North & South Twin Lakes

Vilas County, Wisconsin

Aquatic Plant Management Plan

October 2023

Sponsored by:

North & South Twin Lakes Protection & Rehabilitation District

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Onterra, LLC
Lake Management Planning

North & South Twin Lakes

Vilas County, Wisconsin

Aquatic Plant Management Plan

October 2023

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Funded by: North & South Twin Lakes 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:

District Lake Management Team

Linda Herber - Chair	Joyce Wade
Jay Wittman	Bob Krueger
Joe Fritzsche	

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1.0 INTRODUCTION

The North and South Twin Lake Riparian Association (NSTLRA) was formed in 1995 and was the primary management entity of the Twin Lakes until 2017. In November 2017, the North and South Twin Lake Protection and Rehabilitation District (District) was formed and has taken the responsibility for carrying out lake protection, management, and enhancement activities.

The *Comprehensive Management Plan* (2018) investigated North and South Twin 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* (2018) outlined three management goals and eleven management actions to help guide the District in protecting and enhancing North and South Twin Lake.

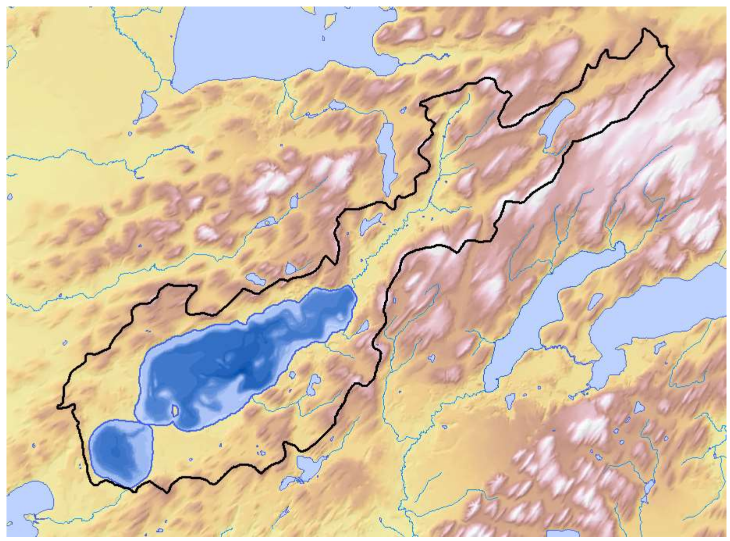


Figure 1.0-1. North and South Twin Lake, Vilas County. Watershed outline in black.

North and South Twin Lakes, Vilas County, are approximate 2,788- and 642-acre drainage lakes, respectively (Map 1). North Twin Lake flows into South Twin Lake, and South Twin Lake is drained via the Twin River flowing into Pioneer Lake (Figure 1.0-1). The outlet is controlled by a dam operated by the Wisconsin Valley Improvement Corporation (WVIC). According to the 2018 *Comprehensive Management Plan*, the North and South Twin Lake watershed (Figure 1.0-1) is approximately 14,144 acres (including the lake's surface area). The North and South Twin 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 Twin Lakes water quality is excellent, with low measured phosphorus, low free-floating algae (measured as chlorophyll-a), and high water clarity. While the total phosphorus levels of North Twin Lake are within the *excellent* category for similar lake types, North Twin Lake is listed on the WDNR's list of impaired waters (303-d) because lake's total phosphorus exceeds the 2016 WisCALM threshold for fish and aquatic life use in a two-story lake. This means that on most lakes that contain similar total phosphorus levels, the productivity of the lake leads to insufficient oxygen in deeper waters of the lake and inhibit the ability of the lake to sustain a coldwater fishery of species like cisco or trout. Analysis in the 2018 *Comprehensive Management Plan* confirms that there is ample three-dimensional space for the systems healthy cisco population and as the WDNR revises their classification for impaired waters, may remove North Twin from this list. The District continued to monitor various water quality parameters as part of the WDNR's Citizen Lake Monitoring Network (CLMN). Over the past few years, a District representative compiles the current and historic water quality data into graphs for updating District members (Appendix C).

By all standard metrics, the ongoing vegetation surveys reveals that the aquatic plant community of the Twin Lakes is of average or higher quality than lakes within the same ecoregion and throughout the state. While some changes have been noted, the aquatic plant community of North Twin Lake remains largely unchanged since a previous study. However, South Twin Lake has experienced changes in its plant community related to the establishment of EWM in the system and the control actions that have taken place in an effort to maintain a reduced EWM population within the lake.

Within *North and South Twin Lakes Comprehensive Management Plan* (June 2018), the District outlined several management actions to help them meet their goal of "Controlling Existing and Preventing Further Aquatic Invasive Species Infestations within the Twin Lakes." In general, herbicide spot treatments would be considered when EWM colonies were of *dominant* density and a strategy could be devised that would be highly likely to meet efficacy goals. Specific to South Twin, the District would initiate discussion, planning, and pretreatment stages of a whole-lake herbicide treatment on South Twin Lake when EWM populations measured from the point-intercept survey exceed 12% littoral frequency of occurrence (LFOO).

Based on evolving Best Management Practices for herbicide spot treatments targeting EWM, the District has adopted ProcellaCOR™ spot treatment strategies in North Twin Lake in 2019 and 2020, and conducted a series of large-scale spot treatments in South Twin in 2021 that were anticipated to also produce EWM impacts extending out from the application area, possibly throughout the whole lake. More discussion of these management efforts and associated monitoring components are detailed in their respective annual reports.

The *North and South Twin Lakes Comprehensive Management Plan* (June 2018), was largely developed before ProcellaCOR™ became a commonly used herbicide for EWM management. Also, since the plan was finalized, the District also has implemented a consistent and relatively substantial contracted EWM manual removal program using DASH. The District would like to update their Aquatic Plant Management (APM) Plan to incorporate lessons learned over the past years, as well as to account for evolved definitions of aquatic plant Best Management Practices (BMPs) and new invasive species management philosophies. This will also align the District for future WDNR grants and permits, as the WDNR requires a lake group's Plan to have a completion date of no more than 5 years prior to the grant application deadline.

2.0 STAKEHOLDER PARTICIPATION

Stakeholder participation is an important part of any management planning exercise. For this project, the District members were the primary stakeholder group interacted with, but also opened up opportunities for review from regulatory agencies (WDNR, GLIFWC) and sovereign tribal entities (LDF tribe).

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 the District Lake Management Team, 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 District Lake Management Team Meetings

District Lake Management Team meetings, were used to gather comments, create management goals and actions, and to deliver study results.

Lake Management Team Meeting I

The 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 attendee questions. The objective of the first meeting was to fortify a solid understanding of their lake among the team members as well as key project partners.

On April 25, 2023, Eddie Heath met with the District Lake Management Team, led by Linda Herber. Also in attendance was Ty Krajewski, WDNR regional permit specialist. This roughly 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. Ty Krajewski was invited to provide the WDNR's perspective on future aquatic plant management preferences and concerns.

Lake Management Team Meeting II

On July 19, 2023, Eddie Heath met virtually with the District Lake Management Team for almost two hours concentrating on the development of management goals and actions that make up the framework of the implementation plan. Prior to this meeting, the District Lake Management Team had various internal conversation that led to the production of a written draft set of management goals and management actions that were specifically addressed at the meeting.

2.2 Management Plan Review and Adoption Process

On July 31, 2023, the Official First Draft of the District's Aquatic Plan Management Plan for North and South Twin Lakes was supplied to WDNR (lakes and fisheries programs) by Onterra via email. The District individually emailed this report to GLIFWC, Lad du Flambeau Band of Lake Superior Chippewa Indians (LDF Tribe), Sokaogon Chippewa Community Mole Lake Band of Lake Superior Chippewa (Mole Lake Tribe), Vilas County, and the Town of Phelps Lakes Committee.

At that time the Official First Draft was made available for public review on the District's website and advertised as an official comment period through a combination of District outreach events (email distribution blast). The public comment period remained active until the WDNR's comments were received, far longer than the minimum 21-day public comment period advised in WDNR guidance. Two public comments were received, both in regards to the swimmers itch section (3.4). Modifications were made to this section and the revised Official First Draft replaced the earlier version posted on the District website on August 30, 2023.

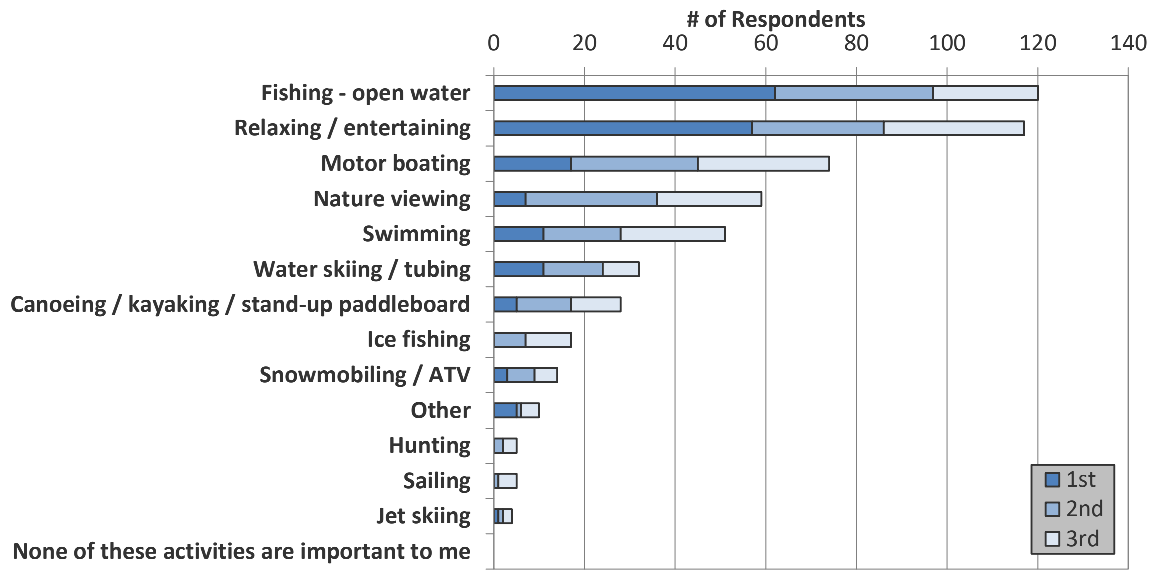
The LDF Tribe provided comments on August 1, 2023. The WDNR (Ty Krajewski) provided official comments on September 26, 2023. These comments are addressed in the Comment-Response Document presented here as Appendix F. No comments from other agencies or entities were received.

2.3 District Stakeholder Survey

As a part of this project, a stakeholder survey was distributed to North & South Twin Lakes Protection & Rehabilitation District members around North and South Twin Lakes. The survey was designed by Onterra staff and the District Lake Management Team and reviewed by a WDNR social scientist. From February to May of 2022, the eight-page, 29-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 District volunteer for analysis. The District also had an email list which was utilized to help distribute the survey. District Lake Management Team members also went door to door in an attempt to recruit more responses. Forty-two percent of the surveys were returned. Please note that typically a benchmark of a 60% response rate is required to portray population projections accurately, and 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 North and South Twin Lakes. 36% of respondents indicated that they live on the lake seasonally, while 32% visit on weekends and/or holidays through the year, 30% are year-round residents, and 2% are rental properties. 68% of respondents have owned their property for over 11 years, and 37% have owned their property for over 25 years.

Question 3: Please rank up to three reasons why you own your property.



Question 8: What types of watercraft do you currently use on North and South Twin Lakes?

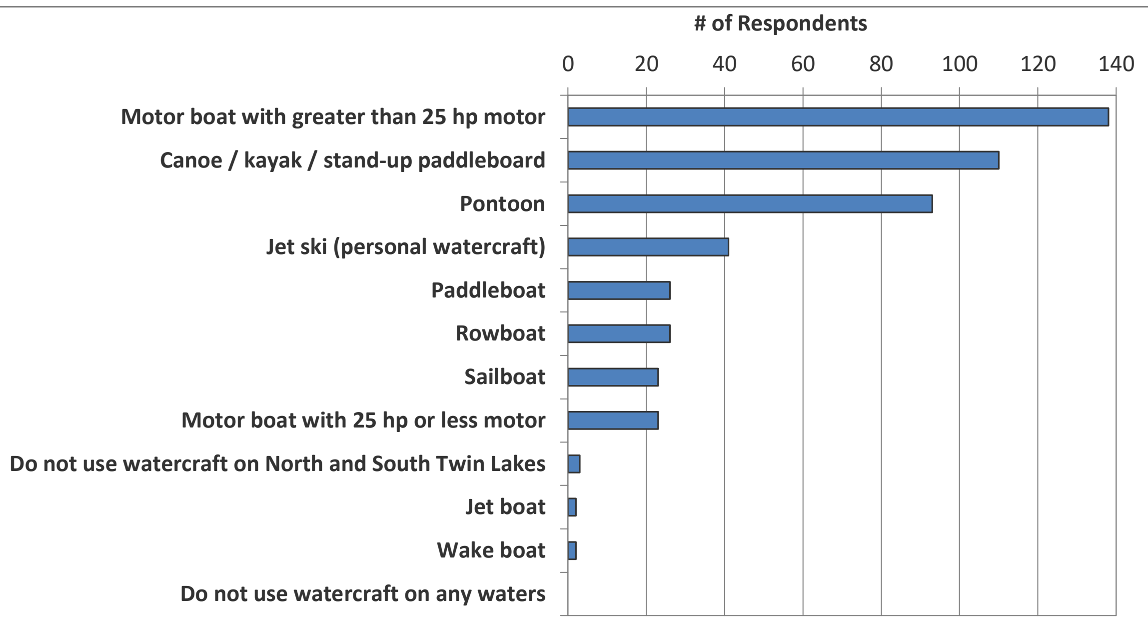


Figure 2.0-1. Select survey responses from the North and South Twin Lakes Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

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 larger motor boat, canoe/kayak, pontoon boat, or a combination of these three vessels on North and South Twin Lakes (Question 8). Jetskis were also a popular option. 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 3, several of the top recreational activities on the lake involve boat use. Although boat traffic was listed as a factor potentially impacting North and South Twin Lakes in a negative manner, it was ranked almost last on a list of stakeholder's top concerns regarding the lake (Question 10). Of those concerns, swimmer's itch was ranked 1st.

A concern of stakeholders noted throughout the stakeholder survey (see Questions 10,15 and survey comments – Appendix B) was swimmer's itch within North and South Twin Lakes. This topic is touched upon in the Summary & Conclusions section as well as within the Implementation Plan.

Question 10: Please rank your top three concerns regarding North and South Twin Lakes.

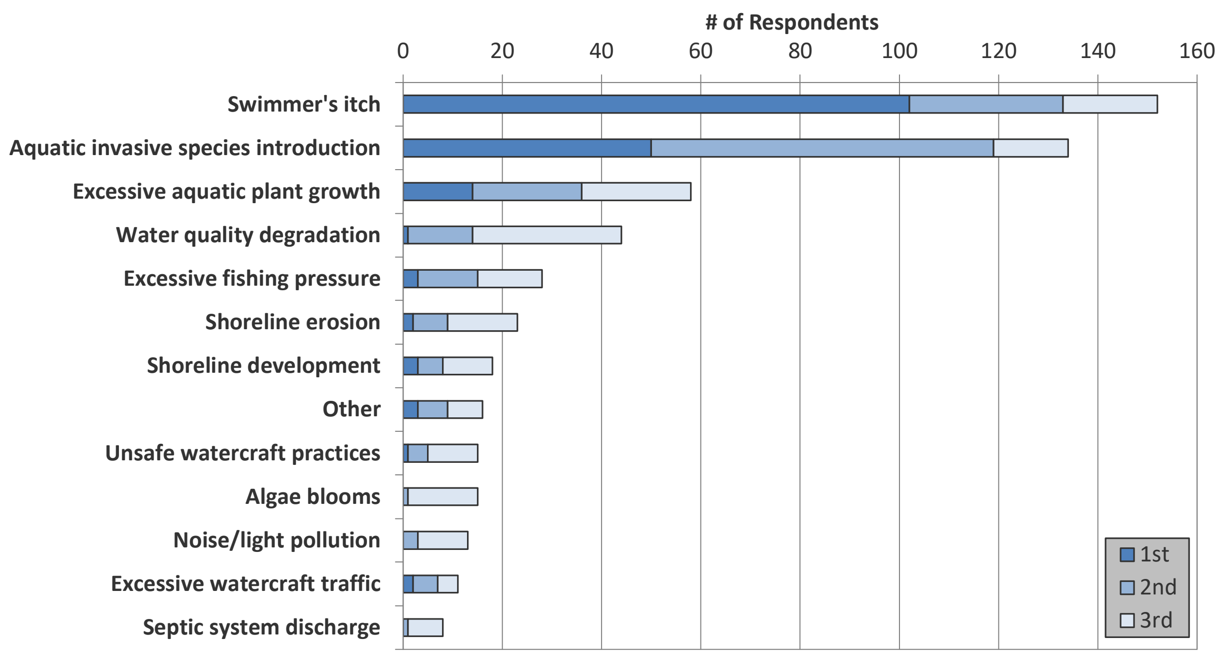


Figure 2.0-2. Select survey responses from the North and South Twin Lakes Stakeholder Survey, continued. Additional questions and response charts may be found in Appendix B.

