the population reached that level.

2. Nuisance Control: The concept of ecosystem services is that the natural world provides a multitude of services to humans, such as the production of food and water (provisioning), control of climate and disease (regulating), nutrient cycles and pollination (supporting), and spiritual and recreational benefits (cultural). Some lake groups acknowledge that the most pressing issues with their AIS population is the reduced recreation, navigation, and aesthetics compared to before the AIS became established in their lake. Particularly on lakes with large EWM populations that may be impractical or unpopular to target on a lake-wide basis, the lake group would coordinate (secure permits and financially support the effort) a strategy to improve the navigability within the lake. This was discussed at length within the *Comprehensive Management Plan* (2019).

There has been a change in preferred strategy in recent years amongst many lake managers and regulators when it comes to established EWM population. Instead of chasing the entire EWM population with management, perhaps focusing on the areas that are causing the largest impacts can be more economical and cause less ecological stress. This is typically accomplished by targeting EWM populations in high-use parts of the through mechanical harvesting or spot herbicide treatments and allowing other areas of low use to remain unmanaged.

3. Lake-Wide Population Management: Some believe that there is an intrinsic responsibility to correct for changes in the environment that are caused by humans. For lakes with AIS populations, that may mean to manage the AIS population at a reduced level with the perceived goal to allow the lake to function as it had prior to EWM establishment. Due to the inevitable collateral impacts from most forms of AIS management, lake managers and natural resource regulators question whether that is an achievable goal.

The repeated need for exposing the same areas of a lake to herbicides as is required when engaged in an annual spot treatment program has gone out of favor with some lake managers due to concerns over the non-target impacts that can accompany this type of strategy. Unless there are documented ecological impacts, established CLP populations are typically not targeted for lake-wide management, as the repeated use of herbicides is impactful on the lake. Because CLP had only been present in Lost Lake for a few years prior to the control strategy being initiated in 2017, it was theorized that the turion base may be small and would not require as many successive treatments as a more established population would. Combining the fact that CLP has been in the lake for a decade and the major population area has been untreated for two years, the population is now considered established and probably not applicable to lake-wide management strategies.

In recent years, lake managers have sought actions that achieve multiyear EWM population suppression, such as whole-lake or whole-basin treatments. The EWM population reductions are more commensurate with the financial costs and risks of the treatment. For many lakes, lake-wide management is not ecologically and/or financially feasible. Sometimes this is because the system is too large or the EWM rebounds too quickly following management.

Herbicide Resistance

While understood in terrestrial herbicide applications for years, tolerance evolution is an emerging topic amongst aquatic herbicide applicators, lake management planners, regulators, and researchers. Herbicide resistance is when a population of a given species develops reduced susceptibility to an herbicide over time, such that an herbicide use pattern that once was effective no longer produces the same level of effect. This occurs in a population when some of the targeted plants have an innate tolerance to the herbicide and some do not. Following an herbicide treatment, the more tolerant strains will rebound whereas the more sensitive strains will be controlled. Thus, the plants that re-populate the lake will be those that are more tolerant to that herbicide resulting in a more tolerant population over time.

Repetitive treatments with the same herbicide mode-of-action may cause a shift towards increased herbicide tolerance in the population, especially if the genetic variation or hybrids exist in the system. Rotating herbicide use-patterns can help avoid population-level herbicide tolerance evolution from occurring.

Lost Lake Prevention & Containment

Lost Lake is an extremely popular destination by recreationists and anglers, making the lake vulnerable to new infestations of exotic species. The intent of a watercraft inspection program is not only be to prevent additional invasive species from entering the system through its public access locations, but also to prevent the infestation of other waterways with invasive species that originated in the system. The goal is typically to cover the landings during the busiest times in order to maximize contact with lake users, spreading the word about the negative impacts of AIS on lakes and educating people about how they are the primary vector of its spread.

The LLPRD utilizes WDNR grant funding to sponsor watercraft inspections through the WDNR’s Clean Boats Clean Waters (CBCW) program at its primary public boat launch (Access off of Lost Colony Road). Like many Vilas County Lakes, the CBCW inspection is conducted by the University of Wisconsin – Oshkosh (UW-O). UW-O recruits the student intern boat inspectors, sets up schedules and housing, handles all payroll, and reports all the interns' hours to the WDNR”s online database (SWIMS). UW-O charges a per-hour fee every year to cover all costs with intern payroll and other associated costs. The LLPRD contracts UW-O to conduct roughly 152 hours of inspections each year, The LLPRD provides at least 84 hours of volunteer effort as an inkind match to their CBCW grant, which totals roughly 236 hours of watercraft inspections per year. The LLPRD's Clean Boats Clean Waters program has been well organized, with numerous watercraft inspections occurring annually (Table 3.4-1 showing recent history).

Table 3.4-1. Watercraft inspections conducted on Lost Lake 2013-2022. Data from WDNR, SWIMS.

Lost Lake -- Access Off Lost Colony Rd										
	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Boats Inspected	149	138	310	262	531	223	206	229	281	285
Hours Spent	149	150	295	290	452	256	232	252	263	231
Boats Inspected/Hrs Spent	1.00	1.09	0.95	1.11	0.85	1.15	1.13	1.10	0.94	0.81

Based upon modeling by the University of Wisconsin Center for Limnology, Lost Lake is one of the state's top 300 AIS Prevention Priority Waterbodies. This means that Lost Lake has a high number of boats arriving from lakes that have AIS (receiving) and a high number of boats moving from Lost Lake to uninvaded waters (sending). Therefore, the WDNR encourages additional supplemental prevention efforts above just watercraft inspections, offering additional grant funds for these activities for applicable lakes. Supplemental prevention efforts such as decontamination stations (e.g., pressure washer) and remote video surveillance (e.g., I-Lids™) could be funded through this program.

4.0 SUMMARY & CONCLUSIONS

The design of this project was intended to fulfill four primary objectives;

1) Collect detailed information regarding invasive plant species within the lake, with the primary emphasis being on Eurasian watermilfoil and curly-leaf pondweed.
2) Update understanding of Lost Lake water quality condition based upon data collected since the 2019 *Comprehensive Management Plan.*
3) Collect sociological information from Lost Lake stakeholders regarding their use of the lake and their thoughts pertaining to the past and current condition of the lake and its management.
4) Create an updated aquatic-plant management centric plan for the LLPRD considering the evolution of BMPs and changes on regulatory support for various techniques since the previous management planning effort.

The four objectives were fulfilled during the project and have led to a good understanding of the Lost Lake ecosystem and the folks that care about the lake.

The native aquatic plant community of Lost Lake continues to be highly dynamic. Little vegetation was observed greater than 8 feet deep in 2017 and 2018 whereas, some of the greatest abundance of aquatic plants during 2007, 2010, and 2014 was found in waters of 8 to 14 feet. Often the factor reducing vegetation abundance at greater water depths is decreased water clarity, especially during spring when species are emerging from winter dormancy. Spring water clarity was slightly increased in 2021 and may correspond to increased aquatic plant presence at greater water depths during the summer. Decreased overall water clarity returned in 2022, which may have resulted again in reduced overall aquatic plant abundance.

Total phosphorus concentrations in Lost Lake, the primary driver of aquatic plant and algae growth, are unexpectedly high based upon watershed characteristics indicating an unaccounted source(s) of phosphorus is being delivered to the lake. Data collected to date suggests that at least a portion of this phosphorus is originating from bottom sediments, but it is unclear if that is the main factor in low water quality conditions in some years. Other factors that could potentially be large drivers of high phosphorus include zooplankton-fisheries dynamics and watershed from major precipitation events. This project proposes an investigation into internal nutrient loading, as this may be the most manageable and documentable source of unaccounted phosphorus in Lost Lake. The study would indicate whether or not internal nutrient loading is the major driver of low water clarity, whether this is a new phenomenon or part of Lost Lake's historical function, and potentially if there are management options that can be taken to lessen these impacts.

Eurasian watermilfoil (EWM) and curly-leaf pondweed (CLP) are established in Lost Lake. Early detection and response activities, such as manual removal for EWM and consecutive herbicide treatments for CLP, were unable to have long-term impacts on the overall populations of these species in Lost Lake. The district is encouraged to continue monitoring these populations to see if they have largely plateaued and will fluctuate from year-to-year, or if they will continue to increase in the lake.

The district has developed a multi-pronged integrated pest management strategy, considering all available management tools. Particularly in regards to EWM, the district will focus its management goals towards reducing the periodic nuisance conditions that EWM causes on Lost Lake, as opposed to trying to manage for an overall lowered EWM population lake-wide. The Lost Lake would like to conduct a trial ProcellaCOR™ treatment in the easter part of the lake to gain multiple years of reduced EWM population. It is likely that a measurable but potentially nominal amount of the herbicide from this treatment would be detected at downstream wild rice populations. At the time of this writing, WDNR policy is that no aquatic herbicide permits would be approved on waters containing or are upstream of culturally-important wild rice unless the WDNR has confidence that the activity will not impact the wild rice population. With little-to-no available published studies on the impacts of ProcellaCOR™ on wild rice, the district acknowledges this uncertainty exists for lost lake. In light of that reality, the LLPRD has expressed more interest in perusing mechanical harvesting to minimize the nuisance conditions caused by EWM and CLP in the system, particularly if they are permitted to manage blocks of areas as opposed to be restricted to narrow navigation lanes.

A great benefit of this project was to bring together multiple perspectives from various stakeholder groups. Some of these conversations were difficult, involving bidirectional communication, objective listening, and validation. While the result of the project does not necessarily result in an agreed upon shared management direction for Lost Lake, the district has a better understanding of the different management perspectives and why they are held.

5.0 AQUATIC PLANT IMPLEMENTATION PLAN SECTION

The district's *Comprehensive Management Plan* for Lost Lakes was finalized and approved by the WDNR in 2019. This *Plan* can be found on the WDNR website located here:

https://dnr.wi.gov/lakes/grants/project.aspx?project=143401772

The Implementation Plan Section of the *2019 Plan* includes the following management goals along with specific management actions developed to help reach those goals.

1. Manage Existing and Prevent Further Aquatic Invasive Species Infestations within Lost Lake
   - Continue Clean Boats Clean Waters watercraft inspections at critical public access locations
   - Coordinate annual professional monitoring of AIS, particularly CLP
     - Annually
   - Coordinate Periodic Quantitative Vegetation Monitoring
     - Point-Intercept Survey every 3years, Community Mapping every 10 years
   - Conduct CLP population management using herbicide spot treatments
     - Implementation trigger, monitoring plan
2. Maintain Current Water Quality Conditions
   - Monitor water quality of Lost Lake through WDNR Citizens Lake Monitoring Network.
   - Ensure water quality of upstream lakes within Lost Lake's watershed are being monitored
3. Increase LLPRD's Capacity to Communicate with Lake Stakeholders and Facilitate Partnerships with Other Management Entities
   - Use education to promote lake protection and enjoyment through stakeholder education
   - Continue LLPRD's involvement with other entities that have responsibilities in managing (management units) Lost Lake
   - Conduct Periodic Riparian Stakeholder Surveys
4. Improve Lake and Fishery Resource of Lost Lake
   - Educate Stakeholders on the Importance of Shoreland Condition and Shoreland Restoration
   - Coordinate with WDNR and private landowners to expand coarse woody habitat in Lost Lake
   - Develop a fisheries management plan for Lost Lake
   - Investigate requesting transfer of ownership of the Lost Lake dam

Figure 5.0-1. LLPPRD management goals (numbered) and actions developed to assist in reaching the goal. From *Lost Comprehensive Management Plan (2019)*

The objective of this project was to revisit the aquatic plant-related goals and actions of the Lost Lake Comprehensive Management Plan and adjust them appropriately based upon current best management practices (BMPs), the lessons learned during the years since the last plan was developed, and the information gathered during the studies completed in 2022 As a result, this project largely updates the Implementation Plan Management Goals #1 and #2 of the LLPRD's Comprehensive Management Plan (Figure 5.0-1).

The updated Implementation Plan presented below was created through the collaborative efforts of Lost Lake Protection & Rehabilitation District Board of Commissioners and ecologist/planners from Onterra. The Implementation Plan represents the path the Lost Lake Protection & Rehabilitation District will follow in order to meet their lake management goals. The goals detailed within the plan are realistic and based upon the findings of the studies completed in conjunction with this planning project and the needs of the Lost Lake stakeholders as portrayed by the members of the Board of Commissioners. The Implementation Plan is a living document that will be under constant review and adjustment depending on the condition of the lake, availability of funds, level of volunteer involvement, and needs of the stakeholders.

Management Goal 1: Ensure the LLPRD has a Functioning and Up-to-Date Management Plan

Management Action:	Periodically update lake management plan
Timeframe:	Periodic
Facilitator:	Board of Commissioners
Description:	The term *Best Management Practice (BMP)* is often used in environmental management fields to represent the management option that is currently supported by that latest science and policy. When used in an action plan, the term can be thought of as a placeholder with anticipation of having an evolving definition over time. ***Comprehensive Management Plan*** The WDNR recommends *Comprehensive Lake Management Plans* generally get updated every 10 years. Implementation projects require a completion data of "no more than 10 years prior to the year in which an implementation grant application is submitted. The department may determine a longer lifespan is appropriate if the applicant can demonstrate a plan has been actively implemented and updated during its lifespan." This allows a review of the available data from the lake, as well as to consider changing BMPs for water quality, watershed, and shoreland management. The 2019 *Comprehensive Lake Management Plan* will be updated by 2029 or if prompted by a specific rationale such as the need to investigate a specific water quality parameter. ***Aquatic Plant Management Plan*** BMPs for aquatic plant management change rapidly, as new information about effectiveness, non-target impacts, and risk assessment emerges. To be eligible to apply for grants that provide cost share for AIS control and monitoring, "a current plan has a completion date of no more than 5 years prior to submittal of the recommendation for approval. The department may determine that a longer lifespan is appropriate for a given management plan if the applicant can demonstrate it has been actively implemented and updated during its lifespan. However, a [whole-lake] point-intercept survey of the aquatic plant community conducted within 5 years of the year an applicant applies for a grant is

	required." It is important to work with the regional WDNR Lakes Biologist to understand what is required at this time, as it is more subjective in comparison to the requirements of a *Comprehensive Lake Management Plan* as it relates to the specific management actions being considered. *Aquatic Plant Management (APM) Plan* presented here will be formally updated in roughly 2028-2029, likely as a part of a *Comprehensive Lake Management Plan*. ***<u>Annual Control & Monitoring Plan</u>*** It is important to note that the management plan provides a framework to guide the management action, but does not include the specific control plan for a given year. If the action being considered does not fall within the framework of the overall management plan, it is likely that an updated plan is needed regardless of its relative age. If the LLPRD intends to conduct active management towards aquatic plants, a proceeding written control and monitoring plan, consistent with the *Management Plan*, would be produced typically January-March prior to its implementation. The control plan is useful for WDNR and other regulators when considering approval of the action, as well as to convey the control plan to LLPRD members for their understanding.
Action Steps:	
	See description above.

<u>Management Action:</u>	Conduct periodic riparian stakeholder surveys
Timeframe:	Periodic: every 5 years, corresponding with management plan updates
Facilitator:	Board of Commissioners
Description:	Formal riparian stakeholder user surveys have been performed by the association in 2017 and 2022. Approximately once every 5-6 years, potentially at the time of a Plan update or prior to a large management effort, an updated stakeholder survey would be distributed to the LLPRD members. Periodically conducting an anonymous stakeholder survey would gather comments and opinions from lake stakeholders to gain important information regarding their understanding of the lake and thoughts on how it should be managed. This information would be critical to the development of a realistic plan by supplying an indication of the needs of the stakeholders and their perspective on the management of the lake. The stakeholder survey could partially replicate the design and administration methodology conducted during 2022, with modified or additional questions as appropriate. The survey would again need to receive approval from a WDNR Research Social Scientist, particularly if WDNR grant funds are used to offset the cost of the effort.

Management Goal 2: **Enhance Water Quality Conditions on Lost Lake**

Management Action:	Monitor water quality of Lost Lake through WDNR Citizens Lake Monitoring Network.
Timeframe:	Continuation of current effort
Facilitator:	Jim Guckenberg – current CLMN volunteer
Description:	Monitoring water quality is an important aspect of every lake management planning activity. Collection of water quality data at regular intervals aids in the management of the lake by building a database that can be used for long-term trend analysis. Early discovery of negative trends may lead to the reason of why the trend is occurring. Volunteer water quality monitoring should be completed annually by Lost Lake riparians through the Citizen Lake Monitoring Network (CLMN). The CLMN is a WDNR program in which volunteers are trained to collect water quality information on their lake. The LLPRD restarted involvement in 2021 by monitoring Secchi disk readings in each lake. Starting in 2023, the LLPRD was enrolled in the advanced CLMN program where water chemistry samples are also collected (chlorophyll-*a*, and total phosphorus). Samples are collected three times during the summer and once during the spring. As a part of the program the data collected are automatically added to the WDNR database and available through their Surface Water Integrated Monitoring System (SWIMS) by the volunteer. CLMN volunteer and/or LLPRD Board of Commissioners would facilitate new volunteer(s) as needed to ensure consistence of data collection over time. As a part of this management planning process, the data suggest that internal nutrient loading is likely occurring, with the severity of impacts being tied to the interval of destratification events. The LLPRDD is encouraged to conduct temperature and dissolved oxygen profiles as often as possible (weekly would be best), but especially in conjunction with the CLMN monitoring schedule. It is recommended that the LLPRD or the Town of Saint Germain Lakes Committee purchase a probe to make available for this sampling. The WDNR recommends: YSI ProSolo ODO – Optical Dissolved Oxygen Meter. WDNR grant opportunities are available for this type of sampling equipment purchase. It also must be noted that the CLMN program may be changing in the near future, as enrollment in the program is currently capped. If there is not an ability for the LLPRD to participate in the advanced CLMN program, they are open to considering self-funding the analysis of these samples on an annual or semi-annual basis.

Management Action:	Ensure water quality of upstream lakes within Lost Lake's watershed are being monitored
Timeframe:	Continuation of current effort
Facilitator:	Board of Commissioners
Description:	As discussed within the 2019 *Comprehensive Management Plan*, approximately 47% of Lost Lake's total watershed is composed of Stella Lake's subwatershed, 27% of Found Lake's subwatershed, and 26% of its own direct watershed. Ensuring that water quality monitoring is occurring in Found Lake and Stella Lake may allow earlier detection of trends than may impact Lost Lake. Found Lake has an active lake association and currently monitors water clarity through the CLMN program. The Stella Lake District is currently inactive and has not conducted water quality monitoring since 2005. The LLPRD have set a goal to collect Secchi disk transparency on Stella Lake following CLMN protocols starting in 2023.

Management Action:	Investigate the role of internal nutrient loading in Lost Lake
Timeframe:	Begin 2024
Facilitator:	Board of Commissioners
Description:	As discussed in the Water Quality section, total phosphorus concentrations in Lost Lake are unexpectedly high based upon watershed characteristics indicating an unaccounted source(s) of phosphorus is being delivered to the lake. Data collected to date suggests that at least a portion of this phosphorus is originating from bottom sediments, but it is unclear if that is the main factor in low water quality conditions in some years. Other factors that could potentially be large drivers of high phosphorus include zooplankton-fisheries dynamics and watershed inputs in association with major precipitation events. Lost Lake is polymictic, meaning top and bottom waters mix throughout much of the year but may temporarily stratify. When Lost Lake becomes stratified, the lower layer of water (the hypolimnion) becomes anoxic which allows phosphorus to unbind and be released from bottom sediments. When the lake ultimately breaks stratification, the high concentrations of phosphorus within the hypolimnion are mixed throughout the water column where it can fuel algae blooms. Onterra proposes an investigation into internal nutrient loading, as this may be the most manageable and documentable source of unaccounted phosphorus in Lost Lake. The study would indicate whether or not internal nutrient loading is the major driver of low water clarity, whether

this is a new phenomenon or part of Lost Lake's historical function, and potentially if there are management options that can be taken to lessen these impacts. The following text outlines preliminary perspectives on study design.

Sediment Core - Paleoecology

Onterra recommends that a full sediment core from Lost Lake be collected to understand phosphorus concentrations and environmental conditions (plant vs algae domination) over time. However, in shallow lakes like Lost Lake, the diatoms in the bottom of the core can sometimes be degraded, diminishing the utility of the core. This was the case for a sediment core taken from nearby Found Lake. Before collecting and analyzing a full core, Onterra recommends an exploratory and more economical top-bottom core be collected first.

The top-bottom sediment core would be collected in the deep area of the lake and would be long enough to cover a time period of the last 130 years. The top 1 cm of sediment represents present day conditions. A sample near the bottom of the core represents pre-European settlement conditions. To assure that the bottom sample represents pre-settlement conditions, a portion of it is analyzed at the WSLH for the isotope, lead 210. This isotope remains at detectable levels for about 130 years, so if concentrations are negligible, it can be confirmed that the sediment was deposited over 130 years ago. The diatom community is examined in the top and bottom samples. Diatom species can be differentiated based upon their silica shells. Different species of diatoms grow under different environmental conditions, shedding light on how a lake has changed over time.

Depending on the results of the exploratory top-bottom core, the collection of a full sediment core may be warranted. During a full-core, sediment samples are removed at defined intervals from the core, with carbon dating allowing an understanding of the age of each sample. The diatom community of each partition can be used to reconstruct the phosphorus concentrations through time. Geochemistry data, sedimentation rates, and inferred aquatic plant abundance could also be explored on roughly a decade by decade scale.

Quantify internal nutrient loading

Onterra recommends an investigation into internal nutrient loading on Lost Lake. Prior to a full professional investigation into this aspect, Onterra recommends a precursor study that can be carried out with volunteer field data collection. At two-week intervals, volunteers would collect temperature and dissolved oxygen profiles from the deep hole of Lost Lake. In addition, surface and bottom water samples would be collected with a Van-dorn sampler and analyzed for phosphorus concentrations by the WI State Lab of Hygiene. Due to the variability

	of internal nutrient loading, this may need to be a two-year investigation. The results of this preliminary study would indicate how important internal nutrient loading is to Lost Lake's water clarity, and whether the full study below is warranted. If the precursory study continues to suggest internal nutrient is a significant driver of the water quality condition of Lost Lake, the following advanced internal nutrient loading surveys would take place. These studies would consist of an intense sampling regime over the course of two growing seasons, which will increase the opportunities to capture and document the mass of phosphorus being released into the overlaying waters. Weekly or bi-weekly professionally-collected phosphorus concentration profiles would be collected from Lost Lake from May through September and include multiple sampling depths from one-foot above the bottom sediments to three-feet below the water surface. Concentrations in the hypolimnion are the highest and most important; therefore, the majority of samples would be collected from that layer. The results of these studies would be used to determine the mass of phosphorus that is being internally loaded during the growing season. The internal load would be viewed in terms of its significance in the full nutrient budget of the lake and whether or not interventions aimed at reducing it would lead to better water quality in Lost Lake.

Management Goal 3: Monitor Aquatic Vegetation on Lost Lake

Management Action:	Periodically monitor the Eurasian watermilfoil population
Timeframe:	Periodic: annually; Timing: during latter part of growing season
Facilitator:	Board of Commissioners
Description:	As the name implies, the Late-Season EWM Mapping Survey is a professionally contracted survey completed towards the end of the growing season when the plant is at its anticipated peak growth stage, allowing for a true assessment of the amount of this exotic within the lake. For the Lost Lake, this survey would likely take place in late-August to the end of September, dependent on the growing conditions of the particular year. This survey would include a complete or focused meander survey of the system's littoral zone by professional ecologists and mapping using GPS technology (sub-meter accuracy is preferred). Late Season EWM Mapping Surveys have been conducted annually since EWM was first detected in 2013. These data allow lake stakeholders to understand annual EWM populations in response to natural variation and directed management activities.

Management Action:	Periodically monitor the curly-leaf pondweed population
Timeframe:	Periodic: once every other year, unless prompted; Timing: mid-June
Facilitator:	Board of Commissioners
Description:	Early Season CLP Mapping Surveys have been conducted annually since CLP was first detected in 2014. CLP populations are known to be variable from year to year, with little information known about the drivers to turion sprouting. Although CLP populations do not always reach levels that can cause nuisance conditions or changes in the lake's ecological function, CLP populations reached those levels in only a few years after detection. After four consecutive years of CLP management on Lost Lake with herbicides, it was determined that more years of consecutive herbicide treatments would be required to further deplete the turion base. Consistent with recommendations from the Lac du Flambeau Tribe, the WDNR determined that the collateral impacts of the management effort were too great to permit, particularly the unknown downstream impacts of wild rice populations. The LLPRD intends to periodically check-in on the CLP population, but does not have management intentions at this time. Approximately every-other year (odd years), the LLPRD would coordinate an Early-Season CLP Mapping survey.

Management Action:	Coordinate periodic point-intercept aquatic plant surveys
Timeframe:	Periodic: at least once every 5 years, likely once every 3 years; Timing: during July-August
Facilitator:	Board of Commissioners
Description:	The point-intercept aquatic plant monitoring methodology as described Wisconsin Department of Natural Resources Bureau of Science Services, PUB-SS-1068 2010 (Hauxwell et al. 2010) has been used on the Lost Lake System periodically since 2007. This survey provides quantitative population estimates for all aquatic plant species within the lake and is designed to allow comparisons with past surveys in Lost Lake as well as to other waterbodies throughout the state. At each point-intercept location within the *littoral zone,* information regarding the depth, substrate type (soft sediment, sand, or rock), and the plant species sampled along with their relative abundance (rake fullness) on the sampling rake is recorded. The LLPRD will ensure the point-intercept surveys is conducted at least once every five years, but aims to complete this quantitative survey of its aquatic vegetation more frequently considering recent shifts and declines aquatic plants. If the LLPRD is considering large-scale aquatic plant management, point-intercept surveys would occur more frequently, likely annually.

Management Action:	Consider periodic community mapping (floating-leaf and emergent) surveys
Timeframe:	Periodic: every 5 years or when prompted
Facilitator:	Board of Commissioners
Description:	This survey would delineate the margins of floating-leaf (e.g., water lilies) and emergent (e.g., cattails, bulrushes) plant species using GPS technology (preferably sub-meter accuracy) as well as document the primary species present within each community. Three community mapping surveys have been completed in 2004, 2010, and 2017. The lake currently contains a healthy population of floating-leaf and emergent plant communities as well, with many riparian concerns about white-water lily populations and their periodic uprooted tubers. While many lakes to choose to conduct this survey every 10 years, the riparian concerns about floating-leaf community expansion justifies a more frequent investigation.

Management Goal 4: Prevent Establishment of New Aquatic Invasive Species

Management Action:	Monitor Lost Lake entry points for aquatic invasive species
Timeframe:	Ongoing
Facilitator:	Board of Commissioners – Gary Heeler
Description:	The intent of this program is not only be to prevent additional invasive species from entering the Lost Lake, but also to prevent the infestation of other waterways with invasive species that originated in Lost Lake. The LLPRD utilizes WDNR grant funding to sponsor watercraft inspections through the WDNR's Clean Boats Clean Waters (CBCW) program at its primary public boat launch (Access off of Lost Colony Road). Like many Vilas County Lakes, the CBCW inspection is conducted by the University of Wisconsin – Oshkosh (UW-O). UW-O recruits the student intern boat inspectors, sets up schedules and housing, handles all payroll, and reports all the interns' hours to the WDNR"s online database (SWIMS). UW-O charges a per-hour fee every year to cover all costs with intern payroll and other associated costs. The LLPRD contracts UW-O to conduct roughly 152 hours of inspections each year, The LLPRD provides at least 84 hours of volunteer effort as an inkind match to their CBCW grant, which totals roughly 236 hours of watercraft inspections per year. The LLPRD's Clean Boats Clean Waters program has been well organized, with numerous watercraft inspections occurring annually. The LLPRD will continue to seek cost share assistance through the WDNR's streamline Clean Boats Clean Waters (CBCW) program: *https://dnr.wi.gov/Aid/documents/SurfaceWater/CleanBoatsCleanWatersFactSheet.pdf*

Management Action:	Investigate supplemental aquatic invasive species prevention and containment methods.
Timeframe:	Ongoing
Facilitator:	Board of Commissioners
Description:	Lost is an extremely popular regional destination, especially from anglers, making the lake vulnerable to new infestations of exotic species. In addition to its watercraft inspection program, the LLPRD would like to investigate supplemental prevention steps it can take to project Lost Lake from new aquatic invasive species. The LLPRD will strive to have updated signage at its main state-owned public landing promoting CBCW messaging. They will also consider supplemental prevention efforts as described below. Supplemental prevention efforts such as decontamination stations (e.g., pressure washer), water-less cleaning stations (e.g. CD3 systems), and remote video surveillance (e.g., I-Lids™) have been taken on a few waterbodies throughout the state. The LLPRD will research these options and determine applicability for Lost Lake.

Management Goal 5: Actively manage EWM to keep the population from negatively impacting recreation, navigation, and aesthetics

Management Action:	Conduct Integrated Pest Management Program towards HWM
Timeframe:	Ongoing
Facilitator:	AIS Committee
Description:	The objective of this action will be to minimize the periodic nuisance conditions that EWM causes on Lost Lake by restoring navigation, recreation, and aesthetics. In order to reach this objective, the LLPRD has developed a multi-pronged approach as part of this Integrated Pest Management (IPM) Program. Each management technique described below is discussed in regards to site selection and corresponding monitoring strategy. The following bullets are a general guide to the IPM Program: • ***Herbicide Treatment*** It would be the LLPRD's preference to gain multi-year control of problematic areas through the use of spatially-targeted herbicide spot treatments. • ***Manual Removal*** The LLPRD would consider EWM manual removal, likely with the aid of Diver-Assisted Suction Harvest (DASH) equipment to target scale-appropriate EWM occurrences. This typically would occur in the years after herbicide treatment to maintain the gains made from that effort. • ***Mechanical Harvesting*** The LLPRD has historically had reservations about contracting mechanical harvesting efforts on the lake, due to concerns of increasing the spread of EWM through fragmentation, the high

cost of implementation vs the short-term gain of the effort, and the collateral impacts of bi-catch, especially small fish. Following this updated planning process, the LLPRD has expressed more interest in this technique, particularly if herbicide options are not permitted and the district is able to manage blocks of areas vs narrow navigation lanes.

1. **Herbicide Treatment** To date, no herbicide treatments have occurred on Lost Lake targeting EWM. The LLPRD would like to pursue a trial herbicide treatment in areas where EWM is impacting navigation, recreation, and aesthetics, particularly areas delineated from a late-season EWM Mapping Survey as being *dominant*, *highly dominant*, or *surface matting*.

   At this time, Onterra believes the use of ProcellaCOR™ treatments are the most likely to be effective in Lost Lake. While the LLPRD largely conducted risk assessment efforts during this project on ProcellaCOR™, they would be open to considering future herbicides shown to be effective in short concentration and exposure time scenarios. ProcellaCOR™ is in a new class of synthetic auxin mimic herbicides (arylpicolinates) with short concentration and exposure time (CET) requirements compared to other systemic herbicides. The active ingredient of ProcellaCOR™, florpyrauxifen-benzyl, is primarily degraded by photolysis (light exposure), with some microbial degradation. The active ingredient is relatively short-lived in the environment, with half-lives of 4-6 days in aerobic environments and 2 days in anerobic environments (WSDE 2017). The primary breakdown product of florpyrauxifen-benzyl is florpyrauxifen acid. Florpyrauxifen acid has been shown to persist in the lake longer than the active ingredient. This chemical metabolite is reported to have activity as an herbicide on aquatic plants, albeit to a lower degree than the active ingredient. It is unclear at this time the exact role that the acid metabolite may play in contributing to EWM reductions, particularly in areas not located directly within the herbicide application area. Native plant impacts from ProcellaCOR™ are anticipated to be less and more specific to susceptibly species than fluridone treatments. While ProcellaCOR™ has shown to have almost no impacts to submergent monocot plant species, no specific research has been conducted on its impacts to wild rice. Therefore, the Great Lakes Indian Fish & Wildlife Commission (GLIFWC) and Lac du Flambeau Tribe have strong reservations against its use in systems containing wild rice.

   If the LLPRD decides to pursue future herbicide management towards EWM, the following set of bullet points would occur:

   - Early consultation with WDNR would occur.
   - The preceding annual *EWM Control & Monitoring Report* would outline the precise control and monitoring strategy.
   - EWM efficacy would occur by comparing annual late-summer EWM mapping surveys and point-intercept surveys. Specifically, these would be conducted during the *year prior to treatment*, *year of treatment*, and *year after treatment*.

- Herbicide concentration monitoring would occur surrounding the treatment, including in downstream areas of wild rice.
- An herbicide applicator firm would be selected in late-winter and a permit application would be applied to the WDNR as early in the calendar year as possible, allowing interested parties sufficient time to review the control plan outlined within the annual report as well as review the permit application.
- Unless specified otherwise by the manufacturer of the herbicide, an early-season use-pattern would likely occur. This would consist of the herbicide treatment occurring towards the beginning of the growing season (typically in early- to mid-June), active growth tissue is confirmed on the target plants, and is after sensitive fish species of concern have outgrown their vulnerable life stage. A focused pretreatment survey would take place approximately a week or so prior to treatment. This site visit would evaluate the growth stage of the EWM (and native plants) as well as to confirm the proposed treatment area extents and water depths. This information would be used to finalize the permit, potentially with adjustments and dictate approximate ideal treatment timing. Additional aspects of the treatment may also be investigated, depending on the use pattern being considered, such as the role of stratification.

2. **Manual Removal (includes DASH)** The objective of this action will be to target low-density areas of the lake with hand-harvesting, including Diver-Assisted Suction Harvest (DASH) techniques, to maintain a low EWM population in these areas. At this time, the EWM population is too large and dense to be feasibly or financially practical to target with this management tool. The LLPRD would mainly initiate this activity following herbicide management actions in an effort to preserve the gains made in EWM reductions. Contracted hand-harvesting operations with DASH would adhere to the following bullet points in addition to WDNR permit conditions:

- During the winter following a late-season EWM mapping survey, a hand-harvesting strategy would be developed. The management and monitoring strategy would be formally outlined in an annual report that would be made available to the LLPRD and WDNR. Areas appliable for manual removal include EWM mapped with point-based methods as well as low-density and smaller areas of EWM mapped with polygon.
- If a Diver Assisted Suction Harvest (DASH) component is utilized, the LLPRD and contracted firm would be responsible for the WDNR permit procedures. The contracted firm would be guided with GPS data from the consultant and would track their efforts (when, where, time spent, quantity removed) for post assessments.
- The hand-harvesting would occur from approximately mid-June to mid-September, but could be slightly extend earlier or later if climactic conditions allow. Generally conducting hand-harvesting earlier or later in the year can reduce the effectiveness of the strategy, as plants are more brittle and extraction of the roots more difficult.

	• A Late-Summer EWM Mapping Survey would take place following the hand-harvesting and be compared to the previous year for assessment. Hand-removal sites will be deemed successful if the level of HWM within the hand-removal areas were at least maintained to pretreatment levels. 3. **<u>Mechanical Harvesting</u>** When EWM populations are above levels applicable to manual removal, but before herbicide treatments are implemented, the LLPRD would consider contracting a mechanical harvesting firm to restore navigation and recreational access in these areas. If herbicide treatments become unsupported by the LLPRD or WDNR, this tool may play a greater role in EWM management on Lost Lake. Mechanical harvesting operations would have the following guidelines: • Harvesting locations are limited to areas on the permit map. • The harvester would not be permitted in waters less than 3-feet to minimize sediment disturbance. • Cut no more than half the water depth. • Harvesting operations shall not disturb spawning or nesting fish. Harvesting shall be done in a manner to minimize accidental capture of fish. An attempt would be made to return all gamefish, panfish, amphibians, and turtles to the water immediately. • Submerged plants, specifically EWM, would be the target for this permit. Removal of emergent (e.g. bulrushes) and floating-leaf (e.g. water lilies) species needs to be avoided because of their ecological value and niche occupation. • A reasonable effort must be made to capture all aquatic plant fragments during operation. The WDNR may consider allowing "floaters" to be picked up even if they occur outside the areas delineated on the permit map. • Reports summarizing harvesting activities shall be given to the WDNR by November 30, each harvesting season. The report shall include a map showing the areas harvested, the total amount of plant material removed from each site, and amount of effort (time) spent at each site. The report shall also include a summary of the composition and quantity of plants removed by species (rough percent of each species from each operation).

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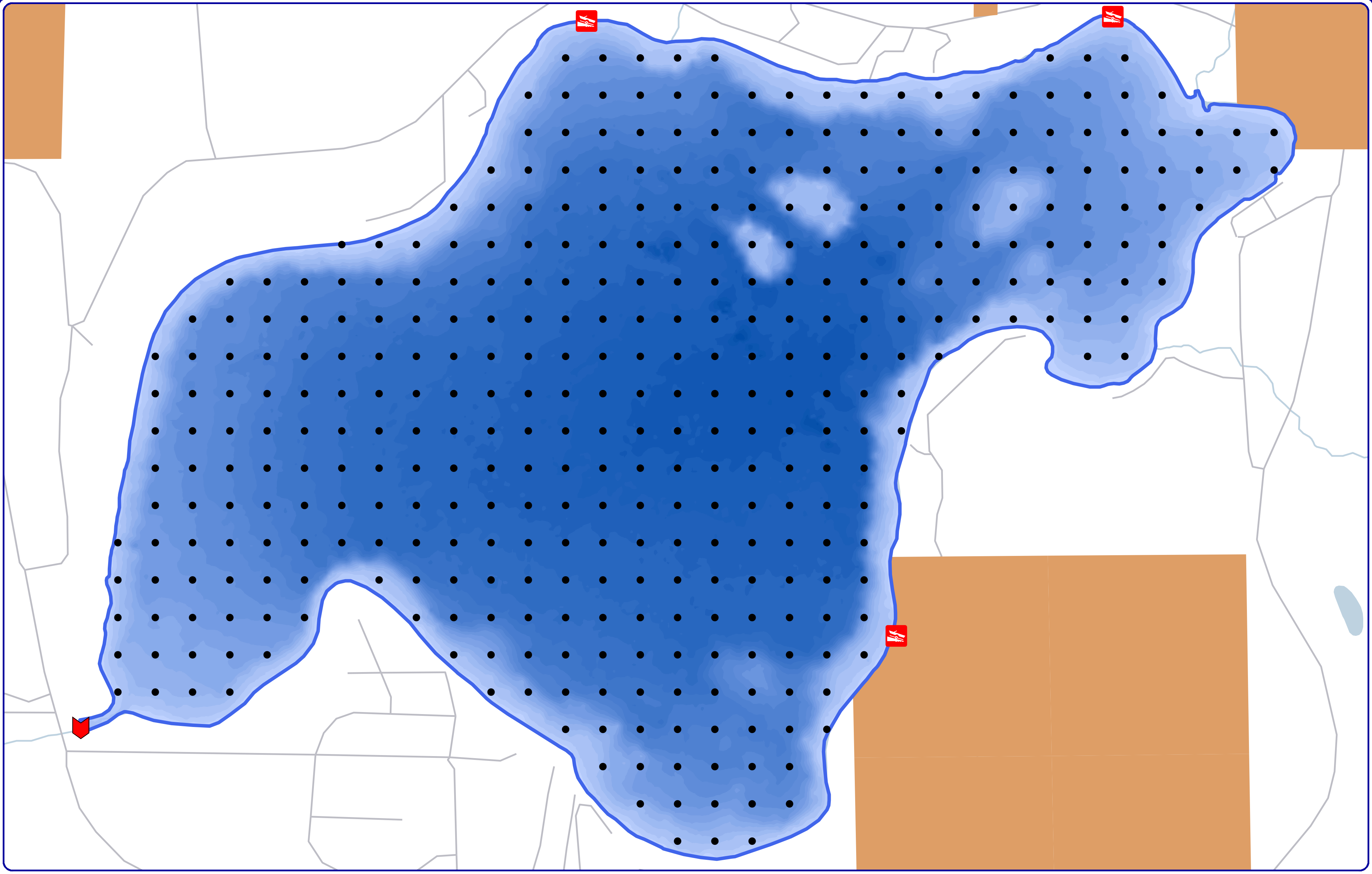

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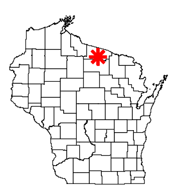
Onterra LLC
Lake Management Planning
815 Prosper Road
De Pere, WI 54115
920.338.8860
www.onterra-eco.com

Sources:
Roads and Hydro: WDNR
Map Date: April 16, 2018
Filename: *Map1_Lost_Location.mxd*



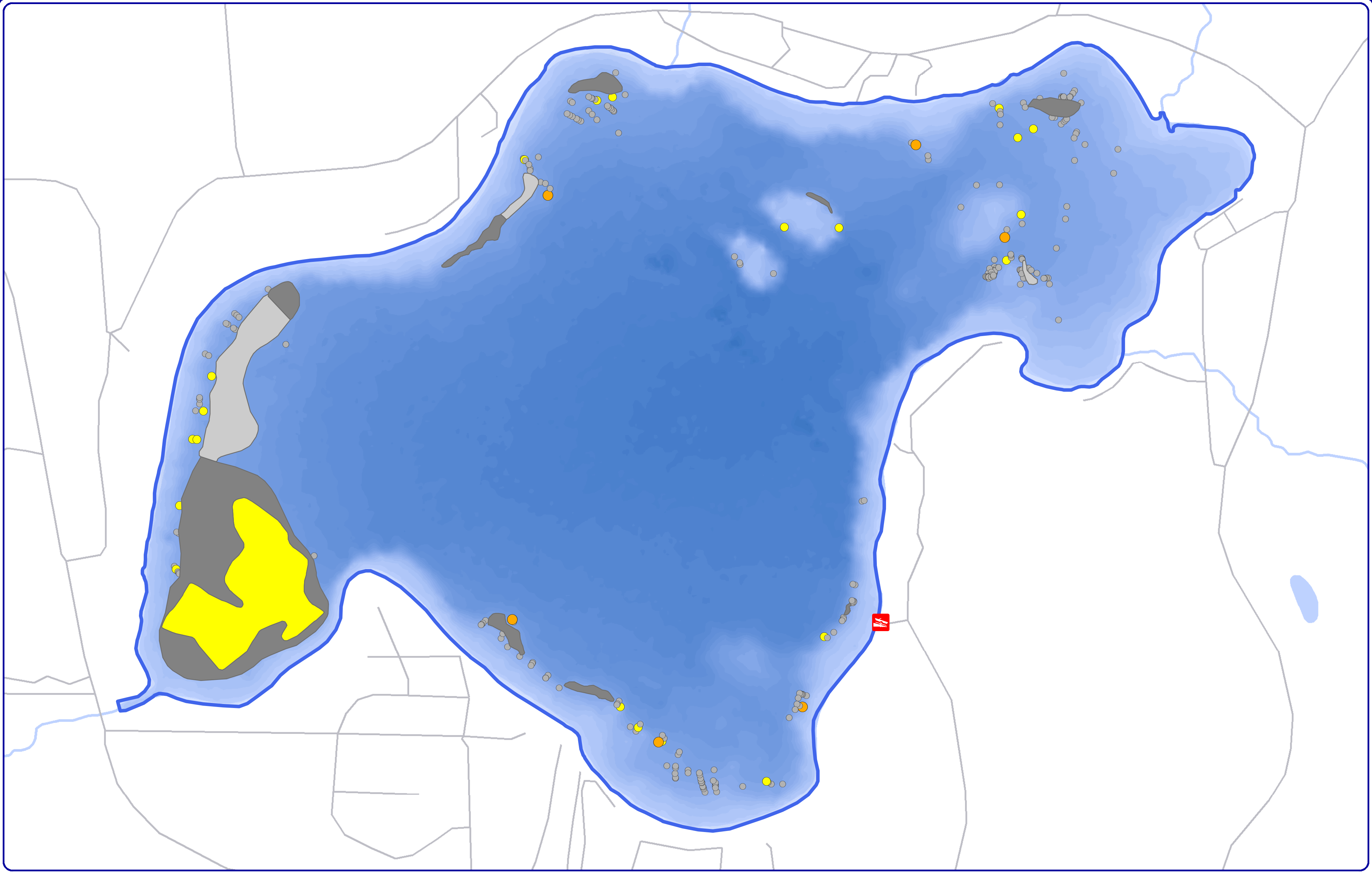
Project Location in Wisconsin

Legend

Lost Lake ~ 539 acres
WDNR Definition
WDNR Managed Lands
Point-intercept Sample Location
75 meter points
Public Access
Dam

Map 1
Lost Lake
Vilas County, Wisconsin

Project Location & Lake Boundaries



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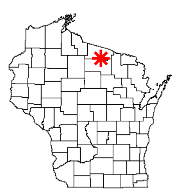
Onterra LLC
Lake Management Planning
815 Prosper Rd
De Pere, WI 54115
920.338.8860
www.onterra-eco.com

Sources:
Roads & Hydro: WDNR
Bathymetry: Onterra, 2017;
Aquatic Plant Survey: Onterra, 2021
Map date: June 29, 2021 AMS



Project Location in Wisconsin

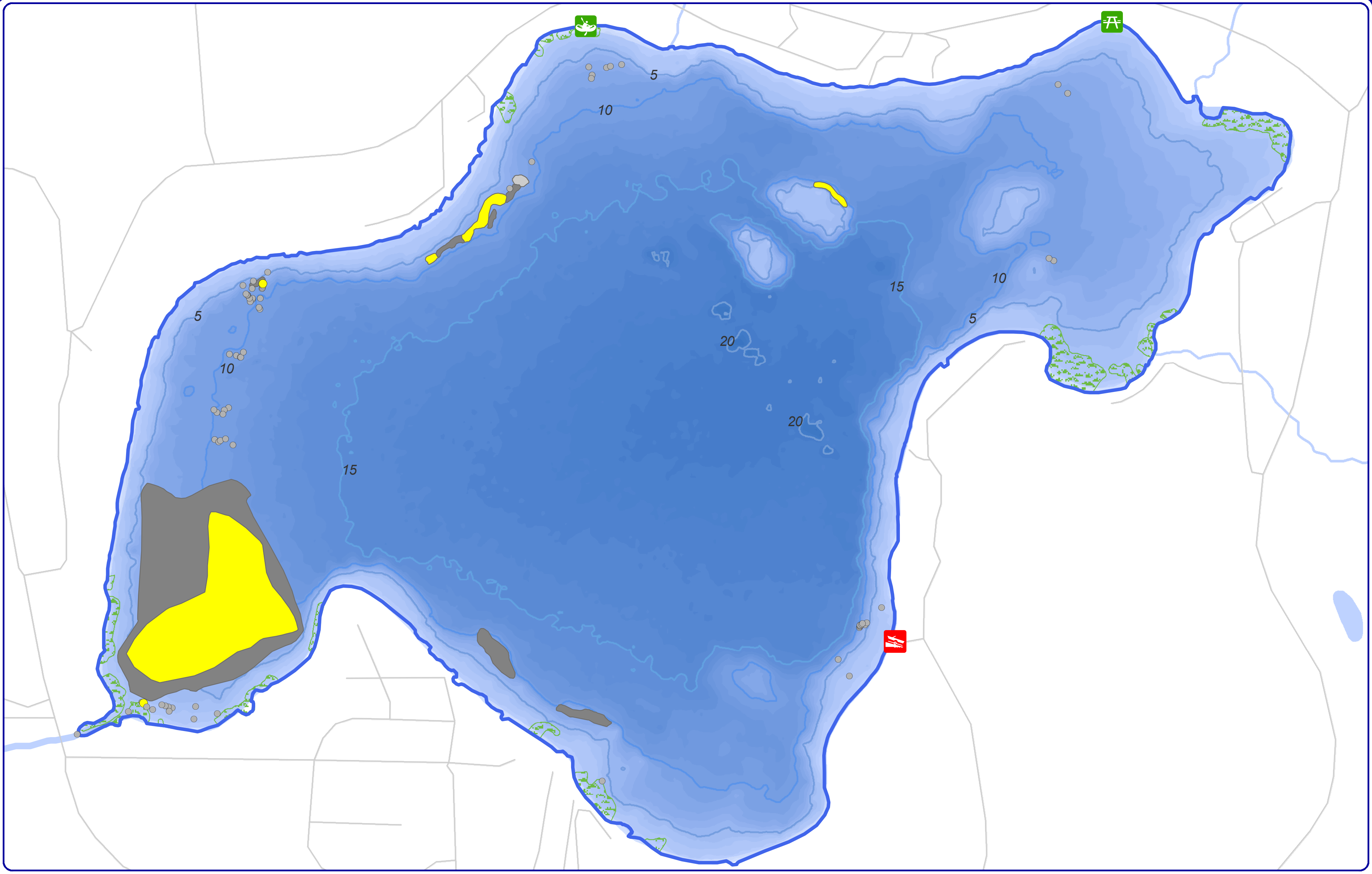
Legend

***Curly-Leaf Pondweed Survey Results** (June 15, 2021)*

- Highly Scattered
- Scattered
- Dominant
- Highly Dominant *(none found)*
- Surface Matting *(none found)*
- Single or Few Plants
- Clump of Plants
- Small Plant Colony

Map 2
Lost Lake
Vilas County, Wisconsin

June 2021
Curly-leaf Pondweed Survey Results



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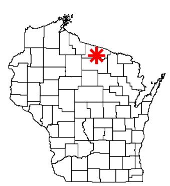
Onterra LLC
Lake Management Planning
815 Prosper Road
De Pere, WI 54115
920.338.8860
www.onterra-eco.com

Sources:
Roads and Hydro: WDNR
Bathymetry: Onterra, 2017
Aquatic Plants: Onterra, 2022
Map Date: July 8th, 2022 JMB/KLW
Filename:LostVilas_CLP_2022.mxd



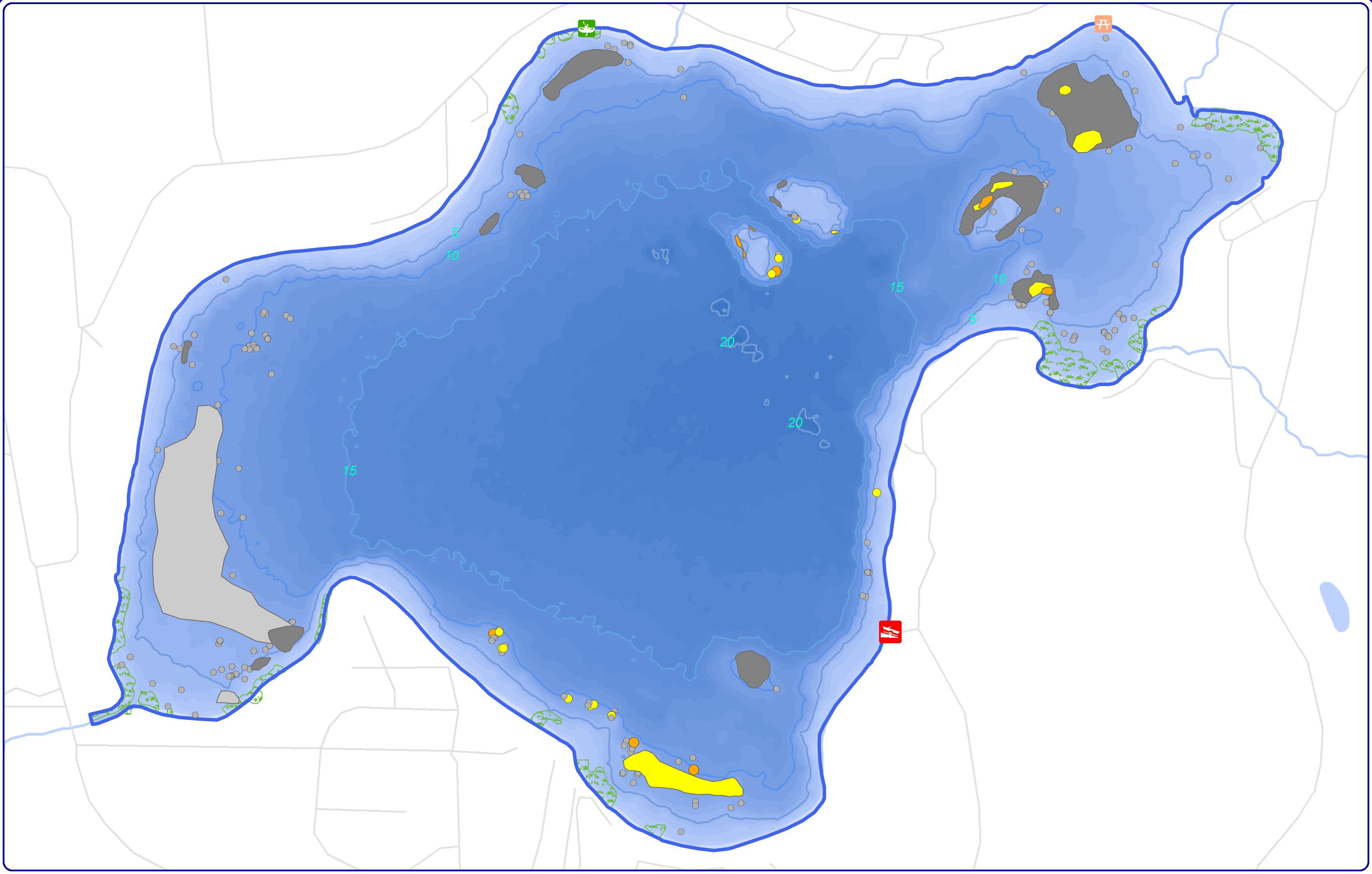
Project Location in Wisconsin

Legend

Curly-leaf pondweed (June 28, 2022)

- Highly Scattered
- Scattered
- Dominant
- Highly Dominant *(None)*
- Surface Matting *(None)*
- Single or Few Plants
- Clumps of Plants
- Small Plant Colony
- Floating-leaf and/or Emergent Plant Colony *(Mapped in 2017)*

Map 3
Lost Lake
Vilas County, Wisconsin
June 2022 CLP Survey Results



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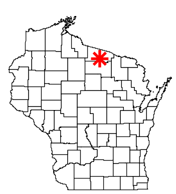
Onterra LLC
Lake Management Planning
815 Prosper Rd
De Pere, WI 54115
920.338.8860
www.onterra-eco.com

Sources:
Roads and Hydro: WDNR
Aquatic Plants: Onterra, 2022
Bathymetry: Onterra, 2017
Map date: September 2, 2022 TWH



Project Location in Wisconsin

Legend

EWM Survey Results ***(August 23, 2022)***

- Highly Scattered
- Scattered
- Dominant
- Highly Dominant
- Surface Matting
- Single or Few Plants
- Clump of Plants
- Small Plant Colony
- Floating-leaf and/or Emergent Plant Colony *(Mapped in 2017)*

Map 4
Lost Lake
Vilas County, Wisconsin
August 2022
EWM Survey Results

A

APPENDIX A

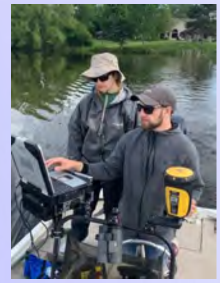
Public Participation Materials

Management Planning Meeting I Presentation Materials

Management Planning Meeting II Presentation Materials

Presentation Outline

- Lake Management Planning
- Water Quality
- Aquatic Plants
- Non-Native Aquatic Plants
  - Curly-leaf Pondweed (CLP)
  - Eurasian Watermilfoil (EWM)
- EWM Management/Applied Science
  - ProcellaCOR EWM Efficacy
  - ProcellaCOR Concentration Monitoring
  - Aquatic Plant Response to ProcellaCOR
  - 2,4-D Impacts on Fishes
- Development of an EWM Mgmt. Plan



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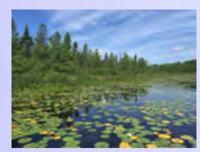
Why Create a Lake Management Plan?

- Preserve/restore ecological function
- To create a better understanding of lake's positive and negative attributes.
- To discover ways to minimize the negative attributes and maximize the positive attributes.
- Snapshot of lake's current status or health.
- Foster realistic expectations and dispel any misconceptions.



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What is a Lake Management Plan?

- Many organizations have plans for managing waterbodies that include Lost Lake
- This would be the local lake organization's *Plan* for managing Lost Lake
  - Based upon the district's capacity
  - Addressing the district's concerns
  - Complimentary to other *Plans*
  - Acknowledge Public Trust Doctrine

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Management Plan and Grants

- WDNR recommends ***Comprehensive Management Plans*** generally get updated every 10 years
  - Particularly for grants/permits related to water quality improvements (implementation grants)
- WDNR recommends lakes conducting active management update aspects of the plan every 5 years (***APM Plan***)
  - Particularly for grants/permits related to aquatic plant management (AIS control grants, NR107, NR109)
  - Whole-lake PI survey needs to be within 5 years
  - Management action in AIS Grant needs to be supported by Plan

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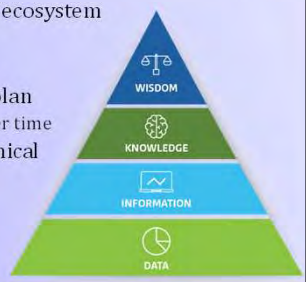
Management Planning Project Overview

- Foster holistic understanding of ecosystem
- Collect & analyze data
  - Technical & sociological
- Construct long-term & useable plan
  - Living plan subject to revision over time
- Onterra's role is to provide technical direction
  - Not really recommendations



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Aquatic Plant Management Plan Outline

- 1.0 Introduction
- 2.0 Stakeholder Participation
- 3.0 Aquatic Plants
  - 3.1 Primer on Aquatic Plant Data Analysis & Interpretation
  - 3.2 Lost Lake Aquatic Plant Survey Results
  - 3.3 Water Quality Summary
  - 3.4 Non-Native Plants in Lost Lake
- 4.0 Summary & Conclusions
- 5.0 Implementation Plan
- 6.0 Literature Cited

2022 District Survey
- 192 Sent, 118 returned = 61%
- >60% = statistically valid representation of population sampled

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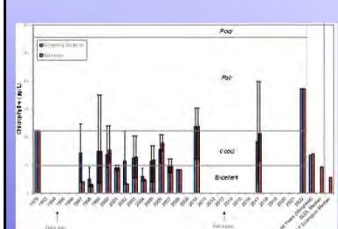
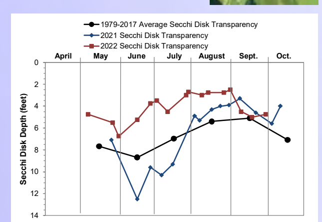
Water Quality

Water Quality

- Water clarity is primary driver of aquatic plant growth
- CLMN Secchi monitoring in place since 2021





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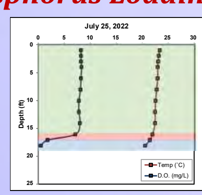
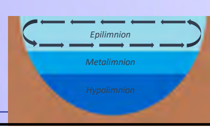
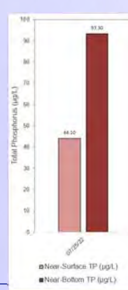
Lost Lake Water Quality
Internal Phosphorus Loading

What is internal loading?

- Iron binds P with oxygen in oxygenated waters
- Iron releases P when no oxygen is present (anoxic)
- P is then made available to algae following turnover event
- Cyanobacteria (Oscillatoria) can access P, N, & ferrous Iron from hypo when stratified







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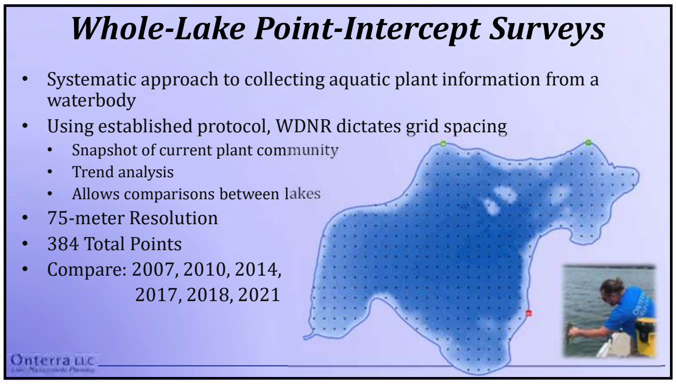
Aquatic Plants


Whole-Lake Point-Intercept Surveys
Systematic approach to collecting aquatic plant information from a waterbody
Using established protocol, WDNR dictates grid spacing
Snapshot of current plant community
Trend analysis
Allows comparisons between lakes
75-meter Resolution
384 Total Points
Compare: 2007, 2010, 2014, 2017, 2018, 2021
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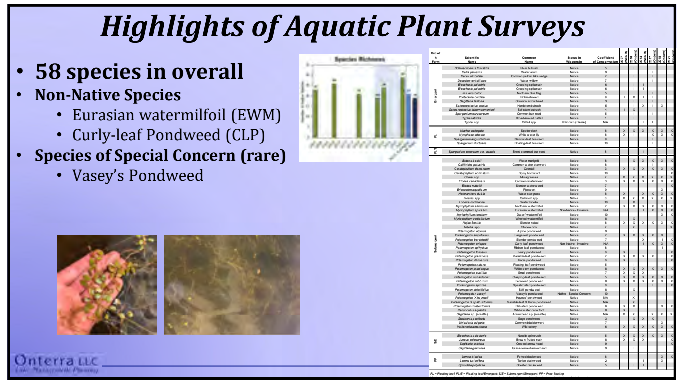
Highlights of Aquatic Plant Surveys
58 species in overall
Non-Native Species
Eurasian watermilfoil (EWM)
Curly-leaf Pondweed (CLP)
Species of Special Concern (rare)
Vasey's Pondweed
Species Richness
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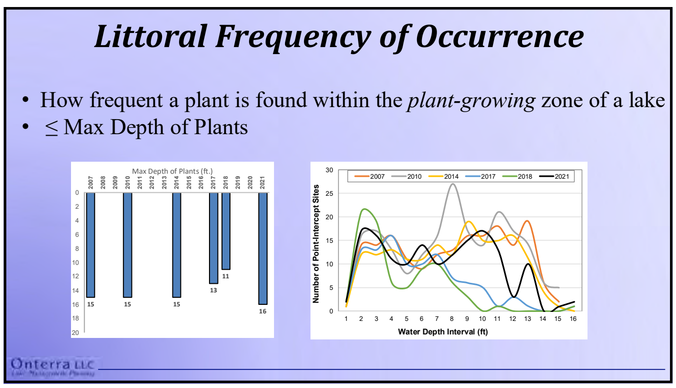
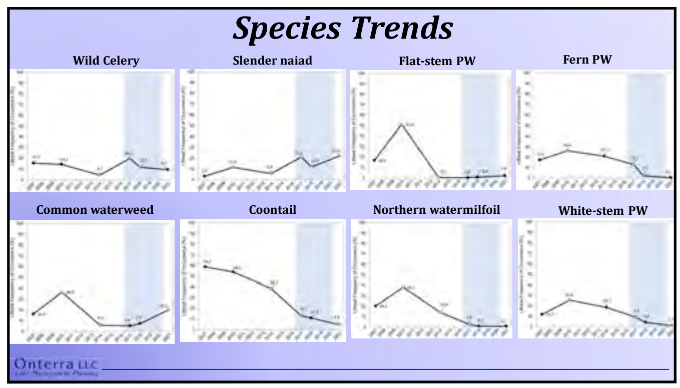

Littoral Frequency of Occurrence
How frequent a plant is found within the plant-growing zone of a lake
≤ Max Depth of Plants
Max Depth of Plants (ft.)
15
15
15
13
11
16
Number of Point-Intercept Sites
Water Depth Interval (ft)
2007
2010
2014
2017
2018
2021
Onterra LLC


Species Trends
Wild Celery
Slender naiad
Flat-stem PW
Fern PW
Common waterweed
Coontail
Northern watermilfoil
White-stem PW
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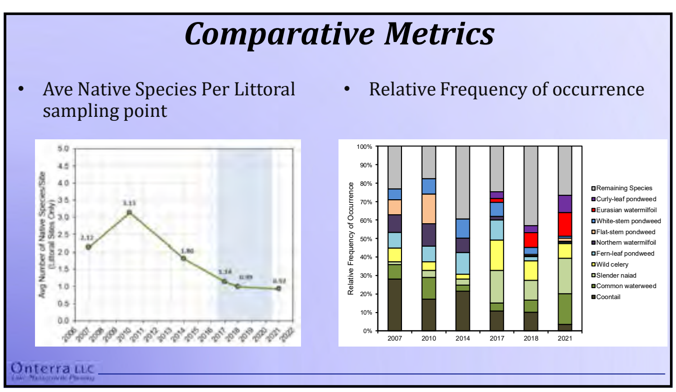
Comparative Metrics
Ave Native Species Per Littoral sampling point
Relative Frequency of occurrence
Avg Number of Native Species/Site (Littoral Sites Only)
2.12
3.13
1.80
1.14
0.99
0.92
Relative Frequency of Occurrence
2007
2010
2014
2017
2018
2021
Remaining Species
Curly-leaf pondweed
Eurasian watermilfoil
White-stem pondweed
Flat-stem pondweed
Northern watermilfoil
Fern-leaf pondweed
Wild celery
Slender naiad
Common waterweed
Coontail
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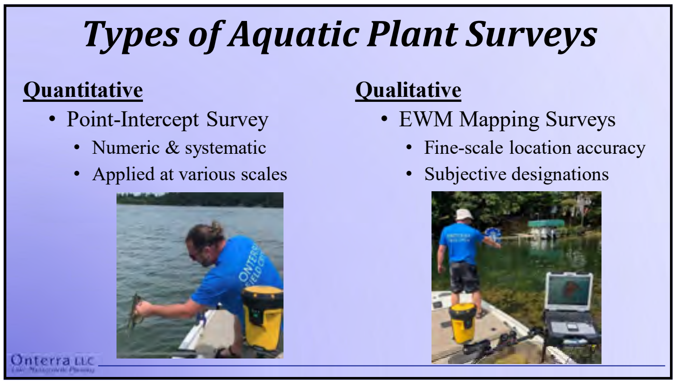
Aquatic Invasive Species


Types of Aquatic Plant Surveys
Quantitative
• Point-Intercept Survey
• Numeric & systematic
• Applied at various scales
Qualitative
• EWM Mapping Surveys
• Fine-scale location accuracy
• Subjective designations
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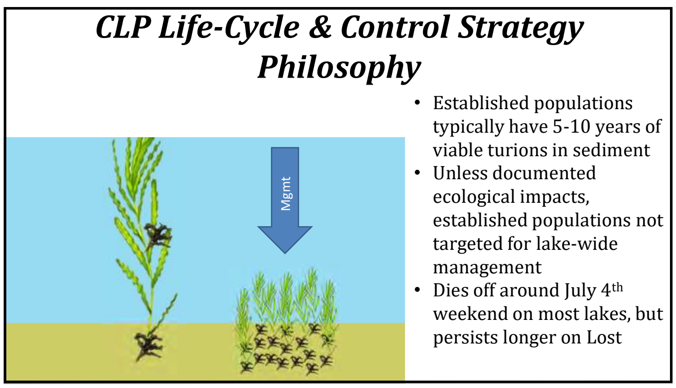
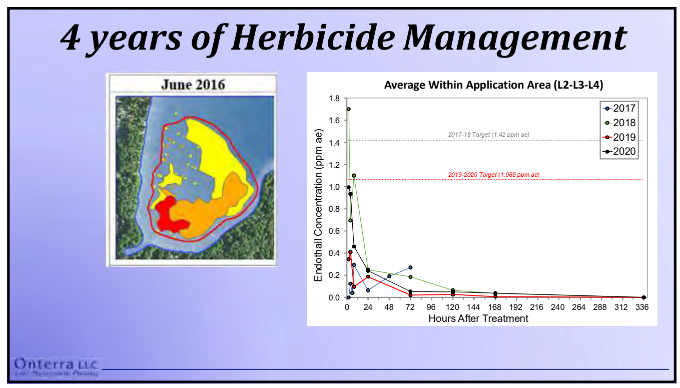
Non-Native Aquatic Plants
Curly-Leaf Pondweed
• First documented in 2014


CLP Life-Cycle & Control Strategy Philosophy
Mgmt
• Established populations typically have 5-10 years of viable turions in sediment
• Unless documented ecological impacts, established populations not targeted for lake-wide management
• Dies off around July 4th weekend on most lakes, but persists longer on Lost


4 years of Herbicide Management
June 2016
Average Within Application Area (L2-L3-L4)
2017
2018
2019
2020
Endothall Concentration (ppm ae)
Hours After Treatment
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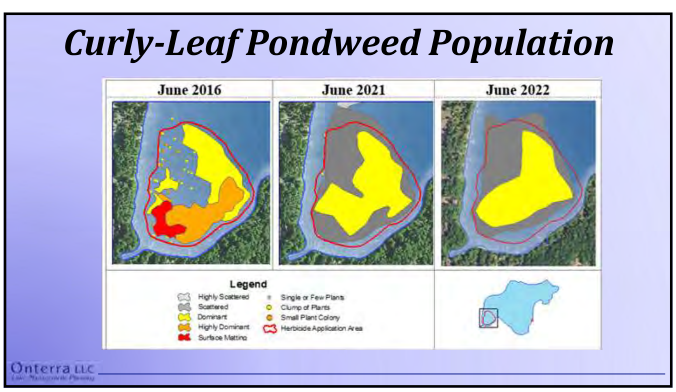
Curly-Leaf Pondweed Population
June 2016
June 2021
June 2022
Legend
Highly Scattered
Scattered
Dominant
Highly Dominant
Surface Matting
Single or Few Plants
Clump of Plants
Small Plant Colony
Herbicide Application Area
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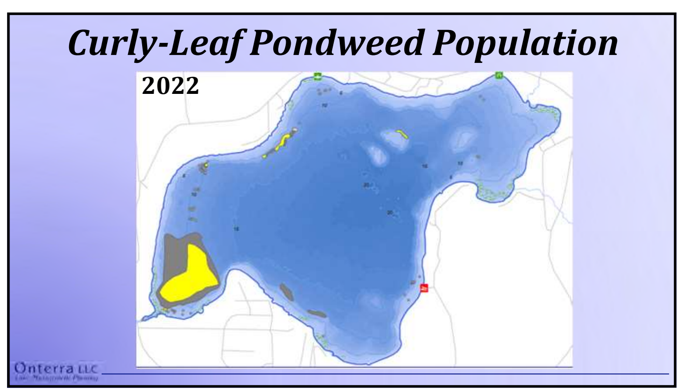
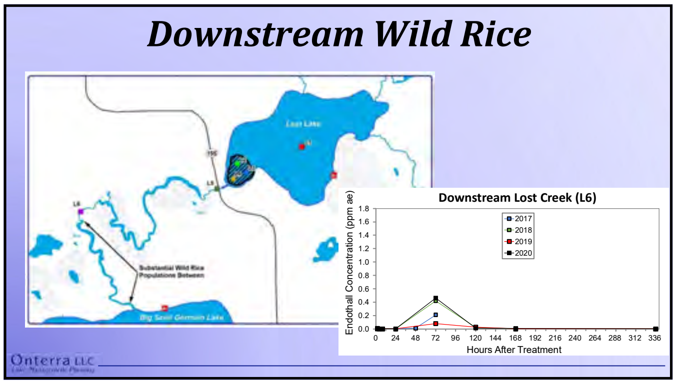
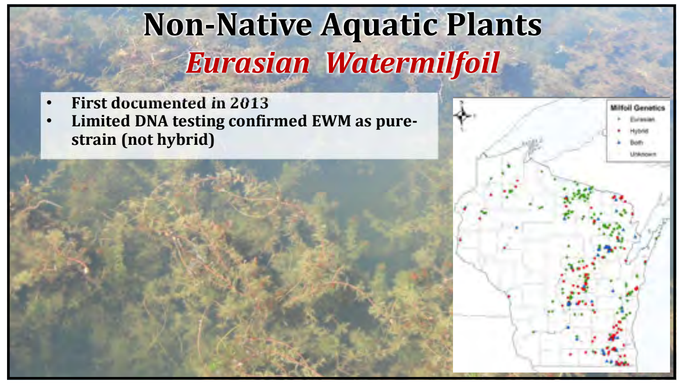
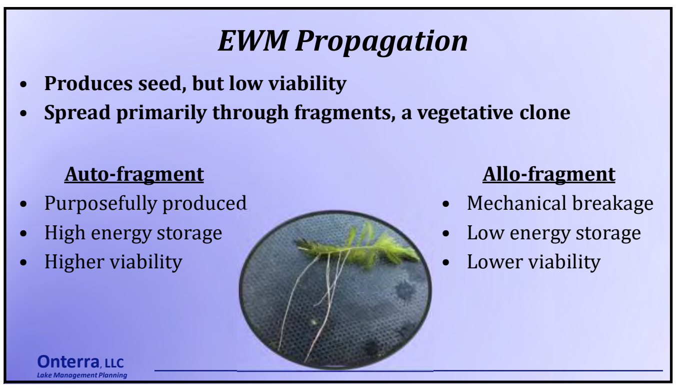
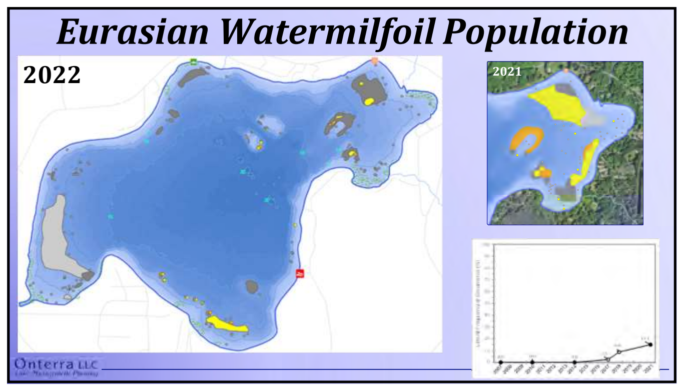
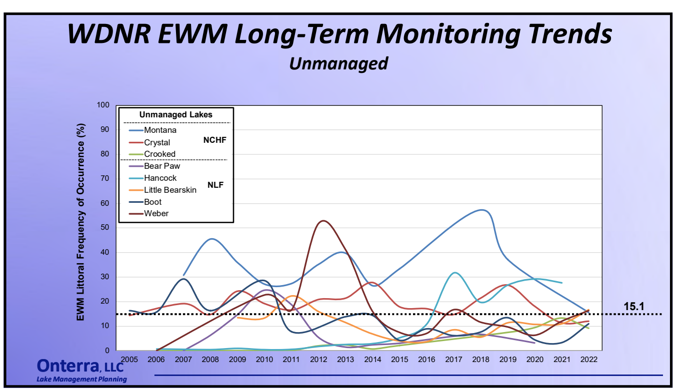

Curly-Leaf Pondweed Population
2022
Onterra LLC


Downstream Wild Rice
Lost Lake
Substantial Wild Rice Populations Between
Big Saint Germain Lake
Downstream Lost Creek (L6)
Endothall Concentration (ppm ae)
2017
2018
2019
2020
Hours After Treatment
Onterra LLC


Non-Native Aquatic Plants
Eurasian Watermilfoil
First documented in 2013
Limited DNA testing confirmed EWM as pure-strain (not hybrid)
Milfoil Genetics


EWM Propagation
Produces seed, but low viability
Spread primarily through fragments, a vegetative clone
Auto-fragment
Purposefully produced
High energy storage
Higher viability
Allo-fragment
Mechanical breakage
Low energy storage
Lower viability
Onterra, LLC
Lake Management Planning


Eurasian Watermilfoil Population
2022
2021
Onterra LLC


WDNR EWM Long-Term Monitoring Trends
Unmanaged
EWM Littoral Frequency of Occurrence (%)
Unmanaged Lakes
Montana
Crystal
Crooked
NCHF
Bear Paw
Hancock
Little Bearskin
Boot
Weber
NLF
15.1
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
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Lake Management Planning


EWM Management

Best Management Practices (BMPs)

- **A "placeholder" term to represent the management option that is currently supported by that latest science and policy**
- **Definition evolves over time**
  - Pre 2010 - small spot treatments with granular products
  - Early 2010s - larger spot treatments with liquid products
  - Mid 2010s – whole-lake treatments, spot treatments with herbicide combos, hand-harvesting/DASH
  - Current– new herbicides, whole-lake/basin approaches, nuisance maintenance vs population management, mechanical harvesting, increasing human tolerance

Learned that Concentration & Exposure Time (CET) is important!