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 the North Twin Lake in 2011, 2016, and 2021. Point intercept surveys have been done on South Twin Lake in 2008 – 2011, 2013 – 2018, and 2020 – 2022. Table 3.1-1 displays the point-intercept survey spacing and total number of sampling points for each lake. 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.

Table 3.1-1. Point-intercept survey statistics. Littoral sample locations are those determined to be less than or equal to the maximum depth of aquatic plants.

	Point Spacing (meters)	Total Sampling Locations	Littoral Sample Locations (≤ max depth of plants)												
			2008	2009	2010	2011	2013	2014	2015	2016	2017	2018	2020	2021	2022
North Twin Lake	100	1164	-	-	-	368	-	-	-	353	-	-	-	335	-
South Twin Lake	63	622	304	303	309	304	311	302	305	295	307	304	303	309	295

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 all surveys completed in the North and South Twin Lakes. 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

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

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 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 the North and South Twin Lakes to be compared to other lakes within the region and state.

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

The North and South Twin Lakes 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.

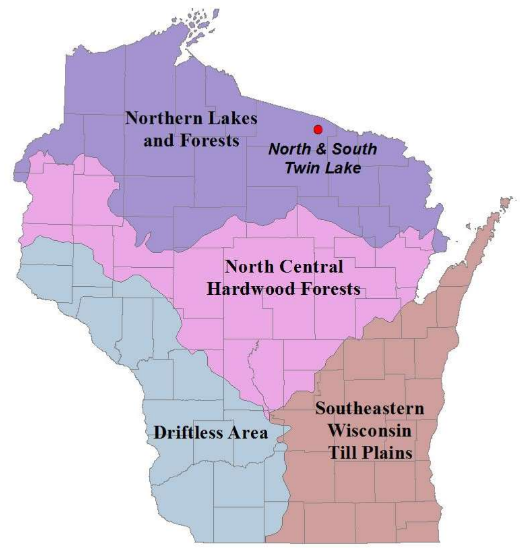


Figure 3.1-1. Location within the ecoregions of Wisconsin. After Nichols 1999.

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 the North and South Twin Lakes 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 North and South Twin Lakes Aquatic Plant Survey Results

The point-intercept survey has been conducted on the North Twin Lake in 2011, 2016, and 2021. Point intercept surveys have been done on South Twin Lake in 2008 – 2011, 2013 – 2018, and 2020 – 2022. This report will highlight the 2021 point-intercept survey results from North Twin Lake and the 2022 survey from South Twin Lake. The waterbodies will be analyzed separately and will integrate comparisons to the previous surveys throughout the section.

North Twin Lake

The North Twin Lake portion of North and South Twin Lakes makes up the majority of the water in the project waters at approximately 2,871 acres. Onterra ecologists conducted a whole-lake point-intercept survey on North Twin Lake on July 27-28, 2021. Point-intercept surveys have also taken place in North Twin Lake during 2011 and 2016 and these data are comparable to the 2021 survey. A comparison of these surveys allows for detecting changes in the aquatic plant community over time. The maximum depth of plant growth in the 2021 survey was 15' compared to 17' in 2016, and 20' in 2011. A total of 48 aquatic plant species were found during all surveys on North Twin Lake of which two are considered non-native species: Eurasian watermilfoil and reed canary grass (Table 3.2-1). Because the non-native plants found in North Twin Lake have the ability to negatively impact lake ecology, recreation, and aesthetics, the populations of these plants are discussed in greater detail within the subsequent *Non-Native Aquatic Plants in North and South Twin Lake* section.

During the 2022 point-intercept survey, information regarding substrate type was collected at locations sampled with a pole-mounted rake (less than 15 feet). These data indicate that 67% of the point-intercept locations contained sand sediments, 18% contained soft sediments, and 15% contained rock (Figure 3.4-2). The mixture of sand and soft organic sediment throughout the majority of North Twin Lake is very conducive for supporting lush aquatic plant growth.

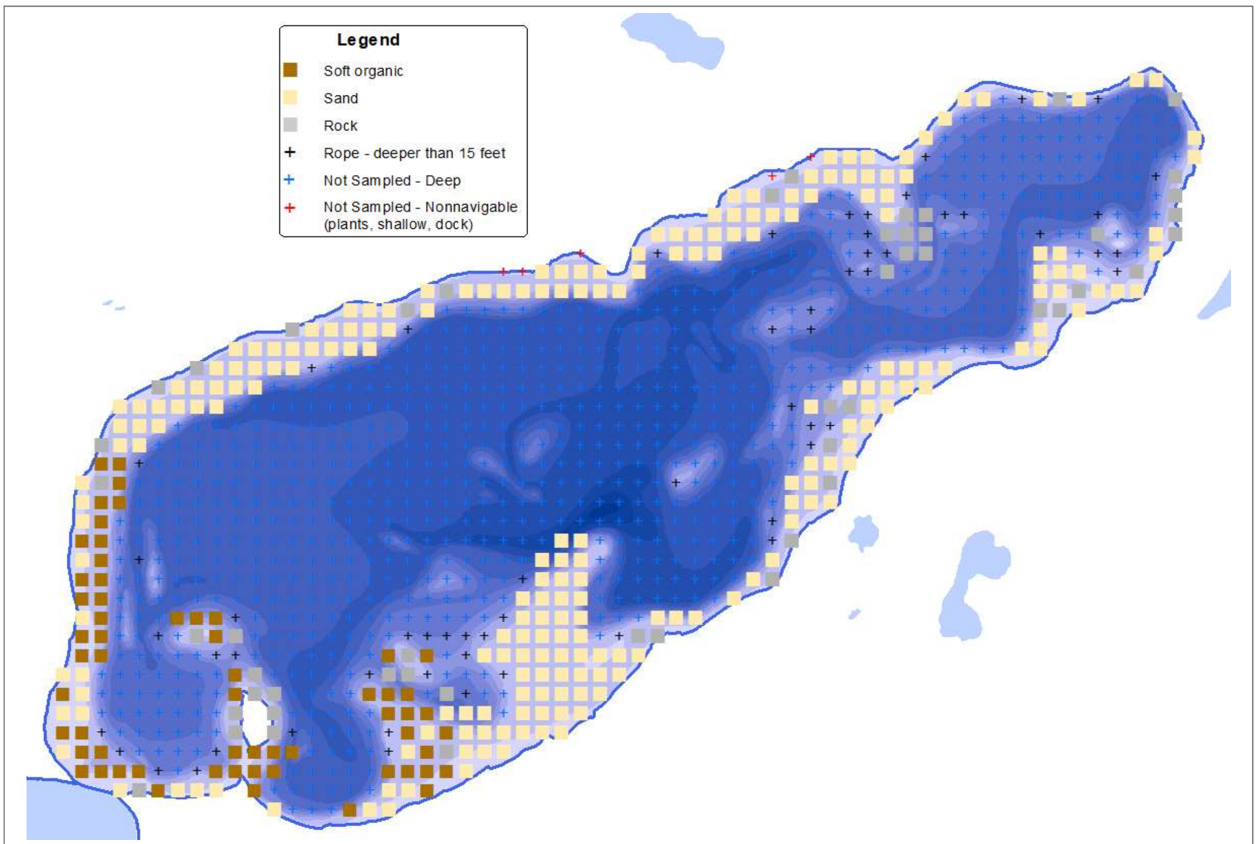


Figure 3.2-1. North Twin Lake proportion of substrate types within littoral areas.

Table 3.2-1. Aquatic plant species located in North Twin Lake. From 2011, 2016, and 2021 point-intercept surveys.

Growth Form	Scientific Name	Common Name	Status in Wisconsin	Coefficient of Conservatism	2011	2016	2021
Emergent	*Carex lacustris*	Lake sedge	Native	6	I		
	Eleocharis palustris	Creeping spikerush	Native	6	X	X	X
	Iris spp. (sterile)	Iris spp. (sterile)	Unknown (Sterile)	N/A		I	
	Iris versicolor	Northern blue flag	Native	5	I		
	Juncus effusus	Soft rush	Native	4	I		
	Phalaris arundinacea	Reed canary grass	Non-Native - Invasive	N/A	I		
	Phragmites australis subsp. americanus	Common reed	Native	5	I	I	
	Sagittaria rigida	Stiff arrowhead	Native	8	I	I	
	Schoenoplectus acutus	Hardstem bulrush	Native	5	X	X	X
	Schoenoplectus tabernaemontani	Softstem bulrush	Native	4		X	
	Scirpus cyperinus	Wool grass	Native	4	I		
	Typha spp.	Cattail spp.	Unknown (Sterile)	N/A	I	I	
FL	*Nuphar variegata*	Spatterdock	Native	6	I	I	
	Sparganium angustifolium	Narrow-leaf bur-reed	Native	9	I	I	
Submergent	*Bidens beckii*	Water marigold	Native	8	X	X	X
	Ceratophyllum demersum	Coontail	Native	3	X	X	X
	Chara spp.	Muskgrasses	Native	7	X	X	X
	Elodea canadensis	Common waterweed	Native	3	X	X	X
	Heteranthera dubia	Water stargrass	Native	6	X	X	X
	Isoetes spp.	Quillwort spp.	Native	8	X	X	X
	Myriophyllum alterniflorum	Alternate-flowered watermilfoil	Native	10	X	X	X
	Myriophyllum sibiricum	Northern watermilfoil	Native	7	X	X	X
	Myriophyllum spicatum	Eurasian watermilfoil	Non-Native - Invasive	N/A	X	X	X
	Myriophyllum tenellum	Dwarf watermilfoil	Native	10			X
	Najas flexilis	Slender naiad	Native	6	X	X	X
	Nitella spp.	Stoneworts	Native	7	X	X	X
	Potamogeton amplifolius	Large-leaf pondweed	Native	7	X	X	
	Potamogeton amplifolius x P. praelongus	Large-leaf x white-stem pondweed hybrid	Native	N/A			X
	Potamogeton berchtoldii	Slender pondweed	Native	7		X	X
	Potamogeton friesii	Fries' pondweed	Native	8	X	X	X
	Potamogeton gramineus	Variable-leaf pondweed	Native	7	X	X	X
	Potamogeton perfoliatus	Perfoliate pondweed	Native - Special Concern	10			X
	Potamogeton praelongus	White-stem pondweed	Native	8	X	X	X
	Potamogeton pusillus	Small pondweed	Native	7	X		X
	Potamogeton richardsonii	Clasping-leaf pondweed	Native	5	X	X	X
	Potamogeton robbinsii	Fern-leaf pondweed	Native	8	X	X	X
	Potamogeton spirillus	Spiral-fruited pondweed	Native	8			X
	Potamogeton strictifolius	Stiff pondweed	Native	8	X	X	X
	Potamogeton zosteriformis	Flat-stem pondweed	Native	6	X	X	X
	Ranunculus aquatilis	White water crowfoot	Native	8	X	X	X
	Sagittaria sp. (rosette)	Arrowhead sp. (rosette)	Native	N/A	X	X	X
	Stuckenia pectinata	Sago pondweed	Native	3		X	
	Utricularia vulgaris	Common bladderwort	Native	7		X	
	Vallisneria americana	Wild celery	Native	6	X	X	X
S/E	*Eleocharis acicularis*	Needle spikerush	Native	5	X	X	X
	Juncus pelocarpus	Brown-fruited rush	Native	8	X		
	Sagittaria cristata	Crested arrowhead	Native	9		X	X
	Sagittaria cuneata	Arum-leaved arrowhead	Native	7	I		

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

In the field, it is often difficult to distinguish between certain species of aquatic plants that are very similar morphologically, especially when flowering/fruiting material is not present. Because of this, the littoral occurrences of the following morphologically-similar species were combined for this analysis: small pondweed (*Potamogeton pusillus*) and slender pondweed (*P. berchtoldii*) as well as muskgrasses (*Chara* spp.) and stoneworts (*Nitella* spp.) will be referenced together as charophytes. Figure 3.2-2 displays the littoral frequency of occurrence of aquatic plants from whole-lake point-intercept surveys conducted in 2011, 2016, and 2021 in North Twin Lake.

Slender naiad was the most-frequently encountered native species in the lake with an occurrence of 38.5%. Variable-leaf pondweed (30.1%), and charophytes (26.3%), which comprise the combined occurrences of muskgrasses and stoneworts, were the second and third-most frequently encountered native species in North Twin Lake. Eurasian watermilfoil was present on five sampling locations in the 2021 survey representing an occurrence of 1.5% compared to 1.6% in 2011 and 1.1% in 2016. A full matrix of the littoral frequency of occurrence data is from whole-lake point-intercept surveys in North Twin Lake is included in Appendix C.

Several native aquatic plant species showed statistically valid changes in occurrence between the point-intercept surveys (Figure 3.2-2). Wild celery, white water crowfoot, northern watermilfoil, and alternate-flowered watermilfoil exhibited valid decreases in occurrence from 2016-2021. Water marigold, slender naiad, charophytes, and small/slender pondweed were amongst the species that showed valid increases between 2016-2021.

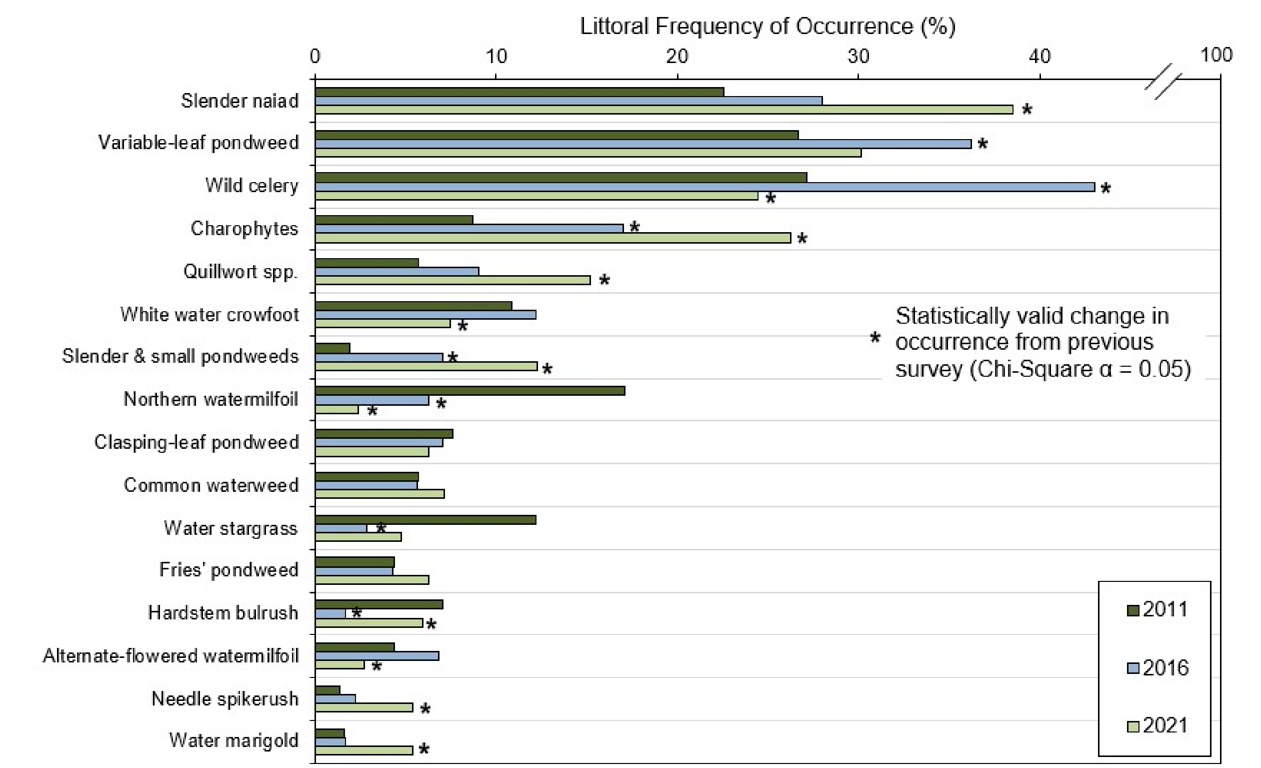


Figure 3.2-2. LFOO of aquatic plants in North Twin Lake. Asterisk represents statistically valid change from previous survey (Chi-Square α = 0.05).

The data that continues to be collected from Wisconsin lake's is revealing that aquatic plant communities are highly dynamic, and populations of individual species have the capacity to fluctuate, sometimes greatly, in their occurrence from year to year and over longer periods of time. These fluctuations can be driven by a combination of natural factors including variations in temperature, ice and snow cover (winter light availability), nutrient availability, water levels and flow, water clarity, length of the growing season, herbivory, disease, and competition (Lacoul and

Freedman 2006). Adding to the complexity of factors which affect aquatic plant community dynamics, human-related disturbances such as the application of herbicides for non-native plant management, mechanical harvesting, watercraft use, and pollution runoff also affect aquatic plant community composition (Asplund and Cook 1997); (Lacoul and Freedman 2006).

Figure 3.2-3 investigates the average number of native plant species at each littoral point-intercept sampling location from each of the point-intercept surveys. These data show a slight decrease in this metric between 2016-2021 with the 2021 survey indicating 1.94 species per sampling site compared to 2.02 in 2016.

One way to visualize the diversity of a lake's plant community is to examine the relative frequency of occurrence of aquatic plant species (Figure 3.2-4). Relative frequency of occurrence is used to evaluate how often each plant species is encountered in relation to all the other species found. Figure 3.2-8 displays the relative frequency of occurrence of aquatic plant species from each of the three point-intercept surveys in North Twin Lake. These data indicate wild celery comprised higher portions of the relative frequency in 2016 as compared to 2021. Eurasian watermilfoil accounted for less than 1% of the relative frequency in all point intercept surveys. Looking at relative frequency of occurrence (Figure 3.2-4), nine species comprise approximately 70% of the plant community in North Twin Lake.

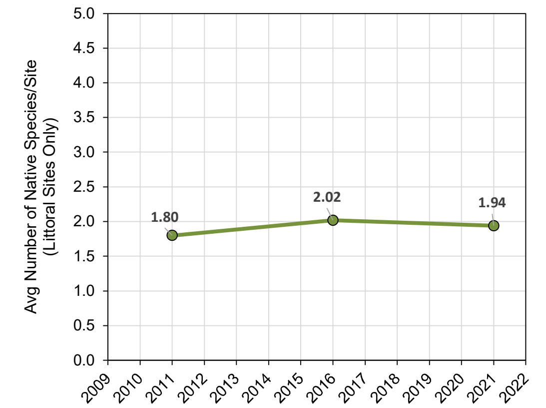


Figure 3.2-3. Average native aquatic plant species per littoral sampling site in North Twin Lake. Created using data from whole lake-lake point intercept surveys.

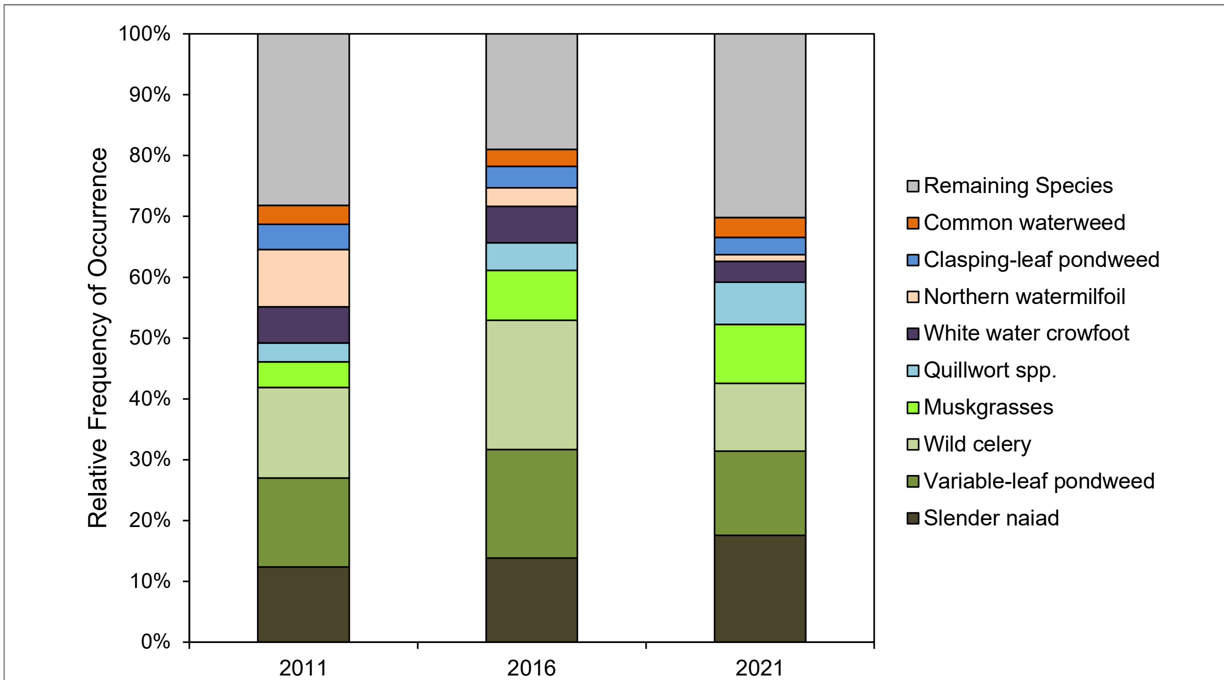


Figure 3.2-4. Relative frequency of aquatic vegetation in North Twin Lake.

A comparison of the species richness, average conservatism, and floristic quality from each of the four point-intercept surveys in North Twin Lake is displayed on Figure 3.2-5. In the 2021 point-intercept survey, the total richness was 30 compared to 29 in 2016 and 26 in 2011. Average conservatism values increased from 6.5 in 2016 to 7.0 in 2021. The floristic quality in North Twin Lake increased as well from 35.0 in 2016 to 38.3 in the 2021 survey. All of the 2021 survey values are well above the ecoregion and state median values.

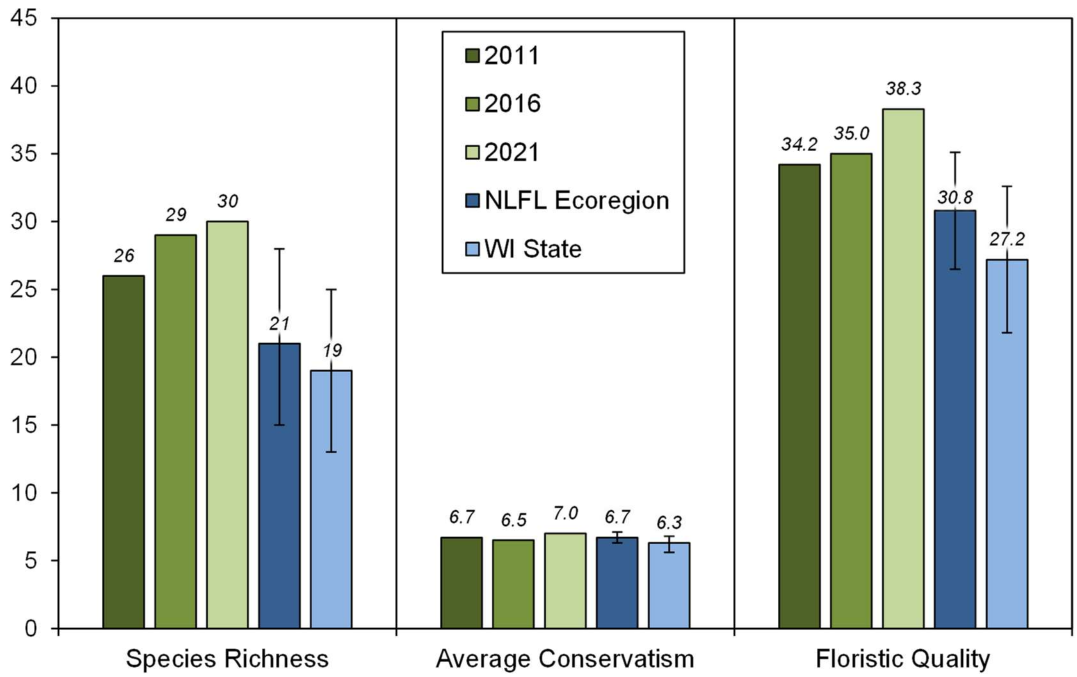


Figure 3.2-5. North Twin Lake Floristic Quality Index. Analysis follows (Nichols 1999).

Onterra LLC
Lake Management Planning

South Twin Lake

The South Twin Lake portion of North and South Twin Lakes makes up approximately 628 acres. Onterra ecologists conducted a whole-lake point intercept survey in South Twin on August 10-11, 2022. Whole-lake point-intercept surveys have been conducted in South Twin Lake annually between 2008-2021 with the exception of 2012 and 2019. A comparison of these surveys allows for detecting changes in the aquatic plant community over time. A total of 48 species of plants have been located in South Twin Lake during these aquatic plant surveys of which one is considered a non-native species: Eurasian watermilfoil (Table 3.2-7). Eurasian watermilfoil is discussed in greater detail within the subsequent *Non-Native Aquatic Plants in North and South Twin Lake* section.

During the 2022 point-intercept survey, information regarding substrate type was collected at locations sampled with a pole-mounted rake (less than 15 feet). These data indicate that 75% of the point-intercept locations contained sand sediments, 23% contained soft sediments, and 2% contained rock (Figure 3.4-2). The mixture of sand and soft organic sediment throughout the majority of South Twin Lake is very conducive for supporting lush aquatic plant growth.

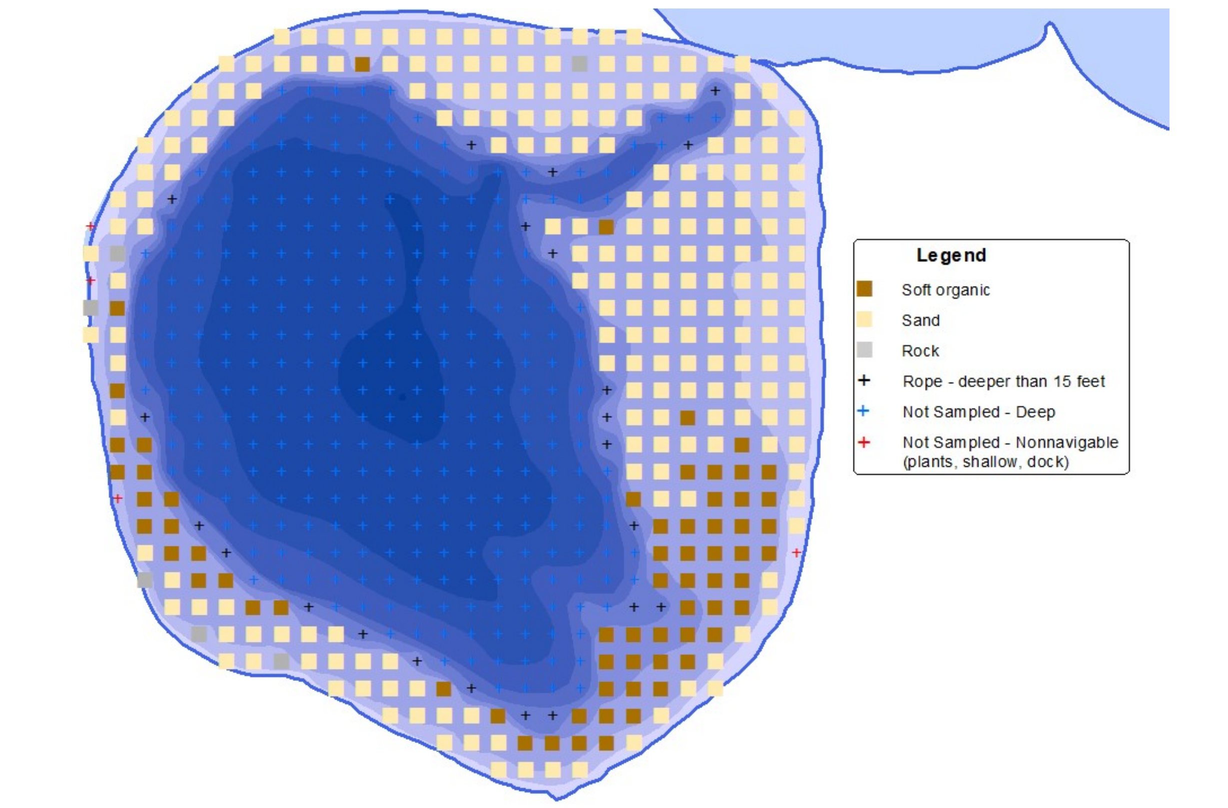


Figure 3.2-4. South Twin Lake proportion of substrate types within littoral areas.

In the field, it is often difficult to distinguish between certain species of aquatic plants that are very similar morphologically, especially when flowering/fruiting material is not present. Because of this, the littoral occurrences of the following morphologically-similar species were combined for this analysis in Table 3.2-2.

Table 3.2-2. Combined species for data analysis and reporting in South Twin Lake.

Referenced in the report/data as	Combined species
Charophytes	Muskgrasses Stoneworts
Thin-leaved pondweeds	Small pondweed Fries' pondweed Stiff pondweed Slender pondweed
Large-leaf, white-stem, & hybrid pondweeds	Large-leaf pondweed White-stem pondweed Large-leaf pondweed X White-stem pondweed hybrid
Clasping-leaf pondweed & hybrid	Clasping-leaf pondweed Clasping-leaf pondweed hybrid

Figures 3.2-8-3.2-12 display the littoral frequency of occurrence of aquatic plants from whole-lake point-intercept surveys conducted 2008-2021 with the exception of 2012 and 2019 in South Twin Lake. A full matrix of the littoral frequency of occurrence data is from whole-lake point-intercept surveys in South Twin Lake is included in Appendix D.

Several native aquatic plant species showed statistically valid changes in occurrence between the point-intercept surveys. Two native species initially exhibited statistically valid decreases in occurrence when comparing the occurrences from the 2020-2021 whole-lake point-intercept surveys (Figure 3.2-5). Water stargrass (*Heteranthera dubia*) exhibited a statistically valid 33.3% decrease from 16.5% in 2020 to 11.0% in 2021. Continued monitoring in 2022 yielded an occurrence of 9.2% for water stargrass. The occurrences of charophytes exhibited a statistically valid decrease from 25.1% in 2020 to 16.2% in 2021 and then a statistically-valid increase to 29.5% in 2022 (Figure 3.2-6).

Water stargrass *(Heteranthera dubia)*

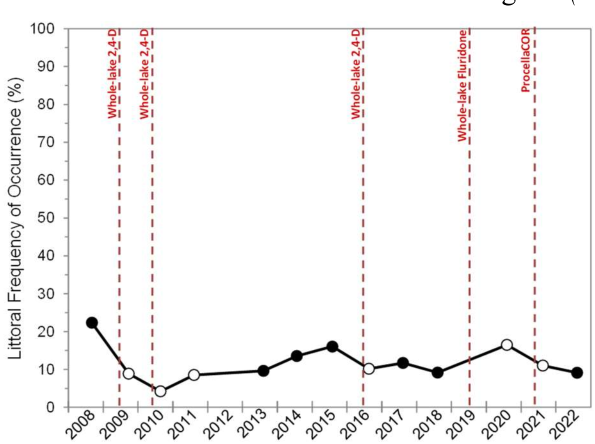


Figure 3.2-5. Littoral frequency of occurrence of select aquatic plants from whole lake point-intercept surveys in South Twin Lake. Photo credit: Onterra.