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Florpyrauxifen-benzyl (ProcellaCOR™)

- New class of synthetic auxin hormone mimics
  - Much different binding affinity than other auxins
  - Use at PPB rate vs PPM
- Shorter contact exposure time (CET) requirement
- Short environmental fate of active ingredient (mainly photolysis)
- Acid metabolite has activity as an herbicide (longer environmental fate)
- Detailed information on field applications is limited (first in 2019 in WI)
  - Onterra may have the largest field monitoring database

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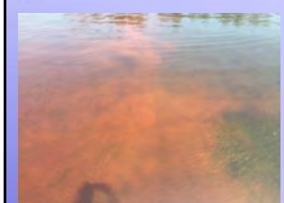
Herbicide Treatment on Lake Metonga

- Tracer Dye (Rhodamine WT)
- A-15 (south) ~ 3 acres
- B-15 (north) ~ 5 acres



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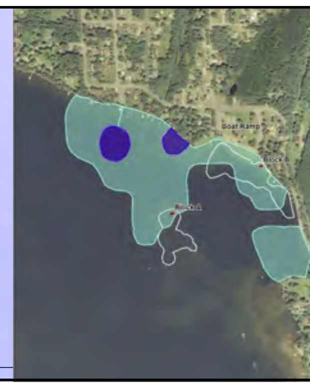
5 HAT

75-100%
50-75%
25-50%
10-25%
5-10%



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Herbicide Treatment on Loon Lake

- Tracer Dye (Rhodamine WT)
- ~24 acres of 305 acre lake (7.8%)

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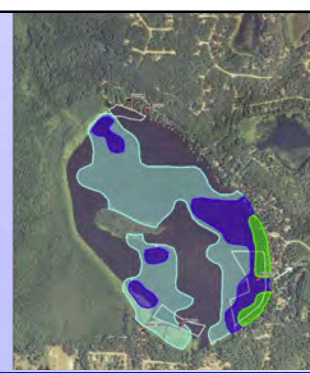
6 HAT

75-100%
50-75%
25-50%
10-25%
5-10%



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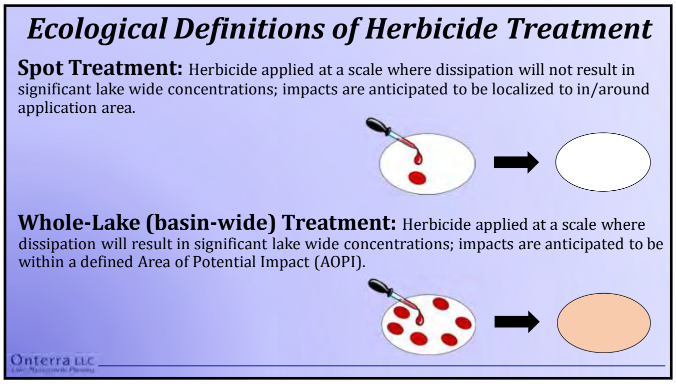
Ecological Definitions of Herbicide Treatment
Spot Treatment: Herbicide applied at a scale where dissipation will not result in significant lake wide concentrations; impacts are anticipated to be localized to in/around application area.
Whole-Lake (basin-wide) Treatment: Herbicide applied at a scale where dissipation will result in significant lake wide concentrations; impacts are anticipated to be within a defined Area of Potential Impact (AOPI).
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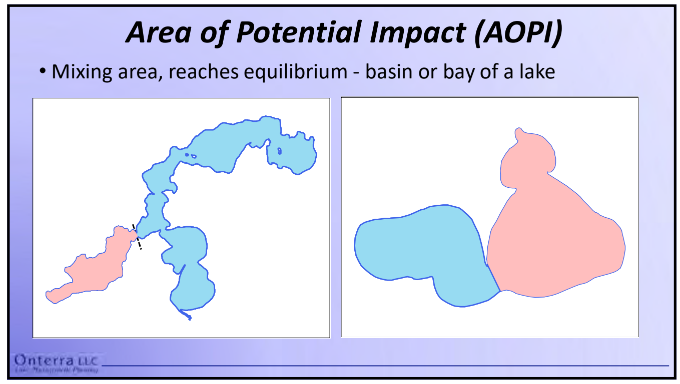
Area of Potential Impact (AOPI)
• Mixing area, reaches equilibrium - basin or bay of a lake
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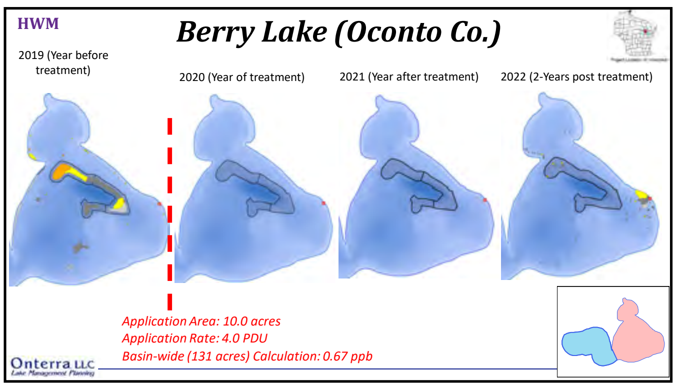
HWM
Berry Lake (Oconto Co.)
2019 (Year before treatment)
2020 (Year of treatment)
2021 (Year after treatment)
2022 (2-Years post treatment)
Application Area: 10.0 acres
Application Rate: 4.0 PDU
Basin-wide (131 acres) Calculation: 0.67 ppb
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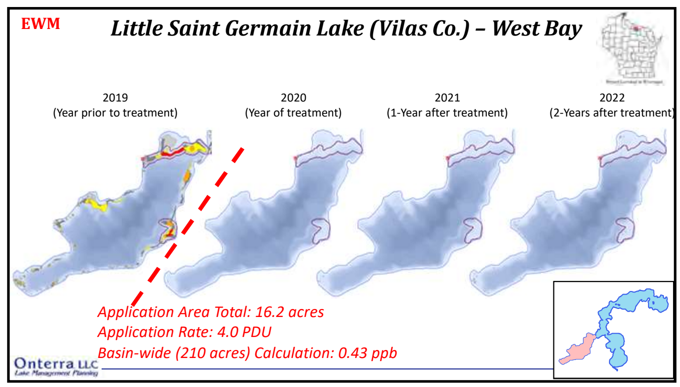
EWM
Little Saint Germain Lake (Vilas Co.) – West Bay
2019 (Year prior to treatment)
2020 (Year of treatment)
2021 (1-Year after treatment)
2022 (2-Years after treatment)
Application Area Total: 16.2 acres
Application Rate: 4.0 PDU
Basin-wide (210 acres) Calculation: 0.43 ppb
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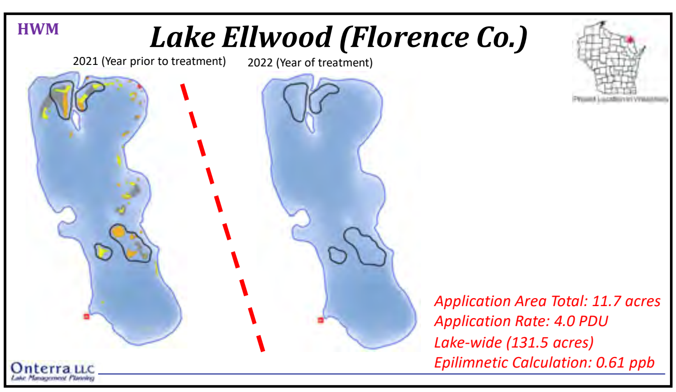
HWM
Lake Ellwood (Florence Co.)
2021 (Year prior to treatment)
2022 (Year of treatment)
Application Area Total: 11.7 acres
Application Rate: 4.0 PDU
Lake-wide (131.5 acres)
Epilimnetic Calculation: 0.61 ppb
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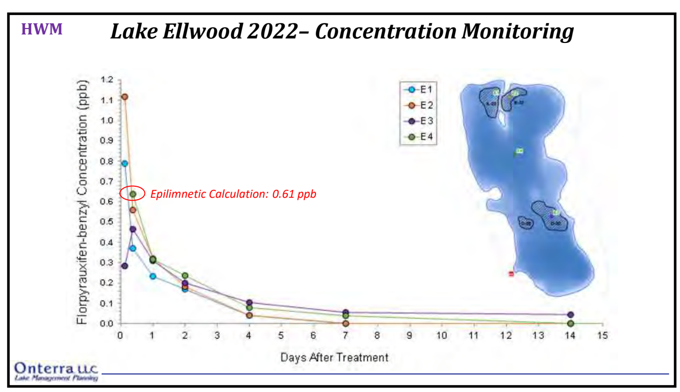
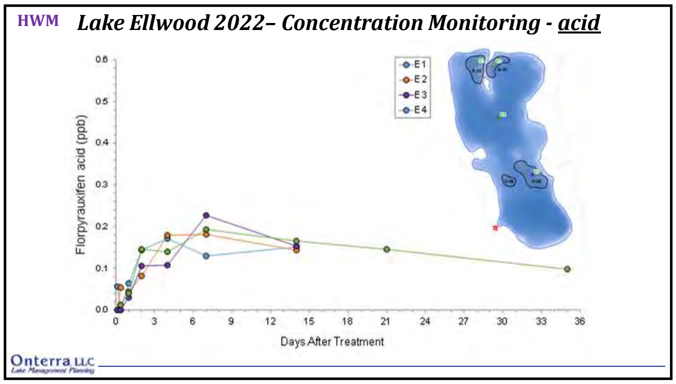

HWM
Lake Ellwood 2022– Concentration Monitoring
Florpyrauxifen-benzyl Concentration (ppb)
Days After Treatment
E1
E2
E3
E4
Epilimnetic Calculation: 0.61 ppb
Onterra LLC


HWM
Lake Ellwood 2022– Concentration Monitoring - acid
Florpyrauxifen acid (ppb)
Days After Treatment
E1
E2
E3
E4
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
3
6
9
12
15
18
21
24
27
30
33
36
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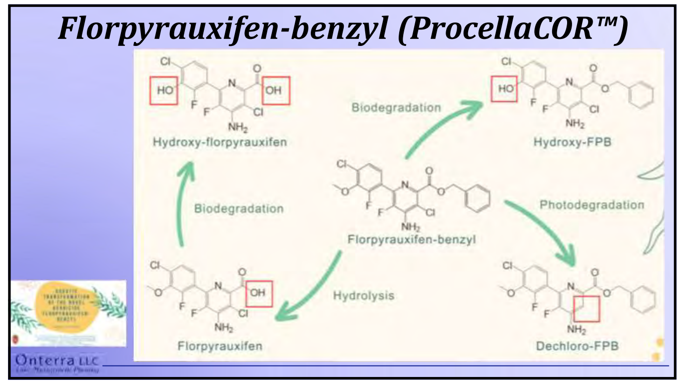
Florpyrauxifen-benzyl (ProcellaCOR™)
Hydroxy-florpyrauxifen
Biodegradation
Hydroxy-FPB
Biodegradation
Florpyrauxifen-benzyl
Photodegradation
Hydrolysis
Florpyrauxifen
Dechloro-FPB
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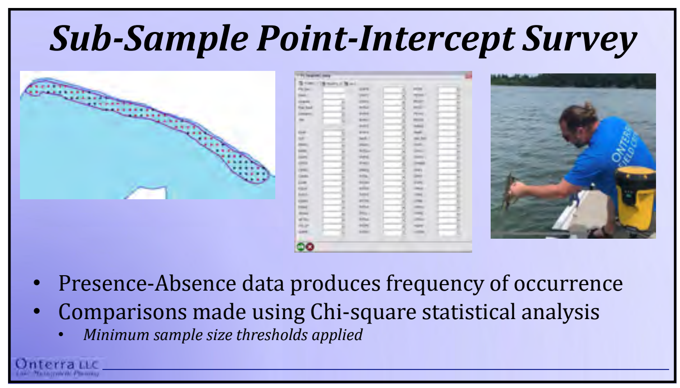
Aquatic Plant Response


Sub-Sample Point-Intercept Survey
Presence-Absence data produces frequency of occurrence
Comparisons made using Chi-square statistical analysis
Minimum sample size thresholds applied
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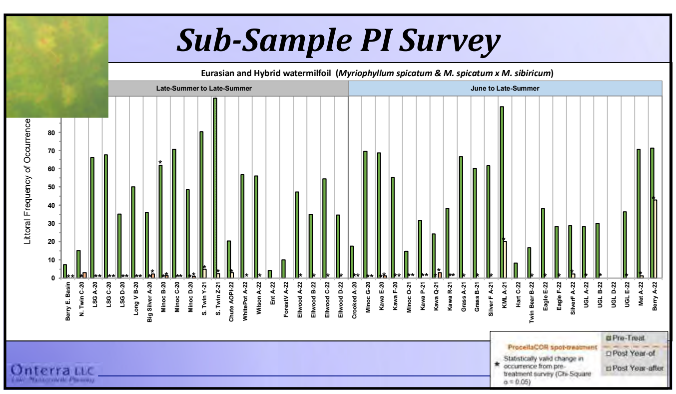
Sub-Sample PI Survey
Eurasian and Hybrid watermilfoil (Myriophyllum spicatum & M. spicatum x M. sibiricum)
Late-Summer to Late-Summer
June to Late-Summer
Littoral Frequency of Occurrence
Pre-Treat
Post Year-of
Post Year-after
ProcellaCOR spot-treatment
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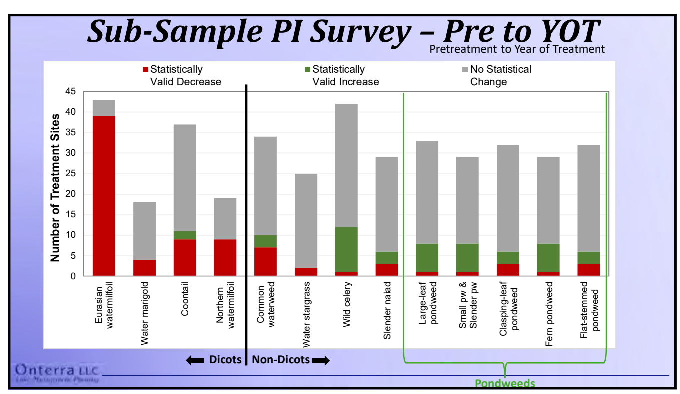
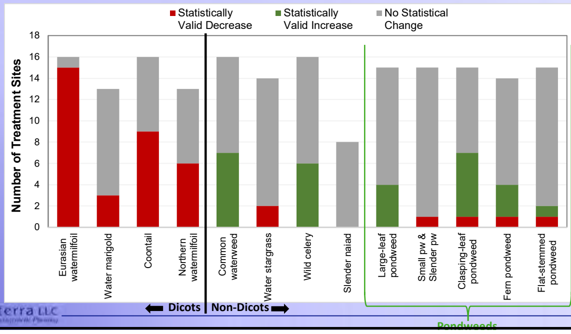

Sub-Sample PI Survey – Pre to YOT
Pretreatment to Year of Treatment
Statistically Valid Decrease
Statistically Valid Increase
No Statistical Change
Number of Treatment Sites
Eurasian watermilfoil
Water marigold
Coontail
Northern watermilfoil
Common waterweed
Water stargrass
Wild celery
Slender naiad
Large-leaf pondweed
Small pw & Slender pw
Clasping-leaf pondweed
Fern pondweed
Flat-stemmed pondweed
Dicots
Non-Dicots
Pondweeds
Onterra LLC

Sub-Sample PI Survey – Pre to YAT



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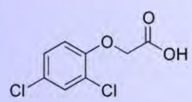
2.4-D Impacts on Fish Early Life Stages

- DeQuattro and Karasov 2016 demonstrated statistically valid reduction in fathead minnow larval survivability when 2,4-D is exposed to embryo (eggs) and larval (hatched). Also demonstrated sub-lethal endocrine disruption impacts (tubercles).
- Dehnert et. al 2018 indicates the first 14 days post hatch (dph) is the most critical period for fathead minnow.
- Dehnert et. al 2021 investigated multiple gamefish species, exposing to 30 dph to conform with EPA's definition of "chronic"



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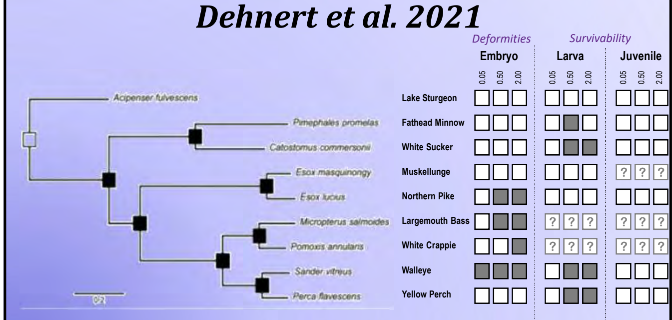
Dehnert et al. 2021



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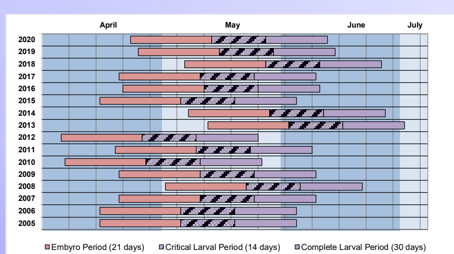
Application of UW Studies - Walleye

- Example from a Bayfield County Lake
- Peak tribal walleye spear harvest = fertilization date
- 21 day embryo period (5 days in lab due to Temp)
- 14 day critical larval period
- 30 day full larval period



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EWM Management Perspectives

1. **No Coordinated Active Management (Let Nature Take its Course)**
   - Focus on education of manual removal by property owners
   - Assoc. does not oppose contracted efforts, but does not organize or pay for them
2. **Reduce AIS Population on a lake-wide level (Population Management – "Control")**
   - Would likely rely on herbicide treatment (risk assessment)
   - Will not "eradicate" EWM
   - Set triggers (thresholds) of implementation and tolerance
   - May not be consistent with regulatory framework
3. **Minimize navigation and recreation impediment (Nuisance Control)**
   - Hand-harvesting alone is not able to accomplish this goal during high populations of EWM, herbicides and/or mechanical harvester would be required

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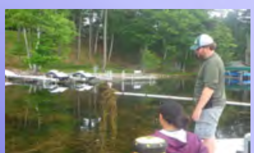
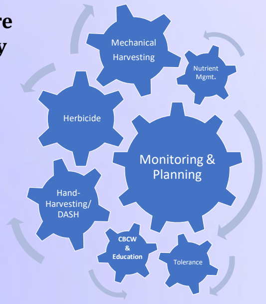
Integrated Pest Management (IPM)

Using a combination of methods that are more effective when applied collectively as part of defined strategy than when conducted separately





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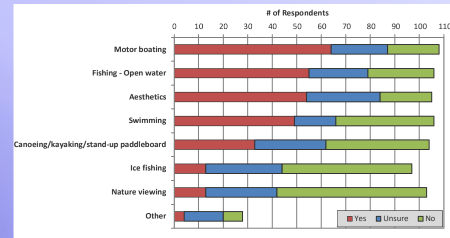
Stakeholder Perceptions of EWM Management

61% Response Rate

Has the Eurasian watermilfoil population ever had a negative impact on your enjoyment of Lost Lake?



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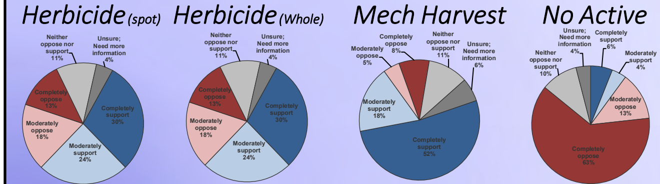
Stakeholder Perceptions of EWM Management

61% Response Rate

What is your level of support for the future use of the following EWM management techniques?



	Herbicide (spot)	Herbicide (Whole)	Mech Harvest	No Active
Support	82%	54%	70%	10%
Not Support	9%	31%	13%	76%
Unsure/Neutral	9%	15%	17%	14%

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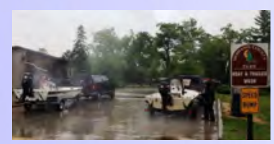
AIS Prevention & Containment

Clean Boats Clean Waters

Lost Lake -- Access Off Lost Colony Rd										
	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Boats Inspected	149	138	310	262	531	223	206	229	281	285
Hours Spent	149	150	295	290	452	256	232	252	263	231
Boats Inspected/Hrs Spent	1.00	1.09	0.95	1.11	0.85	1.15	1.13	1.10	0.94	0.81

Supplemental?

- UW-CFL identified as top 300 AIS Prevention
  - Decontamination stations
  - Remove video surveillance



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Implementation Plan Development

Goal

- Reflects big picture
- Can be ambitious, but attainable

Action

- Step to meet goal
- Measurable outcome
- Timeframe
- Facilitator

- Management goals are statements, were as management actions are detailed.

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Thank You

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Lake Management Planning

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What is a Lake Management Plan?

- Many organizations have "plans for managing waterbodies that include Lost Lake
  - WDNR (fisheries, lakes), LDF Tribe, GLIFWC, Town
- This would be the Lost Lake P&R District's *Plan* for managing Lost Lake
  - Based upon the district's capacity
  - Addressing the district's concerns
  - Complimentary to other *Plans*
  - Acknowledging the Public Trust Doctrine

Implementation Plan Development

Goal
- Reflects big picture
- Can be ambitious, but attainable

Action
- Step to meet goal
- Measurable outcome
- Timeframe
- Facilitator

- Management goals are statements, were as management actions are detailed.

Integrated Pest Management (IPM)

Using a combination of methods that are more effective when applied collectively as part of defined strategy than when conducted separately

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Lake Management Planning

Comp Mgmt Plan (2019): Implementation Plan

Goal 1: Manage Existing and Prevent Further AIS within Lost Lake
- Continue Clean Boats Clean Waters watercraft inspections at critical public access locations
- Coordinate annual professional monitoring of AIS, particularly CLP (Annually)
- Coordinate Periodic Quantitative Vegetation Monitoring (PI – 3 years, Community Mapping - 10 years)
- Conduct CLP population management using herbicide spot treatments (Implementation trigger, monitoring plan)

Goal 2: Maintain Current Water Quality Conditions
- Monitor water quality of Lost Lake through WDNR Citizens Lake Monitoring Network
- Ensure water quality of upstream lakes within Lost Lake's watershed are being monitored

Goal 3: Increase LLPRD's Communication Capacity
- Use education to promote lake protection and enjoyment through stakeholder education
- Continue LLPRD's involvement with other entities that have responsibilities in managing (management units) Lost Lake
- Conduct Periodic Riparian Stakeholder Surveys

Goal 4: Improve Lake and Fishery Resource of Lost Lake
- Educate Stakeholders on the Importance of Shoreland Condition and Shoreland Restoration
- Coordinate with WDNR and private landowners to expand coarse woody habitat in Lost Lake
- Develop a fisheries management plan for Lost Lake
- Investigate requesting transfer of ownership of the Lost Lake dam

Thank You

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Lake Management Planning

Onterra LLC
Lake Management Planning

B

APPENDIX B

District Stakeholder Survey Response Charts & Comments

Lost Lake - Anonymous Stakeholder Survey

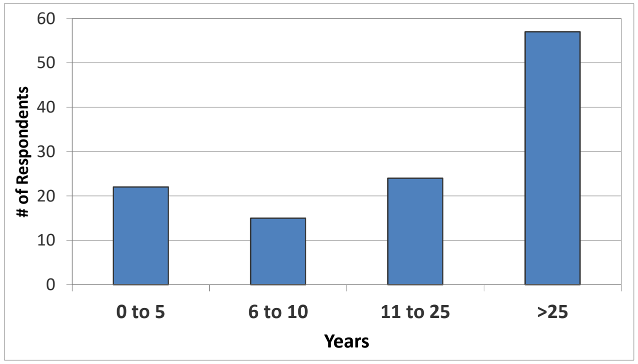
Surveys Distributed: *192*
Surveys Returned: *118*
Response Rate: *61%*

Lost Lake Property

1. How many years have you owned or rented your property on or near Lost Lake?

Answer Options	Response Count
	118
answered question	**118**
skipped question	**0**

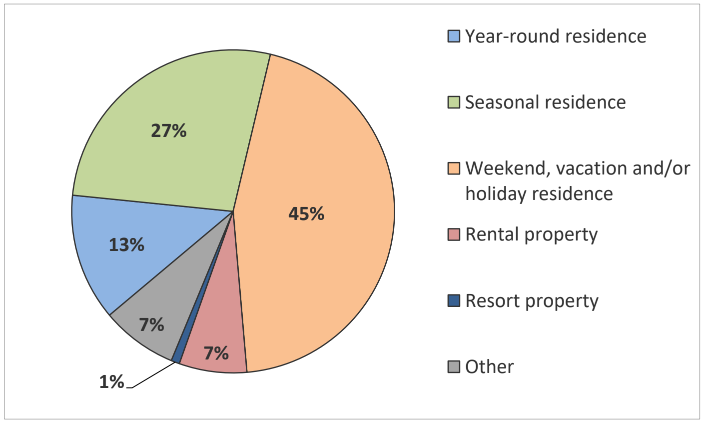
Category (# of years)	Responses	% Response
0 to 5	**22**	**19%**
6 to 10	**15**	**13%**
11 to 25	**24**	**20%**
>25	**57**	**48%**



2. How is your property on Lost Lake used?

Answer Options	Response Percent	Response Count
Year-round residence	12.7%	15
Seasonal residence	27.1%	32
Weekend, vacation and/or holiday residence	44.9%	53
Rental property	6.8%	8
Resort property	0.8%	1
Other	7.6%	9
answered question		**118**
skipped question		**0**

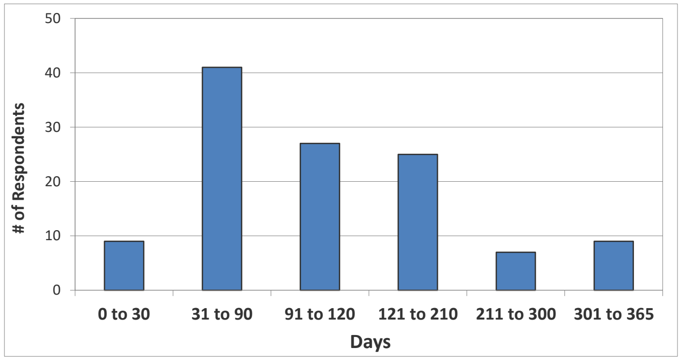
Number	"Other" responses
1	Waterfront Lot
2	seasonal and rental
3	Seasonal & rental
4	May - Sept. about 60% of th days
5	Both rental and weekend, vacation, and/or holiday
6	Rentals and personal use
7	Partial Rental and Partial residential use year round
8	Summer, Fall, but also rent on the lake
9	future building site



3. Considering the past three years, how many days each year is your property used by you or others?

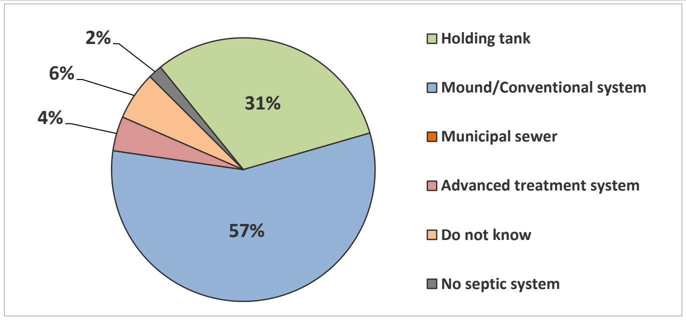
	Response Count
answered question	**118**
skipped question	**0**

Category (# of days)	Responses	%
0 to 30	**9**	**8%**
31 to 90	**41**	**35%**
91 to 120	**27**	**23%**
121 to 210	**25**	**21%**
211 to 300	**7**	**6%**
301 to 365	**9**	**8%**



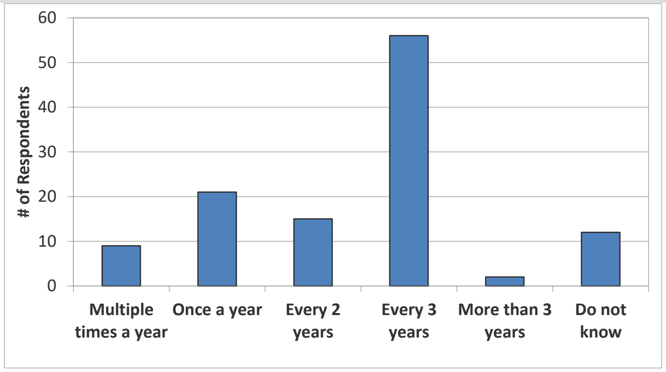
4. What type of septic system does your property have?

Answer Options	Response Percent	Response Count
Holding tank	31.4%	37
Mound/Conventional system	56.8%	67
Municipal sewer	0.0%	0
Advanced treatment system	4.2%	5
Do not know	5.9%	7
No septic system	1.7%	2
answered question		**118**
skipped question		**0**



5. How often is the septic system on your property pumped?

Answer Options	Response Percent	Response Count
Multiple times a year	7.8%	9
Once a year	18.3%	21
Every 2 years	13.0%	15
Every 3 years	48.7%	56
More than 3 years	1.7%	2
Do not know	10.4%	12
	answered question	**115**
	skipped question	**3**

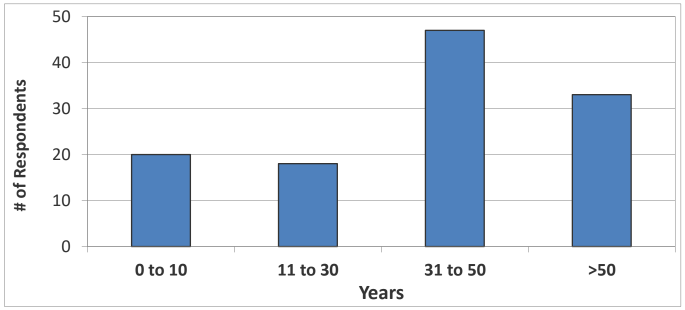


Recreational Activity on Lost Lake

6. How many years ago did you first visit Lost Lake?

Answer Options	Response Count
answered question	**118**
skipped question	**0**

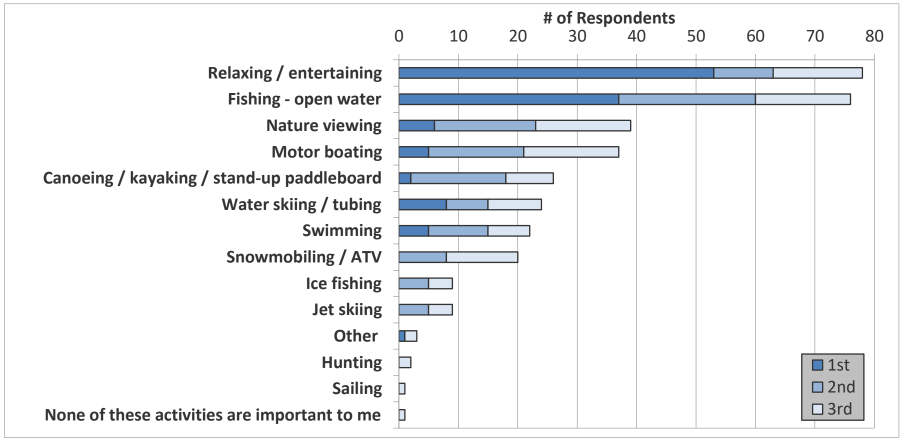
Category (# of years)	Response Percent	Response Count
0 to 10	**17.0%**	**20**
11 to 30	**15.3%**	**18**
31 to 50	**39.8%**	**47**
>50	**28.0%**	**33**



7. Please rank up to three activities that are important reasons for owning your property on Lost Lake, with 1st being the most important.

Answer Options	1st	2nd	3rd	Rating Average	Response Count
Relaxing / entertaining	53	10	15	1.51	78
Fishing - open water	37	23	16	1.72	76
Nature viewing	6	17	16	2.26	39
Motor boating	5	16	16	2.3	37
Canoeing / kayaking / stand-up paddleboard	2	16	8	2.23	26
Water skiing / tubing	8	7	9	2.04	24
Swimming	5	10	7	2.09	22
Snowmobiling / ATV	0	8	12	2.6	20
Ice fishing	0	5	4	2.44	9
Jet skiing	0	5	4	2.44	9
Other	1	0	2	2.33	3
Hunting	0	0	2	3	2
Sailing	0	0	1	3	1
None of these activities are important to me	0	0	1	3	1
				answered question	**117**
				skipped question	**1**

Number	"Other" responses
1	Future Building Site
2	The lake is used year round. All activities.
3	nature viewing and hiking
4	atv utv

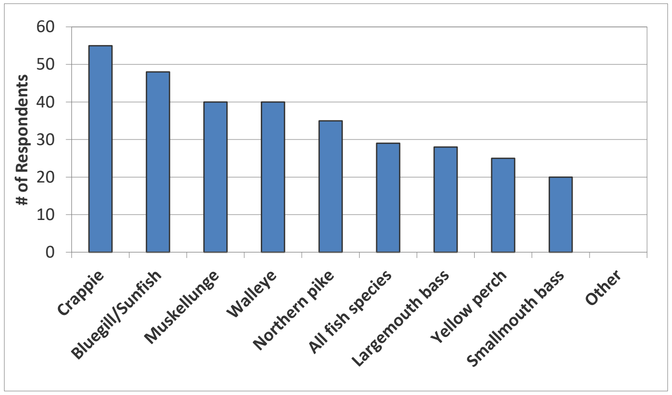


8. Have you personally fished on Lost Lake in the past three years?

Answer Options	Response Percent	Response Count
Yes	88.1%	104
No	11.9%	14
	answered question	**118**
	skipped question	**0**

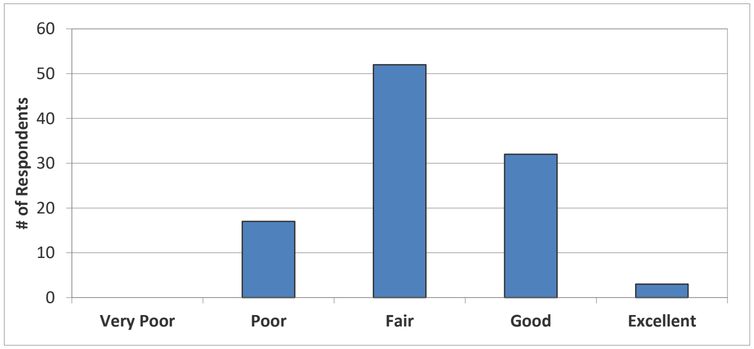
9. What species of fish do you try to catch on Lost Lake?

Answer Options	Response Percent	Response Count
Crappie	52.9%	55
Bluegill/Sunfish	46.2%	48
Muskellunge	38.5%	40
Walleye	38.5%	40
Northern pike	33.7%	35
All fish species	27.9%	29
Largemouth bass	26.9%	28
Yellow perch	24.0%	25
Smallmouth bass	19.2%	20
Other	0.0%	0
	answered question	**104**
	skipped question	**14**



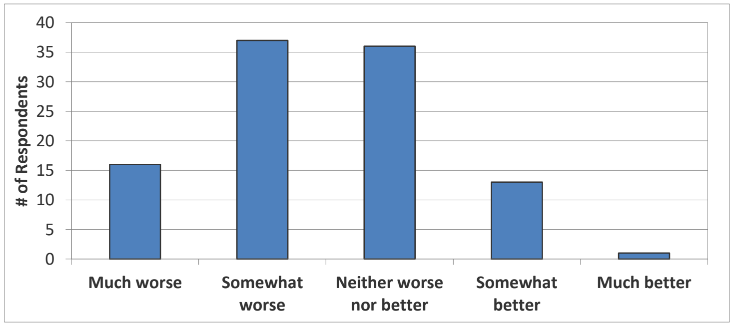
10. How would you describe the current quality of fishing on Lost Lake?

Answer Options	Very Poor	Poor	Fair	Good	Excellent	Response Count
	0	17	52	32	3	104
					answered question	**104**
					skipped question	**14**



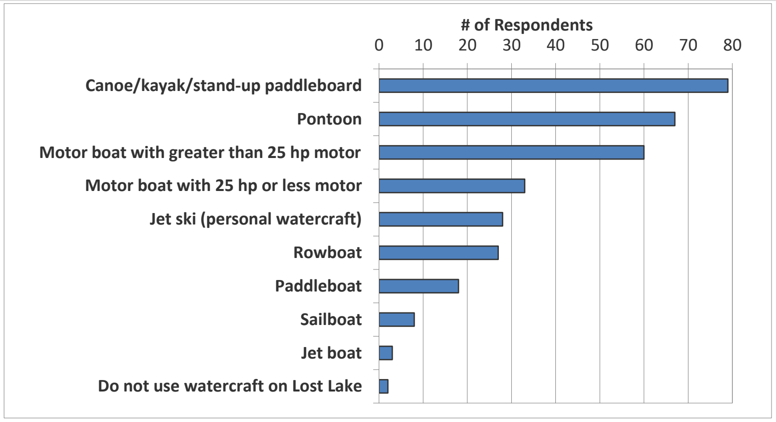
11. How has the quality of fishing changed on Lost Lake since you have started fishing the lake?