Charophytes (*Nitella* spp. & *Chara* spp.)

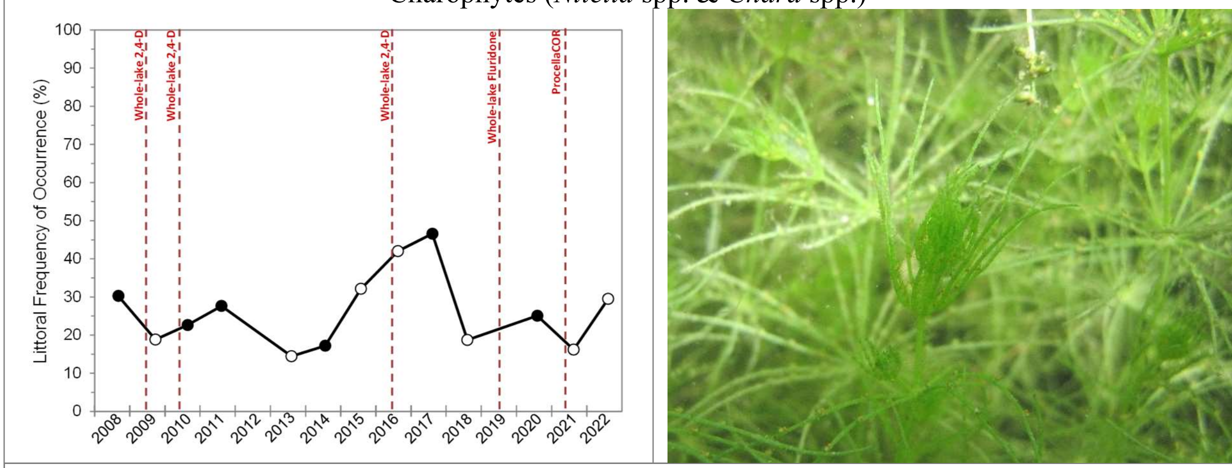


Figure 3.2-6. LFOO of select aquatic plants in South Twin Lake. Photo credit: Onterra.

The occurrence of clasping-leaf pondweed increased from 4.6% in 2020 to 17.5% in 2021 and increased further to 20.5% in the 2022 survey (Figure 3.2-7). Field observations by Onterra staff have been that this species has been prevalent within the same general locations in South Twin Lake as where previously dense EWM colonies had been prior to treatment. Clasping-leaf pondweed has shown valid increases in occurrence following ProcellaCOR™ treatments in several case studies that Onterra has monitored in recent years.

Clasping-leaf pondweed & hybrid (*Potamogeton richardsonii & P. hybrid*)

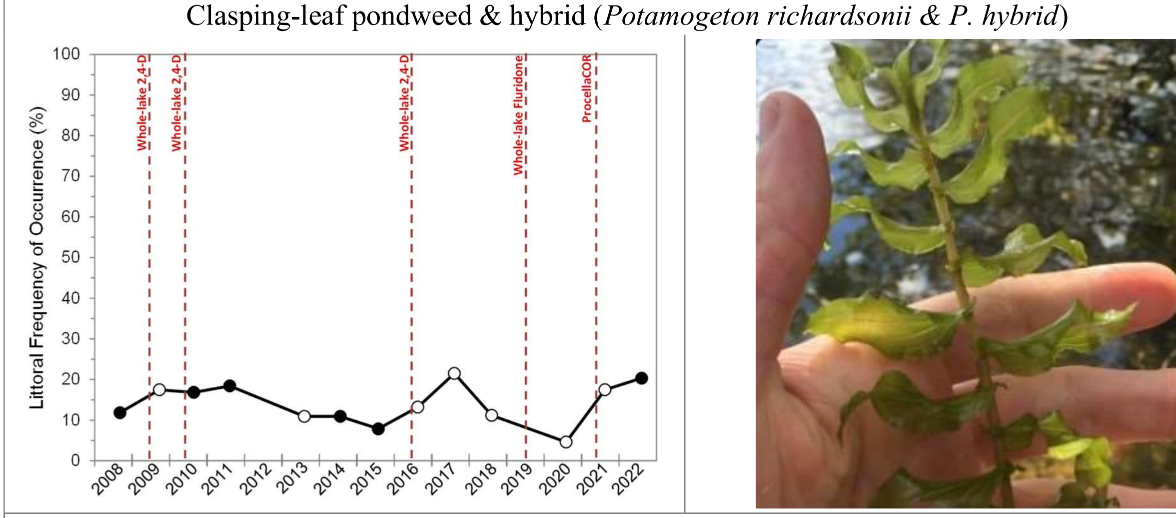


Figure 3.2-7. LFOO of select aquatic plants in South Twin Lake. Photo credit: Onterra.

The population of common waterweed exhibited a valid increase in occurrence in 2022 with an occurrence of 14.2% (Figure 3.2-8). This species had been reduced to less than 1% occurrence following the 2019 fluridone treatment and had remained at just 1% in 2021. The occurrence in 2022 is similar to the occurrence documented in 2018 prior to the fluridone treatment, demonstrating rebound.

Common waterweed (*Elodea canadensis*)

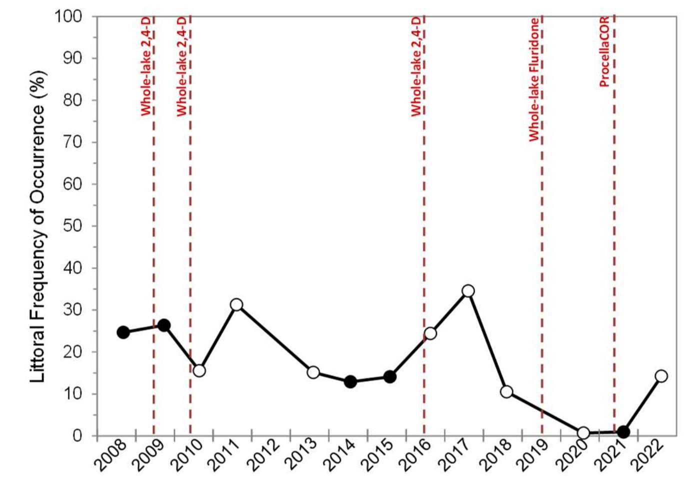


Figure 3.2-8. LFOO of select aquatic plants in South Twin Lake. Photo credit: Onterra.

In addition to common waterweed and the charophytes listed above, other native species that exhibited statistically valid increases in occurrence between the 2021-2022 include coontail (+52.9%), as well as the collective grouping of large-leaf pondweed, white-stem pondweed, and a hybrid large-leaf/white-stem pondweed (+71.8%) (Figure 3.2-11).

Native dicot species including northern watermilfoil, water marigold, white water crowfoot, and alternate-flowered watermilfoil have demonstrated susceptibility to ProcellaCOR in case studies conducted to date in Wisconsin. Each of these species have been documented in past surveys in South Twin Lake and were either not present or had a low frequency of occurrence in the survey completed during 2020 prior to the 2021 ProcellaCOR™ treatments. Water marigold was present at one sampling location in the 2022 survey (0.3%) while white water crowfoot was present at two sites (0.7%). Northern watermilfoil and alternate-flowered watermilfoil were not present on any sampling locations in the 2022 survey (Figure 3.2-9-10.)

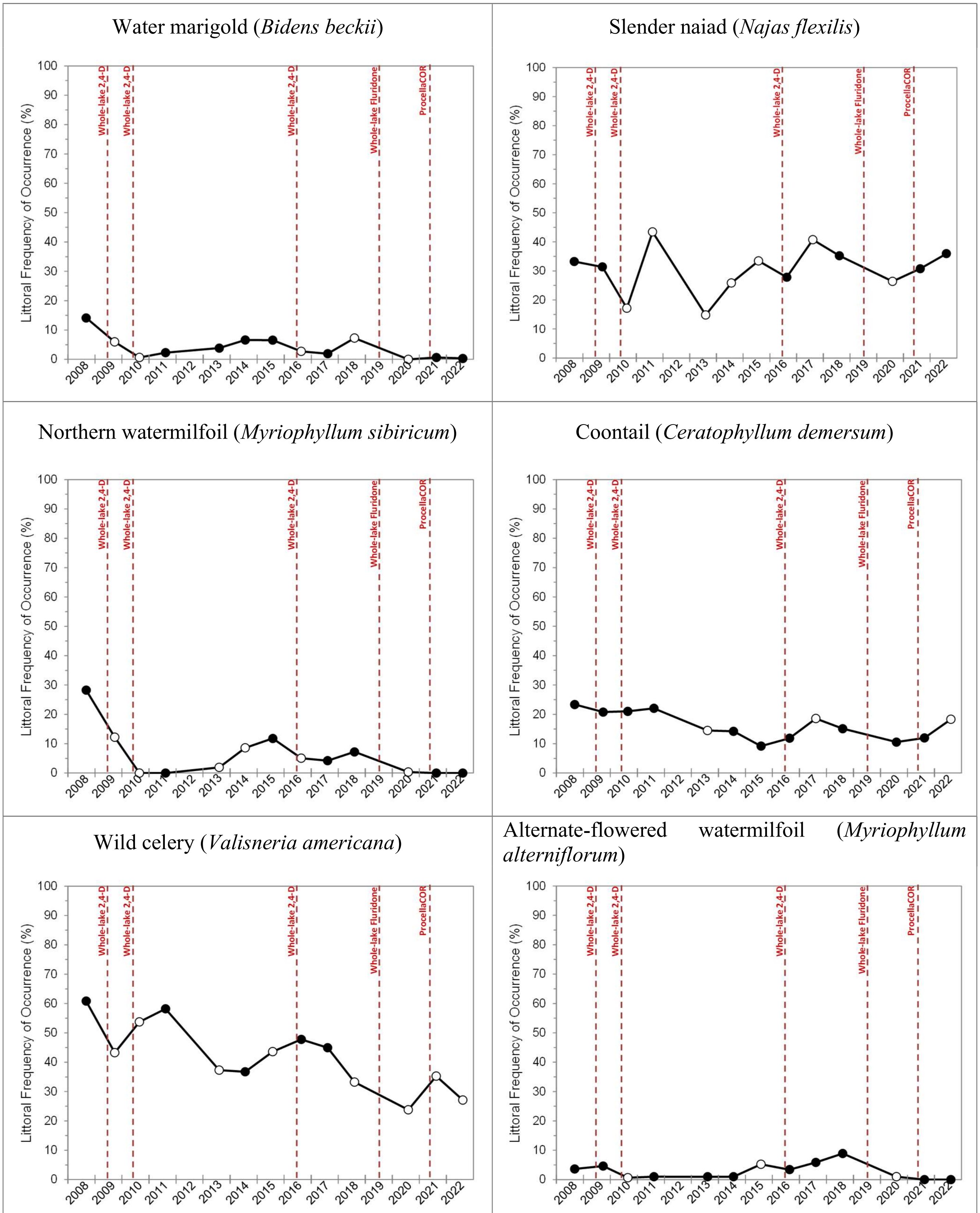
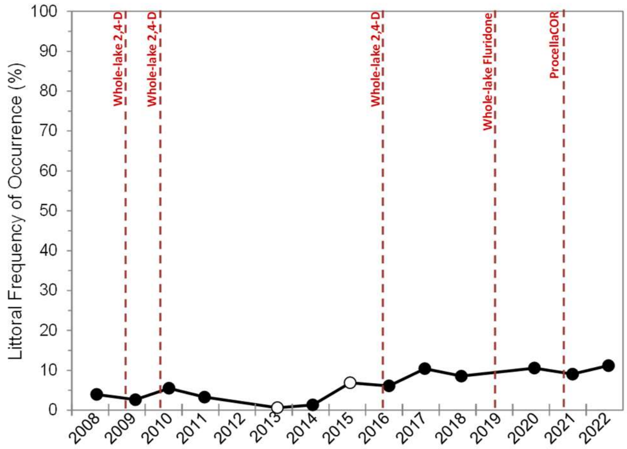
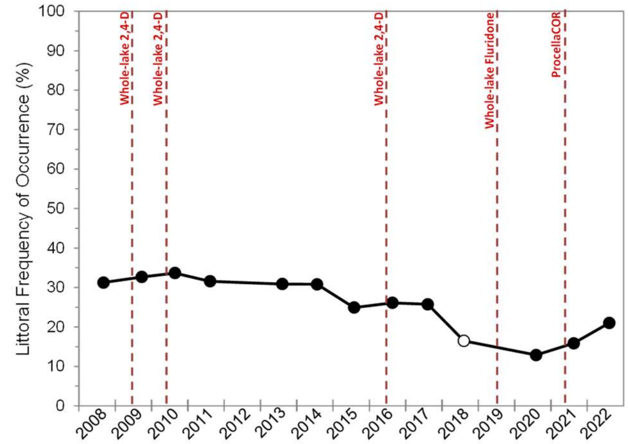


Figure 3.2-9. LFOO of select aquatic plants in South Twin Lake. Open circle represents statistically valid change in occurrence from previous survey.

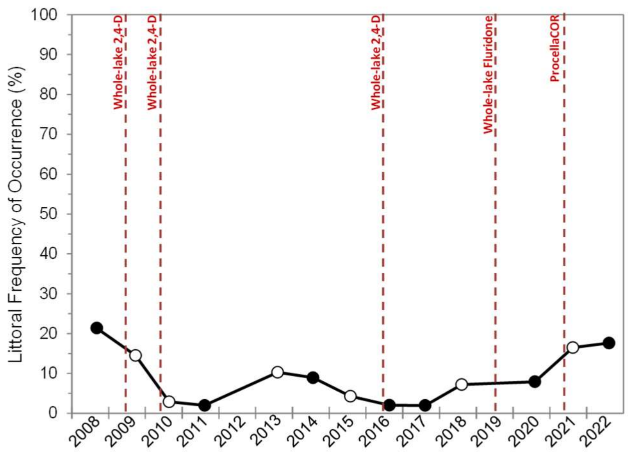
Quillworts (*Isoetes* spp.)



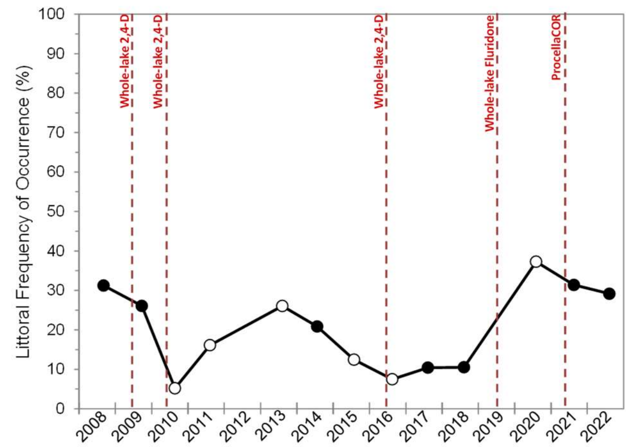
Fern pondweed (*Potamogeton robbinsii*)



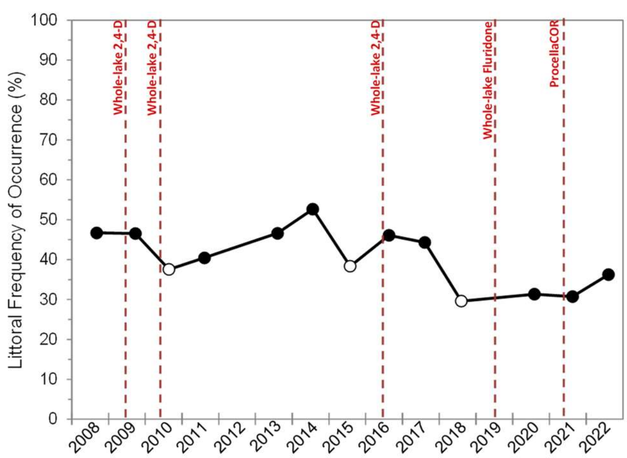
Thin-leaved pondweeds (*Potamogeton pusillus, P. berchtoldii, P. friesii, P. strictifolius*)



Flat-stem pondweed (*Potamogeton zosteriformis*)



Variable-leaf pondweed (*Potamogeton gramineus*)



Large-leaf pondweed (*Potamogeton amplifolius)*, white-stem pondweed (*P. praelongus*), and hybrid pondweed (*P. amplifolius X . praelongus*)

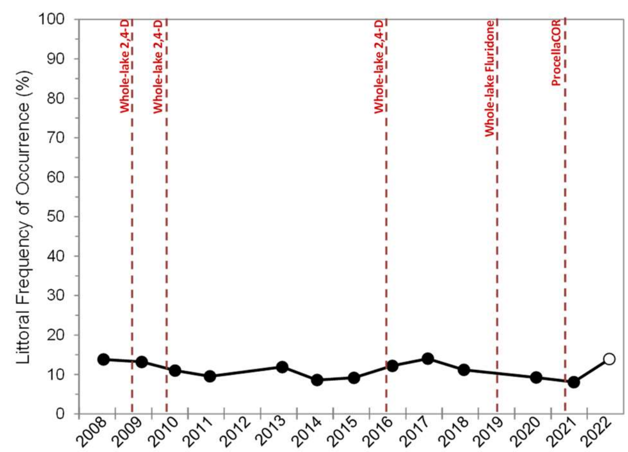


Figure 3.2-10. LFOO of select aquatic plants in South Twin Lake. Open circle represents statistically valid change in occurrence from previous survey.

The data that continues to be collected from Wisconsin lake's is revealing that aquatic plant communities are highly dynamic, and populations of individual species have the capacity to fluctuate, sometimes greatly, in their occurrence from year to year and over longer periods of time. These fluctuations can be driven by a combination of natural factors including variations in temperature, ice and snow cover (winter light availability), nutrient availability, water levels and flow, water clarity, length of the growing season, herbivory, disease, and competition (Lacoul and Freedman 2006). Adding to the complexity of factors which affect aquatic plant community dynamics, human-related disturbances such as the application of herbicides for non-native plant management, mechanical harvesting, watercraft use, and pollution runoff also affect aquatic plant community composition (Asplund and Cook 1997); (Lacoul and Freedman 2006).

Figure 3.2-11 investigates the average number of native plant species at each littoral point-intercept sampling location from each of the point-intercept surveys. These data show a slight increase in this metric between 2020-2022 with the 2022 survey indicating 3.20 species per sampling site compared to 2.55 in 2021 and 2.37 in 2020.

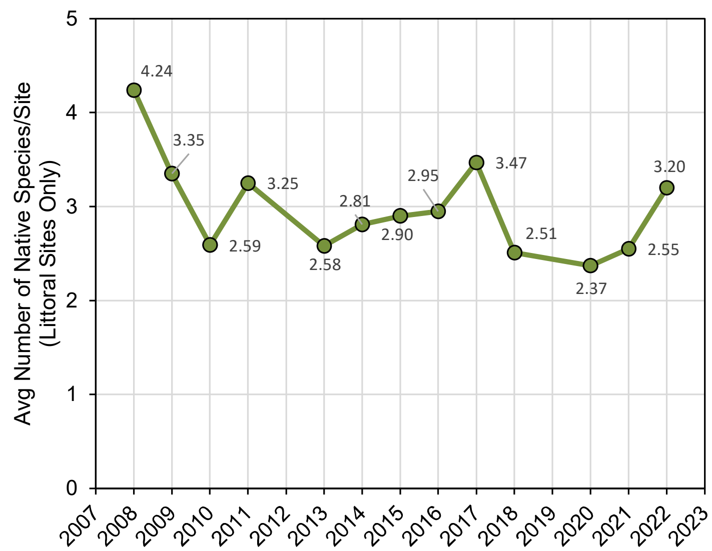


Figure 3.2-11. Average native aquatic plant species per littoral sampling site in South Twin Lake. Created using data from whole lake-lake point intercept surveys.

One way to visualize the diversity of a lake's plant community is to examine the relative frequency of occurrence of aquatic plant species (Figure 3.2-12). Relative frequency of occurrence is used to evaluate how often each plant species is encountered in relation to all the other species found. Figure 3.2-15 displays the relative frequency of occurrence of aquatic plant species from each of the three point-intercept surveys in South Twin Lake. These data indicate native plants have varied in portions over the years with Eurasian watermilfoil being the likely factor influencing those changes. Eurasian watermilfoil accounted for 1.2% of the relative frequency in the 2022 point intercept survey. Looking at relative frequency of occurrence, the top nine species comprise approximately 56% of the plant community in South Twin Lake.

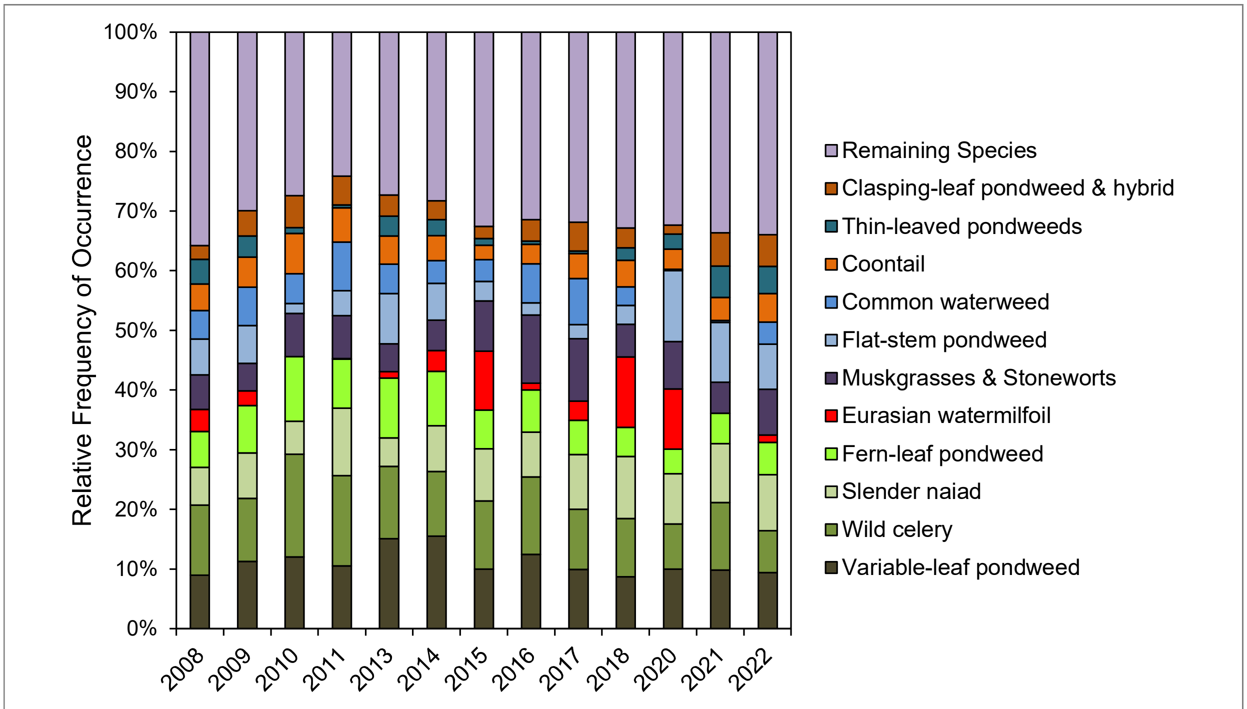


Figure 3.2-12. Relative frequency of aquatic vegetation in South Twin Lake.

A comparison of the species richness, average conservatism, and floristic quality from each of the 13 point-intercept surveys in South Twin Lake is displayed on Figure 3.2-13. In the 2022 point-intercept survey, the total richness was 22 compared to 24 in 2021 and 26 in 2020. Average conservatism values have remained about the same between 6.6 and 6.7 in recent years. The floristic quality in South Twin Lake decreased as well from 34.2 in 2020 to 31.0 in the 2022 survey. Even though there was a slight decline in recent years, all of the 2022 survey values remain above the ecoregion and state median values.

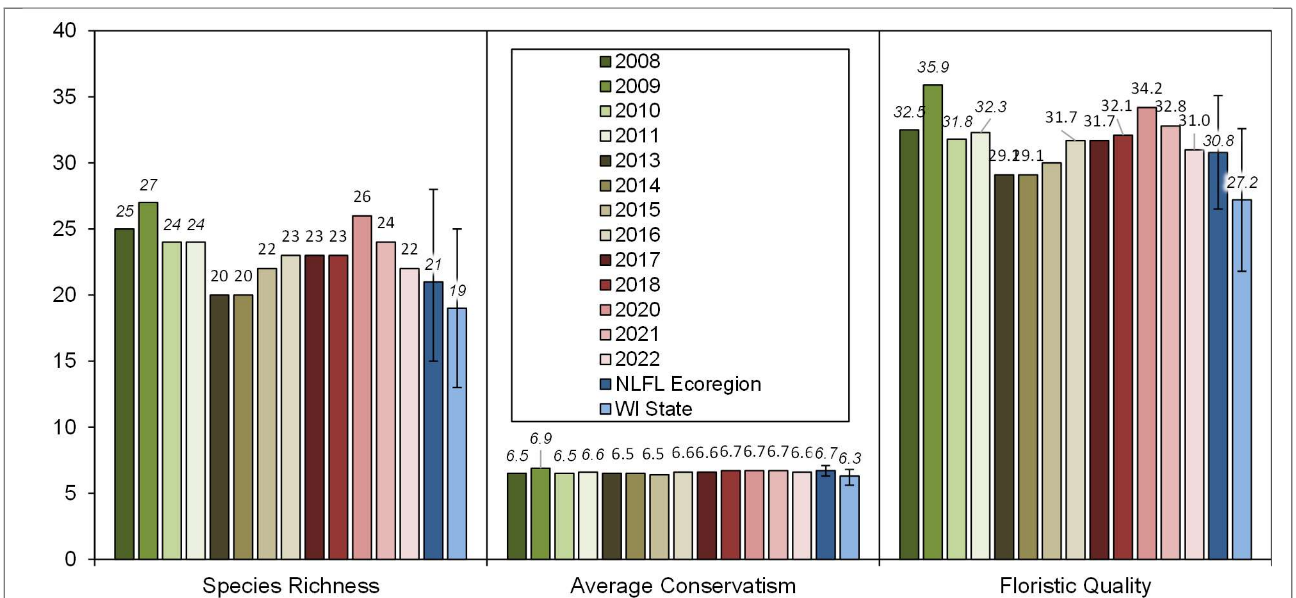


Figure 3.2-13. South Twin Lake Floristic Quality Index. Analysis follows (Nichols 1999).

3.3 Eurasian watermilfoil *(Myriophyllum spicatum)*

All the aquatic plant data discussed so far was collected as part of point-intercept surveys. The subsequent materials will also incorporate data from EWM 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 3.3-1). 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 3.3-1. 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 mapping survey, the entire littoral area of the lake is surveyed through visual observations from the boat (Photograph 3.3-2). Field crews supplemented the visual survey by deploying a submersible camera along with periodically doing rake tows. The EWM 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 3.3-2. 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.

EWM Biology

Eurasian watermilfoil is an invasive species, native to Europe, Asia and North Africa, that has spread to most Wisconsin counties (Figure 3.3-1). Eurasian watermilfoil is unique in that its primary mode of propagation is not by seed. It actually spreads by shoot fragmentation, which has supported its transport between lakes via boats and other equipment. In addition to its propagation method, Eurasian watermilfoil has two other competitive advantages over native aquatic plants, 1) it starts growing very early in the spring when water temperatures are too cold for most native plants to grow, and 2) once its stems reach the water surface, it does not stop growing like most native plants, instead it continues to grow along the surface creating a canopy that blocks light from reaching native plants. Eurasian watermilfoil can create dense stands and dominate submergent communities, reducing important natural habitat for fish and other wildlife, and impeding recreational activities such as swimming, fishing, and boating. 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.

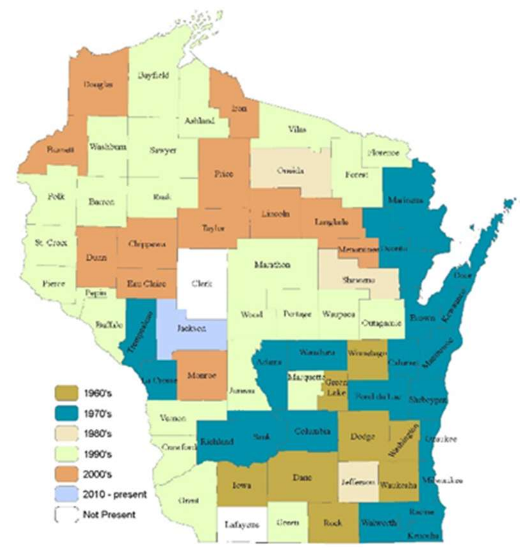


Figure 3.3-1. Spread of EWM within WI counties. WDNR Data 2022 mapped by Onterra.

The non-native plant that is of primary concern in the Twin Lakes is Eurasian watermilfoil (Photograph 3.3-3). In multiple years, Onterra has sent in invasive watermilfoil samples from the system to Grand Valley State University or Montana 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). All samples tested have been confirmed as pure-strain EWM.

Photograph 3.3-3. Surface matting Eurasian watermilfoil colony on South Twin Lake. Photo credit: Onterra.

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. 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 3.3-2).

The results of the study clearly indicate that EWM populations in unmanaged lakes can fluctuate greatly between years (Figure 3.3-2). 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.

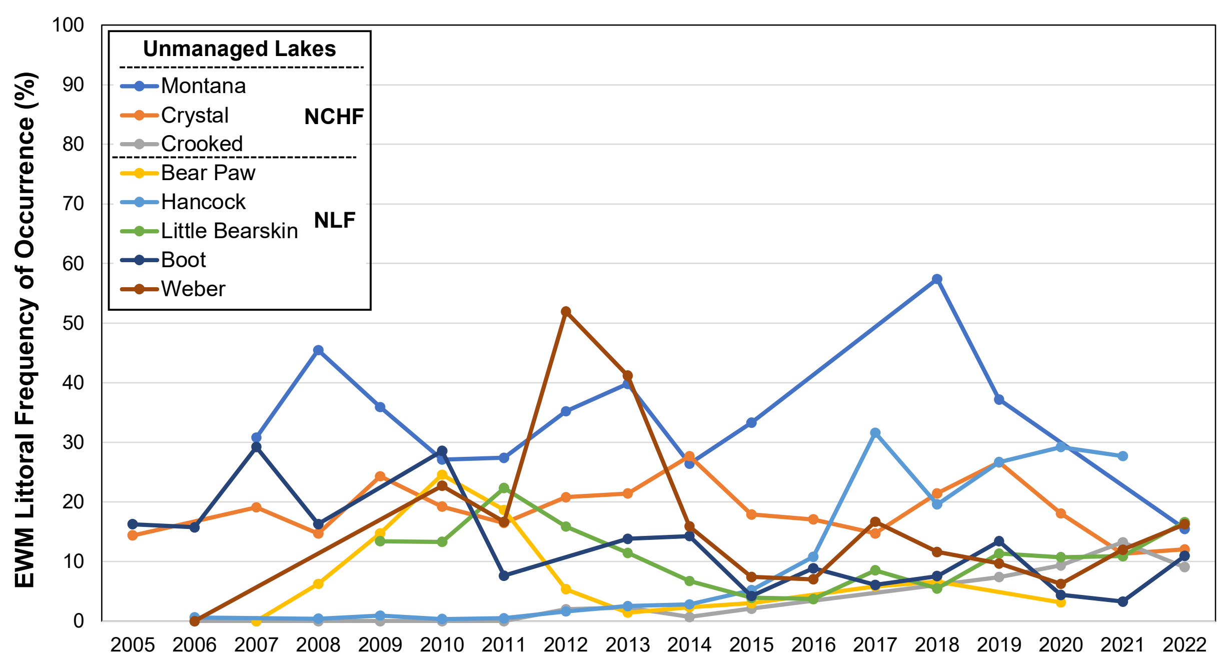


Figure 3.3-2. LFOO of EWM in northern ecoregions without management. Data provided by and used with permission from WDNR. LFOO = littoral frequency of occurrence.

EWM population of North and South Twin Lake

Using data from the point-intercept surveys that have been completed over the years, the littoral frequency of occurrence of EWM can be compared for each lake (Figure 3.3-3). The frequency of occurrence of EWM in North Twin Lake has been relatively the same while South Twin Lake has seen statistically valid decrease and increases in occurrence due to whole-lake herbicide treatments.