Answer Options	Much worse	Somewhat worse	Neither worse nor better	Somewhat better	Much better	Response Count
	16	37	36	13	1	103
					answered question	**103**
					skipped question	**15**



12. What types of watercraft do you currently use on Lost Lake?

Answer Options	Response Percent	Response Count
Canoe/kayak/stand-up paddleboard	67.0%	79
Pontoon	56.8%	67
Motor boat with greater than 25 hp motor	50.9%	60
Motor boat with 25 hp or less motor	28.0%	33
Jet ski (personal watercraft)	23.7%	28
Rowboat	22.9%	27
Paddleboat	15.3%	18
Sailboat	6.8%	8
Jet boat	2.5%	3
Do not use watercraft on Lost Lake	1.7%	2
Do not use watercraft on any waters	0.0%	0
answered question		**118**
skipped question		**0**



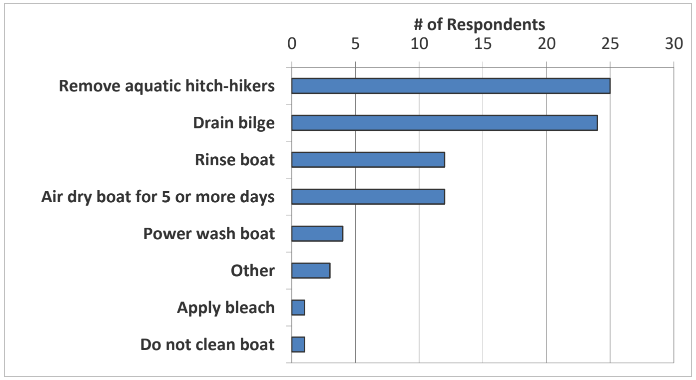
13. Do you use your watercraft on waters other than Lost Lake?

Answer Options	Response Percent	Response Count
Yes	25.4%	29
No	74.6%	85
answered question		114
skipped question		4

14. What is your typical cleaning routine after using your watercraft on waters other than Lost Lake?

Answer Options	Response Percent	Response Count
Remove aquatic hitch-hikers (ex. - plant material, clams, mussels)	78.1%	25
Drain bilge	75.0%	24
Rinse boat	37.5%	12
Air dry boat for 5 or more days	37.5%	12
Power wash boat	12.5%	4
Other	9.4%	3
Apply bleach	3.1%	1
Do not clean boat	3.1%	1
answered question		32
skipped question		86

Number	"Other" responses
1	not applicable
2	Clean everything including trailer very knowledgeable about invasive aquatic plants and such
3	wash with soap and water

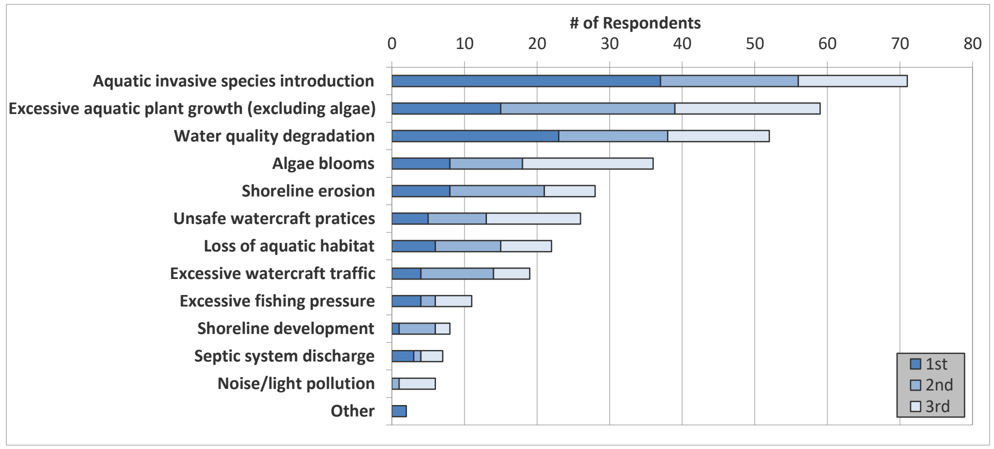


Lost Lake Current and Historic Condition, Health and Management

15. From the list below, please rank your top three concerns regarding Lost Lake, with 1 being your greatest concern.

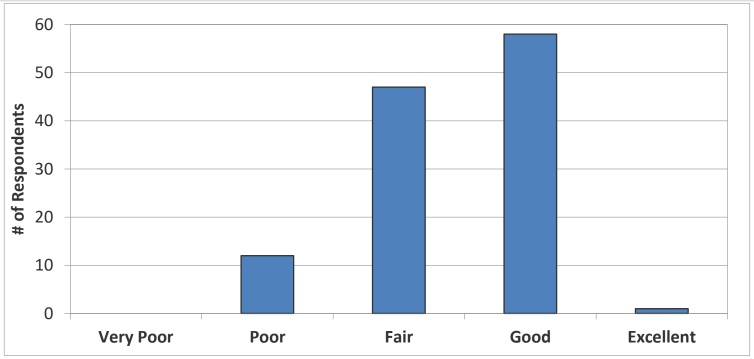
Answer Options	1st	2nd	3rd	Response Count
Aquatic invasive species introduction	37	19	15	71
Excessive aquatic plant growth (excluding algae)	15	24	20	59
Water quality degradation	23	15	14	52
Algae blooms	8	10	18	36
Shoreline erosion	8	13	7	28
Unsafe watercraft pratices	5	8	13	26
Loss of aquatic habitat	6	9	7	22
Excessive watercraft traffic	4	10	5	19
Excessive fishing pressure	4	2	5	11
Shoreline development	1	5	2	8
Septic system discharge	3	1	3	7
Noise/light pollution	0	1	5	6
Other	2	0	0	2
			answered question	**118**
			skipped question	**0**

Number	"Other" responses
1	Jet skis are a real concern on this lake. They come dangerously close to swimmers and other boats!
2	Lawn fertilizer run in lake
3	Geese
4	Lily Pad growth
5	Oversized and wakeboard boat traffic



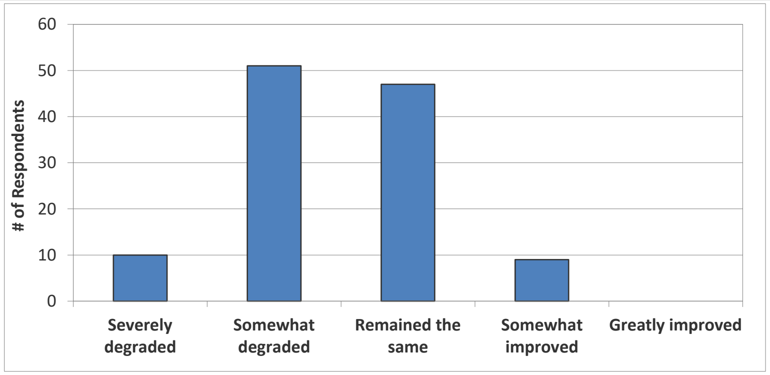
16. How would you describe the overall current water quality of Lost Lake?

Answer Options	Very Poor	Poor	Fair	Good	Excellent	Response Count
	0	12	47	58	1	118
					answered question	**118**
					skipped question	**0**



17. How has the overall water quality changed in Lost Lake since you first visited the lake?

Answer Options	Severely degraded	Somewhat degraded	Remained the same	Somewhat improved	Greatly improved	Response Count
	10	51	47	9	0	117
					answered question	**117**
					skipped question	**1**



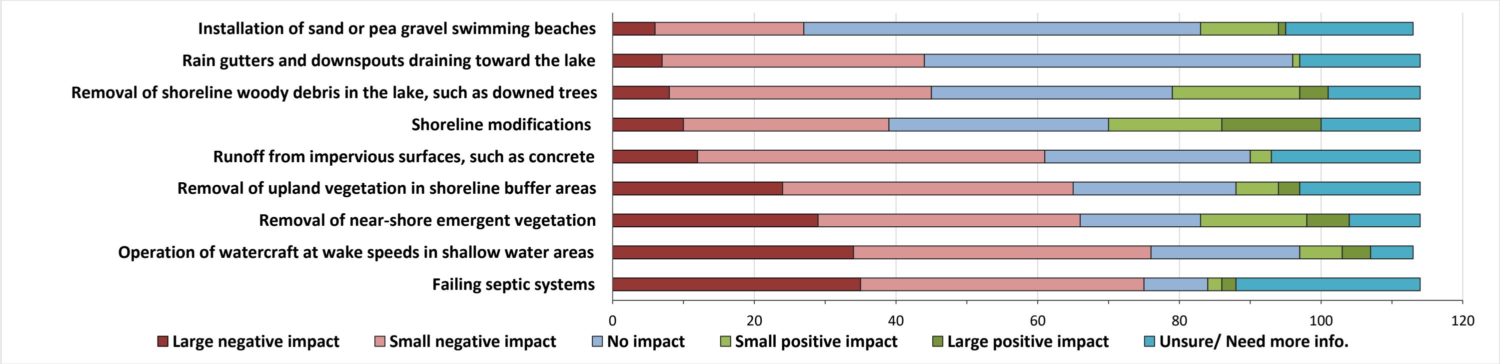
18. Which of the following would you say is the single most important aspect when considering water quality?

Answer Options	Response Percent	Response Count
Water clarity (clearness of water)	38.5%	45
Water color	0.9%	1
Aquatic plant growth	35.0%	41
Algae blooms	21.4%	25
Smell/odors	1.7%	2
Water level	0.9%	1
Fish kills	0.9%	1
Other	0.9%	1
	answered question	117
	skipped question	1

Number	"Other" responses
1	Jet propulsion watercraft usage that directs water stream to lake bottom stirring the natural lake bottom and releasing weeds damaging spawning grounds. Much of the lake bottom is less than 8 ft deep. This creates water quality issues and natural fish reproduction issues.

19. Using the following scale, what impact, if any, do you believe each of the following practices have on the water quality of Lost Lake?

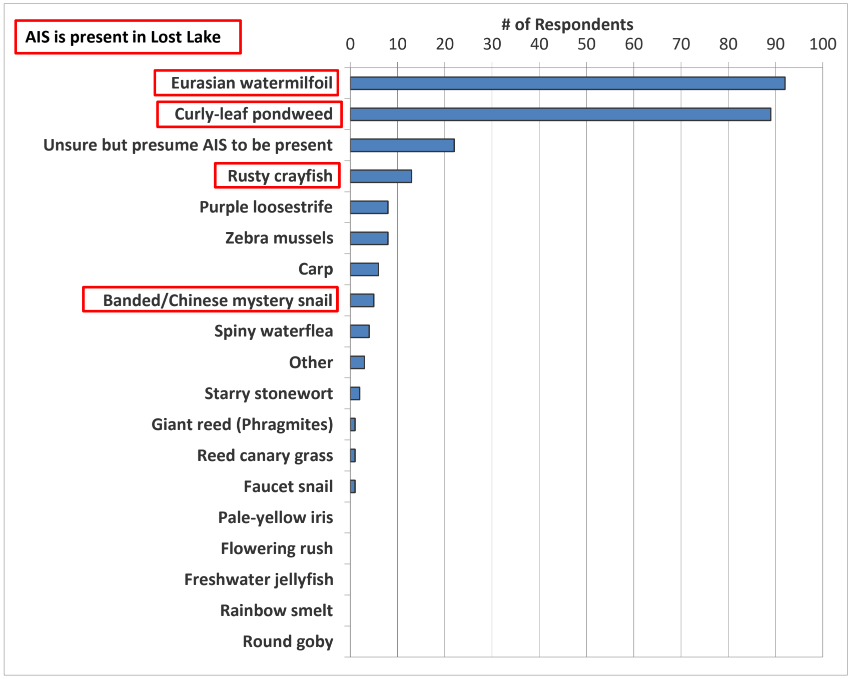
Answer Options	Large negative impact	Small negative impact	No impact	Small positive impact	Large positive impact	Unsure/ Need more info.	Response Count
Failing septic systems	35	40	9	2	2	26	114
Operation of watercraft at wake speeds in shallow water areas	34	42	21	6	4	6	113
Removal of near-shore emergent vegetation, such as bulrushes, lily pads, cattails, etc.	29	37	17	15	6	10	114
Removal of upland vegetation in shoreline buffer areas	24	41	23	6	3	17	114
Runoff from impervious surfaces, such as concrete	12	49	29	3	0	21	114
Shoreline modifications (rip-rap retaining walls, etc.)	10	29	31	16	14	14	114
Removal of shoreline woody debris in the lake, such as downed trees	8	37	34	18	4	13	114
Rain gutters and downspouts draining toward the lake	7	37	52	1	0	17	114
Installation of sand or pea gravel swimming beaches	6	21	56	11	1	18	113
						answered question	114
						skipped question	4



20. Before reading the statement above, had you ever heard of aquatic invasive species?		
Answer Options	Response Percent	Response Count
Yes	100.0%	117
No	0.0%	0
	answered question	**117**
	skipped question	**1**

21. Do you believe aquatic invasive species are present within Lost Lake?		
Answer Options	Response Percent	Response Count
Yes	94.0%	109
I think so but am not certain	0.0%	0
No	6.0%	7
	answered question	**116**
	skipped question	**2**

22. Which aquatic invasive species do you believe are present in or immediately around Lost Lake?		
Answer Options	Response Percent	Response Count
Eurasian watermilfoil	83.6%	92
Curly-leaf pondweed	80.9%	89
Unsure but presume AIS to be present	20.0%	22
Rusty crayfish	11.8%	13
Purple loosestrife	7.3%	8
Zebra mussels	7.3%	8
Carp	5.5%	6
Banded/Chinese mystery snail	4.6%	5
Spiny waterflea	3.6%	4
Other	2.7%	3
Starry stonewort	1.8%	2
Giant reed (Phragmites)	0.9%	1
Reed canary grass	0.9%	1
Faucet snail	0.9%	1
Pale-yellow iris	0.0%	0
Flowering rush	0.0%	0
Freshwater jellyfish	0.0%	0
Rainbow smelt	0.0%	0
Round goby	0.0%	0
	answered question	**110**
	skipped question	**8**

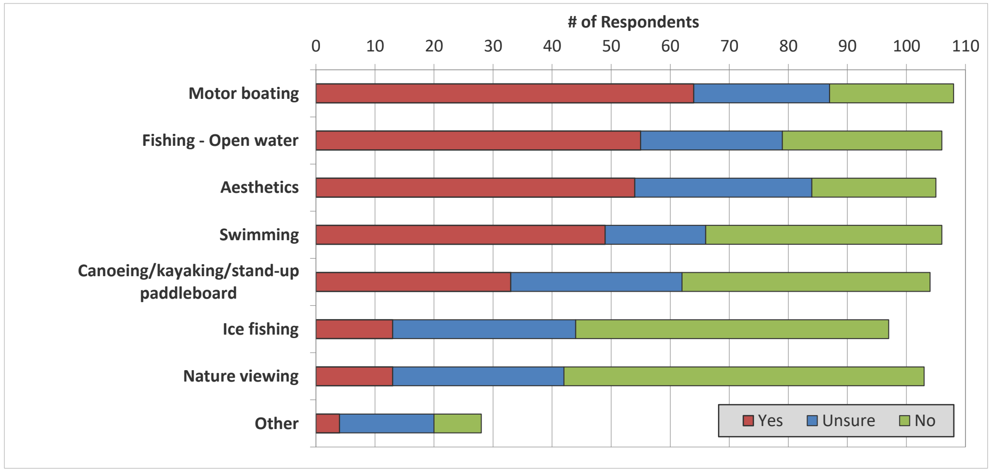


Number	"Other" responses
1	Unsure
2	Just what I am told
3	Abundance of common sea weed

23a. Has Eurasian watermilfoil (EWM) ever had a negative impact on your enjoyment of Lost Lake?

Answer Options	Yes	Unsure	No	Response
Motor boating	64	23	21	108
Fishing - Open water	55	24	27	106
Aesthetics	54	30	21	105
Swimming	49	17	40	106
Canoeing/kayaking/stand-up paddleboard	33	29	42	104
Ice fishing	13	31	53	97
Nature viewing	13	29	61	103
Other	4	16	8	28
			answered question	110
			skipped question	8

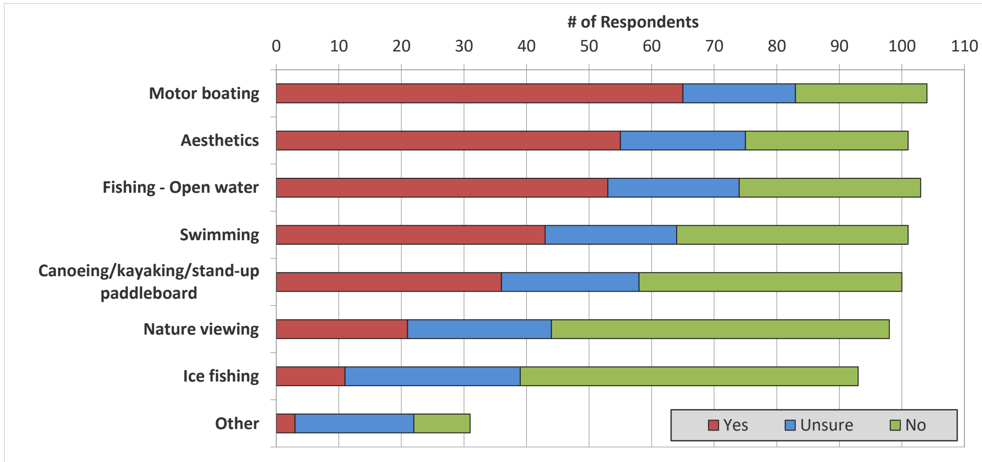
Number	"Other" responses
1	Do not use the lake
2	Wondering if this is why the loon population seems to be dwindling.
3	Floating weed clumps can be overwhelming fishing and swimming.
4	treatment for EWM has removed all vegetation from Sunrise Cove area



23b. Has curly-leaf pondweed (CLP) ever had a negative impact on your enjoyment of Lost Lake?

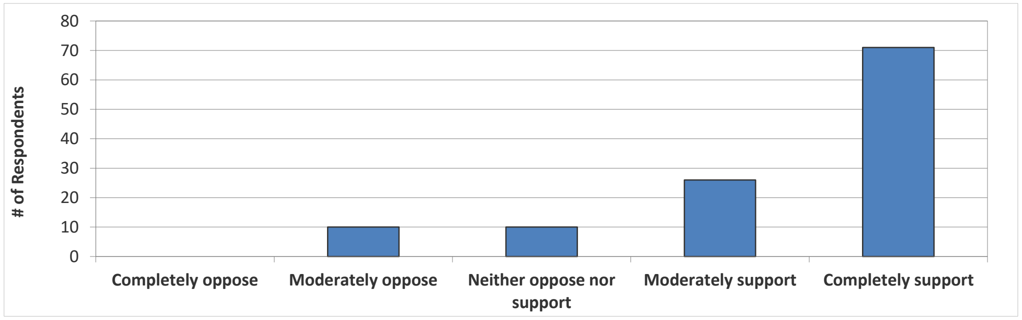
Answer Options	Yes	Unsure	No	Response
Motor boating	65	18	21	104
Aesthetics	55	20	26	101
Fishing - Open water	53	21	29	103
Swimming	43	21	37	101
Canoeing/kayaking/stand-up paddleboard	36	22	42	100
Nature viewing	21	23	54	98
Ice fishing	11	28	54	93
Other	3	19	9	31
			answered question	**107**
			skipped question	**11**

Number	"Other" responses
1	Worrried about degradation in property value
2	Again concerned it may affect the loon population
3	Treatment has removed all vegetation and seems to have increased algae blooms in Sunset Bay area by *name removed*



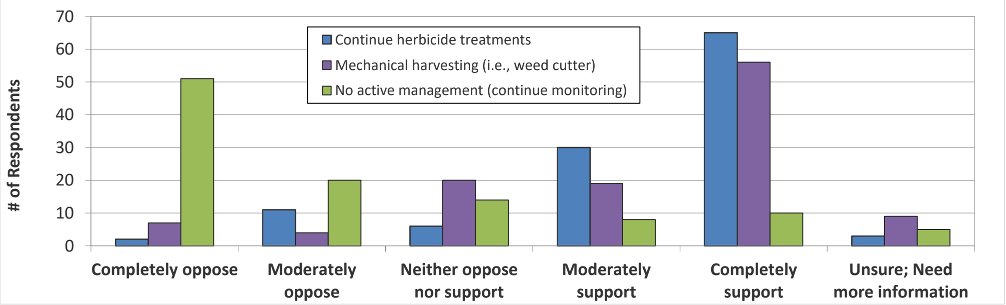
24. Curly-leaf pondweed (CLP) was first discovered in Lost Lake in 2014. Following its discovery, the Lost Lake Protection & Rehabilitation District (LLPRD) received a WDNR Early Detection and Response Grant to conduct multiple annual herbicide treatments to manage this pioneering population. What is your level of support or opposition for the past use of aquatic herbicides to treat CLP in previous years?

Answer Options	Completely oppose	Moderately oppose	Neither oppose nor support	Moderately support	Completely support	Rating Average	Response Count
	0	10	10	26	71	4.35	117
						answered question	**117**
						skipped question	**1**



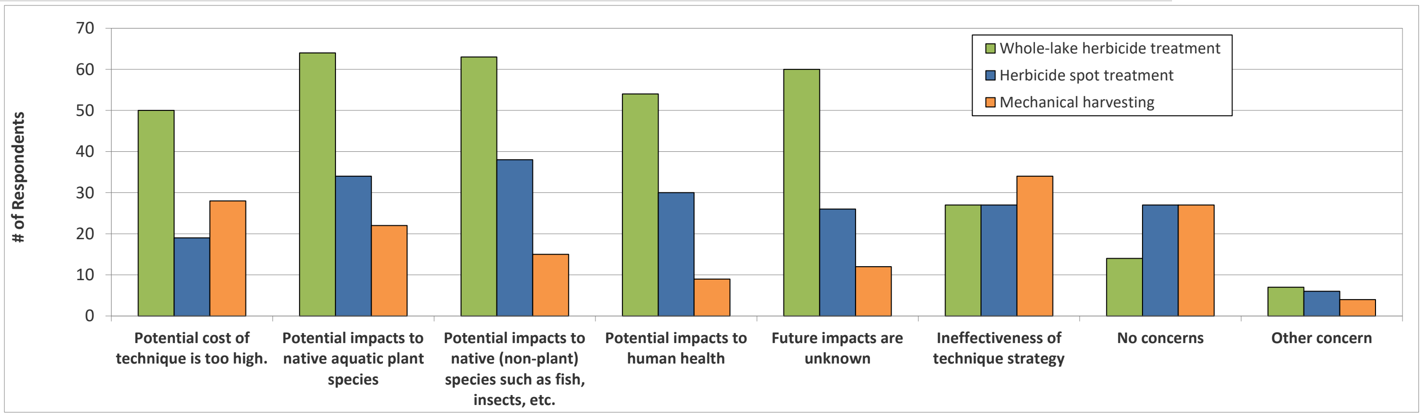
25. Now that the CLP population is past a pioneering stage (the initial time period before an invasive species becomes established), what is your level of support for the future use of the following CLP management techniques in Lost Lake?

Answer Options	Completely oppose	Moderately oppose	Neither oppose nor support	Moderately support	Completely support	Unsure; Need more information	Response Count
Continue herbicide treatments	2	11	6	30	65	3	117
Mechanical harvesting (i.e., weed cutter)	7	4	20	19	56	9	115
No active management (continue monitoring)	51	20	14	8	10	5	108
						answered question	**117**
						skipped question	**1**



26. What concerns, if any, do you have for the future use of whole-lake aquatic herbicide treatments, spatially targeted herbicide spot treatments, and/or mechanical harvesting to target CLP in Lost Lake?

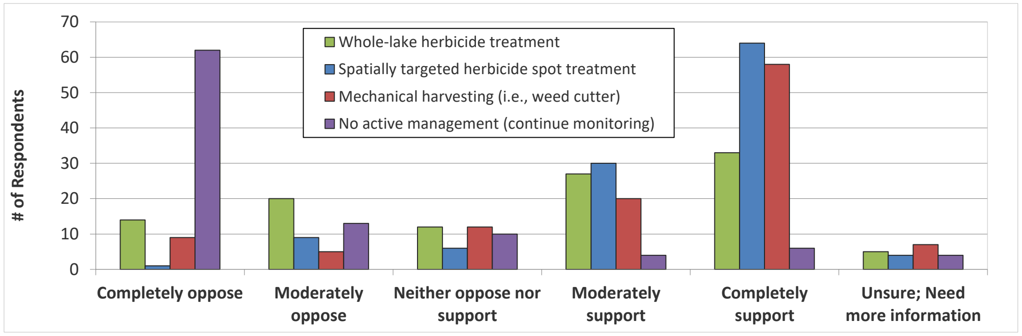
Answer Options	Whole-lake herbicide treatment	Herbicide spot treatment	Mechanical harvesting	Response Count
Potential cost of technique is too high.	50	19	28	71
Potential impacts to native aquatic plant species	64	34	22	84
Potential impacts to native (non-plant) species such as fish, insects, etc.	63	38	15	82
Potential impacts to human health	54	30	9	68
Future impacts are unknown	60	26	12	73
Ineffectiveness of technique strategy	27	27	34	63
No concerns	14	27	27	43
Other concern	7	6	4	11
			answered question	**107**
			skipped question	**11**



Number	"Other" responses
1	Don't have enough understanding of concerns.
2	Will this pose a danger to eagles, loons and other wildlife?
3	The methods previously used kill ‘good’ weeds leaving the targeted areas free to newly or repopulate with ‘bad’ weeds. There should be more done to develop a reseeding of good weeds post treatment. This may be difficult or costly but so is the treatment and I don’t think it has been seriously considered.
4	Not knowledgeable enough to comment.
5	Do what you need to do to get rid of
6	I think the current treatment strategy adversely affects native plant species and affects both water quality and biological health of the lake
7	No concern, we need to get rid of the problem species.
8	eliminated all vegetation in areas of Sunrise cove

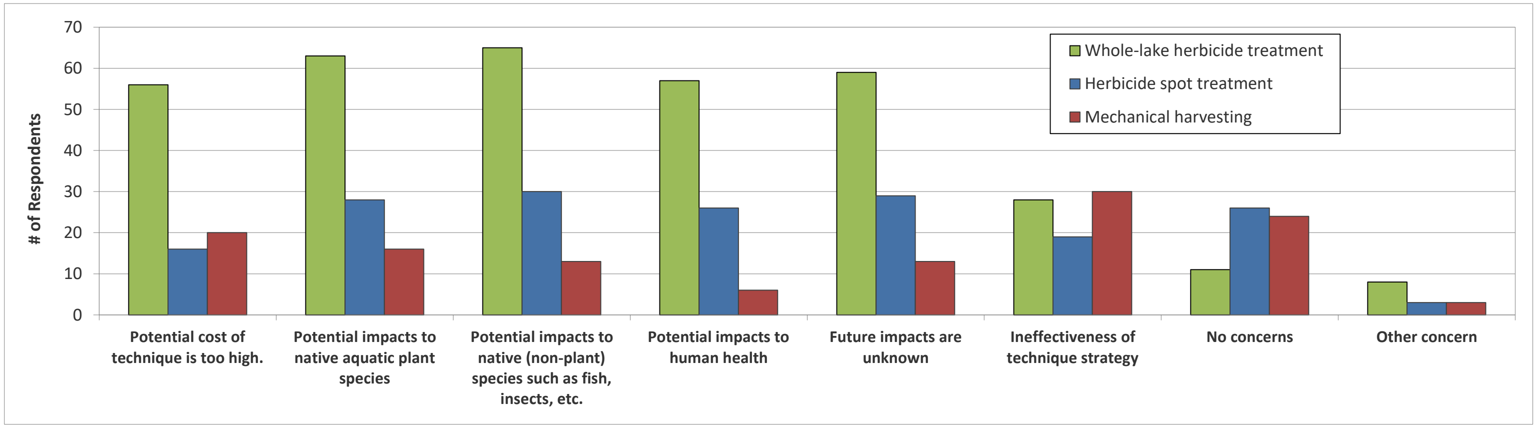
27. Eurasian watermilfoil (EWM) was first discovered in Lost Lake in 2013. Originally the LLPRD used hand-harvesting for EWM management (2014-2015) until the population expanded to a point where it was no longer feasible. The LLPRD has monitored the population in absence of active management in recent years (2016 – current) but are now considering active management again. What is your level of support for the use of the following EWM management techniques in Lost Lake?

Answer Options	Completely oppose	Moderately oppose	Neither oppose nor support	Moderately support	Completely support	Unsure; Need more information	Response Count
Whole-lake herbicide treatment	14	20	12	27	33	5	111
Spatially targeted herbicide spot treatment	1	9	6	30	64	4	114
Mechanical harvesting (i.e., weed cutter)	9	5	12	20	58	7	111
No active management (continue monitoring)	62	13	10	4	6	4	99
						answered question	**114**
						skipped question	**4**



28. What concerns, if any, do you have for the future use of whole-lake aquatic herbicide treatments, spatially targeted herbicide spot treatments, and/or mechanical harvesting to target EWM in Lost Lake?

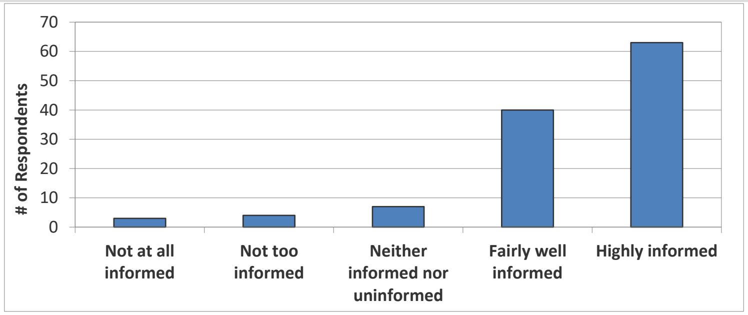
Answer Options	Whole-lake herbicide treatment	Herbicide spot treatment	Mechanical harvesting	Response Count
Potential cost of technique is too high.	56	16	20	68
Potential impacts to native aquatic plant species	63	28	16	76
Potential impacts to native (non-plant) species such as fish, insects, etc.	65	30	13	75
Potential impacts to human health	57	26	6	67
Future impacts are unknown	59	29	13	69
Ineffectiveness of technique strategy	28	19	30	58
No concerns	11	26	24	37
Other concern	8	3	3	10
			answered question	**102**
			skipped question	**16**



Number	"Other concern" responses
1	Don't have enough understanding of costs/benefits
2	Again concerned about adverse effects to wildlife
3	Good weeds are also killed by treatments leaving areas open for invasive to replace good native weeds. Not enough done so far to investigate on large or small scale tast of reseeding good weeds post treatments.
4	Not knowledgeable enough to comment.
5	Do what needs to be done to get rid of
6	eliminated all vegetation in sunrise cove area

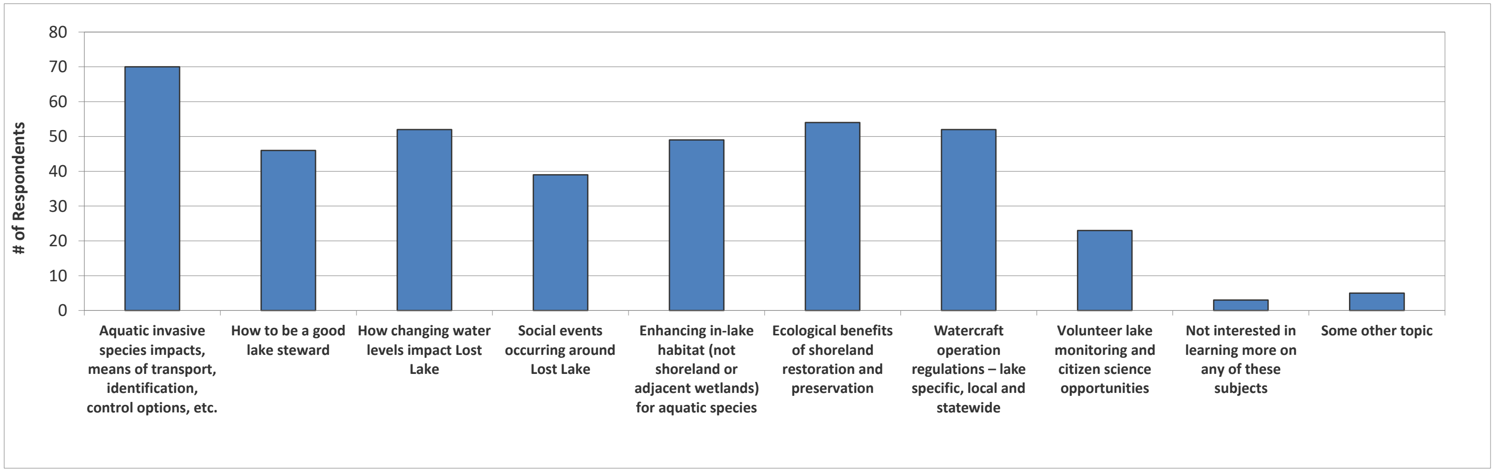
Lost Lake Protection and Rehabilitation District (LLPRD)

29. How informed has (or had) the LLPRD kept you regarding issues with Lost Lake and its management?						
Answer Options	**Not at all informed**	**Not too informed**	**Neither informed nor uninformed**	**Fairly well informed**	**Highly informed**	**Response Count**
	3	4	7	40	63	117
					answered question	**117**
					skipped question	**1**



30. Stakeholder education is an important component of every lake management planning effort. Which of these subjects would you like to learn more about?		
Answer Options	**Response Percent**	**Response Count**
Aquatic invasive species impacts, means of transport, identification, control options, etc.	64.8%	70
How to be a good lake steward	42.6%	46
How changing water levels impact Lost Lake	48.2%	52
Social events occurring around Lost Lake	36.1%	39
Enhancing in-lake habitat (not shoreland or adjacent wetlands) for aquatic species	45.4%	49
Ecological benefits of shoreland restoration and preservation	50.0%	54
Watercraft operation regulations – lake specific, local and statewide	48.2%	52
Volunteer lake monitoring and citizen science opportunities	21.3%	23
Not interested in learning more on any of these subjects	2.8%	3
Some other topic	4.6%	5
	answered question	**108**
	skipped question	**10**

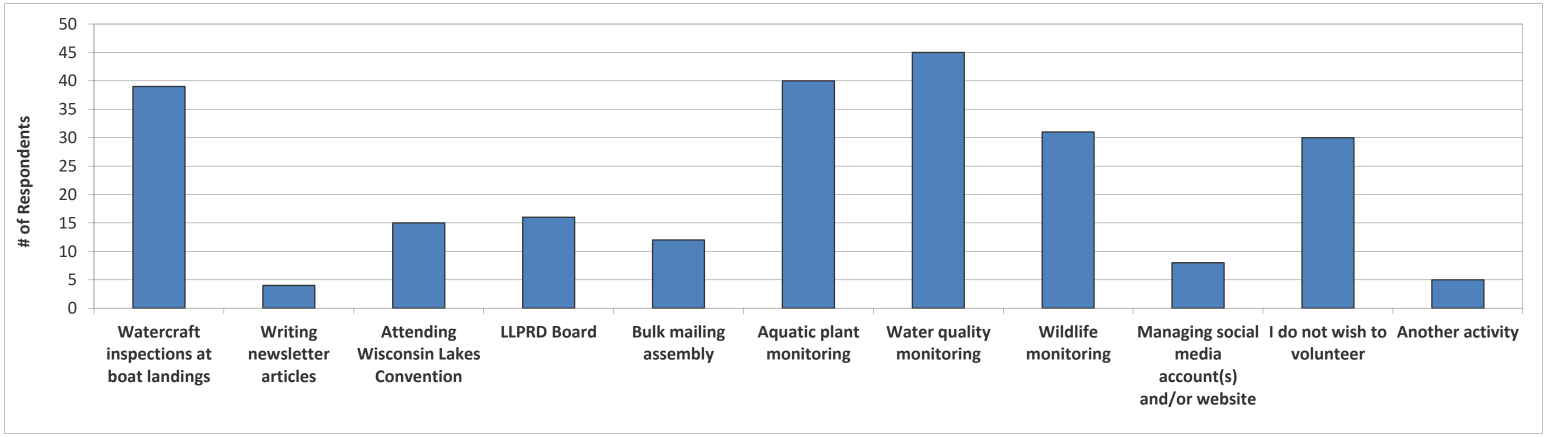
Number	"Some other topic" responses
1	Due to illness, have not been able to keep up with info.
2	lake patrol , no wake bays
3	Reseeding potential, even for small trials, of good native weeds.
4	Enforce Slow no wake after 6pm
5	Education is key to understanding



31. The effective management of Lost Lake will require the cooperative efforts of numerous volunteers. Please select the activities you would be willing to participate in if the LLPRD requires additional assistance.

Answer Options	Response Percent	Response Count
Watercraft inspections at boat landings	36.1%	39
Writing newsletter articles	3.7%	4
Attending Wisconsin Lakes Convention	13.9%	15
LLPRD Board	14.8%	16
Bulk mailing assembly	11.1%	12
Aquatic plant monitoring	37.0%	40
Water quality monitoring	41.7%	45
Wildlife monitoring	28.7%	31
Managing social media account(s) and/or website	7.4%	8
I do not wish to volunteer	27.8%	30
Another activity	4.6%	5
	answered question	**108**
	skipped question	**10**

Number	"Another activity" responses
1	Interested but not able to participate at this time.
2	We are sporadically at the Lake so at thus time unable to volunteer. In t
3	I am not at Lost Lake enough to participate
4	Willing to participate in some way
5	educational campaign on impact of watercraft on waterquality



32. Would you be interested in representing Lost Lake Protection and Rehabilitation District on the St. Germain Town Lakes committee?

Answer Options	Response Percent	Response Count
Yes	16.7%	19
No	83.3%	95
	answered question	**114**
	skipped question	**4**

33. Please feel free to provide written comments concerning Lost Lake, its current and/or historic condition and its management.

Answer Options	Response Count
	41
answered question	**41**
skipped question	**77**

Number	Response Text
1	No one is looking at the effects rentals are having on the lake and the livability of retirees. The whole environment has changed, loud vehicles, parties, gun toting renters. No concern about preserving the lake. Renters do not follow fish limits!!!! Renters are dumping tons of salt on their parking areas. You guys are doing a great job!!
2	I believe there has been good communication by the LLPRD board, but I have not been able to give it my attention. Hope they will continue to be active. Appreciate their work.
3	I think the District Board has done an excellent job. I would support whatever future decisions you make.
4	Over the past 50 years the use of Lost Lake has increased greatly. The needed education for each property on this lake is needed. An information poster in needed for each rental and home on this lake. Owners must get involved and save Lost Lake!
5	I appreciate all the hard work the LLPRD is doing
6	No comment at this time.
7	Lost Lake is a beautiful lake and we hope it stays that way.
8	Wave runners, wake surfing boats and jet skis create havoc, cut off weeds that are deposited on shores, create huge waves that are eroding our shores, beat docked boats up and are dangerous for swimmers, kayakers, etc.
9	Return lake back to historic conditions by removing the dam at Stella Creek, stay aggressive with the evasive species weed control, keep stocking walleyes because it's working and maybe re-introduce native weeds back into the lake where they were once prevalent in the various bays and shorelines.
10	Lost lake has always been known for large Muskie , over the years I think there is a decline. Since it’s rare to catch Muskie for food. It would be nice to see a Trophy size limit on the lake. In addition, 60 years ago my grandfather caught Walleyes all the time, many large one are on the cabin walls. Today, walleye fishing is not very good.
11	We are fairly new to the lake but enjoy our time on the lake. We would like to see the lake taken care of now and well into the future
12	Control of lake use by jet ski's
13	Encourage Town Board to update Vandervort Park to make it safe and attractive.Lake District board has done a commendable job overall since inception.
14	Sincere thanks to the LLPRD and the board for all the efforts and commitments made to help improve and maintain Lost Lake as a quality resource.
15	I appreciate being updated on what is going on with protection and rehabilitation. Because I am a seasonal resident, I still need to be involved in some way when I am staying at the lake, which is about 6 weeks between May and November.
16	Have to do something about all the weeds.
17	Thank you for your time and effort to preserve and enhance the water quality at Lost Lake. I love clear water. I hate algae blooms and weeds that ruin swimming experiences. I am happy to help in any way. *Name Removed*
18	None. Thanks to all who are actively working to improve Lost Lake.
19	I was one of the few who supported the creation of a Lake District before it became popular. But since its creation non full time residents have been actively discouraged from Board participation.

20	I've been vacationing on Lost Lake since the '60s and over that time I have noted the slow 'strangulation' of the lake by the aquatic plants. Clear swimming spots close to shore are now fewer, fishing spots that used to require a reasonable amount of lure de-weeding during a morning of casting are hard to find, instances of weeds tangling props are up except for in the deeper areas of the lake, and overall abundance has decreased. Something needs to be done.
21	Lake seems to be maintained. It is not any worse after all my years here. Must be due to the well operated maintenance.
22	I believe east Bay is most in need of treatment
23	The current committee is doing a great job. I know it is time consuming. Thank you for all you do for lost lake.
24	It seems like the quality of fishing has declined over the past 5 years.
25	The presence of geese and their droppings are becoming a concern….is there something that can be done about that?
26	My main concern is the increasing percentage of AIS in the lake. Each year the amount of these invasive species is negatively impacting fishing and other water sport activities. Thank you for your efforts in helping improve the water quality.
27	Loss of walleyes. Improve areas for spawning and stock extended growth fish. Panfish size has decreased due to over fishing. Reduce limits on panfish to 10-10-5. Everyone contact the DNR asking for their participation in improving our lake!
28	Walleye population seems to have declined and Algal blooms seem to be worse. These trends are concerning. Musky populations seem to be high and bluegills seem to be a little bit bigger which is good.
29	Keep up the good work.
30	Thanks!Keep up the good work!
31	Why was the walleye stocking not completed in 2021?
32	We need to rid the lake of any invasive species, so that the lake is clean for gyrations to come after us.
33	Gary has done a tremendous job with everything. Much appreciated.
34	I am concerned about the algae blooms that make the lake almost unfishable after mid- July. The last several years I hardly put my boat in the water due to the green slime floating on the water. In my 40 years on the lake it has never been as bad as the last several years. Maybe its a coincidence that it seems to have started after the treatments for Envasive Species I dont know
35	I think people are trying their best in providing a safe and useful Lost Lake and I thank them for all their efforts. The one factor that concerns me most is the algae blooms that are happening more often and more severe. In years past it seems as thou they weren't this bad. It makes it undesirable to swim, kayak or fish when this occurs. My little knowledge tells me that factors like fertilizing lawns, flower on piers and leakage from septics are contributing factors. I would like to see a more vigorous approach in remedying these things. Thank you
36	The laker used to be about 3 feet lower in the 1940's... Having the dam and maintaining it is a must.
37	Im very concerned about the large ,heavy boat wakes disturbing the lake bottom, fish habitat and stirring up sediment. Residents may not be aware of this insidious problem and should be "schooled" on the long term consequences these have on the lake quality and property values.
38	Thanks for your efforts on this - fishing (other than Musky) has been really bad the last 3 years - I really hope we can get lost lake back as a premier fishing lake
39	The LLPRD does an excellent job managing the lake as well as keeping us informed via their timely news-emails. Thank you, commissioners!
40	The single most likely source of excessive nutrients degrading water quality can be attributed to improper or failed septic systems. Has there been any consideration to evaluate the impact of septic systems on Lost Lake water quality?
41	Believe boat inspection is key to keeping invasive species out. Would applying dated lake stickers (state wide) to boats warn what boats require closer inspection?
42	I have been a user and visiter to the this Lost Lake property since 1971 when my parents purchased the property - but with the passing of my parents in the last 12 years, I have not spent much time there - and have not done any fishing on the lake - I was an avid fisherman on the lake especially for crappie and walleye in the 70s and 80s - I have always been seriously concerned about the environment and wildlife in the area. I think having an active LLPRD working on invasive weeds in Lost Lake is very important and a necessary tool in keeping the lake healthy for the future. I would like to continue to be informed of their activities and intentions of their work in the future. Its extremely important to me to be able to fish and boat without the negative impact of too many invasive weeds in the lake. I also believe in the upkeep of septic systems and keeping the shorelines of Lost Lake wild and pristine as I found them in 1971

C

APPENDIX C

Aquatic Plant Point-Intercept Survey Data Matrix

Scientific Name	Common Name	LFOO (%)					
		2007	2010	2014	2017	2018	2021
Ceratophyllum demersum & C. echinatum	Coontail & Spiny hornwort	58.8	54.0	38.7	13.2	11.3	4.9
Ceratophyllum demersum	Coontail	58.8	54.0	38.7	13.2	11.3	4.3
Elodea canadensis & E. nuttallii	Common & slender waterweeds	16.4	36.9	6.0	5.4	7.5	20.3
Elodea canadensis	Common waterweed	16.4	36.9	6.0	5.4	7.5	19.7
Najas flexilis	Slender naiad	3.4	11.9	6.0	21.5	11.9	22.6
Vallisneria americana	Wild celery	15.5	14.7	4.7	20.0	11.9	9.5
Potamogeton robbinsii	Fern-leaf pondweed	17.6	26.6	21.3	13.2	2.5	0.7
Myriophyllum sibiricum	Northern watermilfoil	20.2	38.1	14.0	2.4	0.6	0.7
Potamogeton x haynesii & P. zosteriformis	Haynes' & Flat-stem pondweeds	16.8	51.6	0.0	0.0	0.6	2.0
Potamogeton zosteriformis	Flat-stem pondweed	16.8	50.0	0.0	0.0	0.6	2.0
Potamogeton praelongus	White-stem pondweed	12.2	25.8	18.7	9.3	4.4	1.3
Isoetes spp.	Quillwort spp.	8.4	4.4	3.8	10.2	15.1	4.6
Myriophyllum spicatum	Eurasian watermilfoil	0.0	0.0	0.0	2.4	8.8	15.1
Potamogeton berchtoldii & P. pusillus	Slender & small pondweeds	0.4	2.8	38.7	0.0	0.0	1.6
Potamogeton amplifolius	Large-leaf pondweed	19.3	9.9	9.8	4.4	1.3	0.0
Potamogeton crispus	Curly-leaf pondweed	0.0	0.0	0.0	4.4	4.4	11.1
Potamogeton pusillus	Small pondweed	0.4	2.8	27.2	0.0	0.0	0.0
Chara spp. & Nitella spp.	Charophytes	3.8	2.8	0.9	1.0	12.6	4.6
Potamogeton richardsonii	Clasping-leaf pondweed	1.7	4.4	3.4	2.4	1.9	5.2
Chara spp.	Muskgrasses	3.8	2.0	0.9	1.0	12.6	3.0
Potamogeton berchtoldii	Slender pondweed	0.0	0.0	17.9	0.0	0.0	1.6
Sagittaria sp. (rosette)	Arrowhead sp. (rosette)	2.1	4.8	0.0	5.4	3.8	1.0
Potamogeton gramineus	Variable-leaf pondweed	4.2	4.0	3.4	1.5	0.0	1.3
Potamogeton strictifolius	Stiff pondweed	0.0	12.7	0.0	0.0	0.0	0.0
Heteranthera dubia	Water stargrass	0.8	0.0	0.4	0.5	3.1	3.6
Eleocharis acicularis	Needle spikerush	3.4	1.2	0.9	1.0	1.3	1.6
Bidens beckii	Water marigold	0.0	2.4	0.9	1.5	2.5	1.3
Nuphar variegata	Spatterdock	1.7	0.8	0.4	0.5	1.3	0.7
Nitella spp.	Stoneworts	0.0	0.8	0.0	0.0	0.0	1.6
Nymphaea odorata	White water lily	0.8	0.0	0.0	1.0	1.3	0.3
Juncus pelocarpus	Brown-fruited rush	0.8	0.8	0.4	0.0	0.0	0.3
Stuckenia pectinata	Sago pondweed	0.0	0.8	1.3	0.5	0.0	0.0
Sagittaria cristata	Crested arrowhead	0.0	0.0	0.0	0.0	0.0	1.0
Potamogeton illinoensis	Illinois pondweed	0.4	0.0	0.0	0.0	0.0	0.7
Myriophyllum tenellum	Dwarf watermilfoil	0.0	0.0	0.0	0.0	0.6	0.7
Lemna trisulca	Forked duckweed	0.0	0.0	0.0	0.0	0.6	0.7
Potamogeton X haynesii	Haynes' pondweed	0.0	1.6	0.0	0.0	0.0	0.0
Elodea nuttallii	Slender waterweed	0.0	0.0	0.0	0.0	0.0	0.7
Ceratophyllum echinatum	Spiny hornwort	0.0	0.0	0.0	0.0	0.0	0.7
Potamogeton foliosus	Leafy pondweed	0.4	0.0	0.0	0.0	0.0	0.3
Fissidens spp. & Fontinalis spp.	Aquatic Moss	0.0	0.0	0.0	0.5	0.0	0.3
Schoenoplectus acutus	Hardstem bulrush	0.0	0.0	0.4	0.0	0.6	0.0
Potamogeton X spathuliformis	Variable-leaf X Illinois pondweed	0.0	0.8	0.0	0.0	0.0	0.0
Potamogeton spirillus	Spiral-fruited pondweed	0.0	0.0	0.0	0.0	0.0	0.3
Eriocaulon aquaticum	Pipewort	0.0	0.0	0.0	0.0	1.3	0.0
Utricularia vulgaris	Common bladderwort	0.0	0.0	0.0	0.0	0.6	0.0
Schoenoplectus tabernaemontani	Softstem bulrush	0.0	0.4	0.0	0.0	0.0	0.0
Ranunculus aquatilis	White water crowfoot	0.4	0.0	0.0	0.0	0.0	0.0
Pontederia cordata	Pickerelweed	0.0	0.4	0.0	0.0	0.0	0.0
Myriophyllum verticillatum	Whorled watermilfoil	0.0	0.4	0.0	0.0	0.0	0.0
Lobelia dortmanna	Water lobelia	0.0	0.4	0.0	0.0	0.0	0.0
Lemna turionifera	Turion duckweed	0.0	0.0	0.0	0.0	0.6	0.0

D

APPENDIX D

Strategic Analysis of Aquatic Plant Management in Wisconsin (June 2019). Extracted Supplemental Chapters:

- 3.3 Herbicide Treatment
- 3.4 Physical Removal
- 3.5 Biological Control

In 2016-2019, the WDNR conducted a Strategy Analysis of Aquatic Plant Management in Wisconsin, which will serve as a reference document to mold future policies and approaches. The strategy the WDNR is following is outlined on the WDNR's APM Strategic Analysis Webpage:

https://dnr.wi.gov/topic/eia/apmsa.html

Below is a table of contents for the extracted materials for use in risk assessment of the discussed management tools within this project. Please refer to the WDNR's full text document cited above for Literature Cited.

Extracted Table of Contents

S.3.3. Herbicide Treatment

Herbicides are the most commonly employed method for controlling aquatic plants in Wisconsin. They are extremely useful tools for accomplishing aquatic plant management (APM) goals, like controlling invasive species, providing waterbody access, and ecosystem restoration. This Chapter includes basic information about herbicides and herbicide formulations, how herbicides are assessed for ecological and human health risks and registered for use, and some important considerations for the use of herbicides in aquatic environments.

A pesticide is a substance used to either directly kill pests or to prevent or reduce pest damage; herbicides are pesticides that are used to kill plants. Only a certain component of a pesticide product is intended to have pesticidal effects and this is called the active ingredient. The active ingredient is listed near the top of the first page on an herbicide product label. Any product claiming to have pesticidal properties must be registered with the U.S. EPA and regulated as a pesticide.

Inert ingredients often make up the majority of a pesticide formulation and are not intended to have pesticidal activity, although they may enhance the pesticidal activity of the active ingredient. These ingredients, such as carriers and solvents, are often added to the active ingredient by manufacturers, or by an herbicide applicator during use, in order to allow mixing of the active ingredient into water, make it more chemically stable, or aid in storage and transport. Manufacturers are not required to identify the specific inert ingredients on the pesticide label. In addition to inert ingredients included in manufactured pesticide formulations, adjuvants are inert ingredient products that may be added to pesticide formulations before they are applied to modify the properties or enhance pesticide performance. Adjuvants are typically not intended to have pesticidal properties and are not regulated as pesticides under the Federal Insecticide, Fungicide and Rodenticide Act. However, research has shown that inert ingredients can increase the efficacy and toxicity of pesticides especially if the appropriate label uses aren't followed (Mesnage et al. 2013; Defarge et al. 2016).

The combination of active ingredients and inert ingredients is what makes up a pesticide formulation. There are often many formulations of each active ingredient and pesticide manufacturers typically give a unique product or trade name to each specific formulation of an active ingredient. For instance, "Sculpin G" is a solid, granular 2,4-D amine product, while "DMA IV" is a liquid amine 2,4-D product, and the inert ingredients in these formulations are different, but both have the same active ingredient. Care should always be taken to read the herbicide product label as this will give information about which pests and ecosystems the product is allowed to be used for. Some formulations (i.e., non-aquatic formulations of glyphosate such as "Roundup") are not allowed for aquatic use and could lead to environmental degradation even if used on shorelines near the water. There are some studies which indicate that the combination of two chemicals (e.g., 2,4-D and endothall) applied together produces synergistic efficacy results that are greater than if each product was applied alone (Skogerboe et al. 2012). Conversely, there are studies which indicate the combination of two chemicals (i.e. diquat and penxosulam) which result in an antagonistic response between the herbicides, and resulted in reduced efficacy than when applying penoxsulam alone (Wersal and Madsen 2010b).

The U.S. EPA is responsible for registering pesticide products before they may be sold. In order to have their product registered, pesticide manufacturers must submit toxicity test data to the EPA that shows that the intended pesticide use(s) will not create unreasonable risks. “Unreasonable” in this context means that the risks of use outweigh the potential benefits. Once registered, the EPA must re-evaluate each pesticide and new information related to its use every 15 years. The current cycle of registration review will end in 2022, with a new cycle and review schedule starting then. In addition, EPA may decide to only register certain uses of any given pesticide product and can also require that only trained personnel can apply a pesticide before the risks outweigh the benefits. Products requiring training before application are called Restricted Use Pesticides.

As part of their risk assessments, EPA reviews information related to pesticide toxicity. Following laboratory testing, ecotoxicity rankings are given for different organismal groups based on the dosage that would cause harmful ecological effects (e.g., death, reduction in growth, reproductive impairment, and others). For example, the ecotoxicity ranking for 2,4-D ranges from “practically non-toxic” to “slightly toxic” for freshwater invertebrates, meaning tests have shown that doses of >100 ppm and 10-100 ppm are needed to cause 50% mortality or immobilization in the test population, respectively. Different dose ranges and indicators of “harm” are used to assess toxicity depending on the organisms being tested. More information can be found on the EPA’s website.

Beyond selecting herbicide formulations approved for use in aquatic environments, there are additional factors to consider supporting appropriate and effective herbicide use in those environments. Herbicide treatments are often used in terrestrial restorations, so they are also often requested in the management and restoration of aquatic plant communities. However, unlike applications in a terrestrial environment, the fluid environment of freshwater systems presents a set of unique challenges. Some general best practices for addressing challenges associated with herbicide dilution, migration, persistence, and non-target impacts are described in Chapter 7.4. More detailed documentation of these challenges is described below and in discussions on individual herbicides in Supplemental Chapter S.3.3 (Herbicide Treatment).

As described in Chapter 7.4, when herbicide is applied to waters, it can quickly migrate offsite and dilute to below the target concentrations needed to provide control (Hoeppel and Westerdal 1983; Madsen et al. 2015; Nault et al. 2015). Successful plant control with herbicide is dependent on concentration exposure time (CET) relationships. In order to examine actual observed CET relationships following herbicide applications in Wisconsin lakes, a study of herbicide CET and Eurasian watermilfoil (*Myriophyllum spicatum*) control efficacy was conducted on 98 small-scale (0.1-10 acres) 2,4-D treatment areas across 22 lakes. In the vast majority of cases, initial observed 2,4-D concentrations within treatment areas were far below the applied target concentration, and then dropped below detectable limits within a few hours after treatment (Nault et al. 2015). These results indicate the rapid dissipation of herbicide off of the small treatment areas resulted in water column concentrations which were much lower than those recommended by previous laboratory CET studies for effective Eurasian watermilfoil control. Concentrations in protected treatment areas (e.g., bays, channels) were initially higher than those in areas more exposed to wind and waves, although concentrations quickly dissipated to below detectable limits within hours after treatment regardless of spatial location. Beyond confining small-scale treatments to protected areas, utilizing or integrating faster-acting herbicides with shorter CET requirements may also help to compensate for reductions in plant control due to dissipation (Madsen et al. 2015). The use of chemical curtains or adjuvants (weighting or sticking agents) may also help to maintain adequate CET, however more research is needed in this area.

This rapid dissipation of herbicide off of treatment areas is important for resource managers to consider in planning, as treating numerous targeted areas at a 'localized' scale may actually result in low-concentrations capable of having lakewide impacts as the herbicide dissipates off of the individual treatment sites. In general, if the percentage of treated areas to overall lake surface area is >5% and targeted areas are treated at relatively high 2,4-D concentrations (e.g., 2.0-4.0 ppm), then anticipated lakewide concentrations after dissipation should be calculated to determine the likelihood of lakewide effects (Nault et al. 2018).

Aquatic-use herbicides are commercially available in both liquid and granular forms. Successful target species control has been reported with both granular and liquid formulations. While there has been a commonly held belief that granular products are able to 'hold' the herbicide on site for longer periods of time, actual field comparisons between granular and liquid 2,4-D forms revealed that they dissipated similarly when applied at small-scale sites (Nault et al. 2015). In fact, liquid 2,4-D had higher initial observed water column concentrations than the granular form, but in the majority of cases concentrations of both forms decreased rapidly to below detection limits within several hours after treatment Nault et al. 2015). Likewise, according to United Phosphorus, Inc. (UPI), the sole manufacturer of endothall, the granular formulation of endothall does not hold the product in a specific area significantly longer than the liquid form (Jacob Meganck [UPI], *personal communication*).

In addition, the stratification of water and the formation of a thermal density gradient can confine the majority of applied herbicides in the upper, warmer water layer of deep lakes. In some instances, the entire lake water volume is used to calculate how much active ingredient should be applied to achieve a specific lakewide target concentration. However, if the volume of the entire lake is used to calculate application rates for stratified lakes, but the chemical only readily mixes into the upper water layer, the achieved lakewide concentration is likely to be much higher than the target concentration, potentially resulting in unanticipated adverse ecological impacts.

Because herbicides cannot be applied directly to specific submersed target plants, the dissipation of herbicide over the treatment area can lead to direct contact with non-target plants and animals. No herbicide is completely selective (i.e., effective specifically on only a single target species). Some plant species may be more susceptible to a given herbicide than others, highlighting the importance of choosing the appropriate herbicide, or other non-chemical management approach, to minimize potential non-target effects of treatment. There are many herbicides and plant species for which the CET relationship that would negatively affect the plant is unknown. This is particularly important in the case of rare, special concern, or threatened and endangered species. Additionally, loss of habitat following any herbicide treatment or other management technique may cause indirect reductions in populations of invertebrates or other organisms. Some organisms will only recolonize the managed areas as aquatic plants become re-established.

Below are reviews for the most commonly used herbicides for APM in Wisconsin. Much of the information here was pulled directly from DNR's APM factsheets (http://dnr.wi.gov/lakes/plants/factsheets/), which were compiled in 2012 using U.S. EPA herbicide product labels, U.S. Army Corps of Engineers reports, and communications with natural resource agencies in other northern, lake-rich states. These have been supplemented with more recent information from primary research publications.

Each pesticide has at least one mode of action which is the specific mechanism by which the active ingredient exerts a toxic effect. For example, some herbicides inhibit production of the pigments needed for photosynthesis while others mimic plant growth hormones and cause uncontrolled and unsustainable growth. Herbicides are often classified as either systemic or contact in mode of action, although some herbicides are able to function under various modes of action depending on environmental variables such as water temperature. Systemic pesticides are those that are absorbed by organisms and can be moved or translocated within the organism. Contact pesticides are those that exert toxic effects on the part(s) of an organism that they come in contact with. The amount of exposure time needed to kill an organism is based on the specific mode of action and the concentration of any given pesticide. In the descriptions below herbicides are generally categorized into which environment (above or below water) they are primarily used and a relative assessment of how quickly they impact plants. Herbicides can be applied in many ways. In lakes, they are usually applied to the water's surface (or below the water's surface) through controlled release by equipment including spreaders, sprayers, and underwater hoses. In wetland environments, spraying by helicopter, backpack sprayer, or application by cut-stem dabbing, wicking, injection, or basal bark application are also used.

S.3.3.1. Submersed or Floating, Relatively Fast-Acting Herbicides

Diquat

Registration and Formulations

Diquat (or diquat dibromide) initially received Federal registration for control of submersed and floating aquatic plants in 1962. It was initially registered with the U.S. EPA in 1986, evaluated for reregistration in 1995, and is currently under registration review. A registration review decision was expected in 2015 but has not been released (EPA Diquat Plan 2011). The active ingredient is 6,7-dihydrodipyrido[1,2-α:2',1'-c] pyrazinediium dibromide, and is commercially sold as liquid formulations for aquatic use.

Mode of Action and Degradation

Diquat is a fast-acting herbicide that works through contact with plant foliage by disrupting electron flow in photosystem I of the photosynthetic reaction, ultimately causing the destruction of cell membranes (Hess 2000; WSSA 2007). Plant tissues in contact with diquat become impacted within several hours after application, and within one to three days the plant tissue will become necrotic. Diquat is considered a non-selective herbicide and will rapidly kill a wide variety of plants on contact. Because diquat is a fast-acting herbicide, it is oftentimes used for managing plants growing in areas where water exchange is anticipated to limit herbicide exposure times, such as small-scale treatments.

Due to rapid vegetation decomposition after treatment, only partial treatments of a waterbody should be conducted to minimize dissolved oxygen depletion and associated negative impacts on fish and other aquatic organisms. Untreated areas can be treated with diquat 14 days after the first application.

Diquat is strongly attracted to silt and clay particles in the water and may not be very effective under highly turbid water conditions or where plants are covered with silt (Clayton and Matheson 2010).

The half-life of diquat in water generally ranges from a few hours to two days depending on water quality and other environmental conditions. Diquat has been detected in the water column from less than a day up towards 38 DAT, and remains in the water column longer when treating waterbodies with sandy sediments with lower organic matter and clay content (Coats et al. 1964; Grzenda et al. 1966; Yeo 1967; Sewell et al. 1970; Langeland and Warner 1986; Langeland et al. 1994; Poovey and Getsinger 2002; Parsons et al. 2007; Gorzerino et al. 2009; Robb et al. 2014). One study reported that diquat is chemically stable within a pH range of 3 to 8 (Florêncio et al. 2004). Due to the tendency of diquat to be rapidly adsorbed to suspended clays and particulates, long exposure periods are oftentimes not possible to achieve in the field. Studies conducted by Wersal et al. (2010a) did not observe differences in target species efficacy between daytime versus night-time applications of diquat. While large-scale diquat treatments are typically not implemented, a study by Parsons et al. (2007), observed declines in both dissolved oxygen and water clarity following the herbicide treatment.

Diquat binds indefinitely to organic matter, allowing it to accumulate and persist in the sediments over time (Frank and Comes 1967; Simsiman and Chesters 1976). It has been reported to have a very long-lived half-life (1000 days) in sediment because of extremely tight soil sorption, as well as an extremely low rate of degradation after association with sediment (Wauchope et al. 1992; Peterson et al. 1994). Both photolysis and microbial degradation are thought to play minor roles in degradation (Smith and Grove 1969; Emmett 2002). Diquat is not known to leach into groundwater due to its very high affinity to bind to soils.

One study reported that combinations of diquat and penoxsulam resulted in an antagonistic response between the herbicides when applied to water hyacinth (*Eichhornia crassipes*) and resulted in reduced efficacy than when applying penoxsulam alone. The antagonistic response is likely due to the rapid cell destruction by diquat that limits the translocation and efficacy of the slower acting enzyme inhibiting herbicides (Wersal and Madsen 2010b).

Toxicology

There are no restrictions on swimming or eating fish from waterbodies treated with diquat. Depending on the concentration applied, there is a 1-3 day waiting period after treatment for drinking water. However, in one study, diquat persisted in the water at levels above the EPA drinking water standard for at least 3 DAT, suggesting that the current 3-day drinking water restriction may not be sufficient under all application scenarios (Parsons et al. 2007). Water treated with diquat should not be used for pet or livestock drinking water for one day following treatment. The irrigation restriction for food crops is five days, and for ornamental plants or lawn/turf, it varies from one to three days depending on the concentration used. A study by Mudge et al. (2007)

on the effects of diquat on five popular ornamental plant species (begonia, dianthus, impatiens, petunia, and snapdragon) found minimal risks associated with irrigating these species with water treated with diquat up to the maximum use rate of 0.37 ppm.

Ethylene dibromide (EDB) is a trace contaminant in diquat products which originates from the manufacturing process. EDB is a documented carcinogen, and the EPA has evaluated the health risk of its presence in formulated diquat products. The maximum level of EDB in diquat dibromide is 0.01 ppm (10 ppb). EBD degrades over time, and it does not persist as an impurity.

Diquat does not have any apparent short-term effects on most aquatic organisms that have been tested at label application rates (EPA Diquat RED 1995). Diquat is not known to bioconcentrate in fish tissues. A study using field scenarios and well as computer modelling to examine the potential ecological risks posed by diquat determined that diquat poses a minimal ecological impact to benthic invertebrates and fish (Campbell et al. 2000). Laboratory studies indicate that walleye (*Sander vitreus*) are more sensitive to diquat than some other fish species, such as smallmouth bass (*Micropterus dolomieu),* largemouth bass (*Micropterus salmoides*), and bluegills (*Lepomis macrochirus*), with individuals becoming less sensitive with age (Gilderhus 1967; Paul et al. 1994; Shaw and Hamer 1995). Maximum application rates were lowered in response to these studies, such that applying diquat at recommended label rates is not expected to result in toxic effects on fish (EPA Diquat RED 1995). Sublethal effects such as respiratory stress or reduced swimming capacity have been observed in studies where certain fish species (e.g., yellow perch (*Perca flavescens*), rainbow trout (*Oncorhynchus mykiss*), and fathead minnows (*Pimephales promelas*)) have been exposed to diquat concentrations (Bimber et al. 1976; Dodson and Mayfield 1979; de Peyster and Long 1993). Another study showed no observable effects on eastern spiny softshell turtles (*Apalone spinifera spinifera*; Paul and Simonin 2007). Reduced size and pigmentation or increased mortality have been shown in some amphibians but at above recommended label rates (Anderson and Prahlad 1976; Bimber and Mitchell 1978; Dial and Bauer-Dial 1987). Toxicity data on invertebrates are scarce and diquat is considered not toxic to most of them. While diquat is not highly toxic to most invertebrates, significant mortality has been observed in some species at concentrations below the maximum label use rate for diquat, such as the amphipod *Hyalella azteca* (Wilson and Bond 1969; Williams et al. 1984), water fleas (*Daphnia* spp.). Reductions in habitat following treatment may also contribute to reductions of *Hyalella azteca*. For more information, a thorough risk assessment for diquat was compiled by the Washington State Department of Ecology Water Quality Program (WSDE 2002). Available toxicity data for fish, invertebrates, and aquatic plants is summarized in tabular format by Campbell et al. (2000).
Species Susceptibility

Diquat has been shown to control a variety of invasive submerged and floating aquatic plants, including Eurasian watermilfoil (*Myriophyllum spicatum*), curly-leaf pondweed (*Potamogeton crispus*), parrot feather (*Myriophyllum aquaticum*), Brazilian waterweed (*Egeria densa*), water hyacinth, water lettuce (*Pistia stratiotes*), flowering rush (*Butomus umbellatus*), and giant salvinia (*Salvinia molesta*; Netherland et al. 2000; Nelson et al. 2001; Poovey et al. 2002; Langeland et al. 2002; Skogerboe et al. 2006; Martins et al. 2007, 2008; Wersal et al. 2010a; Wersal and Madsen 2010a; Wersal and Madsen 2012; Poovey et al. 2012; Madsen et al. 2016). Studies conducted on the use of diquat for hydrilla (*Hydrilla verticillata*) and fanwort (*Cabomba caroliniana*) control have resulted in mixed reports of efficacy (Van et al. 1987; Langeland et al. 2002; Glomski et al. 2005; Skogerboe et al. 2006; Bultemeier et al. 2009; Turnage et al. 2015). Non-native phragmites (*Phragmites australis* subsp. *australis*) has been shown to not be significantly reduced by diquat (Cheshier et al. 2012).

Skogerboe et al. 2006 reported on the efficacy of diquat (0.185 and 0.37 ppm) under flow-through conditions (observed half-lives of 2.5 and 4.5 hours, respectively). All diquat treatments reduced Eurasian watermilfoil biomass by 97 to 100% compared to the untreated reference, indicating that this species is highly susceptible to diquat. Netherland et al. (2000) examined the role of various water temperatures (10, 12.5, 15, 20, and 25°C) on the efficacy of diquat applications for controlling curly-leaf pondweed. Diquat was applied at rates of 0.16-0.50 ppm, with exposure times of 9-12 hours. Diquat efficacy on curly-leaf pondweed was inhibited as water temperature decreased, although treatments at all temperatures were observed to significantly reduce biomass and turion formation. While the most efficacious curly-leaf pondweed treatments were conducted at 25°C, waiting until water warms to this temperature limits the potential for reducing turion production. Diquat applied at 0.37 ppm (with a 6 to 12-hour exposure time) or at 0.19 ppm (with a 72-hour exposure time) was effective at reducing biomass of flowering rush (Poovey et al. 2012; Madsen et al. 2016).

Native species that have been shown to be affected by diquat include: American lotus (*Nelumbo lutea*), common bladderwort (*Utricularia vulgaris*), coontail (*Ceratophyllum demersum*), common waterweed (*Elodea canadensis*), needle spikerush (*Eleocharis acicularis*), Illinois pondweed (*Potamogeton illinoensis*), leafy pondweed (*P. foliosus*), clasping-leaf pondweed (*P. richardsonii*), fern pondweed (*P. robbinsii*), sago pondweed (*Stuckenia pectinata*), and slender naiad (*Najas flexilis*) (Hofstra et al. 2001; Glomski et al. 2005; Skogerboe et al. 2006; Mudge 2013; Bugbee et al. 2015; Turnage et al. 2015). Diquat is particularly toxic to duckweeds (*Landoltia punctata* and *Lemna* spp.), although certain populations of dotted duckweed (*Landoltia punctata*) have developed resistance of diquat in waterbodies with a long history (20-30 years) of repeated diquat treatments (Peterson et al. 1997; Koschnick et al. 2006). Variable effects have been observed for water celery (*Vallisneria americana*), long-leaf pondweed (*Potamogeton nodosus*), and variable-leaf watermilfoil (*Myriophyllum heterophyllum*; Skogerboe et al. 2006; Glomski and Netherland 2007; Mudge 2013).

Flumioxazin

Registration and Formulations

Flumioxazin (2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propynyl)-2H-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1H-isoindole-1,3(2H)-dione) was registered with the U.S. EPA for agricultural use in 2001 and registered for aquatic use in 2010. The first registration review of flumioxazin is expected to be completed in 2017 (EPA Flumioxazin Plan 2011). Granular and liquid formulations are available for aquatic use.

Mode of Action and Degradation

The mode of action of flumioxazin is through disruption of the cell membrane by inhibiting protoporphyrinogen oxidase which blocks production of heme and chlorophyll. The efficacy of this mode of action is dependent on both light intensity and water pH (Mudge et al. 2012a; Mudge and Haller 2010; Mudge et al. 2010), with herbicide degradation increasing with pH and efficacy decreasing as light intensity declines.

Flumioxazin is broken down by water (hydrolysis), light (photolysis) and microbes. The half-life ranges from approximately 4 days at pH 5 to 18 minutes at pH 9 (EPA Flumioxazin 2003). In the majority of Wisconsin lakes half-life should be less than 1 day.

Flumioxazin degrades into APF (6-amino-7-fluro-4-(2-propynyl)-1,4,-benzoxazin-3(2H)-one) and THPA (3,4,5,6-tetrahydrophthalic acid). Flumioxazin has a low potential to leach into groundwater due to the very quick hydrolysis and photolysis. APF and THPA have a high potential to leach through soil and could be persistent.

Toxicology

Tests on warm and cold-water fishes indicate that flumioxazin is "slightly to moderately toxic" to fish on an acute basis, with possible effects on larval growth below the maximum label rate of 0.4 ppm (400 ppb). Flumioxazin is moderately to highly toxic to aquatic invertebrates, with possible impacts below the maximum label rate. The potential for bioaccumulation is low since degradation in water is so rapid. The metabolites APF and THPA have not been assessed for toxicity or bioaccumulation.

The risk of acute exposure is primarily to chemical applicators. Concentrated flumioxazin doesn't pose an inhalation risk but can cause skin and eye irritation. Recreational water users would not be exposed to concentrated flumioxazin.

Acute exposure studies show that flumioxazin is "practically non-toxic" to birds and small mammals. Chronic exposure studies indicate that flumioxazin is non-carcinogenic. However, flumioxazin may be an endocrine disrupting compound in mammals (EPA Flumioxazin 2003), as some studies on small mammals did show effects on reproduction and larval development, including reduced offspring viability, cardiac and skeletal malformations, and anemia. It does not bioaccumulate in mammals, with the majority excreted in a week.

Species Susceptibility

The maximum target concentration of flumioxazin is 0.4 ppm (400 ppb). At least one study has shown that flumioxazin (at or below the maximum label rate) will control the invasive species fanwort (*Cabomba caroliniana*), hydrilla (*Hydrilla verticillata*), Japanese stiltgrass (*Microstegium vimineum*), Eurasian watermilfoil (*Myriophyllum spicatum*), water lettuce (*Pistia stratiotes*), curly-leaf pondweed (*Potamogeton crispus*), and giant salvinia (*Salvinia molesta*), while water hyacinth (*Eichhornia crassipes*) and water pennyworts (*Hydrocotyle* spp.) do not show significant impacts (Bultemeier et al. 2009; Glomski and Netherland 2013a; Glomski and Netherland 2013b; Mudge 2013; Mudge and Netherland 2014; Mudge and Haller 2012; Mudge and Haller 2010). Flowering rush (*Butomus umbellatus*; submersed form) showed mixed success in herbicide trials

(Poovey et al. 2012; Poovey et al. 2013). Native species that were significantly impacted (in at least one study) include coontail (*Ceratophyllum demersum*), water stargrass (*Heteranthera dubia*), variable-leaf watermilfoil (*Myriophyllum heterophyllum*), America lotus (*Nelumbo lutea*), pond-lilies (*Nuphar* spp.), white waterlily (*Nymphaea odorata*), white water crowfoot (*Ranunculus aquatilis*), and broadleaf cattail (*Typha latifolia*), while common waterweed (*Elodea canadensis*), squarestem spikerush (*Eleocharis quadrangulate*), horsetail (*Equisetum hyemale*), southern naiad (*Najas guadalupensis*), pickerelweed (*Pontederia cordata*), Illinois pondweed (*Potamogeton illinoensis*), long-leaf pondweed (*P. nodosus*), broadleaf arrowhead (*Sagittaria latifolia*), hardstem bulrush (*Schoenoplectus acutus*), common three-square bulrush (*S. pungens*), softstem bulrush (*S. tabernaemontani*), sago pondweed (*Stuckenia pectinata*), and water celery (*Vallisneria americana*) were not impacted relative to controls. Other species are likely to be susceptible, for which the effects of flumioxazin have not yet been evaluated.