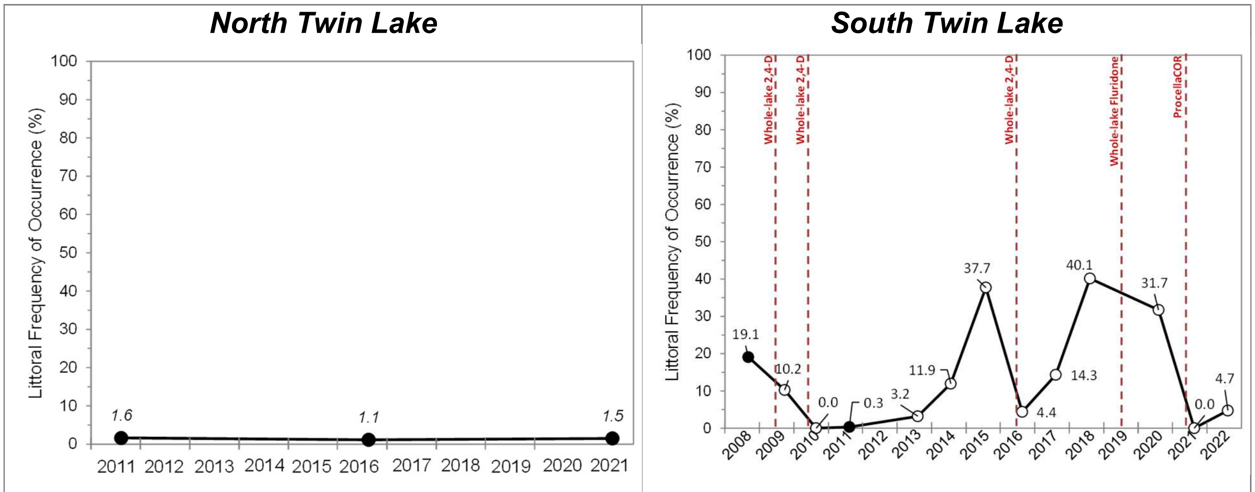


Figure 3.3-3. EWM LFOO within North and South Twin Lake. Open circle is a statically significant increase or decrease from the previous year.

Onterra staff completed the most recent lake-wide assessment of the EWM population on August 24-25, 2022. The entire littoral area of both lakes was included in the scope of the survey. Within South Twin Lake, crews delineated several colonized areas of EWM with the largest colonies being located in the southeast end of the lake near the girl's camp (Map 2, lower right frame). This area contained a combination of *dominant*, *scattered*, and *highly scattered* density colonized areas. Additional small colonized beds of EWM were located in the vicinity of site Y-21 on the lakeward edge of a bullrush community in the northeast end of the lake, and one relatively small *highly scattered* colony was mapped on the north end of the lake. Isolated point-based occurrences consisting mostly of single or few plants or clumps of plants were also located around littoral areas of the lake. In total, 10.8 acres of EWM were delineated during the 2022 survey, while no colonized areas were present in 2021, and compared to 133.3 acres that were present in 2020 prior to the large-scale ProcellaCOR™ treatment (Map 2, upper right frame).

In North Twin Lake, crews encountered colonized EWM in many of the same locations where they have historically been located near the border with South Twin Lake and in the vicinity of the large island on the southeast end of the lake (Map 3). The EWM population in North Twin Lake consisted of 15.9 total acres, of which 10.8 were designated as *dominant* or *highly dominant* in density, while the remainder consisted of either *highly scattered* (0.7 acres) or *scattered* (4.4 acres). Colonized EWM was present within each of the recent past ProcellaCOR spot treatment sites (B-19, and C-20) indicating some level of population recovery or re-establishment in the sites. Additional point-based occurrences were marked in isolated areas around the remainder of the lake with no other large colonized plant beds outside of the southeast end of the lake.

North and South Twin Lakes Historic EWM Management

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. During the early days of management on the system, the BMP for managing EWM was through 2,4-D spot treatments (Figure 3.3-4). Spot treatments are a type of control strategy where the herbicide is applied to a specific area (treatment site) such that when it dilutes from that area, its concentrations are insufficient to cause significant affects outside of that area. Spot treatments typically rely on a short exposure time to cause mortality as the herbicide dissipates out of the spots rapidly. Due to the size and shape of North Twin Lake, essentially all previous herbicide applications have been spot treatments.

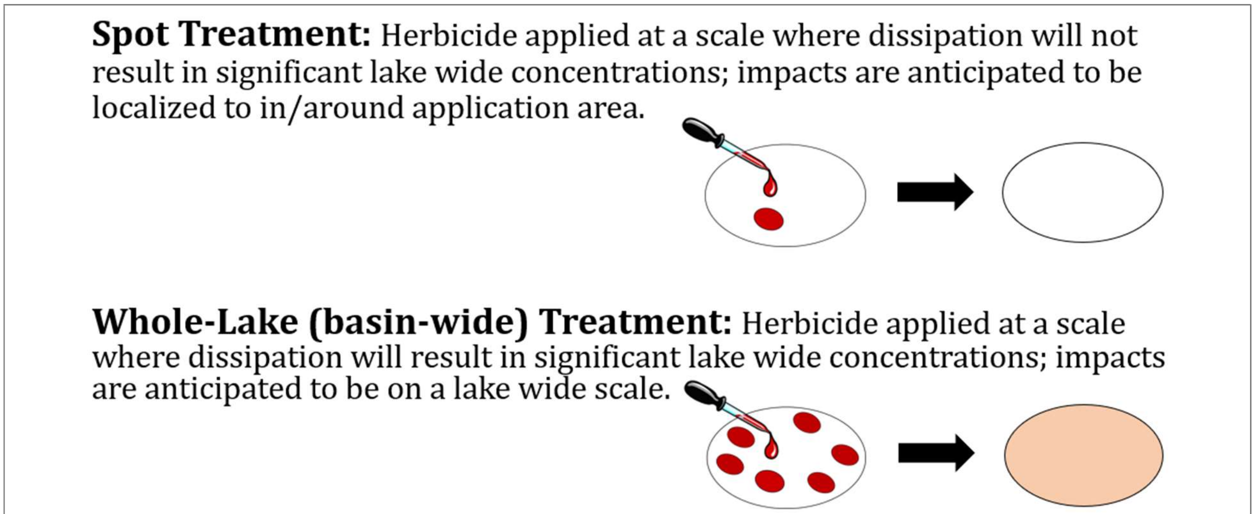


Figure 3.3-4. Ecological definitions of herbicide treatment. Graphics created in conjunction with WDNR.

Herbicide spot treatments with 2,4-D generally lead to short term EWM population reductions, with reductions largely being limited to a single season. This type of strategy can be analogous to the "whack-a-mole" arcade game; where areas are targeted, rebound, and then are targeted again on an every-other year basis. The repeated need for exposing the same areas of the system to herbicides as is required when engaged in an annual 2,4-D 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. In recent years, lake managers have sought actions that achieve multiyear EWM population suppression, such as whole-lake/basin treatments or spot treatments with chemistries theorized to require shorter exposure times. The EWM population reductions are more commensurate with the financial costs and risks of the treatment.

As BMPs for invasive watermilfoil control evolved, the District embraced large-scale or whole-lake 2,4-D treatments in 2009 (Figure 3.3-52). These control efforts have largely provided greater magnitude and longevity of EWM control.

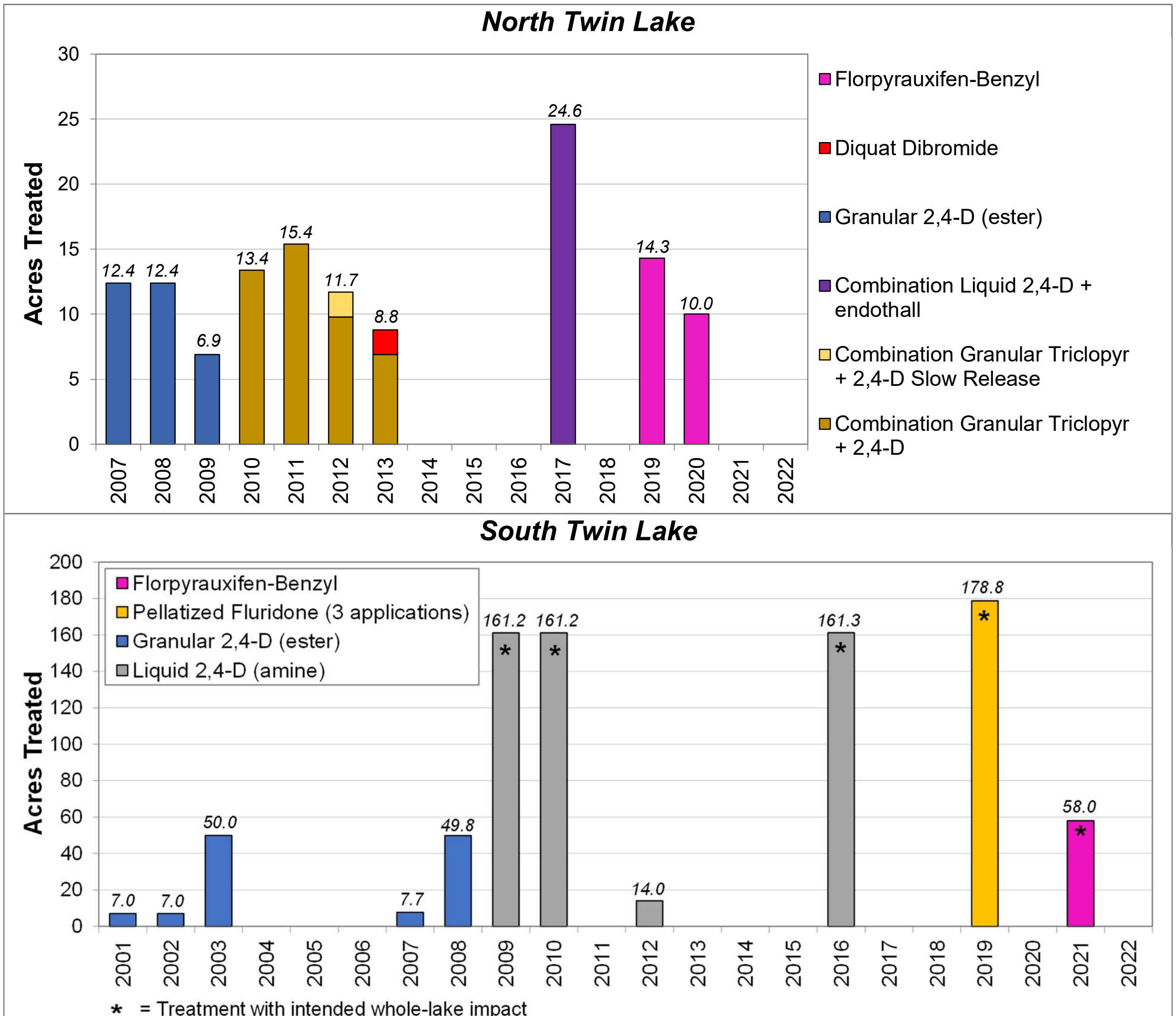
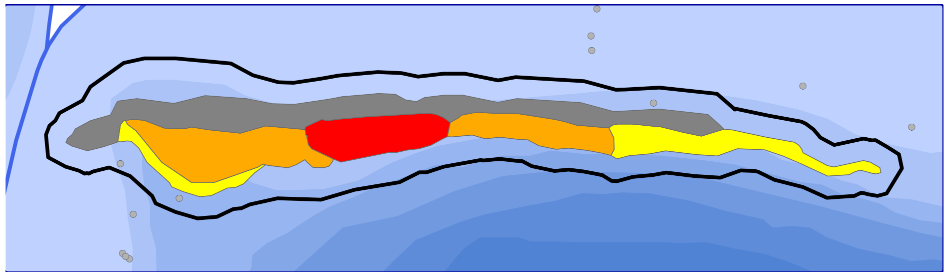
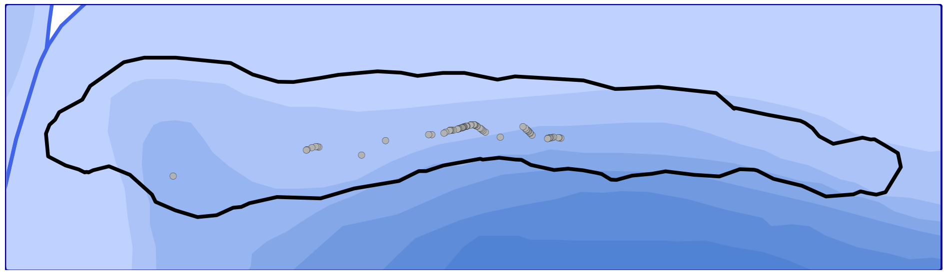
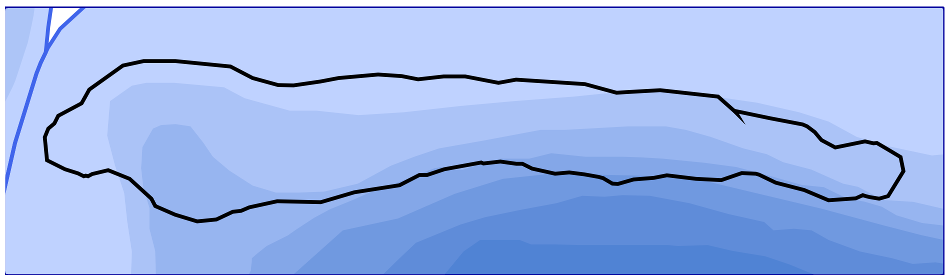
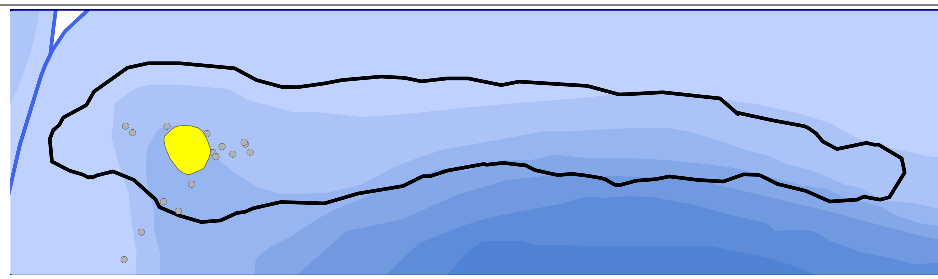
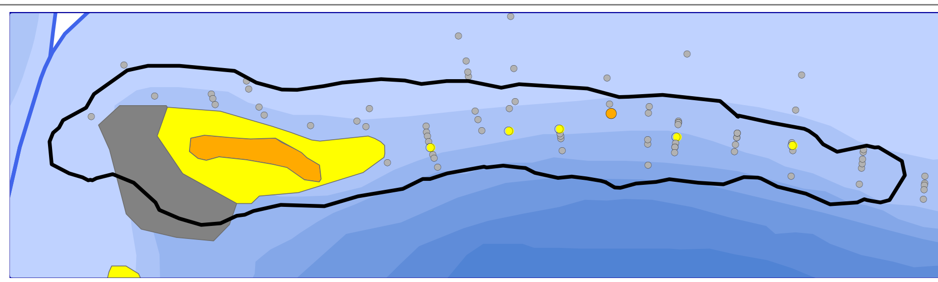


Figure 3.3-5. Historical herbicide management activities on Twin Lakes.

North Twin Lake 2019 & 2020 ProcellaCOR™ Spot Treatments

A 14.3-acre site (B-19) in North Twin Lake was treated with ProcellaCOR™ at a dosing rate of 8.0 PDU's in mid-June 2019. Professional hand harvesting efforts in 2020 targeted remnant EWM plants after which the September 2020 Late-Summer EWM Mapping Survey (1-*year after treatment*) found no EWM within the site. Continued monitoring that took place two-years after treatment (2021) indicated most of the site continued to be clear of EWM with exception of a relatively small but dense *dominant* density colony that was mapped near the southern-most extent of the treatment site (Figure 2.4-3). By three years after treatment (2022), EWM had expanded in the site to include a larger colonized area on the southern end of the site, with point-based occurrences mapped throughout the remainder of the site. The EWM population in 2022 was approaching, yet still below, pretreatment levels mapped during 2018.