Carfentrazone-ethyl

Registration and Formulations

Carfentrazone-ethyl is a contact herbicide that was registered with the EPA in 1998. The active ingredient is ethyl 2-chloro-3-[2 -chloro-4-fluoro-5-[4 -(difluoromethyl)-4,5-diydro-3-methyl-5-oxo-1H-1,2,4-trizol-1-yl)phenyl]propanoate. A liquid formulation of carfentrazone-ethyl is commercially sold for aquatic use.

Mode of Action and Degradation

Carfentrazone-ethyl controls plants through the process of membrane disruption which is initiated by the inhibition of the enzyme protoporphyrinogen oxidase, which interferes with the chlorophyll biosynthetic pathway. The herbicide is absorbed through the foliage of plants, with injury symptoms viable within a few hours after application, and necrosis and death observed in subsequent weeks.

Carfentrazone-ethyl breaks down rapidly in the environment, while its degradates are persistent in aquatic and terrestrial environments. The herbicide primarily degrades via chemical hydrolysis to carfentrazone-chloropropionic acid, which is then further degraded to carfentrazone -cinnamic, -propionic, -benzoic and 3-(hydroxymethyl)-carfentrazone-benzoic acids. Studies have shown that degradation of carfentrazone-ethyl applied to water (pH = 7-9) has a half-life range of 3.4-131 hours, with longer half-lives (>830 hours) documented in waters with lower pH (pH = 5). Extremes in environmental conditions such as temperature and pH may affect the activity of the herbicide, with herbicide symptoms being accelerated under warm conditions.

While low levels of chemical residue may occur in surface and groundwater, risk concerns to non-target organisms are not expected. If applied into water, carfentrazone-ethyl is expected to adsorb to suspended solids and sediment.

Toxicology

There is no restriction on the use of treated water for recreation (e.g., fishing and swimming). Carfentrazone-ethyl should not be applied directly to water within ¼ mile of an active potable water intake. If applied around or within potable water intakes, intakes must be turned off prior to application and remain turned off for a minimum of 24 hours following application; the intake may be turned on prior to 24 hours only if the carfentrazone-ethyl and major degradate level is determined by laboratory analysis to be below 200 ppb. Do not use water treated with carfentrazone-ethyl for irrigation in commercial nurseries or greenhouses. In scenarios where the herbicide is applied to 20% or more of the surface area, treated water should not be used for irrigation of crops until 14 days after treatment, or until the carfentrazone-ethyl and major degradate level is determined by analysis to be below 5 ppb.

In scenarios where the herbicide is applied as a spot treatment to less than 20% of the waterbody surface area, treated water may be used for irrigation by commercial turf farms and on residential turf and ornamentals without restriction. If more than 20% of the waterbody surface area is treated, water should not be used for irrigation of turf or ornamentals until 14 days after treatment, or until the carfentrazone-ethyl and major degradate level is determined by analysis to be below 5 ppb.

Carfentrazone-ethyl is listed as very toxic to certain species of algae and listed as moderately toxic to fish and aquatic animals. Treatment of dense plants beds may result in dissolved oxygen declines from plant decomposition which may lead to fish suffocation or death. To minimize impacts, applications of this herbicide should treat up to a maximum of half of the waterbody at a time and wait a minimum of 14 days before retreatment or treatment of the remaining half of the waterbody. Carfentrazone-ethyl is considered to be practically non-toxic to birds on an acute and sub-acute basis.

Carfentrazone-ethyl is harmful if swallowed and can be absorbed through the skin or inhaled. Those who mix or apply the herbicide need to protect their skin and eyes from contact with the herbicide to minimize irritation and avoid breathing the spray mist. Carfentrazone-ethyl is not carcinogenic, neurotoxic, or mutagenic and is not a developmental or reproductive toxicant.

Species Susceptibility

Carfentrazone-ethyl is used for the control of floating and emergent aquatic plants such as duckweeds (*Lemna* spp.), watermeals (*Wolffia* spp.), water lettuce (*Pistia stratiotes*), water hyacinth (*Eichhornia crassipes*), and salvinia (*Salvinia* spp.). Carfentrazone-ethyl can also be used to control submersed plants such as Eurasian watermilfoil (*Myriophyllum spicatum*).

S.3.3.2. Submersed, Relatively Slow-Acting Herbicides

2,4-D

Registration and Formulations

2,4-D is an herbicide that is widely used as a household weed-killer, agricultural herbicide, and aquatic herbicide. It has been in use since 1946 and was registered with the U.S. EPA in 1986 and evaluated and reregistered in 2005. It is currently being evaluated for reregistration, and the estimated registration review decision date was in 2017 (EPA 2,4-D Plan 2013). The active ingredient is 2,4-dichloro-phenoxyacetic acid. There are two types of 2,4-D used as aquatic herbicides: dimethyl amine salt (DMA) and butoxyethyl ester (BEE). The ester formulations are toxic to fish and some important invertebrates such as water fleas (*Daphnia* spp.) and midges at application rates. 2,4-D is commercially sold as a liquid amine as well as ester and amine granular products for control of submerged, emergent, and floating-leaf vegetation. Only 2,4-D products labeled for use in aquatic environments may be used to control aquatic plants.

Mode of Action and Degradation

Although the exact mode of action of 2,4-D is not fully understood, the herbicide is traditionally believed to target broad-leaf dicotyledon species with minimal effects generally observed on numerous monocotyledon species, especially in terrestrial applications (WSSA 2007). 2,4-D is a systemic herbicide which affects plant cell growth and division. Upon application, it mimics the natural plant hormone auxin, resulting in bending and twisting of stems and petioles followed by growth inhibition, chlorosis (reduced coloration) at growing points, and necrosis or death of sensitive species (WSSA 2007). Following treatment, 2,4-D is taken up by the plant and translocated through the roots, stems and leaves, and plants begin to die within one to two weeks after application, but can take several weeks to decompose. The total length of target plant roots can be an important in determining the response of an aquatic plant to 2,4-D (Belgers et al. 2007). Treatments should be made when plants are growing. After treatment, the 2,4-D concentration in the water is reduced primarily through microbial activity, off-site movement by water, or adsorption to small particles in silty water.

Previous studies have indicated that 2,4-D degradation in water is highly variable depending on numerous factors such as microbial presence, temperature, nutrients, light, oxygen, organic content of substrate, pH, and whether or not the water has been previously exposed to 2,4-D or other phenoxyacetic acids (Howard et al. 1991). Once in contact with water, both the ester and amine formulations dissociate to the acid form of 2,4-D, with a faster dissociation to the acid form under more alkaline conditions. 2,4-D degradation products include 1,2,4-benzenetriol, 2,4-dichlorophenol, 2,4-dichloroanisole, chlorohydroquinone (CHQ), 4-chlorophenol, and volatile organics.

The half-life of 2,4-D has a wide range depending on water conditions. Half-lives have been reported to range from 12.9 to 40 days, while in anaerobic lab conditions the half-life has been measured at 333 days (EPA RED 2,4-D 2005). In large-scale low-concentration 2,4-D treatments monitored across numerous Wisconsin lakes, estimated half-lives ranged from 4-76 days, and the rate of herbicide degradation was generally observed to be slower in oligotrophic seepage lakes. Of these large-scale 2,4-D treatments, the threshold for irrigation of plants which are not labeled for direct treatment with 2,4-D (<0.1 ppm (100 ppb) by 21 DAT) was exceeded the majority of the treatments (Nault et al. 2018). Previous historical use of 2,4-D may also be an important variable to consider, as microbial communities which are responsible for the breakdown of 2,4-D may potentially exhibit changes in community composition over time with repeated use (de Lipthay et al. 2003; Macur et al. 2007). Additional detailed information on the environmental fate of 2,4-D is compiled by Walters 1999.

There have been some preliminary investigations into the concentration of primarily granular 2,4-D in water-saturated sediments, or pore-water. Initial results suggest the concentration of 2,4-D in the pore-water varies widely from site to site following a chemical treatment, although in some locations the concentration in the pore-water was observed to be 2-3 times greater than the application rate (Jim Kreitlow [DNR], *personal communication*). Further research and additional studies are needed to assess the implications of this finding for target species control and non-target impacts on a variety of organisms.

<u>Toxicology</u>

There are no restrictions on eating fish from treated waterbodies, human drinking water, or pet/livestock drinking water. Based upon 2,4-D ester (BEE) product labels, there is a 24-hour waiting period after treatment for swimming. Before treated water can be used for irrigation, the concentration must be below 0.1 ppm (100 ppb), or at least 21 days must pass. Adverse health effects can be produced by acute and chronic exposure to 2,4-D. Those who mix or apply 2,4-D need to protect their skin and eyes from contact with 2,4-D products to minimize irritation and avoid inhaling the spray. In its consideration of exposure risks, the EPA believes no significant risks will occur to recreational users of water treated with 2,4-D.

There are differences in toxicity of 2,4-D depending on whether the formulation is an amine (DMA) or ester (BEE), with the BEE formulation shown to be more toxic in aquatic environments. BEE formulations are considered toxic to fish and invertebrates such as water fleas and midges at operational application rates. DMA formulations are not considered toxic to fish or invertebrates at operational application rates. Available data indicate 2,4-D does not accumulate at significant levels in the tissues of fish. Although fish exposed to 2,4-D may take up very small amounts of its breakdown products to then be metabolized, the vast majority of these products are rapidly excreted in urine (Ghassemi et al. 1981).

On an acute basis, EPA assessment considers 2,4-D to be "practically non-toxic" to honeybees and tadpoles. Dietary tests (substance administered in the diet for five consecutive days) have shown 2,4-D to be "practically non-toxic" to birds, with some species being more sensitive than others (when 2,4-D was orally and directly administered to birds by capsule or gavage, the substance was "moderately toxic" to some species). For freshwater invertebrates, EPA considers 2,4-D amine to be "practically non-toxic" to "slightly toxic" (EPA RED 2,4-D 2005). Field studies on the potential impact of 2,4-D on benthic macroinvertebrate communities have generally not observed significant changes, although at least one study conducted in Wisconsin observed negative correlations in macroinvertebrate richness and abundance following treatment, and further studies are likely warranted (Stephenson and Mackie 1986; Siemering et al. 2008; Harrahy et al. 2014). Additionally, sublethal effects such as mouthpart deformities and change in sex ratio have been observed in the midge *Chironomus riparius* (Park et al. 2010).

While there is some published literature available looking at short-term acute exposure of various aquatic organisms to 2,4-D, there is limited literature is available on the effects of low-concentration chronic exposure to commercially available 2,4-D formulations (EPA RED 2,4-D 2005). The department recently funded several projects related to increasing our understanding of the potential impacts of chronic exposure to low-concentrations of 2,4-D through AIS research and development grants. One of these studies observed that fathead minnows (*Pimephales promelas*) exposed under laboratory conditions for 28 days to 0.05 ppm (50 ppb) of two different commercial formulations of 2,4-D (DMA® 4 IVM and Weedestroy® AM40) had decreases in larval survival and tubercle presence in males, suggesting that these formulations may exert some degree of chronic toxicity or endocrine-disruption which has not been previously observed when testing pure compound 2,4-D (DeQuattro and Karasov 2016). However, another follow-up study determined that fathead minnow larval survival (30 days post hatch) was decreased following exposure of eggs and larvae to pure 2,4-D, as well as to the two commercial formulations (DMA® 4 IVM and Weedestroy® AM40), and also identified a critical window of exposure for effects on survival to the period between fertilization and 14 days post hatch (Dehnert et al. 2018).

Another related follow-up laboratory study is currently being conducted to examine the effects of 2,4-D exposure on embryos and larvae of several Wisconsin native fish species. Preliminary results indicate that negative impacts of embryo survival were observed for 4 of the 9 native species tested (e.g., walleye, northern pike, white crappie, and largemouth bass), and negative impacts of larval survival were observed for 4 of 7 natives species tested (e.g., walleye, yellow perch, fathead minnows, and white suckers; Dehnert and Karasov, *in progress*).

A controlled field study was conducted on six northern Wisconsin lakes to understand the potential impacts of early season large-scale, low-dose 2,4-D on fish and zooplankton (Rydell et al. 2018). Three lakes were treated with early season low-dose liquid 2,4-D (lakewide epilimnetic target rate: 0.3 ppm (300 ppb)), while the other three lakes served as reference without treatment. Zooplankton densities were similar within lakes during the pre-treatment year and year of treatment, but different trends in several zooplankton species were observed in treatment lakes during the year following treatment. Peak abundance of larval yellow perch (*Perca flavescens*) was lower in the year following treatment, and while this finding was not statistically significant, decreased larval yellow perch abundance was not observed in reference lakes. The observed declines in larval yellow perch abundance and changes in zooplankton trends within treatment lakes in the year after treatment may be a result of changes in aquatic plant communities and not a direct effect of treatment. No significant effect was observed on peak abundance of larval largemouth bass (*Micropterus salmoides*), minnows, black crappie (*Pomoxis nigromaculatus*), bluegill (*Lepomis macrochirus*), or juvenile yellow perch. Larval black crappie showed no detectable response in growth or feeding success. Net pen trials for juvenile bluegill indicated no significant difference in survival between treatment and reference trials, indicating that no direct mortality was associated with the herbicide treatments. Detection of the level of larval fish mortality found in the lab studies would not have been possible in the field study given large variability in larval fish abundance among lakes and over time.

Concerns have been raised about exposure to 2,4-D and elevated cancer risk. Some epidemiological studies have found associations between 2,4-D and increased risk of non-Hodgkin lymphoma in high exposure populations, while other studies have shown that increased cancer risk may be caused by other factors (Hoar et al. 1986; Hardell and Eriksson 1999; Goodman et al. 2015). The EPA determined in 2005 that there is not sufficient evidence to classify 2,4-D as a human carcinogen (EPA RED 2,4-D 2005).

Another chronic health concern with 2,4-D is the potential for endocrine disruption. There is some evidence that 2,4-D may have effects on reproductive development, though other studies suggest the findings may have had other causes (Garry et al. 1996; Coady et al. 2013; Goldner et al. 2013; Neal et al. 2017). The extent and implications of this are not clear and it is an area of ongoing research.

Detailed literature reviews of 2,4-D toxicology have been compiled by Garabrant and Philbert (2002), Jervais et al. (2008), and Burns and Swaen (2012).

<u>Species Susceptibility</u>

With appropriate concentration and exposure, 2,4-D is capable of reducing abundance of the invasive plant species Eurasian watermilfoil (*Myriophyllum spicatum*), parrot feather (*M. aquaticum*), water chestnut (*Trapa natans*), water hyacinth (*Eichhornia crassipes*), and water lettuce (*Pistia stratiotes*; Elliston and Steward 1972; Westerdahl et al. 1983; Green and Westerdahl 1990; Helsel et al. 1996, Poovey and Getsinger 2007; Wersal et al. 2010b; Cason and Roost 2011; Robles et al. 2011; Mudge and Netherland 2014). Perennial pepperweed (*Lepidium latifolium)* and fanwort (*Cabomba caroliniana*) have been shown to be somewhat tolerant of 2,4-D (Bultemeier et al. 2009; Whitcraft and Grewell 2012).

Efficacy and selectivity of 2,4-D is a function of concentration and exposure time (CET) relationships, and rates of 0.5-2.0 ppm coupled with exposure times ranging from 12 to 72 hours have been effective at achieving Eurasian watermilfoil control under laboratory settings (Green and Westerdahl 1990). In addition, long exposure times (>14 days) to low-concentrations of 2,4-D (0.1-0.25 ppm) have also been documented to achieve milfoil control (Hall et al. 1982; Glomski and Netherland 2010).

According to product labels, desirable native species that may be affected include native milfoils (*Myriophyllum* spp.), coontail (*Ceratophyllum demersum*), common waterweed (*Elodea canadensis*), naiads (*Najas* spp.), waterlilies (*Nymphaea* spp. and *Nuphar* spp.), bladderworts (*Utricularia* spp.), and duckweeds (*Lemna* spp.). While it may affect softstem bulrush (*Schoenoplectus tabernaemontani*), other species such as American bulrush (*Schoenoplectus americanus*) and muskgrasses (*Chara* spp.) have been shown to be somewhat tolerant of 2,4-D (Miller and Trout 1985; Glomski et al. 2009; Nault et al. 2014; Nault et al. 2018).

In large-scale, low-dose (0.073-0.5 ppm) 2,4-D treatments evaluated by Nault et al. (2018), milfoil exhibited statistically significant lakewide decreases in posttreatment frequency across 23 of the 28 (82%) of the treatments monitored. In lakes where year of treatment milfoil control was achieved, the longevity of control ranged from 2–8 years. However, it is important to note that milfoil was not 'eradicated' from any of these lakes and is still present even in those lakes which have sustained very low frequencies over time. While good year of treatment control was achieved in all lakes with pure Eurasian watermilfoil populations, significantly reduced control was observed in the majority of lakes with hybrid watermilfoil (*Myriophyllum spicatum* x *sibiricum*) populations. Eurasian watermilfoil control was correlated with the mean concentration of 2,4-D measured during the first two weeks of treatment, with increasing lakewide concentrations resulting in increased Eurasian watermilfoil control. In contrast, there was no significant relationship observed between Eurasian watermilfoil control and mean concentration of 2,4-D. In lakes where good (>60%) year of treatment control of hybrid watermilfoil was achieved, 2,4-D degradation was slow, and measured lakewide concentrations were sustained at >0.1 ppm (>100 ppb) for longer than 31 days. In addition to reduced year of treatment efficacy, the longevity of control was generally shorter in lakes that contained hybrid watermilfoil versus Eurasian watermilfoil, suggesting that hybrid watermilfoil may have the ability to rebound quicker after large-scale treatments than pure Eurasian watermilfoil populations. However, it is important to keep in mind that hybrid watermilfoil is broad term for multiple different strains, and variation in herbicide response and growth between specific genotypes of hybrid watermilfoil has been documented (Taylor et al. 2017).

In addition, the study by Nault et al. (2018) documented several native monocotyledon and dicotyledon species that exhibited significant declines posttreatment. Specifically, northern watermilfoil (*Myriophyllum sibiricum*), slender naiad (*Najas flexilis*), water marigold (*Bidens beckii*), and several thin-leaved pondweeds (*Potamogeton pusillus*, *P. strictifolius*, *P. friesii* and *P. foliosus*) showed highly significant declines in the majority of the lakes monitored. In addition, variable/Illinois pondweed (*P. gramineus*/*P. illinoensis*), flat-stem pondweed (*P. zosteriformis*), fern pondweed (*P. robbinsii*), and sago pondweed (*Stuckenia pectinata*) also declined in many lakes. Ribbon-leaf pondweed (*P. epihydrus*) and water stargrass (*Heteranthera dubia*) declined in the lakes where they were found. Mixed effects of treatment were observed with water celery (*Vallisneria americana*) and southern naiad (*Najas guadalupensis*), with some lakes showing significant declines posttreatment and other lakes showing increases.

Since milfoil hybridity is a relatively new documented phenomenon (Moody and Les 2002), many of the early lab studies examining CET for milfoil control did not determine if they were examining pure Eurasian watermilfoil or hybrid watermilfoil (*M. spicatum* x *sibiricum*) strains. More recent laboratory and mesocosm studies have shown that certain strains of hybrid watermilfoil exhibit more aggressive growth and are less affected by 2,4-D (Glomski and Netherland 2010; LaRue et al. 2013; Netherland and Willey 2017; Taylor et al. 2017), while other studies have not seen differences in overall growth patterns or treatment efficacy when compared to pure Eurasian watermilfoil (Poovey et al. 2007). Differences between Eurasian and hybrid watermilfoil control following 2,4-D applications have also been documented in the field, with lower efficacy and shorter longevity of hybrid watermilfoil control when compared to pure Eurasian watermilfoil populations (Nault et al. 2018). Field studies conducted in the Menominee River Drainage in northeastern Wisconsin and upper peninsula of Michigan observed hybrid milfoil genotypes more frequently in lakes that had previous 2,4-D treatments, suggesting possible selection of more tolerant hybrid strains over time (LaRue 2012).

Fluridone

Registration and Formulations

Fluridone is an aquatic herbicide that was initially registered with the U.S. EPA in 1986. It is currently being evaluated for reregistration. The estimated registration review decision date was in 2014 (EPA Fluridone Plan 2010). The active ingredient is (1-methyl-3-phenyl-5-[3-(trifluoromethyl) phenyl]-4(1H)-pyridinone). Fluridone is available in both liquid and slow-release granular formulations.

Mode of Action and Degradation

Fluridone's mode of action is to reduce a plant's ability to protect itself from sun damage. The herbicide prevents the plant from making a protective pigment and as a result, sunlight causes the plant's chlorophyll to break down. Treated plants will turn white or pink at the growing tips a week after exposure and will begin to die one to two months after treatment (Madsen et al. 2002). Therefore, fluridone is only effective if plants are actively growing at the time of treatment. Effective use of fluridone requires low, sustained concentrations and a relatively long contact time (e.g., 45-90 days). Due to this requirement, fluridone is usually applied to an entire waterbody or basin. Some success has been demonstrated when additional follow-up 'bump' treatments are used to maintain the low concentrations over a long enough period of time to produce control. Fluridone has also been applied to riverine systems using a drip system to maintain adequate CET.

Following treatment, the amount of fluridone in the water is reduced through dilution and water movement, uptake by plants, adsorption to the sediments, and via breakdown caused by light and microbes. Fluridone is primarily degraded through photolysis (Saunders and Mosier 1983), while depth, water clarity and light penetration can influence degradation rates (Mossler et al. 1989; West et al. 1983). There are two major degradation products from fluridone: n-methyl formamide (NMF) and 3-trifluoromethyl benzoic acid.

The half-life of fluridone can be as short as several hours, or hundreds of days, depending on conditions (West et al. 1979; West et al. 1983; Langeland and Warner 1986; Fox et al. 1991, 1996; Jacob et al. 2016). Preliminary work on a seepage lake in Waushara County, WI detected fluridone in the water nearly 400 days following an initial application that was then augmented to maintain concentrations via a 'bump' treatment at 60 and 100 days later (Onterra 2017a). Light exposure is influential in controlling degradation rate, with a half-life ranging from 15 to 36 hours when exposed to the full spectrum of natural sunlight (Mossler et al. 1989). As light wavelength increases, the half-life increases too, indicating that season and timing may affect fluridone persistence. Fluridone half-life has been shown to be only slightly dependent on fluridone concentration, oxygen concentration, and pH (Saunders and Mosier 1983). One study found that the half-life of fluridone in water was slightly lower when the herbicide was applied to the surface of the water as opposed to a sub-surface application, suggesting that degradation may also be affected by mode of application (West and Parka 1981).

The persistence of herbicide in the sediment has been reported to be much longer than in the overlying water column, with studies showing persistence ranges from 3 months to a year in

sediments (Muir et al. 1980; Muir and Grift 1982; West et al. 1983). Persistence in soil is influenced by soil chemistry (Shea and Weber 1983; Mossler et al. 1993). Fluridone concentrations measured in sediments reach a maximum in one to four weeks after treatment and decline in four months to a year depending on environmental conditions. Fluridone adsorbs to clay and soils with high organic matter, especially in pellet form, and can reduce the concentration of fluridone in the water. Adsorption to the sediments is reversible; fluridone gradually dissipates back into the water where it is subject to chemical breakdown.
Some studies have shown variable release time of the herbicide among different granular fluridone products (Mossler et al. 1993; Koschnick et al. 2003; Bultemeier and Haller 2015). In addition, pelletized formulations may be more effective in sandy hydrosoils, while aqueous suspension formulations may be more appropriate for areas with high amounts of clay or organic matter (Mossler et al. 1993)

Toxicology

Fluridone does not appear to have short-term or long-term effects on fish at approved application rates, but fish exposed to water treated with fluridone do absorb fluridone into their tissues. However, fluridone has demonstrated a very low potential for bioconcentration in fish, zooplankton, and aquatic plants (McCowen et al. 1979; West et al. 1979; Muir et al. 1980; Paul et al. 1994). Fluridone concentrations in fish decrease as the herbicide disappears from the water. Studies on the effects of fluridone on aquatic invertebrates (e.g., midge and water flea) have shown increased mortality at label application rates (Hamelink et al. 1986; Yi et al. 2011). Studies on birds indicate that fluridone would not pose an acute or chronic risk to birds. In addition, no treatment related effects were noted in mice, rats, and dogs exposed to dietary doses. No studies have been published on amphibians or reptiles. There are no restrictions on swimming, eating fish from treated waterbodies, human drinking water or pet/livestock drinking water. Depending on the type of waterbody treated and the type of plant being watered, irrigation restrictions may apply for up to 30 days. There is some evidence that the fluridone degradation product NMF causes birth defects, though NMF has only been detected in the lab and not following actual fluridone treatments in the field, including those at maximum label rate (Osborne et al. 1989; West et al. 1990).

Species Susceptibility

Because fluridone treatments are often applied at a lakewide scale and many plant species are susceptible to fluridone, careful consideration should be given to potential non-target impacts and changes in water quality in response to treatment. Sustained native plant species declines and reductions in water clarity have been observed following fluridone treatments in field applications (O'Dell et al. 1995; Valley et al. 2006; Wagner et al. 2007; Parsons et al. 2009). However, reductions in water clarity are not always observed and can be avoided (Crowell et al. 2006). Additionally, the selective activity of fluridone is primarily rate-dependent based on analysis of pigments in nine aquatic plant species (Sprecher et al. 1998b).

Fluridone is most often used for control of invasive species such as Eurasian and hybrid watermilfoil (*Myriophyllum spicatum* x *sibiricum*), Brazilian waterweed (*Egeria densa*), and hydrilla (*Hydrilla verticillata*; Schmitz et al. 1987; MacDonald et al. 1993; Netherland et al. 1993;

Netherland and Getsinger 1995a, 1995b; Cockreham and Netherland 2000; Hofstra and Clayton 2001; Madsen et al. 2002; Netherland 2015). However, fluridone tolerance has been observed in some hydrilla and hybrid watermilfoil populations (Michel et al. 2004; Arias et al. 2005; Puri et al. 2006; Slade et al. 2007; Berger et al. 2012, 2015; Thum et al. 2012; Benoit and Les 2013; Netherland and Jones 2015). Fluridone has also been shown to affect flowering rush (*Butomus umbellatus*), fanwort (*Cabomba caroliniana*), buttercups (*Ranunculus* spp.), long-leaf pondweed (*Potamogeton nodosus*), Illinois pondweed (*P. illinoensis*), leafy pondweed (*P. foliosus*), flat-stem pondweed (*P. zosteriformis*), sago pondweed (*Stuckenia pectinata*), oxygen-weed (*Lagarosiphon major*), northern watermilfoil (*Myriophyllum sibiricum*), variable-leaf watermilfoil (*M. heterophyllum*), curly-leaf pondweed (*Potamogeton crispus*), coontail (*Ceratophyllum demersum*), common waterweed (*Elodea canadensis*), southern naiad (*Najas guadalupensis*), slender naiad (*N. flexilis*), white waterlily (*Nymphaea odorata*), water marigold (*Bidens beckii*), duckweed (*Lemna* spp.), and watermeal (*Wolffia columbiana*) (Wells et al. 1986; Kay 1991; Farone and McNabb 1993; Netherland et al. 1997; Koschnick et al. 2003; Crowell et al. 2006; Wagner et al. 2007; Parsons et al. 2009; Cheshier et al. 2011; Madsen et al. 2016). Muskgrasses (*Chara* spp.), water celery (*Vallisneria americana*), cattails (*Typha* spp.), and willows (*Salix* spp.) have been shown to be somewhat tolerant of fluridone (Farone and McNabb 1993; Poovey et al. 2004; Crowell et al. 2006).

Large-scale fluridone treatments that targeted Eurasian and hybrid watermilfoils have been conducted in several Wisconsin lakes. Recently, five of these waterbodies treated with low-dose fluridone (2-4 ppb) have been tracked over time to understand herbicide dissipation and degradation patterns, as well as the efficacy, selectivity, and longevity of these treatments. These field trials resulted in a pre- vs. post-treatment decrease in the number of vegetated littoral zone sampling sites, with a 9-26% decrease observed following treatment (an average decrease in vegetated littoral zone sites of 17.4% across waterbodies). In four of the five waterbodies, substantial decreases in plant biomass (≥10% reductions in average total rake fullness) was documented at sites where plants occurred in both the year of and year after treatment. Good milfoil control was achieved, and long-term monitoring is ongoing to understand the longevity of target species control over time. However, non-target native plant populations were also observed to be negatively impacted in conjunction with these treatments, and long-term monitoring is ongoing to understand their recovery over time. Exposure times in the five waterbodies monitored were found to range from 320 to 539 days before falling below detectable limits. Data from these recent projects is currently being compiled and a compressive analysis and report is anticipated in the near future.

Endothall

Registration and Formulations

Endothall was registered with the U.S. EPA for aquatic use in 1960 and reregistered in 2005 (Menninger 2012). Endothall is the common name of the active ingredient endothal acid (7-oxabicyclo[2,2,1] heptane-2,3-dicarboxylic acid). Granular and liquid formulations are currently registered by EPA and DATCP. Endothall products are used to control a wide range of terrestrial and aquatic plants. Two types of endothall are available: dipotassium salt and dimethylalkylamine salt ("mono-N,N-dimethylalkylamine salt" or "monoamine salt"). The dimethylalkylamine salt form is toxic to fish and other aquatic organisms and is faster-acting than the dipotassium salt form.

Mode of Action and Degradation

Endothall is considered a contact herbicide that inhibits respiration, prevents the production of proteins and lipids, and disrupts the cellular membrane in plants (MacDonald et al. 1993; MacDonald et al. 2001; EPA RED Endothall 2005; Bajsa et al. 2012). Although typical rates of endothall application inhibit plant respiration, higher concentrations have been shown to increase respiration (MacDonald et al. 2001). The mode of action of endothall is unlike any other commercial herbicide. For effective control, endothall should be applied when plants are actively growing, and plants begin to weaken and die within a few days after application.

Uptake of endothall is increased at higher water temperatures and higher amounts of light (Haller and Sutton 1973). Netherland et al. (2000) found that while biomass reduction of curly-leaf pondweed (*Potamogeton crispus*) was greater at higher water temperature, reductions of turion production were much greater when curly-leaf pondweed was treated a lower water temperature (18 °C vs 25 °C).

Degradation of endothall is primarily microbial (Sikka and Saxena 1973) and half-life of the dipotassium salt formulations is between 4 to 10 days (Reinert and Rodgers 1987; Reynolds 1992), although dissipation due to water movement may significantly shorten the effective half-life in some treatment scenarios. Half of the active ingredient from granular endothall formulations has been shown to be released within 1-5 hours under conditions that included water movement (Reinert et al. 1985; Bultemeier and Haller 2015). Endothall is highly water soluble and does not readily adsorb to sediments or lipids (Sprecher et al. 2002; Reinert and Rodgers 1984). Degradation from sunlight or hydrolysis is very low (Sprecher et al. 2002). The degradation rate of endothall has been shown to increase with increasing water temperature (UPI, *unpublished data*). The degradation rate is also highly variable across aquatic systems and is much slower under anaerobic conditions (Simsiman and Chesters 1975). Relative to other herbicides, endothall is unique in that is comprised of carbon, hydrogen, and oxygen with the addition of potassium and nitrogen in the dipotassium and dimethylalkylamine formulations, respectively. This allows for complete breakdown of the herbicide without additional intermediate breakdown products (Sprecher et al. 2002).

Toxicology

All endothall products have a drinking water standard of 0.1 ppm and cannot be applied within 600 feet of a potable water intake. Use restrictions for dimethylalkylamine salt formulations have additional irrigation and aquatic life restrictions.

Dipotassium salt formulations

At recommended rates, the dipotassium salt formulations appear to have few short-term behavioral or reproductive effects on bluegill (*Lepomis macrochirus*) or largemouth bass (*Micropterus salmoides;* Serns 1977; Bettolli and Clark 1992; Maceina et al. 2008). Bioaccumulation of dipotassium salt formulations by fish from water treated with the herbicide is unlikely, with studies showing less than 1% of endothall being taken up by bluegill (Sikka et al. 1975; Serns 1977). In addition, studies have shown the dipotassium salt formulation induces no significant adverse effects on aquatic invertebrates when used at label application rates (Serns 1975; Williams et al. 1984). A freshwater mussel species was found to be more sensitive to dipotassium salt endothall than other invertebrate species tested, but significant acute toxicity was still only found at concentrations well above the maximum label rate. However, as with other plant control approaches, some aquatic plant-dwelling populations of aquatic organisms may be adversely affected by application of endothall formulations due to habitat loss.

During EPA reregistration of endothall in 2005, it was required that product labels state that lower rates of endothall should be used when treating large areas, "such as coves where reduced water movement will not result in rapid dilution of the herbicide from the target treatment area or when treating entire lakes or ponds."

Dimethylalkylamine salt formulations

In contrast to the respective low to slight toxicity of the dipotassium salt formulations to fish and aquatic invertebrates, laboratory studies have shown the dimethylalkylamine formulations are toxic to fish and macroinvertebrates at concentrations above 0.3 ppm. In particular, the liquid formulation will readily kill fish present in a treatment site. Product labels for the dimethylalkylamine salt formulations recommend no treatment where fish are an important resource.

The dimethylalkylamine formulations are more active on aquatic plants than the dipotassium formulations, but also are 2-3 orders of magnitude more toxic to non-target aquatic organisms (EPA RED Endothall 2005; Keckemet 1969). The 2005 reregistration decision document limits aquatic use of the dimethylalkylamine formulations to algae, Indian swampweed (*Hygrophila polysperma*), water celery (*Vallisneria americana*), hydrilla (*Hydrilla verticillata*), fanwort (*Cabomba caroliniana*), bur reed (*Sparganium* sp.), common waterweed (*Elodea canadensis*), and Brazilian waterweed (*Egeria densa*). Coontail (*Ceratophyllum demersum*), watermilfoils (*Myriophyllum* spp.), naiads (*Najas* spp.), pondweeds (*Potamogeton* spp.), water stargrass (*Heteranthera dubia*), and horned pondweed (*Zannichellia palustris*) were to be removed from product labels (EPA RED Endothall 2005).

Species Susceptibility

According to the herbicide label, the maximum target concentration of endothall is 5000 ppb (5.0 ppm) acid equivalent (ae). Endothall is used to control a wide range of submersed species, including non-native species such as curly-leaf pondweed and Eurasian watermilfoil (*Myriophyllum spicatum*). The effects of the different formulations of endothall on various species of aquatic plants are discussed below.

Dipotassium salt formulations

At least one mesocosm or lab study has shown that endothall (at or below the maximum label rate) will control the invasive species hydrilla (Netherland et al. 1991; Wells and Clayton 1993; Hofstra and Clayton 2001; Pennington et al. 2001; Skogerboe and Getsinger 2001; Shearer and Nelson 2002; Netherland and Haller 2006; Poovey and Getsinger 2010), oxygen-weed (*Lagarosiphon major*; Wells and Clayton 1993; Hofstra and Clayton 2001), Eurasian watermilfoil (Netherland et al. 1991; Skogerboe and Getsinger 2002; Mudge and Theel 2011), water lettuce (*Pistia stratiotes*; Conant et al. 1998), curly-leaf pondweed (Yeo 1970), and giant salvinia (*Salvinia molesta*; Nelson et al. 2001). Wersal and Madsen (2010a) found that parrot feather (*Myriophyllum aquaticum*) control with endothall was less than 40% even with two days of exposure time at the maximum label rate. Endothall was shown to control the shoots of flowering rush (*Butomus umbellatus*), but control of the roots was variable (Poovey et al. 2012; Poovey et al. 2013). One study found that endothall did not significantly affect photosynthesis in fanwort with 6 days of exposure at 2.12 ppm ae (2120 ppb ae; Bultemeier et al. 2009). Large-scale, low-dose endothall treatments were found to reduce curly-leaf pondweed frequency, biomass, and turion production substantially in Minnesota lakes, particularly in the first 2-3 years of treatments (Johnson et al. 2012).

Native species that were significantly impacted (at or below the maximum endothall label rate in at least one mesocosm or lab study) include coontail (Yeo 1970; Hofstra and Clayton 2001; Hofstra et al. 2001; Skogerboe and Getsinger 2002; Wells and Clayton 1993; Mudge 2013), southern naiad (*Najas guadalupensis*; Yeo 1970; Skogerboe and Getsinger 2001), white waterlily (*Nymphaea odorata*; Skogerboe and Getsinger 2001), leafy pondweed (*Potamogeton foliosus*; Yeo 1970), Illinois pondweed (*Potamogeton illinoensis*; Skogerboe and Getsinger 2001; Shearer and Nelson 2002; Skogerboe and Getsinger 2002; Mudge 2013), long-leaf pondweed (*Potamogeton nodosus*; Yeo 1970; Skogerboe and Getsinger 2001; Shearer and Nelson 2002; Mudge 2013), small pondweed (*P. pusillus*; Yeo 1970), broadleaf arrowhead (*Sagittaria latifolia*; Skogerboe and Getsinger 2001), sago pondweed (*Stuckenia pectinata*; Yeo 1970; Sprecher et al. 1998a; Skogerboe and Getsinger 2002; Slade et al. 2008), water celery (*Vallisneria americana*; Skogerboe and Getsinger 2001; Skogerboe and Getsinger 2002; Shearer and Nelson 2002; Mudge 2013), and horned pondweed (Yeo 1970; Gyselinck and Courter 2015).

Species which were not significantly impacted or which recovered quickly include watershield (*Brasenia schreberi*; Skogerboe and Getsinger 2001), muskgrasses (*Chara* spp.; Yeo 1970; Wells and Clayton 1993; Hofstra and Clayton 2001), common waterweed (Yeo 1970; Wells and Clayton 1993; Skogerboe and Getsinger 2002), water stargrass (Skogerboe and Getsinger 2001), water net (*Hydrodictyon reticulatum*; Wells and Clayton 1993), the freshwater macroalgae *Nitella clavata* (Yeo 1970), yellow pond-lily (*Nuphar advena*; Skogerboe and Getsinger 2002), swamp smartweed (*Polygonum hydropiperoides*; Skogerboe and Getsinger 2002), pickerelweed (*Pontederia cordata*; Skogerboe and Getsinger 2001), softstem bulrush (*Schoenoplectus tabernaemontani*; Skogerboe and Getsinger 2001), and broadleaf cattail (*Typha latifolia*; Skogerboe and Getsinger 2002).

Field trials mirror the species susceptibility above and in addition show that endothall also can impact several high-value pondweed species (*Potamogeton* spp.), including large-leaf pondweed (*P. amplifolius*; Parsons et al. 2004), fern pondweed (*P. robbinsii*; Onterra 2015; Onterra 2018), white-stem pondweed (*P. praelongus*; Onterra 2018), small pondweed (Big Chetac Chain Lake Association 2016; Onterra 2018), clasping-leaf pondweed (*P. richardsonii*; Onterra 2018), and flat-stem pondweed (*P. zosteriformis*; Onterra 2017b).

Dimethylalkylamine salt formulations

The dimethylalkylamine formulations are more active on aquatic plants than the dipotassium formulations (EPA RED Endothall 2005; Keckemet 1969). At least one mesocosm study has shown that dimethylalkylamine formulation of endothall (at or below the maximum label rate) will control the invasive species fanwort (Hunt et al. 2015) and the native species common waterweed (Mudge et al. 2015), while others have shown that the dipotassium formulation does not control these species well.

Imazamox

Registration and Formulations

Imazamox is the common name of the active ingredient ammonium salt of imazamox (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-(methoxymethl)-3-pyridinecarboxylic acid. It was registered with U.S. EPA in 2008 and is currently under registration review with an estimated registration decision between 2019 and 2020 (EPA Imazamox Plan 2014). In aquatic environments, a liquid formulation is typically applied to submerged vegetation by broadcast spray or underwater hose application and to emergent or floating leaf vegetation by broadcast spray or foliar application. There is also a granular formulation.

Mode of Action and Degradation

Imazamox is a systemic herbicide that moves throughout the plant tissue and prevents plants from producing a necessary enzyme, acetolactate synthase (ALS), which is not found in animals. Susceptible plants will stop growing soon after treatment, but plant death and decomposition will occur over several weeks (Mudge and Netherland 2014). If used as a post-emergence herbicide, imazamox should be applied to plants that are actively growing. Resistance to ALS-inhibiting herbicides has appeared in weeds at a higher rate than other herbicide types in terrestrial environments (Tranel and Wright 2002).

Dissipation studies in lakes indicate a half-life ranging from 4 to 49 days with an average of 17 days. Herbicide breakdown does not occur readily in deep, poorly-oxygenated water where there is no light. In this part of a lake, imazamox will tend to bind to sediments rather than breaking down, with a half-life of approximately 2 years. Once in soil, leaching to groundwater is believed to be very limited. The breakdown products of imazamox are nicotinic acid and di- and tricarboxylic acids. It has been suggested that photolytic break down of imazamox is faster than other herbicides, reducing exposure times. However, short-term imazamox exposures have also been associated with extended regrowth times relative to other herbicides (Netherland 2011).

Toxicology

Treated water may be used immediately following application for fishing, swimming, cooking, bathing, and watering livestock. If water is to be used as potable water or for irrigation, the tolerance is 0.05 ppm (50 ppb), and a 24-hour irrigation restriction may apply depending on the waterbody. None of the breakdown products are herbicidal nor suggest concerns for aquatic organisms or human health.

Most concerns about adverse effects on human health involve applicator exposure. Concentrated imazamox can cause eye and skin irritation and is harmful if inhaled. Applicators should minimize exposure by wearing long-sleeved shirts and pants, rubber gloves, and shoes and socks.

Honeybees are affected at application rates so drift during application should be minimized. Laboratory tests using rainbow trout (*Oncorhynchus mykiss*), bluegill (*Lepomis macrochirus*), and water fleas (*Daphnia magna*) indicate that imazamox is not toxic to these species at label application rates.

Imazamox is rated "practically non-toxic" to fish and aquatic invertebrates and does not bioaccumulate in fish. Additional studies on birds indicate toxicity only at dosages that exceed approved application rates.

In chronic tests, imazamox was not shown to cause tumors, birth defects or reproductive toxicity in test animals. Most studies show no evidence of mutagenicity. Imazamox is not metabolized and was excreted by mammals tested. Based on its low acute toxicity to mammals, and its rapid disappearance from the water column due to light and microbial degradation and binding to soil, imazamox is not considered to pose a risk to recreational water users.

<u>Species Susceptibility</u>

In Wisconsin, imazamox is used for treating non-native emergent vegetation such as non-native phragmites (*Phragmites australis* subsp. *australis*) and flowering rush (*Butomus umbellatus*). Imazamox may also be used to treat the invasive curly-leaf pondweed (*Potamogeton crispus*). Desirable native species that may be affected could include other pondweed species (long-leaf pondweed (*P. nodosus*), flat-stem pondweed (*P. zosteriformis*), leafy pondweed (*P. foliosus*), Illinois pondweed (*P. illinoensis*), small pondweed (*P. pusillus*), variable-leaf pondweed (*P. gramineus*), water-thread pondweed (*P. diversifolius*), perfoliate pondweed (*P. perfoliatus*), large-leaf pondweed (*P. amplifolius*), watershield (*Brasenia schreberi*), and some bladderworts (*Utricularia* spp.). Higher rates of imazamox will control Eurasian watermilfoil (*Myriophyllum spicatum*) but would also have greater non-target impacts on native plants. Imazamox can also be used during a drawdown to prevent plant regrowth and on emergent vegetation.

At low concentrations, imazamox can cause growth regulation rather than mortality in some plant species. This has been shown for non-native phragmites and hydrilla (*Hydrilla verticillata*; Netherland 2011; Cheshier et al. 2012; Theel et al. 2012). In the case of hydrilla, some have suggested that this effect could be used to maintain habitat complexity while providing some target species control (Theel et al. 2012). Imazamox can reduce biomass of non-native phragmites though some studies found regrowth to occur, suggesting a combination of imazapyr and glyphosate to be more effective (Cheshier et al. 2012; Knezevic et al. 2013).

Some level of control of imazamox has also been reported for water hyacinth (*Eichhornia crassipes*), parrot feather (*Myriophyllum aquaticum*), Japanese stiltgrass (*Microstegium* *vimineum*), water lettuce (*Pistia stratiotes*), and southern cattail (*Typha domingensis*; Emerine et al. 2010; de Campos et al. 2012; Rodgers and Black 2012; Hall et al. 2014; Mudge and Netherland 2014). Imazamox was observed to have greater efficacy in controlling floating plants than emergents in a study of six aquatic plant species, including water hyacinth, water lettuce, parrot feather, and giant salvinia (*Salvinia molesta*; Emerine et al. 2010). Non-target effects have been observed for softstem bulrush (*Schoenoplectus tabernaemontani*), pickerelweed (*Pontederia cordata*), and the native pondweeds long-leaf pondweed, Illinois pondweed, and coontail (*Ceratophyllum demersum*; Koschnick et al. 2007; Mudge 2013). Giant salvinia, white waterlily (*Nymphaea odorata*), bog smartweed (*Polygonum setaceum*), giant bulrush (*Schoenoplectus californicus*), water celery (*Vallisneria americana*; though the root biomass of wide-leaf *Vallisneria* may be reduced), and several algal species have been found by multiple studies to be unaffected by imazamox (Netherland et al. 2009; Emerine et al. 2010; Rodgers and Black 2012; Mudge 2013; Mudge and Netherland 2014). Other species are likely to be susceptible, for which the effects of imazamox have not yet been evaluated.

Florpyrauxifen-benzyl

Registration and Formulations

Florpyrauxifen-benzyl is a relatively new herbicide, which was first registered with the U.S. EPA in September 2017. The active ingredient is 4-amino-3-chloro-6-(4-chloro-2-fluoro-3-methoxyphenyl)-5-fluoro-pyridine-2-benzyl ester, also identified as florpyrauxifen-benzyl. Florpyrauxifen-benzyl is used for submerged, floating, and emergent aquatic plant control (e.g., ProcellaCORTM) in slow-moving and quiescent waters, as well as for broad spectrum weed control in rice (*Oryza sativa*) culture systems and other crops (e.g., RinskorTM).

Mode of Action and Degradation

Florpyrauxifen-benzyl is a member of a new class of synthetic auxins, the arylpicolinates, that differ in binding affinity compared to other currently registered synthetic auxins such as 2,4-D and triclopyr (Bell et al. 2015). Florpyrauxifen-benzyl is a systemic herbicide (Heilman et al. 2017).

Laboratory studies and preliminary field dissipation studies indicate that florpyrauxifen-benzyl in water is subject to rapid photolysis (Heilman et al. 2017). In addition, the herbicide can also convert partially via hydrolysis to an acid form at high pH (>9) and higher water temperatures (>25°C), and microbial activity in the water and sediment can also enhance degradation (Heilman et al. 2017). The acid form is noted to have reduced herbicidal activity (Netherland and Richardson 2016; Richardson et al. 2016). Under growth chamber conditions, water samples at 1 DAT found that 44-59% of the applied herbicide had converted to acid form, while sampling at 7 and 14 DAT indicated that all the herbicide had converted to acid form (Netherland and Richardson 2016). The herbicide is short-lived, with half-lives ranging from 4 to 6 days in aerobic aquatic environments, and 2 days in anaerobic aquatic environments (WSDE 2017). Degradation in surface water is accelerated when exposed to sunlight, with a reported photolytic half-life in laboratory testing of 0.07 days (WSDE 2017).

There is some anecdotal evidence that initial water temperature and/or pH may impact the efficacy of florpyrauxifen-benzyl (Beets and Netherland 2018). Florpyrauxifen-benzyl has a high soil adsorption coefficient (KOC) and low volatility, which allows for rapid plant uptake resulting in short exposure time requirements (Heilman et al. 2017). Florpyrauxifen-benzyl degrades quickly (2-15 days) in soil and sediment (Netherland et al. 2016). Few studies have yet been completed for groundwater, but based on known environmental properties, florpyrauxifen-benzyl is not expected to be associated with potential environmental impacts in groundwater (WSDE 2017).

Toxicology

No adverse human health effects were observed in toxicological studies submitted for EPA herbicide registration, regardless of the route of exposure (Heilman et al. 2017). There are no drinking water or recreational use restrictions, including swimming and fishing. There are no restrictions on irrigating turf, and a short waiting period (dependent on application rate) for other non-agricultural irrigation purposes.

Florpyrauxifen-benzyl showed a good environmental profile for use in water, and is "practically non-toxic" to birds, bees, reptiles, amphibians, and mammals (Heilman et al. 2017). No ecotoxicological effects were observed on freshwater mussel or juvenile chinook salmon (Heilman et al. 2017). Florpyrauxifen-benzyl will temporarily bioaccumulate in freshwater organisms but is rapidly depurated and/or metabolized within 1 to 3 days after exposure to high (>150 ppb) concentrations (WSDE 2017).

An LC50 value indicates the concentration of a chemical required to kill 50% of a test population of organisms. LC50 values are commonly used to describe the toxicity of a substance. Label recommendations for milfoils do not exceed 9.65 ppb and the maximum label rate for an acre-foot of water is 48.25 ppb. Acute toxicity results using rainbow trout (*Oncorhynchus mykiss*), fathead minnow (*Pimephales promelas*), and sheepshead minnows (*Cyprinodon variegatus variegatus*) indicated LC50 values of greater than 49 ppb, 41 ppb, and 40 ppb, respectively when exposed to the technical grade active ingredient (WSDE 2017). An LC50 value of greater than 1,900 ppb was reported for common carp (*Cyprinus carpio*) exposed to the ProcellaCOR end-use formulation (WSDE 2017).

Acute toxicity results for the technical grade active ingredient using water flea (*Daphnia magna*) and midge (*Chironomus* sp.) indicated LC50 values of greater than 62 ppb and 60 ppb, respectively (WSDE 2017). Comparable acute ecotoxicity testing performed on *D. magna* using the ProcellaCOR end-use formulation indicated an LC50 value of greater than 8 ppm (80,000 ppb; WSDE 2017).

The ecotoxicological no observed effect concentration (NOEC) for various organisms as reported by Netherland et al. (2016) are: fish (>515 ppb ai), water flea (*Daphnia* spp.; >21440 ppb ai), freshwater mussels (>1023 ppb ai), saltwater mysid (>362 ppb ai), saltwater oyster (>289 ppb ai), and green algae (>480 ppb ai). Additional details on currently available ecotoxicological information is compiled by WSDE (2017).

Species Susceptibility

Florpyrauxifen-benzyl is a labeled for control of invasive watermilfoils (e.g., Eurasian watermilfoil (*Myriophyllum spicatum*), hybrid watermilfoil (*M. spicatum* x *sibiricum*), parrot feather (*M. aquaticum*)), hydrilla (*Hydrilla verticillata*), and other non-native floating plants such as floating hearts (*Nymphoides* spp.), water hyacinth (*Eichhornia crassipes*), and water chestnut (*Trapa natans*; Netherland and Richardson 2016; Richardson et al. 2016). Natives species listed on the product label as susceptible to florpyrauxifen-benzyl include coontail (*Ceratophyllum demersum*; Heilman et al. 2017), watershield (*Brasenia schreberi*), and American lotus (*Nelumbo lutea*). In laboratory settings, pickerelweed (*Pontederia cordata*) vegetation has also been shown to be affected (Beets and Netherland 2018).

Based on available data, florpyrauxifen-benzyl appears to show few impacts to native aquatic plants such as aquatic grasses, bulrush (*Schoenoplectus* spp.), cattail (*Typha* spp.), pondweeds (*Potamogeton* spp.), naiads (*Najas* spp.), and water celery (*Vallisneria americana*; WSDE 2017). Laboratory and mesocosm studies also found water marigold (*Bidens beckii*), white waterlily (*Nymphaea odorata*), common waterweed (*Elodea canadensis*), water stargrass (*Heteranthera dubia*), long-leaf pondweed (*Potamogeton nodosus*), and Illinois pondweed (*P. illinoensis*) to be relatively less sensitive to florpyrauxifen-benzyl than labeled species (Netherland et al. 2016; Netherland and Richardson 2016). Non-native fanwort (*Cabomba caroliniana*) was also found to be tolerant in laboratory study (Richardson et al. 2016).

Since florpyrauxifen-benzyl is a relatively new approved herbicide, detailed information on field applications is very limited. Trials in small waterbodies have shown control of parrot feather (*Myriophyllum aquaticum*), variable-leaf watermilfoil (*M. heterophyllum*), and yellow floating heart (*Nymphoides peltata*; Heilman et al. 2017).

S.3.3.3. Emergent and Wetland Herbicides

Glyphosate

Registration and Formulations

Glyphosate is a commonly used herbicide that is utilized in both aquatic and terrestrial sites. It was first registered for use in 1974. EPA is currently re-evaluating glyphosate and the registration decision was expected in 2014 (EPA Glyphosate Plan 2009). The use of glyphosate-based herbicides in aquatic environments that are not approved for aquatic use is very unsafe and is a violation of federal and state pesticide laws. Different formulations of glyphosate are available, including isopropylamine salt of glyphosate and potassium glyphosate.

Glyphosate is effective only on plants that grow above the water and needs to be applied to plants that are actively growing. It will not be effective on plants that are submerged or have most of their foliage underwater, nor will it control regrowth from seed.

Mode of Action and Degradation

Glyphosate is a systemic herbicide that moves throughout the plant tissue and works by inhibiting an important enzyme needed for multiple plant processes, including growth. Following treatment, plants will gradually wilt, appear yellow, and will die in approximately 2 to 7 days. It may take up to 30 days for these effects to become apparent for woody species.

Application should be avoided when heavy rain is predicted within 6 hours. To avoid drift, application is not recommended when winds exceed 5 mph. In addition, excessive speed or pressure during application may allow spray to drift and must be avoided. Effectiveness of glyphosate treatments may be reduced if applied when plants are growing poorly, such as due to drought stress, disease, or insect damage. A surfactant approved for aquatic sites must be mixed with glyphosate before application.

In water, the concentration of glyphosate is reduced through dispersal by water movement, binding to the sediments, and break-down by microorganisms. The half-life of glyphosate is between 3 and 133 days, depending on water conditions. Glyphosate disperses rapidly in water so dilution occurs quickly, thus moving water will decrease concentration, but not half-life. The primary breakdown product of glyphosate is aminomethylphosphonic acid (AMPA), which is also degraded by microbes in water and soil.

Toxicology

Most aquatic forms of glyphosate have no restrictions on swimming or eating fish from treated waterbodies. However, potable water intakes within ½ mile of application must be turned off for 48 hours after treatment. Different formulations and products containing glyphosate may vary in post-treatment water use restrictions.

Most glyphosate-related health concerns for humans involve applicator exposure, exposure through drift, and the surfactant exposure. Some adverse effects from direct contact with the herbicide include temporary symptoms of dermatitis, eye ailments, headaches, dizziness, and nausea. Protective clothing (goggles, a face shield, chemical resistant gloves, aprons, and footwear) should be worn by applicators to reduce exposure. Recently it has been demonstrated that terrestrial formulations of glyphosate can have toxic effects to human embryonic cells and linked to endocrine disruption (Benachour et al. 2007; Gasnier et al. 2009).

Laboratory testing indicates that glyphosate is toxic to carp (*Cyprinus* spp.), bluegills (*Lepomis macrochirus*), rainbow trout (*Oncorhynchus mykiss*), and water fleas (*Daphnia* spp.) only at dosages well above the label application rates. Similarly, it is rated "practically non-toxic" to other aquatic species tested. Studies by other researchers examining the effects of glyphosate on important food chain organisms such as midge larvae, mayfly nymphs, and scuds have demonstrated a wide margin of safety between application rates.

EPA data suggest that toxicological effects of the AMPA compound are similar to that of glyphosate itself. Glyphosate also contains a nitrosamine (n-nitroso-glyphosate) as a contaminant at levels of 0.1 ppm or less. Tests to determine the potential health risks of nitrosamines are not required by the EPA unless the level exceeds 1.0 ppm.

Species Susceptibility

Glyphosate is only effective on actively growing plants that grow above the water's surface. It can be used to control reed canary grass (*Phalaris arundinacea*), cattails (*Typha* spp.; Linz et al. 1992; Messersmith et al. 1992), purple loosestrife (*Lythrum salicaria*), phragmites (*Phragmites australis* subsp. *australis*; Back and Holomuzki 2008; True et al. 2010; Back et al. 2012; Cheshier et al. 2012), water hyacinth (*Eichhornia crassipes*; Lopez 1993; Jadhav et al. 2008), water lettuce (*Pistia stratiotes*; Mudge and Netherland 2014), water chestnut (*Trapa natans*; Rector et al. 2015), Japanese stiltgrass (*Microstegium vimineum*; Hall et al. 2014), giant reed (*Arundo donax*; Spencer 2014), and perennial pepperweed (*Lepidium latifolium*; Boyer and Burdick 2010). Glyphosate will also reduce abundance of white waterlily (*Nymphaea odorata*) and pond-lilies (*Nuphar* spp.; Riemer and Welker 1974). Purple loosestrife biocontrol beetle (*Galerucella calmariensis*) oviposition and survival have been shown not to be affected by integrated management with glyphosate. Studies have found pickerelweed (*Pontederia cordata*) and floating marsh pennywort (*Hydrocotyle ranunculoides*) to be somewhat tolerant to glyphosate (Newman and Dawson 1999; Gettys and Sutton 2004).

Imazapyr

Registration and Formulations

Imazapyr was registered with the U.S. EPA for aquatic use in 2003 and is currently under registration review. It was estimated to have a registration review decision in 2017 (EPA Imazapyr Plan 2014). The active ingredient is isopropylamine salt of imazapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-pyridinecarboxylic acid). Imazapyr is used for control of emergent and floating-leaf vegetation. It is not recommended for control of submersed vegetation.

Mode of Action and Degradation

Imazapyr is a systemic herbicide that moves throughout the plant tissue and prevents plants from producing a necessary enzyme, acetolactate synthase (ALS), which is not found in animals. Susceptible plants will stop growing soon after treatment and become reddish at the tips of the plant. Plant death and decomposition will occur gradually over several weeks to months. Imazapyr should be applied to plants that are actively growing. If applied to mature plants, a higher concentration of herbicide and a longer contact time will be required.

Imazapyr is broken down in the water by light and has a half-life ranging from three to five days. Three degradation products are created as imazapyr breaks down: pyridine hydroxy-dicarboxylic acid, pyridine dicarboxylic acid (quinolinic acid), and nicotinic acid. These degradates persist in water for approximately the same amount of time as imazapyr (half-lives of three to eight days). In soils imazapyr is broken down by microbes, rather than light, and persists with a half-life of one to five months (Boyer and Burdick 2010). Imazapyr doesn't bind to sediments, so leaching through soil into groundwater is likely.

Toxicology

There are no restrictions on recreational use of treated water, including swimming and eating fish from treated waterbodies. If application occurs within a ½ mile of a drinking water intake, then the intake must be shut off for 48 hours following treatment. There is a 120-day irrigation restriction for treated water, but irrigation can begin sooner if the concentration falls below 0.001 ppm (1 ppb). Imazapyr degradates are no more toxic than imazapyr itself and are excreted faster than imazapyr when ingested.

Concentrated imazapyr has low acute toxicity on the skin or if ingested but is harmful if inhaled and may cause irreversible damage if it gets in the eyes. Applicators should wear chemical-resistant gloves while handling, and persons not involved in application should avoid the treatment area during treatment. Chronic toxicity tests for imazapyr indicate that it is not carcinogenic, mutagenic, or neurotoxic. It also does not cause reproductive or developmental toxicity and is not a suspected endocrine disrupter.

Imazapyr is "practically non-toxic" to fish, invertebrates, birds and mammals. Studies have also shown imazapyr to be "practically non-toxic" to "slightly toxic" to tadpoles and juvenile frogs (Trumbo and Waligora 2009; Yahnke et al. 2013). Toxicity tests have not been published on reptiles. Imazapyr does not bioaccumulate in animal tissues.

Species Susceptibility

The imazapyr herbicide label is listed to control the invasive plants phragmites (*Phragmites australis* subsp. *australis*), purple loosestrife (*Lythrum salicaria*), reed canary grass (*Phalaris arundinacea*), non-native cattails (*Typha* spp.) and Japanese knotweed (*Fallopia japonica*) in Wisconsin. Native species that are also controlled include cattails (*Typha* spp.), waterlilies (*Nymphaea* sp.), pickerelweed (*Pontederia cordata*), duckweeds (*Lemna* spp.), and arrowhead (*Sagittaria* spp.).

Studies have shown imazapyr to effectively control giant reed (*Arundo donax*), water hyacinth (*Eichhornia crassipes*), manyflower marsh-pennywort (*Hydrocotyle umbellata*); yellow iris (*Iris pseudacorus*), water lettuce (*Pistia stratiotes*), perennial pepperweed (*Lepidium latifolium*), Japanese stiltgrass (*Microstegium vimineum*), parrot feather (*Myriophyllum aquaticum*), and cattails (Boyer and Burdick 2010; True et al. 2010; Back et al. 2012; Cheshier et al. 2012; Whitcraft and Grewell 2012; Hall et al. 2014; Spencer 2014; Cruz et al. 2015; DiTomaso and Kyser 2016). Giant salvinia (*Salvinia molesta*) was found to be imazapyr-tolerant (Nelson et al. 2001).

S.3.3.4. Herbicides Used for Submersed and Emergent Plants

Triclopyr

Registration and Formulations

Triclopyr was initially registered with the U.S. EPA in 1979, reregistered in 1997, and is currently under review with an estimated registration review decision in 2019 (EPA Triclopyr Plan 2014). There are two forms of triclopyr used commercially as herbicides: the triethylamine salt (TEA) and the butoxyethyl ester (BEE). BEE formulations are considered highly toxic to aquatic organisms, with observed lethal effects on fish (Kreutzweiser et al. 1994) as well as avoidance behavior and growth impairment in amphibians (Wojtaszek et al. 2005). The active ingredient triethylamine salt (3,5,6-trichloro-2-pyridinyloxyacetic acid) is the formulation registered for use in aquatic systems. It is sold both in liquid and granular forms for control of submerged, emergent, and floating-leaf vegetation. There is also a liquid premixed formulation that contains triclopyr and 2,4-D, which when combined together are reported to have synergistic impacts. Only triclopyr products labeled for use in aquatic environments may be used to control aquatic plants.

Mode of Action and Degradation

Triclopyr is a systemic plant growth regulator that is believed to selectively act on broadleaf (dicot) and woody plants. Following treatment, triclopyr is taken up through the roots, stems and leaf tissues, plant growth becomes abnormal and twisted, and plants die within one to two weeks after application (Getsinger et al. 2000). Triclopyr is somewhat persistent and can move through soil, although only mobile enough to permeate top soil layers and likely not mobile enough to potentially contaminate groundwater (Lee et al. 1986; Morris et al. 1987; Stephenson et al. 1990).

Triclopyr is broken down rapidly by light (photolysis) and microbes, while hydrolysis is not a significant route of degradation. Triclopyr photodegrades and is further metabolized to carbon dioxide, water, and various organic acids by aquatic organisms (McCall and Gavit 1986). It has been hypothesized that the major mechanism for the removal of triclopyr from the aquatic environment is microbial degradation, though the role of photolysis likely remains important in near-surface and shallow waters (Petty et al. 2001). Degradation of triclopyr by microbial action is slowed in the absence of light (Petty et al. 2003). Triclopyr is very slowly degraded under anaerobic conditions, with a reported half-life (the time it takes for half of the active ingredient to degrade) of about 3.5 years (Laskowski and Bidlack 1984). Another study of triclopyr under aerobic aquatic conditions yielded a half-life of 4.7 months (Woodburn and Cranor 1987). The initial breakdown products of triclopyr are TCP (3,5,6-trichloro-2-pyridinol) and TMP (3,5,6-trichloro-2-methoxypridine).

Several studies reported triclopyr half-lives between 0.5-7.5 days (Woodburn et al. 1993; Getsinger et al. 2000; Petty et al. 2001; Petty et al. 2003). Two large-scale, low-dose treatments were reported to have longer triclopyr half-lives from 3.7-12.1 days (Netherland and Jones 2015). Triclopyr half-lives have been shown to range from 3.4 days in plants, 2.8-5.8 days in sediment, up to 11 days in fish tissue, and 11.5 days in crayfish (Woodburn et al. 1993; Getsinger et al. 2000; Petty et al. 2003). TMP and TCP may have longer half-lives than triclopyr, with higher levels in bottom-feeding fish and the inedible parts of fish (Getsinger et al. 2000).

Toxicology

Based upon the triclopyr herbicide label, there are no restrictions on swimming, eating fish from treated waterbodies, or pet/livestock drinking water use. Before treated water can be used for irrigation, the concentration must be below 0.001 ppm (1 ppb), or at least 120 days must pass. Treated water should not be used for drinking water until concentrations of triclopyr are less than

0.4 ppm (400 ppb). There is a least one case of direct human ingestion of triclopyr TEA which resulted in metabolic acidosis and coma with cardiovascular impairment (Kyong et al. 2010).

There are substantial differences in toxicity of BEE and TEA, with the BEE shown to be more toxic in aquatic settings. BEE formulations are considered highly toxic to aquatic organisms, with observed lethal effects on fish (Kreutzweiser et al. 1994) as well as avoidance behavior and growth impairment in amphibians (Wojtaszek et al. 2005). Triclopyr TEA is "practically non-toxic" to freshwater fish and invertebrates (Mayes et al. 1984; Gersich et al. 1984). It ranges from "practically non-toxic" to "slightly toxic" to birds (EPA Triclopyr RED 1998). TCP and TMP appear to be slightly more toxic to aquatic organisms than triclopyr; however, the peak concentration of these degradates is low following treatment and depurates from organisms readily, so that they are not believed to pose a concern to aquatic organisms.

Species susceptibility

Triclopyr has been used to control Eurasian watermilfoil (*Myriophyllum spicatum*) and hybrid watermilfoil (*M. spicatum* x *sibiricum*) at both small- and large-scales (Netherland and Getsinger 1992; Getsinger et al. 1997; Poovey et al. 2004; Poovey et al. 2007; Nelson and Shearer 2008; Heilman et al. 2009; Glomski and Netherland 2010; Netherland and Glomski 2014; Netherland and Jones 2015). Getsinger et al. (2000) found that peak triclopyr accumulation was higher in Eurasian watermilfoil than flat-stem pondweed (*Potamogeton zosteriformis*), indicating triclopyr's affinity for Eurasian watermilfoil as a target species.

According to product labels, triclopyr is capable of controlling or affecting many emergent woody plant species, purple loosestrife (*Lythrum salicaria*), phragmites (*Phragmites australis* subsp. *australis*), American lotus (*Nelumbo lutea*), milfoils (*Myriophyllum* spp.), and many others. Triclopyr application has resulted in reduced frequency of occurrence, reduced biomass, or growth regulation for the following species: common waterweed (*Elodea canadensis*), water stargrass (*Heteranthera dubia*), white waterlily (*Nymphaea odorata*), purple loosestrife, Eurasian watermilfoil, parrot feather (*Myriophyllum aquaticum*), variable-leaf watermilfoil (*M. heterophyllum*), watercress (*Nasturtium officinale*), phragmites, flat-stem pondweed (*Potamogeton zosteriformis*), clasping-leaf pondweed (*P. richardsonii*), stiff pondweed (*P. strictifolius*), variable-leaf pondweed (*P. gramineus*), white water crowfoot (*Ranunculus aquatilis*), sago pondweed (*Stuckenia pectinata*), softstem bulrush (*Schoenoplectus tabernaemontani*), hardstem bulrush (*S. acutus*), water chestnut (*Trapa natans*), duckweeds (*Lemna* spp.), and submerged flowering rush (*Butomus umbellatus*; Cowgill et al. 1989; Gabor et al. 1995; Sprecher and Stewart 1995; Getsinger et al. 2003; Poovey et al. 2004; Hofstra et al. 2006; Poovey and Getsinger 2007; Champion et al. 2008; Derr 2008; Glomski and Nelson 2008; Glomski et al. 2009; True et al. 2010; Cheshier et al. 2012; Netherland and Jones 2015; Madsen et al. 2015; Madsen et al. 2016). Wild rice (*Zizania palustris*) biomass and height has been shown to decrease significantly following triclopyr application at 2.5 mg/L. Declines were not significant at lower concentrations (0.75 mg/L), though seedlings were more sensitive than young or mature plants (Madsen et al. 2008). American bulrush (*Schoenoplectus americanus*), spatterdock (*Nuphar variegata*), fern pondweed (*Potamogeton robbinsii*), large-leaf pondweed (*P. amplifolius*), leafy pondweed (*P. foliosus*), white-stem pondweed (*P. praelongus*), long-leaf pondweed (*P. nodosus*), Illinois pondweed (*P. illinoensis*), and water celery (*Vallisneria americana*) can be somewhat tolerant of triclopyr applications depending on waterbody characteristics and application rates (Sprecher and Stewart 1995; Glomski et al. 2009; Wersal et al. 2010b; Netherland and Glomski 2014).

Netherland and Jones (2015) evaluated the impact of large-scale, low-dose (~0.1-0.3 ppm) granular triclopyr) applications for control of non-native watermilfoil on several bays of Lake Minnetonka, Minnesota. Near complete loss of milfoil in the treated bays was observed the year of treatment, with increased milfoil frequency reported the following season. However, despite the observed increase in frequency, milfoil biomass remained a minor component of bay-wide biomass (<2%). The number of points with native plants, mean native species per point, and native species richness in the bays were not reduced following treatment. However, reductions in frequency were seen amongst individual species, including northern watermilfoil (*Myriophyllum sibiricum*), water stargrass, common waterweed, and flat-stem pondweed.

Penoxsulam

Registration and Formulations

Penoxsulam (2-(2,2-difluoroethoxy)--6-(trifluoromethyl-N-(5,8-dimethoxy[1,2,4] triazolo[1,5-c]pyrimidin-2-yl))benzenesulfonamide), also referred to as DE-638, XDE-638, XR-638 is a post-emergence, acetolactate synthase (ALS) inhibiting herbicide. It was first registered for use by the U.S. EPA in 2009. It is liquid in formulation and used for large-scale control of submerged, emergent, and floating-leaf vegetation. Information presented here can be found in the EPA pesticide fact sheet (EPA Penoxsulam 2004).

Mode of Action and Degradation

Penoxsulam is a slow-acting herbicide that is absorbed by above- and below-ground plant tissue and translocated throughout the plant. Penoxsulam interferes with plant growth by inhibiting the AHAS/ALS enzyme which in turn inhibits the production of important amino acids (Tranel and Wright 2002). Plant injury or death usually occurs between 2 and 4 weeks following application.

Penoxsulam is highly mobile but not persistent in either aquatic or terrestrial settings. However, the degradation process is complex. Two degradation pathways have been identified that result in at least 13 degradation products that persist for far longer than the original chemical. Both microbial- and photo-degradation are likely important means by which the herbicide is removed from the environment (Monika et al. 2017). It is relatively stable in water alone without sunlight, which means it may persist in light-limited areas.

The half-life for penoxsulam is between 12 and 38 days. Penoxsulam must remain in contact with plants for around 60 days. Thus, supplemental applications following initial treatment may be required to maintain adequate concentration exposure time (CET). Due to the long CET requirement, penoxsulam is likely best suited to large-scale or whole-lake applications.

Toxicology

Penoxsulam is unlikely to be toxic to animals but may be "slightly toxic" to birds that consume it. Human health studies have not revealed evidence of acute or chronic toxicity, though some indication of endocrine disruption deserves further study. However, screening-level assessments of risk have not been conducted on the major degradates which may have unknown non-target effects. Penoxsulam itself is unlikely to bioaccumulate in fish.

Species Susceptibility

Penoxsulam is used to control monocot and dicot plant species in aquatic and terrestrial environments. The herbicide is often applied at low concentrations of 0.002-0.02 ppm (2-20 ppb), but as a result long exposure times are usually required for effective target species control (Cheshier et al. 2011; Mudge et al. 2012b). For aquatic plant management applications, penoxsulam is most commonly utilized for control of hydrilla (*Hydrilla verticillata*). It has also been used for control of giant salvinia (*Salvinia molesta*), water hyacinth (*Eichhornia crassipes*), and water lettuce (*Pistia stratiotes*; Richardson and Gardner 2007; Mudge and Netherland 2014). However, the herbicide is only semi-selective; it has been implicated in injury to non-target emergent native species, including arrowheads (*Sagittaria* spp.) and spikerushes (*Eleocharis* spp.) and free-floating species like duckweed (Mudge and Netherland 2014; Cheshier et al. 2011). Penoxsulam can also be used to control milfoils such as Eurasian watermilfoil (*Myriophyllum spicatum*) and variable-leaf watermilfoil (*M. heterophyllum*; Glomski and Netherland 2008). Seedling emergence as well as vegetative vigor is impaired by penoxsulam in both dicots and monocots, so buffer zone and dissipation reduction strategies may be necessary to avoid non-target impacts (EPA Penoxsulam 2004).

When used to treat salvinia, the herbicide was found to have effects lasting through 10 weeks following treatment (Mudge et al. 2012b). The herbicide is effective at low doses, but while low-concentration applications of slow-acting herbicides like penoxsulam often result in temporary growth regulation and stunting, plants are likely to recover following treatment. Thus, complementary management strategies should be employed to discourage early regrowth (Mudge et al. 2012b). In particular, joint biological and herbicidal control with penoxsulam has shown good control of water hyacinth (Moran 2012). Alternately, a low concentration may be maintained over time by repeated low-dose applications. Studies show that maintaining a low concentration for at least 8-12 weeks provided excellent control of salvinia, and that a low dose followed by a high-dose application was even more efficacious (Mudge et al. 2012b).

S.3.4. Physical Removal Techniques

There are several management options which involve physical removal of aquatic plants, either by manual or mechanical means. Some of these include manual and mechanical cutting and hand-pulling or Diver-Assisted Suction Harvesting (DASH).

S.3.4.1. Manual and Mechanical Cutting

Manual and Mechanical Cutting

Manual and mechanical cutting involve slicing off a portion of the target plants and removing the cut portion from the waterbody. In addition to actively removing parts of the target plants, destruction of vegetative material may help prevent further plant growth by decreasing photosynthetic uptake, and preventing the formation of rhizomes, tubers, and other growth types (Dall Armellina et al. 1996a, 1996b; Fox et al. 2002). These approaches can be quick to allow recreational use of a waterbody but because the plant is still established and will continue to grow from where it was cut, it often serves to provide short-term relief (Bickel and Closs 2009; Crowell et al. 1994). A synthesis of numerous historical mechanical harvesting studies is compiled by Breck et al. 1979.