September 2018 (Pretreatment)	
September 2019 (Year-of-Treatment)	
September 2020 (1-Year Post-Treatment)	
September 2021 (2-Years Post-Treatment)	
August 2022 (3-Years Post-Treatment)	

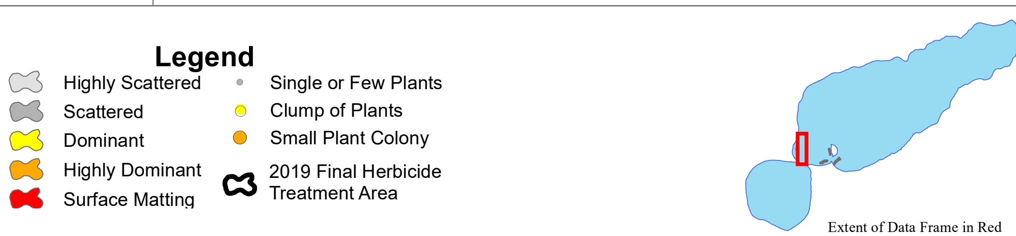


Figure 3.3-6. EWM Mapping Survey results from before (2018) and after (2019-2022) ProcellaCOR™ herbicide treatment in site B-19 in North Twin Lake.

A separate 10-acre site in North Twin Lake, East of the island, was treated with ProcellaCOR with an application rate of 7.0 PDU's in mid-June 2020. Prior to treatment, the occurrence of EWM was 15.2% and declined to 0% in the year-of-treatment (2020) and was 3.0% in the *year after treatment* (2021). Quantitative monitoring of this site did not occur during 2022, instead the site was assessed through the replication of a late-summer EWM mapping survey that represents two-years after treatment. These data indicate that EWM was nearing pretreatment levels with a core *dominant/scattered* colony in the site as well as other single plants occurrences (Figure 3.3-7)

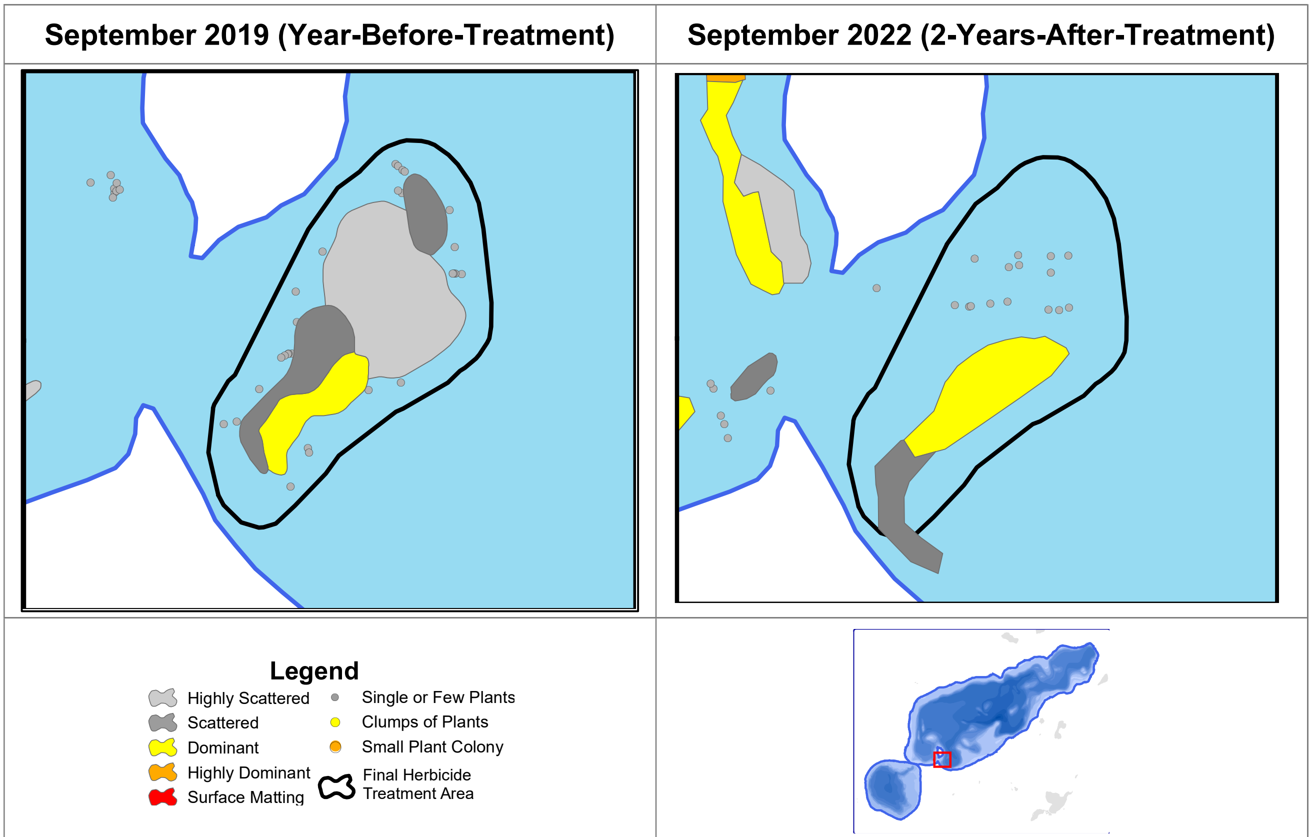


Figure 3.3-7. EWM population before (September 2019) and two-years after (August 2022) ProcellaCOR treatment in site C-20 in North Twin Lake. No EWM was located in the site in the year-of-treatment survey (September 2020), and one clump and several single plants in one-*year after treatment* (September 2021).

<u>*South Twin Lake 2021 ProcellaCOR™ Spot Treatments*</u>

The District participated in discussions with Onterra, WDNR, and SePRO in developing the 2021 herbicide treatment with ProcellaCOR™ in South Twin Lake. Three sites were identified for herbicide control in 2021. The sites were chosen based on the dense EWM population that is causing nuisance conditions to lake users as well as their proximity to high traffic areas of the lake. The District believed that a herbicide management strategy in 2021 utilizing ProcellaCOR™ would result in a high level of EWM control as has been observed in recent treatments in North Twin Lake.

The 2021 herbicide spot treatment strategy in South Twin Lake included treating three sites totaling 58.0 acres with ProcellaCOR™ at a dosing rate of between 4.0 and 4.5 PDU's. Calculations indicated that if all three applications are treated simultaneously, a potential whole-lake epilimnetic concentration of 0.41 ppb active ingredient would be possible. Based upon Onterra's experience, theoretical mixing area concentrations of 0.4 ppb of ProcellaCOR active ingredient (florpyrauxifen-benzyl) have the potential to result in impacts to EWM throughout the water volume in which herbicide mixes. This means that along with the upfront high concentration in the application area, the entire lake or basin can reach an equilibrium concentration that at an extended exposure (days to a week) could have the potential to impact EWM throughout this area of potential impact (AOPI).

Florpyrauxifen-benzyl is the active ingredient in ProcellaCOR™. One of the primary breakdown products 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.

The EWM population in the targeted areas were qualitatively mapped through the completion of Late-Summer EWM Mapping Surveys conducted before (September 2020) and after (September 2021) the herbicide treatments in South Twin Lake (Map 2). Prior to treatment, large and dense contiguous colonies were present within the targeted areas and totaled over 133 acres throughout South Twin Lake. Particularly dense areas of EWM including highly dominant or surface matting colonies were the target of the 2021 herbicide application areas. Following treatment, the September 2021 EWM mapping survey indicated no EWM located within any of the three application areas.

Onterra ecologists completed an Early Season AIS Survey on June 29, 2022. The main purpose of the survey was to better understand the population of the rebounding EWM on the lakes, to determine if the District would consider herbicide management yet that early summer, and to guide the professional hand harvesting strategy during the upcoming growing season. The survey yielded two relatively small *highly scattered* density colonies were delineated in the southeast end of the lake with one colony within the extents of site Y-21, and the other being located south of Y-21 approximately out from a girl's camp on the lakeshore (Map 2, lower left frame). Several *single or few* EWM occurrences were marked along the northern end of the lake, just west of the public boat landing. A few other isolated occurrences were also located around littoral areas of the lake.

Professional Hand Harvesting/Diver Assisted Suction Harvest (DASH)

The District took a leading role in determining how to prioritize hand harvesting operations in these sites based on their budgeted resources and the strategies outlined within the District's management matrix as outlined in Table 3.3-1. Ultimately, the District chose to target the rebounding EWM occurrences in South Twin Lake in an attempt to maintain the gains made by the 2021 ProcellaCOR™ treatment.

Table 3.3-1. EWM Management Matrix developed by the District and employed until 2022.

Colony Size	Surface Matting	Highly Dominant	Dominant	Scattered	Highly Scattered
< 1 acre	1,2,3	1,2,3	2,3,	2,3,4	4
1 - 5 acres	1,2	1,2	1,2	2,3,4	3,4
5 - 10 acres	1	1,2	1,2	2,4	4
> 10 acres	1	1	1	2	4

Activity
1 Herbicide spot treatment
2 DASH
3 Hand Pulling
4 No active just monitor

Since 2015, the District has contracted with Aquatic Plant Management, LLC (APM) to provide professional hand-harvesting services, including with DASH technologies. The District, in consultation with Onterra and APM, have created an annual site prioritization methodology that considered EWM density from the previous year's Late Season EWM Mapping Survey, traffic patterns, riparian frontage, and recent herbicide management history. Over the past seven years, manual efforts have removed over 2,500 cubic feet of EWM (Figure 3.3-8)

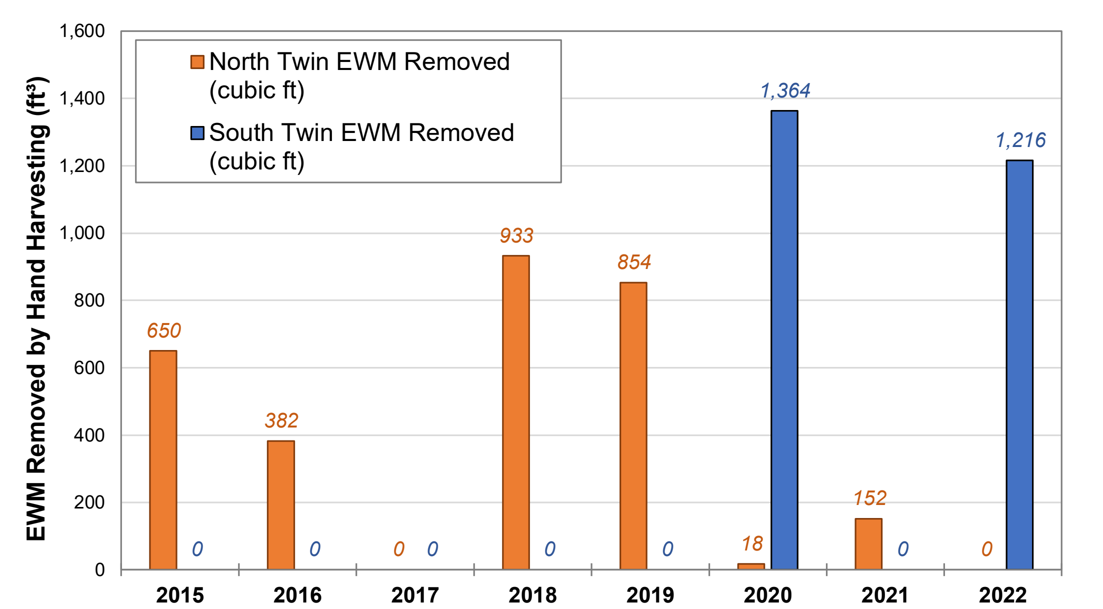


Figure 3.3-8. 2015-2022 Manual Removal Totals. Data provided by APM, LLC

Future AIS Management Philosophy

During the District Lake Management Team meetings held as part of this project, three broad Eurasian watermilfoil 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 District to weigh the benefits of the management strategy with the collateral impacts each management action may have on the Twin Lakes ecosystem. These chapters are included as Appendix D. The District Lake Management Team also reviewed these management perspectives in the context of perceived riparian stakeholder support, which is discussed in the subsequent sub-section.

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 EWM population, either through an EWM mapping 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 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 EWM 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.

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 EWM populations, that may mean to manage the EWM 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 EWM 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. 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. The District has historically taken a lake-wide population management approach, attempting to manage for an overall suppressed EWM population.

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. Rotating herbicide use-patterns can help avoid population-level herbicide tolerance evolution from occurring. While florpyrauxifen-benzyl is a similar mode of action to 2,4-D (auxin hormone mimic), differences in molecular configuration and binding affinity are hypothesized to generate a different enough response in the plant than in 2,4-D.

Stakeholder Survey Responses to Eurasian Watermilfoil Management

As discussed in Section 2.0, the stakeholder survey asks many questions pertaining to perception of the lake and how it may have changed over the years. The return rate of the 2022 survey was 42% and the response rate of an earlier 2017 survey was 39%. Because the response rate was below 60% in both instances, it is important to reiterate that the stakeholder survey results need to be understood in the context of the respondents to the survey, not to the overall population sampled.

In an effort to understand how EWM impacts stakeholders, the 2022 stakeholder survey asked if the Eurasian watermilfoil population ever had a negative impact on your enjoyment of the North and South Twin Lakes. The category with the highest number of respondents indicating *Yes* was motor boating (Figure 3.3-9). This was ranked as the third-highest reason for owning or renting property on North and South Twin Lake (Section 2.3, Figure 2.3-3). Stakeholder respondents also indicated that fishing-open water, aesthetics, and silent sports were also negatively impacted by EWM in North and South Twin Lakes.

Queston 18 (2022): Has the Eurasian watermilfoil (EWM) population ever had a negative impact on your enjoyment of North and South Twin Lakes?

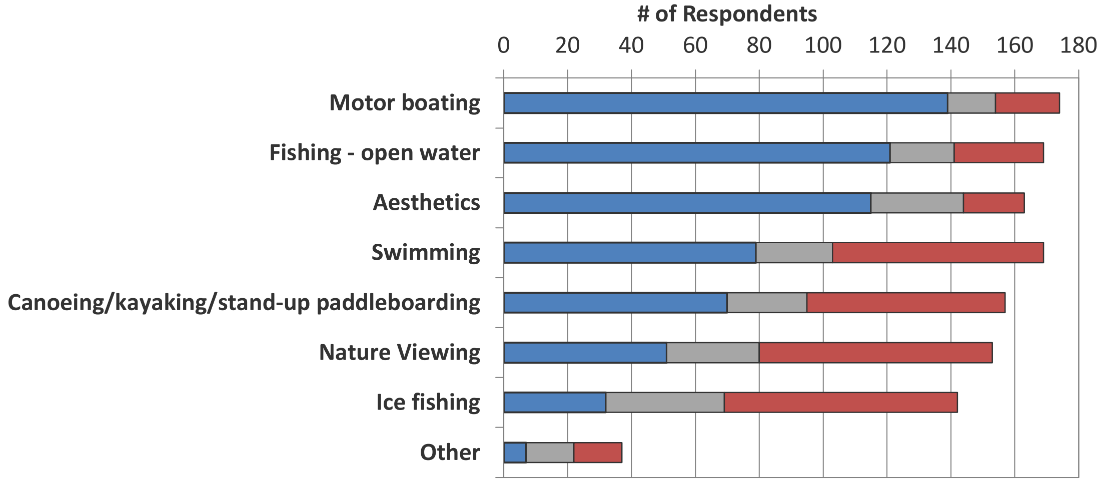


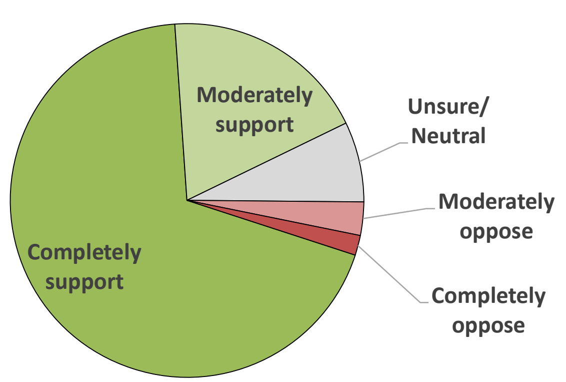
Figure 3.3-9. Select survey responses from the District Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

In both 2017 and 2022, riparian and District members were asked about a number of management techniques for managing non-native aquatic plants. It is important to note that these questions were worded a little differently between surveys. To assist with understanding the comparisons, the responses of *Neither oppose nor support* and *Unsure; Need more information* from the 2022 survey were combined together under "Unsure/*Neutral*". Figure 3.3-10 highlights the level of support amongst stakeholder respondents who oppose or support an herbicide treatment. The top concerns for herbicide use in both surveys on North and South Twin Lake included potential impacts to native plant and non-plant species, potential impacts to human health, and future impacts are unknown.