The amount of time for macrophytes to return to pre-cutting levels can vary between waterbodies and with the dominant plant species present (Kaenel et al. 1998). Some studies have suggested that annual or biannual cutting of Eurasian watermilfoil (*Myriophyllum spicatum*) may be needed, while others have shown biomass can remain low the year after cutting (Kimbel and Carpenter 1981; Painter 1988; Barton et al. 2013). Hydrilla (*Hydrilla verticillata*) has been shown to recover beyond pre-harvest levels within weeks in some cases (Serafy et al. 1994). In deeper waters, greater cutting depth may lead to increased persistence of vegetative control (Unmuth et al. 1998; Barton et al. 2013). Higher frequency of cutting, rather than the amount of plant that is cut, can result in larger reductions to propagules such as turions (Fox et al. 2002).

The timing of cutting operations, as for other management approaches, is important. For species dependent on vegetative propagules, control methods should be taken before the propagules are formed. However, for species with rhizomes, cutting too early in the season merely postpones growth while later-season cutting can better reduce plant abundance (Dall Armellina et al. 1996a, 1996b). Eurasian watermilfoil regrowth may be slower if cutting is conducted later in the summer (June or later). Cutting in the fall, rather than spring or summer, may result in the lowest amount of Eurasian watermilfoil regrowth the year after management (Kimbel and Carpenter 1981). However, managing early in the growing season may reduce non-target impacts to native plant populations when early-growing non-native plants are the dominant targets (Nichols and Shaw 1986). Depending on regrowth rate and management goals, multiple harvests per growing season may be necessary (Rawls 1975).

Vegetative fragments which are not collected after cutting can produce new localized populations, potentially leading to higher plant densities (Dall Armellina et al. 1996a). Eurasian watermilfoil and common waterweed (*Elodea canadensis*) biomass can be reduced by cutting (Abernethy et al. 1996), though Eurasian watermilfoil can maintain its growth rate following cutting by developing a more-densely branched form (Rawls 1975; Mony et al. 2011). Cutting and physical removal tend to be less expensive but require more effort than benthic barriers, so these approaches may be best used for small infestations or where non-native and native species inhabit the same stand (Bailey and Calhoun 2008).

Ecological Impacts of Manual and Mechanical Cutting

Plants accrue nutrients into their tissues, and thus plant removal may also remove nutrients from waterbodies (Boyd 1970), though this nutrient removal may not be significant among all lake types. Cutting and harvesting of aquatic plants can lead to declines in fish as well as beneficial zooplankton, macroinvertebrate, and native plant and mussel populations (Garner et al. 1996; Aldridge 2000; Torn et al. 2010; Barton et al. 2013). Many studies suggest leaving some vegetated areas undisturbed to reduce negative effects of cutting on fish and other aquatic organisms (Swales 1982; Garner et al. 1996; Unmuth et al. 1998; Aldridge 2000; Greer et al. 2012). Recovery of these populations to cutting in the long-term is understudied and poorly understood (Barton et al. 2013). Effects on water quality can be minimal but nutrient cycling may be affected in wetland systems (Dall Armellina et al. 1996a; Martin et al. 2003). Cutting can also increase algal production, and turbidity temporarily if sediments are disturbed (Wile 1978; Bailey and Calhoun 2008).

Some changes to macroinvertebrate community composition can occur as a result of cutting (Monahan and Caffrey 1996; Bickel and Closs 2009). Studies have also shown 12-85% reductions in macroinvertebrates following cutting operations in flowing systems (Dawson et al. 1991; Kaenel et al. 1998). Macroinvertebrate communities may not rebound to pre-management levels for 4-6 months and species dependent on aquatic plants as habitat (such as simuliids and chironomids) are likely to be most affected. Reserving cutting operations for summer, rather than spring, may reduce impacts to macroinvertebrate communities (Kaenel et al. 1998).

Mechanical harvesting can also incidentally remove fish and turtles inhabiting the vegetation and lead to shifts in aquatic plant community composition (Engel 1990; Booms 1999). Studies have shown mechanical harvesting can remove between 2%-32% of the fish community by fish number, with juvenile game fish and smaller species being the primary species removed (Haller et al. 1980; Mikol 1985). Haller et al. (1980) estimated a 32% reduction in the fish community at a value of $6000/hectare. However, fish numbers rebounded to similar levels as an unmanaged area within 43 days after harvesting in the Potomac River in Maryland (Serafy et al. 1994). In addition to direct impacts to fish populations, reductions in fish growth rates may correspond with declines in zooplankton populations in response to cutting (Garner et al. 1996).

S.3.4.2. Hand Pulling and Diver-Assisted Suction Harvesting

Hand-pulling and DASH involve removing rooted plants from the bottom sediment of the water body. The entire plant is removed and disposed of elsewhere. Hand-pulling can be done at shallower depths whereas DASH, in which SCUBA divers do the pulling, may be better suited for deeper aquatic plant beds. As a permit condition, DASH and hand-pulling may not result in lifting or removal of bottom sediment (i.e., dredging). Efforts should be made to preserve water clarity because turbid conditions reduce visibility for divers, slowing the removal process and making species identification difficult. When operated with the intent to distinguish between species and minimize disturbance to desirable vegetation, DASH can be selective and provide multi-year control (Boylen et al. 1996). One study found reduced cover of Eurasian watermilfoil both in the year of harvest and the following year, along with increased native plant diversity and reduced overall plant cover the year following DASH implementation (Eichler et al. 1993). However, hand harvesting or DASH may require a large time or economic investment for Eurasian watermilfoil and other aquatic vegetation control on a large-scale (Madsen et al. 1989; Kelting and Laxson 2010). Lake type, water clarity, sediment composition, underwater obstacles and presences of dense native plants, may slow DASH efforts or even prohibit the ability to utilized DASH. Costs of DASH per acre have been reported to typically range from approximately $5,060-8,100 (Cooke et al. 1993; Mattson et al. 2004). Additionally, physical removal of turions from sediments, when applicable, has been shown to greatly reduce plant abundance for multiple subsequent growing seasons (Caffrey and Monahan 2006), though this has not been implemented in Wisconsin due to the significant effort it requires.

Ecological Impacts of Hand-Pulling and DASH

Because divers are physically uprooting plants from the lake bed, hand removal may disturb benthic organisms. Additionally, DASH may also result in some accidental capture of fish and invertebrates, small amounts of sediment removal, or increased turbidity. It is possible that equipment modifications could help minimize some of these unintended effects. Because DASH is a relatively new management approach, less information is available about potential impacts than for some more established techniques like large-scale mechanical harvesting.

S.3.4.3. Benthic Barriers

Benthic barriers can be used to kill existing plants or prevent their growth from the outset. They are sometimes referred to as benthic mats, or screens, and involve placing some sort of covering over a plant bed, which provides a physical obstruction to plant growth and reduces light availability. They may be best used for dense, confined infestations or along shore or for providing boat lanes (Engel 1983; Payne et al. 1993; Bailey and Calhoun 2008). Reductions in abundance of live aquatic plants beneath the barrier may be seen within weeks (Payne et al. 1993; Carter et al. 1994). The target plant species, light availability, and sediment accumulation have been shown to influence the efficacy of benthic barriers for aquatic plant control. Effects on the target plants may be more rapid in finer sediments because anoxic conditions are reached more quickly due to higher sediment organic content and oxidization by bacteria (Carter et al. 1994). Benthic barriers may be more expensive but less time intensive than some of the physical removal approaches described above (Carter et al. 1994; Bailey and Calhoun 2008). Engel (1983) suggests that benthic barriers may be useful in situations where plants are growing too deep for other physical removal approaches or effective herbicide application. They may also improve plant control when used in combination with herbicide treatments to hold most of the herbicide to a given treatment area (Helsel et al. 1996).

There is some necessary upkeep associated with the use of benthic barriers. Some barriers can be difficult to re-use because of algae and plants that can grow on top of the barrier. Periodically removing sediment that accumulates on the barrier can help offset this (Engel 1983; Carter et al. 1994; Laitala et al. 2012). Some materials are made to be removed after the growing season, which may make cleaning and re-use easier (Engel 1983). Additionally, gases often accumulate beneath benthic barriers as a result of plant decay, which can cause them to rise off the bottom of the waterbody, requiring further maintenance (Engel 1983; Ussery et al. 1997; Bailey and Calhoun 2008). Eurasian watermilfoil (*Myriophyllum spicatum*) and other plant species have been shown to recolonize the managed area quickly following barrier removal (Eichler et al. 1995; Boylen et al. 1996), so this approach may require hand-pulling or other integrated approaches once the barrier is removed (Carter et al. 1994; Eichler et al. 1995; Bailey and Calhoun 2008). Some studies have observed low abundance of plants maintained for 1-2 months after barriers were removed (Engel 1983). Others found that combining 2,4-D treatments with benthic barriers could reduce Eurasian watermilfoil to a degree that helped native plants recolonize the target site (Helsel et al. 1996).

The material used to create benthic barriers can vary and include biodegradable jute matting, fiberglass screens, and woven polypropylene fibers (Mayer 1978; Perkins et al. 1980; Lewis et al. 1983; Hoffman et al. 2013). Some plants such as Eurasian watermilfoil and common waterweed (Elodea canadensis; Eichler et al. 1995) are able to growth through the mesh in woven barriers but this material can be effective in reducing growth on certain target plant species (Payne et al. 1993; Caffrey et al. 2010; Hoffman et al. 2013). Hofstra and Clayton (2012) suggested that less dense materials barriers may provide selective control of some species while allowing more tolerant species, such as some charophytes (*Chara* spp. and *Nitella* spp.), to grow through. More dense materials may prevent growth of a wider range of aquatic plants (Hofstra and Clayton 2012). Most materials must be well anchored to the bottom of the waterbody, which can be accomplished early in the growing season or by placing the barriers on ice before thawing of the waterbody (Engel 1983). Gas accumulation can occur in using both fibrous mesh and screen-type barriers (Engel 1983).

Eurasian watermilfoil and common waterweed have been found to be somewhat resistant to control by benthic barriers (Perkins et al. 1980; Engel 1983) while affected species include hydrilla (*Hydrilla verticillata*), curly-leaf pondweed (*Potamogeton crispus*), and coontails (*Ceratophyllum* spp.; Engel 1983; Payne et al. 1993; Carter et al. 1994). One study found that an 8-week barrier placement removed Eurasian watermilfoil while allowing native plant regrowth after the barrier was retrieved; while shorter durations were less effective in reducing Eurasian watermilfoil abundance and longer durations negatively impacted native plant regrowth (Laitala et al. 2012).

<u>Ecological Impacts of Benthic Barriers</u>

Macroinvertebrates will be negatively affected by benthic barriers while they are in place (Engel 1983) but have been shown to rebound to pre-management conditions shortly after removal of the barrier (Payne et al. 1993; Ussery et al. 1997). Benthic barriers may also affect spawning of some warm water fish species through direct disruption of spawning habitat (NYSFOLA 2009). Additionally, increased ammonium and decreased dissolved oxygen contents are often observed beneath benthic barriers (Carter et al. 1994; Ussery et al. 1997). These water chemistry considerations may partially explain decreases in macroinvertebrate populations (Engel 1983; Payne et al. 1993) and ammonium content is likely to increase with sediment organic content (Eakin 1992). Toxic methane gas has also been found to accumulate beneath benthic barriers (Gunnison and Barko 1992).

There may be some positive ecological aspects of benthic barriers. Barriers may reduce turbidity and nutrient release from sediments (Engel 1983). They may also provide channels that improve ease of fish foraging when other aquatic plant cover is present near the managed area. Fish may feed on the benthic organisms colonizing any sediment accumulating on top of the barrier (Payne et al. 1993). Payne et al. (1993) also suggest that, despite negative impacts in the managed area, the overall impact of benthic barriers is negligible since they typically are only utilized in small areas of the littoral zone. However, further research is needed on the effects of benthic barriers on fish and wildlife populations and their ability to rebound following barrier removal (Eichler et al. 1995).

S.3.4.4. Dredging

Dredging is a method that involves the removal of top layers of sediment and associated rooted plants, sediment-dwelling organisms, and sediment-bound nutrients. This approach is "non-selective" (USACE 2012), meaning that it offers limited control over what material is removed. In addition to being employed as an APM technique, dredging is often used to manage water flow, provide navigation channels, and reduce the chance of flooding (USACE 2012). Due to the expense of this method, APM via dredging is often an auxiliary effect of dredging performed for other purposes (Gettys et al. 2014). However, reduced sediment nutrient load and decreased light penetration due to greater depth post-dredging may result in multi-season reductions in plant biomass and density (Gettys et al. 2014).

Several studies discuss the utility of dredging for APM. Dredging may be effective in controlling species that propagate by rhizomes, by removing the rhizomes from the sediment before they have a chance to grow (Dall Armellina et al. 1996b). Additionally, invasive phragmites has been controlled in areas where dredging increases water depth to ≥ 5-6 feet; though movement of the equipment used in dredging activities has been implicated in expanding the range of invasive phragmites (Gettys et al. 2014). In streams, dredging resulted in a significant reduction in plant biomass (≥ 90%). However, recovery of plant populations reflected the timing of management actions relative to flowering: removal prior to flowering allowed for plant population recovery within the same growing season, while removal after flowering meant populations did not rebound until the next spring (Kaenel and Uehlinger 1999). Sediment testing for chemical residue levels high enough to be considered hazardous waste (from historically used sodium arsenite, copper, chromium, and other inorganic compounds) should be conducted before dredging, to avoid stirring of toxic material into the water column. The department routinely requires sediment analysis before dredging begins and destination approval of spoils to prevent impacts from sediment leachate outside of the disposal area. Planning and testing can be an extensive component to a dredging project.

<u>Ecological effects of Dredging</u>

Repeated dredging may result in plant communities consisting of populations of fast-growing species that are capable of rebounding quickly (Sand-Jensen et al. 2000). In experimental studies, faster growing invasive plant species with a higher tolerance for disturbance were able to better recover from simulated dredging than slower growing native plant species, suggesting that post-dredging plant communities may be comprised of undesirable invasives (Stiers et al. 2011).

Macroinvertebrate biomass has been shown to decrease up to 65% following dredging, particularly among species which use plants as habitat. Species that live deeper in sediments, or those that are highly mobile, were less affected. As macroinvertebrates are valuable components of aquatic ecosystems, it is recommended that plant removal activities consider impacts on macroinvertebrates (Kaenel and Uehlinger 1999). Dredging can also result in declines to native mussel populations (Aldridge 2000).

Impacts to fish and water quality parameters have also been observed. Dredging to remove aquatic plants significantly increased both dissolved oxygen levels and the number of fish species found inhabiting farm ponds (Mitsuo et al. 2014). This increase in fish abundance may have been due to extremely high pre-dredging density of aquatic plants, which can negatively influence fish foraging success. In another study, aquatic plant removal decreased the amplitude of daily oxygen fluctuations in streams. However, post-dredging changes in metabolism were short-lived, suggesting that algae may have taken over primary productivity (Kaenel et al. 2000). Finally, several studies have also documented or suggested a reduction in sediment phosphorous levels after dredging, which may in turn reduce nutrient availability for aquatic plant growth (Van der Does et al. 1992; Kleeberg and Kohl 1999; Meijer et al. 1999; Søndergaard et al. 2001; Zuccarini et al. 2011). However, consideration must be given to factors affecting whether goals are obtainable via dredging (e.g., internal or external phosphorus inputs, water retention time, sediment characteristics, etc.).

S.3.4.5. Drawdown

Water-level drawdown is another approach for aquatic plant control as well as aquatic plant restoration. Exposure of aquatic plant vegetation, seeds, and other reproductive structures may reduce plant abundance by freezing, drying, or consolidation of sediments. This management technique is not effective for control of all aquatic plant species. Due to potential ecological impacts, it is necessary to consider other factors such as: waterfowl habitat, fisheries enhancement, release of nutrients and solids downstream, and refill and sediment consolidation potential. Often drawdowns for aquatic plant control and/or restoration can be coordinated to time with dam repair or repair of shoreline structures. A review by Cooke (1980), suggests drawdown can provide at least short-term aquatic plant control (1-2 years) when the target species is vulnerable to drawdown and where sediment can be dewatered under rigorous heat or cold for 1-2 months. Costs can be relatively low when a structure for manipulating water level is in place (otherwise high capacity pumps must be used). Conversely, costs can be high to reimburse an owner for lost power generation if the water control structure produces hydro-electric power. The aesthetic and recreational value of a waterbody may be reduced during a drawdown, as large areas of sediment are exposed prior to revegetation. Bathymetry is also important to consider, as small decreases in water level may lead to drop-offs if a basin does not have a gradual slope (Cooke 1980). The downcutting of the stream to form a new channel can also release high amounts of solids and organic matter that can impair water quality downstream. For example, in July 2005, the Waupaca Millpond, Waupaca Co. had to conduct an emergency drawdown that resulted in the river downcutting a new channel. High suspended solid concentrations and BOD resulted in decreased water clarity, sedimentation and depressed dissolved oxygen levels. A similar case occurred in 2015 with the Amherst Mill Pond, Portage Co. during a drawdown at a rate of six inches per day (Scott Provost [WDNR], *personal communication*).

Because extreme heat or cold provide optimal conditions for aquatic plant control, drawdowns are typically conducted in the summer or winter. Because of Wisconsin’s cold winters, winter drawdown is likely to have several advantages when used for aquatic plant management, including avoiding many conflicts with recreational use, potential for cyanobacterial blooms, and terrestrial and emergent plant growth in sediments exposed by reduced water levels (ter Heerdt and Drost 1994; Bakker and Hilt 2016).

A synthesis of the abiotic and biotic responses to annual and novel winter water level drawdowns in littoral zones of lakes and reservoirs is summarized by Carmignani and Roy 2017. Climatic conditions also determine the capacity of a waterbody to support drawdown (Coops et al. 2003). Resources managers pursuing drawdown must carefully calculate the waterbody's water budget and the potential for increased cyanobacterial blooms in the future may reduce the number of suitable waterbodies (Callieri et al. 2014). Additionally, mild winters and groundwater seepage in some waterbodies may prevent dewatering, leading to reduced aquatic plant control (Cooke 1980). Complete freezing of sediment is more likely to control aquatic plants. Sediment exposure during warmer temperatures (>5° C) can also result in the additional benefit of oxidizing and compacting organic sediments (Scott Provost and Ted Johnson [DNR], *personal communication*). When drawdowns are conducted to improve migratory bird habitat, summer drawdowns prove to be more beneficial for species of shorebirds, as mudflats and shallow water are exposed to promote the production of and accessibility to invertebrates during late summer months that coincide with southward migration (Herwig and Gelvin-Innvaer 2015). Drawdowns conducted during mid-late summer can result in conditions that are favorable for cattails (*Typha* spp.) germination and expansion. However, cattails can be controlled if certain stressors are implemented in conjunction with a drawdown, such as cutting, burning or herbicide treatment during the peak of the growing season. The ideal situation is to cut cattail during a drawdown and flood over cut leaves when water is raised. However, this option is not always feasible due to soil conditions and equipment limitations.

<u>Ecological Impacts of Water-level Drawdown</u>

Artificial manipulation of water level is a major disturbance which can affect many ecological aspects of a waterbody. Because drawdown provides species-selective aquatic plant control, it can alter aquatic plant community composition and relative abundance and distribution of species (Boschilia et al. 2012; Keddy 2000). Sometimes this is the intent of the drawdown, which creates plant community characteristics that are desired for wildlife or fish habitat. Consecutive annual drawdowns may prevent the re-establishment of native aquatic plants or lead to reduced control of aquatic plant abundance as drawdown-tolerant species begin to dominate the community (Nichols 1975). Sediment exposure can also lead to colonization of emergent vegetation in the drawdown zone. In one study, four years of consecutive marsh drawdown led to dominance of invasive phragmites (*Phragmites australis subsp. australis*; ter Heerdt and Drost 1994). However, when drawdowns are conducted properly, it can provide a favorable response to native emergent plants for providing food and cover for migrating waterfowl in the fall. Population increases in emergent plant species such as bulrush (*Schoenoplectus* spp.), bur-reeds (*Sparganium* spp.), and wild rice (*Zizania palustris*) is often a goal of drawdowns, which provides a great food source for fish and wildlife, and provides important spawning and nesting habitat. Full or partial drawdowns that are conducted after wild rice production in the fall tend to favor early successional emergent germination such as wild rice and bulrush the following spring. Spring drawdowns are also possible for producing wild rice but must be done during a tight window following ice-out and slowly raised prior to the wild rice floating leaf stage.

Drawdown can also have various effects on ecosystem fauna. Drawdowns can influence the mortality, movement and behavior of native freshwater mussels (Newton et al. 2014). Although mussels can move with lowering water levels, they can be stranded and die if they are unable to move fast enough or get trapped behind logs or other obstacles (WDNR et al. 2006). Some mussels will burrow down into the mud or sand to find water but can desiccate if the water levels continue to lower (Watters et al. 2001). Maintaining a slow drawdown rate can allow mussels to respond and stranded individuals can be relocated to deeper water during the drawdown period to reduce mussel death (WDNR et al. 2006). Macroinvertebrate communities may experience reduced species diversity and abundance from changes to their environment due to drawdown and loss of habitat provided by aquatic plants (Wilcox and Meeker 1992; McEwen and Butler 2008). These effects may be reduced by considering benthic invertebrate phenology in determining optimal timing for drawdown release. Adequate moisture is required to support the emergence of many macroinvertebrate species and complete drawdown may also result in hardening of sediments which can trap some species (Coops et al. 2003). Reduced macroinvertebrate availability can have negative effects on waterfowl and game fish species which rely on macroinvertebrate food sources (Wilcox and Meeker 1992). Depending on the time of year, drawdown may also lead to decreased reproductive success of some waterfowl through nest loss, including common loon (*Gavia immer*) and red-necked grebe (*Podiceps grisegena*; Reiser 1998). However, drawdown may lead to increased production of annual plants and seed production, thereby increasing food availability for brooding and migrating waterfowl. Semi-aquatic mammals such as muskrats and beavers may also be adversely affected by water level drawdown (Smith and Peterson 1988, 1991). DNR Wildlife Management staff follow guidance to ensure drawdowns are timed with the seasons or temperature to minimize negative impacts to wildlife. Negative impacts to reptiles are possible during the spring if water is raised following a drawdown, as nests may be flooded. In the fall, negative impacts to reptiles and amphibians are possible if water is lowered when species are attempting to settle into sediments for hibernation. The impact may be reduced dissolved oxygen if they are below the water or freezing if the water is dropped below the point of hibernation (Herwig and Smith 2016a, 2016b). Surveying and relocation of stranded organisms may help to mitigate some of these impacts. In Wisconsin there are general provisions for conducting drawdowns for APM that are designed to mitigate or even eliminate potential negative impacts.

Water chemistry can also be affected by water level fluctuation. Beard (1973) describes a substantial algal bloom occurring the summer following a winter drawdown which provided successful aquatic plant control. Other studies reported reduced dissolved oxygen, severe cyanobacterial blooms with summer drawdown, or increased nutrient concentrations and reduced water clarity during summer drawdown for urban water supply (Cooke 1980; Geraldes and Boavida 2005; Bakker and Hilt 2016). Water clarity and trophic state may be improved when drawdown level is similar to a waterbody's natural water level regime (Christensen and Maki 2015).

Species Susceptibility to Water-level Drawdown

Not all plant species are susceptible to management by water level drawdown and some dry- or cold-tolerant species may benefit from it (Cooke 1980). Generally, plants and charophytes which reproduce primarily by seed benefit from drawdowns while those that reproduce vegetatively tend to be more negatively affected. Marsh vegetation can be dependent on water level fluctuation (Keddy and Reznicek 1986). Cooke (1980) provides a summary table of drawdown responses for 63 aquatic plant species. Watershield (Brasenia schreberi), fern pondweed (*Potamogeton robbinsii*), pond-lilies (*Nuphar* spp.) and watermilfoils (*Myriophyllum* spp.) tend to be controlled by drawdown. Increases in abundance associated with drawdown have often been seen for duckweed (*Lemna minor*), rice cutgrass (*Leersia oryzoides*) and slender naiad (*Najas flexilis*; Cooke 1980). One study showed drawdown reduced Eurasian watermilfoil (*Myriophyllum spicatum*) at shallow depths while another cautioned that Eurasian watermilfoil vegetative fragments may be able to grow even after complete desiccation (Siver et al. 1986; Evans et al. 2011). Similarly, a tank-simulated drawdown experiment suggested short-term summer drawdown may be effective in controlling monoecious hydrilla (*Hydrilla verticillata*; Poovey and Kay 1998). However, other studies have shown hydrilla fragments to be resistant to drying following drawdown (Doyle and Smart 2001; Silveira et al. 2009). A study on Brazilian waterweed (*Egeria densa*) showed that stems were no longer viable after 22 days of exposure due to drawdown (Dugdale et al. 2012).

Two examples of recent drawdowns in Wisconsin that were evaluated for their efficacy in controlling invasive aquatic plants occurred in Lac Sault Dore and Musser Lake, both in Price County, which were conducted in 2010 and 2013, respectively. Dam maintenance was the initial reason for these drawdowns, with the anticipated control of nuisance causing aquatic invasive species as a secondary benefit. Aquatic plant surveys showed that the drawdown in Lac Sault Dore resulted in a 99% relative reduction in the littoral cover of Eurasian watermilfoil when comparing pre- vs. post-drawdown frequencies. Native plant cover expanded following the drawdown and Eurasian watermilfoil cover has continued to remain low (82% relative reduction compared to pre-drawdown) as of 2017 (Onterra 2013). Lake-wide cover of curly-leaf pondweed in Musser Lake decreased following drawdown (63% relative reduction compared to pre-drawdown), and turion viability was also reduced. Reductions in native plant populations were observed, though population recovery could be seen in the second year following the drawdown (Onterra 2016). These examples of water-level drawdowns in Wisconsin show that they can be valuable approaches for aquatic invasive species control in some waterbodies. Water level reduction must be conducted such that a sufficient proportion of the area occupied by the target species is exposed. Numerous other single season winter drawdowns monitored in central Wisconsin by department staff show similar results (Scott Provost [DNR], *personal communication*). Careful timing and proper duration is needed to maximize control of target species and growth of favorable species.

S.3.5.Biological Control

Biological control refers to any method involving the use of one organism to control another. This method can be applied to both invasive and native plant populations, since all organisms experience growth limitation through various mechanisms (e.g., competition, parasitism, disease, predation) in their native communities. As such, when control of aquatic plants is desired it is possible that a growth limiting organism, such as a predator, exists and is suitable for this purpose.

Care must be taken to ensure that the chosen biological control method will effectively limit the target population and will not cause unintended negative effects on the ecosystem. The world is full of examples of biological control attempts gone wrong: for example, Asian lady beetles (*Harmonia axyridis*) have been introduced to control agricultural aphid pests. While the beetles have been successful in controlling aphid populations in some areas, they can also outcompete native lady beetles and be a nuisance to humans by amassing on buildings (Koch 2003). Additionally, a method of control that works in some Wisconsin lakes may not work in other parts of the state where differing water chemistry and/or biological communities may affect the success of the organism. The department recognizes the variation in control efficacy and well as potential unintentional effects of some organisms and is very cautious in allowing their use for control of aquatic plants.

Purple loosestrife beetles

The use of herbivorous insects to reduce populations of aquatic plants is another method of biocontrol. Several beetle species native to Eurasia (*Galerucella calmariensis*, *G. pusilla*, *Hylobius transversovittatus*, and *Nanophyes marmoratus*) have been well-studied and intentionally released in North America for their ability to suppress populations of the invasive wetland plant, purple loosestrife (*Lythrum salicaria*). These beetles only feed on loosestrife plants and therefore are not a threat to other wetland plant species (Kok et al. 1992; Blossey et al. 1994a, 1994b; Blossey and Schroeder 1995). The department implements a purple loosestrife biocontrol program, in which citizens rear and release beetles on purple loosestrife stands to reduce the plants' ability to overtake wetlands, lakeshores, and other riparian areas.

Beetle biocontrol can provide successful long-term control of purple loosestrife. The beetles feed on purple loosestrife foliage which in turn can reduce seed production (Katovich et al. 2001). This approach typically does not eradicate purple loosestrife but stresses loosestrife populations such that other plants are able to compete and coexist with them (Katovich et al. 1999). Depending on the composition of the plant community invaded by purple loosestrife and the presence of other non-native invasive species, further restoration efforts may be needed following biocontrol efforts to support the regrowth of beneficial native plants (McAvoy et al. 2016).

Several factors have been identified that may influence the efficacy of beetle biocontrol of purple loosestrife. Purple loosestrife beetles have for the most part been shown to be capable of successfully surviving and establishing in a variety of locations (Hight et al. 1995; McAvoy et al. 2002; Landis et al. 2003). The different species have different preferred temperatures for feeding and reproduction (McAvoy and Kok 1999; McAvoy and Kok 2004). In addition, one study suggests that the number of beetles introduced does not necessarily correlate with greater beetle colonization (Yeates et al. 2012). Disturbance, such as flooding and predation by other animals on the beetles, can also reduce desired effects on loosestrife populations (Nechols et al. 1996; Dech and Nosko 2002; Denoth and Myers 2005). Finally, one study suggests that the use of triclopyr amine for purple loosestrife control may be compatible with beetle biocontrol, although there may be negative effects on beetle egg-batch size or indirect effects if the beetle's food source is too greatly depleted (Lindgren et al. 1998). Some mosquito larvicides may harm purple loosestrife beetles (Lowe and Hershberger 2004).

Milfoil weevils

Similar to the use of beetles for biological control of purple loosestrife, the use of milfoil weevils (*Euhrychiopsis lecontei*) has been investigated in North America to control populations of non-native Eurasian and hybrid watermilfoils (*Myriophyllum spicatum* x *sibiricum*). This weevil species is native to North America and is often naturally present in waterbodies that contain native watermilfoils, such as northern watermilfoil (*M. sibiricum*). The weevils have the potential to damage Eurasian watermilfoil (*M. spicatum*) by feeding on stems and leaves and/or burrowing into stems. Weevils may reduce milfoil plant biomass, inhibit growth, and compromise buoyancy (Creed and Sheldon 1993; Creed and Sheldon 1995; Havel et al. 2017a). Damage caused to the milfoil tissue may then indirectly increase susceptibility to pathogens (Sheldon and Creed 1995).

In experiments, weevils have been shown to negatively impact Eurasian watermilfoil populations to varying degrees. Experiments by Creed and Sheldon (1994) found that plant weight was negatively affected when weevils were at densities of 1 and 2 larvae/tank, and Eurasian watermilfoil in untreated control tanks added more root biomass than those in tanks with weevils, suggesting that weevil larvae may interfere with the plant's ability to move nutrients. Similarly, experiments by Newman et al. (1996) found that weevils at densities of 6, 12, and 24 adults/tank caused significant decreases in Eurasian watermilfoil stem and root biomass, and that higher weevil densities generally produced more damage.

In natural communities, effects of weevils have been mixed, likely because waterbody characteristics may play a role in determining weevil effects on Eurasian watermilfoil populations in natural lakes. In a 56 ha (138 acre) pond in Vermont, weevil density was negatively associated with Eurasian watermilfoil biomass and distribution; Eurasian watermilfoil beds were reduced from 2.5 (6.2 acres) to 1 ha (2.5 acres) in one year, and biomass decreased by 4 to 30 times (Creed and Sheldon 1995). A survey of Wisconsin waterbodies conducted by Jester et al. (2000) revealed that most lakes containing Eurasian watermilfoil also contained weevils. Weevil abundance varied from functionally non-detectable to 2.5 weevils/stem and was positively associated with the presence of large, shallow Eurasian watermilfoil beds (compared to deep, completely submerged beds). There was no relationship between natural weevil abundance and Eurasian watermilfoil density between lakes. However, when the authors augmented natural weevil populations in plots in an attempt to achieve target densities of 1, 2, or 4/stem, they found that augmentation was associated with significant decreases in Eurasian watermilfoil biomass, stem density and length, and tips/stem (Jester et al. 2000). However, another more recent study conducted in several northern Wisconsin lakes found no effect of weevil stocking on Eurasian watermilfoil or native plant biomass (Havel et al. 2017a).

There are several factors to consider when determining whether weevils are an appropriate method of biocontrol. First, previous research has suggested that densities of at least 1.5 weevils per stem are required for control (Newman and Biesboer 2000). Adequate densities may not be achievable due to factors including natural population fluctuations, the amount of available milfoil biomass within a waterbody, the presence of insectivorous predators, such as bluegills (*Lepomis macrochirus*), and the availability of nearshore overwintering habitat (Thorstenson et al. 2013; Havel et al. 2017a). In addition, weevils fed and reproduce on native milfoil species and biocontrol efforts could potentially impact these species, although experiments conducted by Sheldon and Creed (2003) found that native milfoil weevil density was lower and weevils caused less damage than when they were found on Eurasian watermilfoil. Adult weevils spend their winters on land, so available habitat for adults must be present for a waterbody to sustain weevil populations (Reeves and Lorch 2011; Newman et al. 2001). Additionally, one study found that lakes with no Eurasian watermilfoil (despite the presence of other milfoil species) and lakes that had a recent history of herbicide treatment had lower weevil densities than similar, untreated lakes or lakes with Eurasian watermilfoil (Havel et al. 2017b).

Grass carp – not allowed in Wisconsin

The use of grass carp (*Ctenopharyngodon idella*) to control aquatic plants is not allowed in Wisconsin; they are a prohibited invasive species under ch. NR 40, Wis. Admin. Code, which makes it illegal to possess, transport, transfer, or introduce grass carp in Wisconsin.

Sterile (also known as triploid) grass carp have been used to control populations of aquatic plants with varying success (Pípalová 2002; Hanlon et al. 2000). Whether this method is effective depends on several factors. For instance, each individual fish must be tested to ensure sterility before stocking, which can be a time- and resource-consuming process. Since the sterile fish do not reproduce, it can be difficult to achieve the desired density in a given waterbody. In addition, grass carp, like many fish species, have dietary preferences for different plant species which must be considered (Pine and Anderson 1991). Further information summarizing the effects of stocking triploid grass carp can be found in Pípalová (2006), Dibble and Kovalenko (2009), and Bain (1993).

E

Appendix E

Comment Response Document for the Official First Draft

Lost Lake Draft Aquatic Plant Management Plan
Official First Daft: July 28, 2023

Response Comments by Eddie Heath (Onterra)

WDNR Comments from Kevin Gauthier (Water Resources Management Specialist), 9/7/2023

We have finished a review of the draft Lost Lake Plan and offer these comments:

- Intro. Maybe this is in the larger Comprehensive plan, but if not, could expand text on the operation of the Dam and how dams/operations/head all have an influence on the ecology of Lost Lake. A few sentences were added to the Intro section, although an advanced discussion of the ecological impact of this small dam has not been conducted.
- Appendix B. Q 15. In list of concerns, shoreline development is 10th on this list – seems like an educational opportunity here as it seems this would/should be higher up on folks concerns. The district continues to provide educational information to its membership. The three bullet points below are discussed within the 2019 Comprehensive Management Plan.
  - There is a Dept shoreland assessment protocol that can be done to help inform/educate folks using the results.
  - There is a Healthy Lakes program which has practices that can help folks slow down/eliminate polluted runoff from coming off their properties directly into Lost Lake and also improve habitat.
  - Cathy Higley, from Vilas County, is available to work with interested property owners on near shore assessments and in designing Healthy Lakes practices.
- This might all be in the Comprehensive Plan, but if not, would be valuable to include this in this update – all things are connected….EWM/CLP/Plants in general/nutrients/shoreland practices/health…. Correct, these concepts are expanded upon in the 2019 Comprehensive Management Plan, particularly the Shoreland Condition Section (3.3)
- Thanks for the heads up and I will watch for a grant regarding Mgmt Goal 2/Action 3. Grant App has been submitted.
- Agree that communications regarding Mgmt Goal 5 is a good idea. Agreed.
- Let us know when you are considering applying for grants for any other recommendations. Agreed.

Thanks for your efforts and looking forward to receiving an updated/final version.

GLIFWC Comments from Adam Ray (Inland Fisheries Biologist), 8/21/2023

I would like to start by stating this is a professional review by GLIFWC staff to address some potential concerns. The Voigt Intertribal Task Force, which is made up of ten of our member tribes, is opposed to the use of any herbicide/chemical treatments in this waterbody and these comments do not prevent us or the tribes from responding to any future APM applications. Understood. The potential use of herbicides to manage Aquatic Invasive Plants is only one aspect of this multifaceted plan.

That being said, we have a couple comments regarding this plan:

1. During previous treatments for CLP, high levels of herbicide were detected near the down river manoomin bed. In this plan if a chemical treatment is proposed there should be effort to protect this bed from any exposure. While monitoring of previous treatments showed what we believe to be low levels of herbicide active ingredient near the downstream wild rice beds, we acknowledge this position of desired zero exposure by GLIFWC. That being said, it is unlikely that herbicides can be used at a meaningful way in Lost Lake to manage AIS that would result in zero exposure to downstream wild rice.
2. 2) In other plans, we've noticed threshold values for when chemical treatments might be considered. This should be at least considered for this plan as to provide guidance for the lake association and its stakeholders. The district set a future threshold or "trigger" for herbicides to be considered when the EWM population is "impacting navigation, recreation, and aesthetics, particularly areas delineated from a late-season EWM Mapping Survey as being *dominant*, *highly dominant*, or *surface matting*." Management of CLP with herbicides is not part of this updated APM Plan.