Question 28 (2017): What is your level of support or opposition for future aquatic herbicide use to target Eurasian watermilfoil in the Twin Lakes?

Queston 19 (2022-Herbicide treatment responses only): What is your level of support for the use of the following EWM management techniques in North and South Twin Lakes?

2017



2022

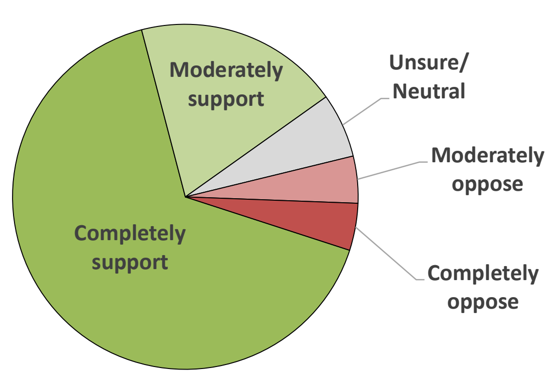


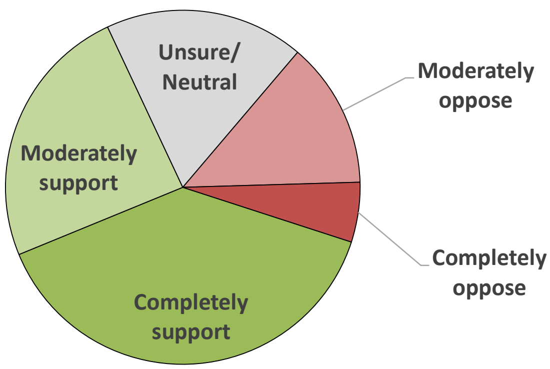
Figure 3.3-10. Select survey responses from the District Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

The District has utilized professional hand-harvesting with DASH (Diver Assisted Suction Harvesting) firms to assist in managing the Eurasian watermilfoil population and extending the time of relief from nuisance conditions. Figure 3.3-11 highlights the level of support amongst stakeholder respondents who oppose or support DASH harvesting. The top concerns for hand-harvesting with DASH use in both surveys on North and South Twin Lake included potential cost is too high and ineffectiveness of technique strategy.

Question 31 (2017): What is your level of support or opposition for hand harvesting/removal to target Eurasian watermilfoil in the Twin Lakes?

Queston 19 (2022-Hand-harvesting with DASH treatment responses only): What is your level of support for the use of the following EWM management techniques in North and South Twin Lakes?

2017



2022

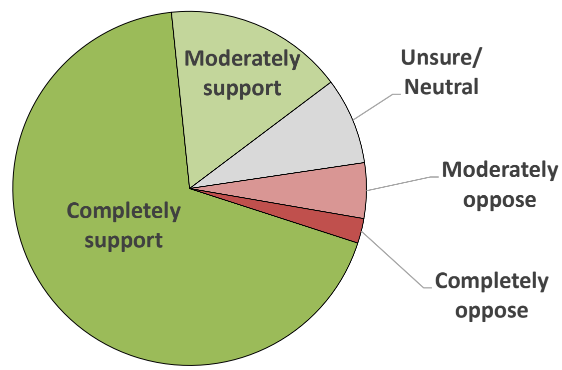


Figure 3.3-11. Select survey responses from the District Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

Within the 2022 survey, stakeholders were also asked if they believed the previous 2019/2020 North Twin Lake and 2021 South Twin Lake treatments were effective (Figure 3.3-12). About 45% of respondents answered "*Yes"* while 48% answered "*I think so but can't say for certain"*. This question was filtered by using answers from year-round residents and within that data, 55% of the respondents believed the treatments were effective.

Queston 21 (2022): In 2019 and 2020 on North Twin and 2021 on South Twin, the lakes spot treatments were conducted with the herbicide ProcellaCOR to manage EWM. Do you believe these treatments have been effective?

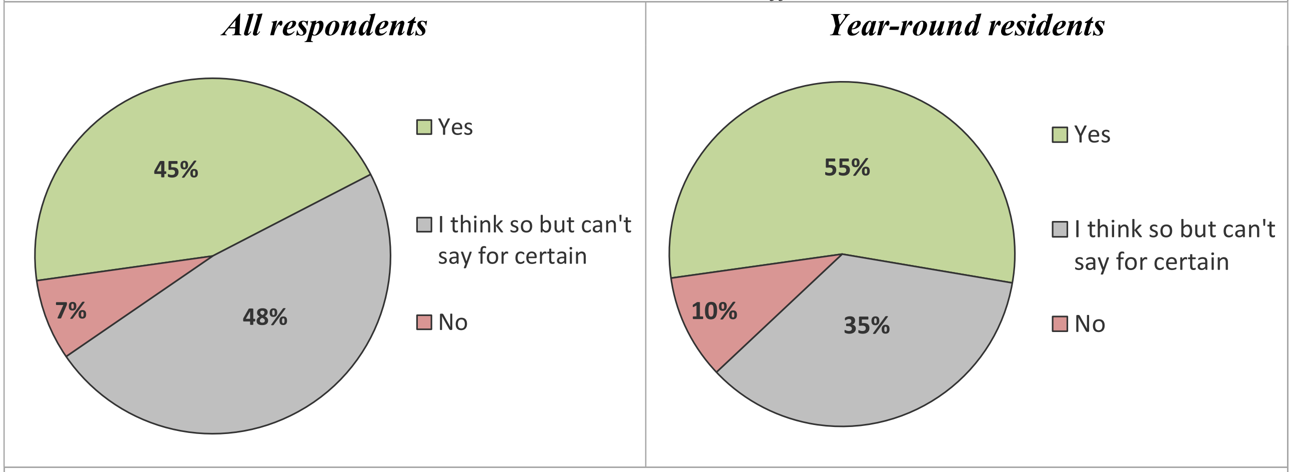


Figure 3.3-12. Select survey responses from the District Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

North and South Twin Lakes Prevention & Containment

The North and South Twin Lakes 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 District utilizes WDNR grant funding to sponsor watercraft inspections through the WDNR's Clean Boats Clean Waters (CBCW) program at three public boat launches (South Twin Lake Rd Landing, North Twin Lakota Rd Landing, and the North Twin Millerville Rd Landing). The District targets 400 hours of combined watercraft inspects at these landings; 200 hrs at the Phelps landing and 100 hrs each at the Lakota Rd and Twin Lake Rd landings. The District's Clean Boats Clean Waters program has been well organized, with numerous watercraft inspections occurring annually (Figure 3.3-12 showing recent history).

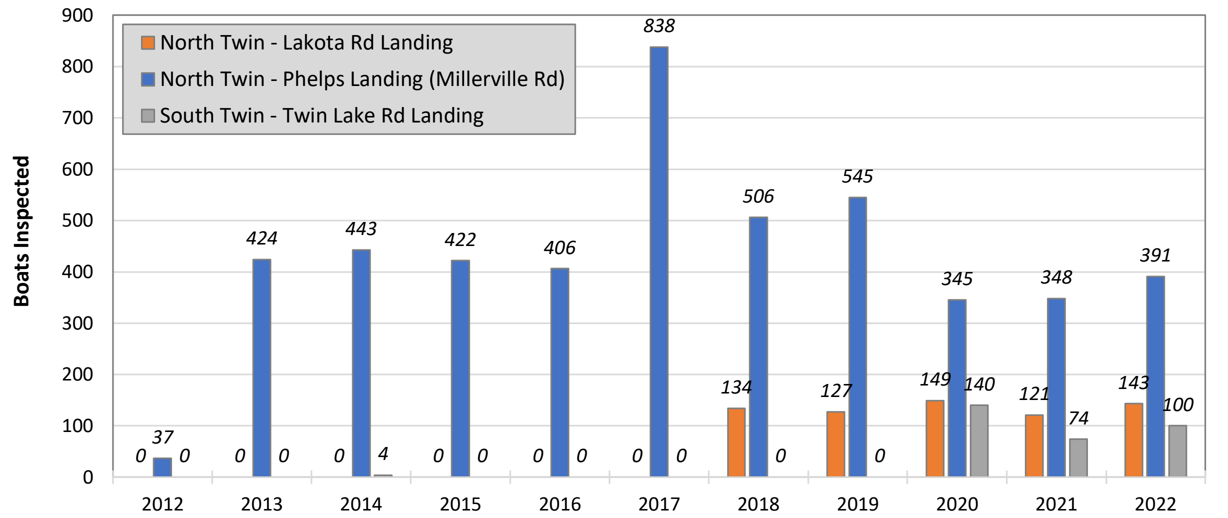


Figure 3.3-12. Watercraft inspections conducted on North and South Twin Lakes 2012-2022. Data from WDNR, SWIMS.

Based upon modeling by the University of Wisconsin Center for Limnology, North and South Twin Lakes is one of the state's top 300 AIS Prevention Priority Waterbodies. This means that North and South Twin Lakes has a high number of boats arriving from lakes that have AIS (receiving) and a high number of boats moving from North and South Twin Lakes 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), water-less cleaning stations (e.g. CD3 systems), and remote video surveillance (e.g., I-Lids™) could be partially funded through this program.

3.4 Swimmers Itch

Cercarea dermatitis or swimmer's itch is a type of skin reaction that is caused when the larval stage of a shistosome flatworm accidentally burrows into a human's skin when that person is spending time in the water (Figure 3.4-1).

The skin reaction varies from one individual to another, but is usually accompanied by intense itching and a rash of small red bumps that look similar to insect bites. Each of the red bumps is caused by localized, inflammatory immune response to an individual parasite which will die within hours of entering into the skin. The allergic reaction can greatly compromise the recreational value for those who enjoy spending time in the water. A Medical Doctor who is a Twin Lakes Riparian and whose specialty is Pathology reports that for some individuals, the reaction can be so severe they may require medical attention (due to the intense inflammatory response or a secondary skin infection). Young children seem to be more affected by this condition; as they typically spend more time in the water, have more sensitive skin, and have a tendency to spend more time in near-shore areas of the lake where the flatworms may be more concentrated.

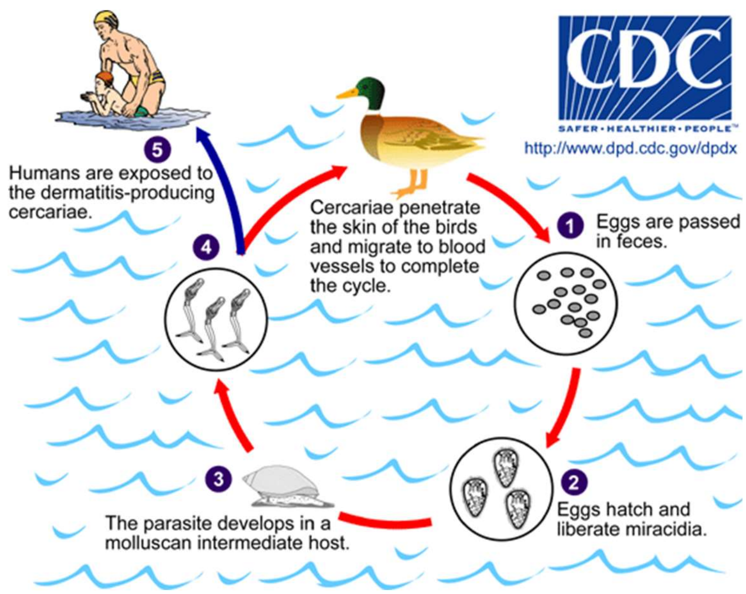


Figure 3.4-1. Swimmer's itch life cycle. Obtained directly from the Centers for Disease Control & Prevention website (CDC 2012).

The larval stage (cercariae) of this group of flatworms needs to burrow into the skin of certain bird species to complete its lifecycle ❹. While the primary hosts are ducks, gulls, geese, swans, and red-winged blackbirds, other non-bird species (e.g. muskrats, mice) have also been shown to complete this parasite's life cycle. Mergansers have been known to have some of the highest infection rates of this group of parasites. After the flatworm matures in the bird host, it produces eggs that are released into the water through the bird's feces ❶. The eggs hatch ❷ and the immature life stage (miracidia) of the parasite seeks out a snail host to continue maturation ❸. While not all snail species will suffice as intermediate hosts for the flatworms, nine or more species have been known to host flatworm species associated with swimmer's itch. Once the flatworm matures the larval cercaria emerges and seeks out a definitive host to complete the lifecycle. However, sometimes the cercariae accidently encounter a human and attempt to burrow into the skin ❺, causing the skin reaction discussed above.

Historically, molluscicides have been used to combat swimmer's itch by targeting the intermediate host, snails. The pesticides are non-selective towards snails, mussels, and other mollusks that play an integral part of the aquatic ecosystem. For that reason, along with the high expense and uncertain long-term consequences of applying these metal-based pesticides, this management technique has gone out of favor and typically is not permitted in Wisconsin.

Below are the following steps that can be taken to prevent or reduce the discomfort caused by swimmer's itch. The following summary list is based off information available on the WDNR's website:

- Avoid spending time in shallow water, especially if swimmer's itch has been known to be a problem in the area.
- Avoid spending time in the water between noon and 2 p.m, during which cercariae are most prevalent.
- Towel off immediately after getting out of the water. Cercariae will not penetrate the skin until after the person leaves the water. There may be an opportunity to remove the parasite before this occurs.
- Discourage ducks and other waterfowl from congregating in or near swimming areas by keeping near-shore areas vegetated, and by avoiding feeding the birds.

Avoid using riprap or seawalls along the shoreline, as this provides an excellent substrate for many snail species. Host snails are known to live on all types of substrate (sand, rock, mulch, vegetation) with an increased preference for sandy beaches.

Research and Management of Swimmers Itch on Twin Lakes

In 2021 The District engages Swimmers Itch Solutions, LLC (SIS) to perform an assessment of swimmers itch (SI) on the Twin lakes. Molecular data from snail collections during the assessment by SIS scientists confirmed the existence of the SI problem in North and South Twin Lakes. The District continued to monitor the incidences and locations where swimmers itch occurred in 2022 and 2023. The District collaborated with SIS in filing two separate applications for a permit with the WDNR to consider a research project to break the host-to-host dynamic which exists between snails (as the intermediate host) and specifically mergansers (the definitive host) on the Twins. Both permit applications to conduct research projects to mitigate swimmers itch were denied by the WDNR. The District's SI committee continues to explore ways secure a permit from the WDNR to address the SI problem on the Twin Lakes and pursues identifying other alternatives that may offer a solution to this problem. The District intends to converse with other lakes to determine how extensive SI is throughout northern WI.

4.0 SUMMARY & CONCLUSIONS

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

1) Collect detailed information regarding invasive plant species within the Twin Lakes, with the primary emphasis being on Eurasian watermilfoil.
2) Collect sociological information from District riparians regarding their use of the lake and their thoughts pertaining to the past and current condition of the lake and its management.
3) Create an updated aquatic-plant management plan for the District considering the evolution of BMPs and changes on regulatory support for various techniques since the previous management planning effort.

The three objectives were fulfilled during the project and have led to a good understanding of the Twin Lake's aquatic plant community, the lake in general, and the folks that care about the lake. In addition to point 3 above, the District Lake Management Team also took this opportunity to update some of their non-aquatic plant management goals and actions from the *North and South Twin Lakes Comprehensive Management Plan* (June 2018). The District continues to strive for a healthy lake that can be enjoyed by lake users, particularly supporting high quality opportunities for swimming, fishing, recreating, and enjoying the natural aesthetic beauty of the Northwoods.

By all standard metrics, the ongoing vegetation surveys reveals that the aquatic plant community of the Twin Lakes is of average or higher quality than lakes within the same ecoregion and throughout the state. While some changes have been noted, the aquatic plant community of North Twin Lake continues to be healthy and relatively stable since earlier surveys in 2011 and 2016. The aquatic plant community of South Twin Lake has experienced more changes, related to the establishment of EWM in the system and the control actions that have taken place in an effort to maintain a reduced EWM population within the lake. At this time, the aquatic plant community of South Twin has some of the highest populations of native species, particularly pondweed species.

The EWM population of the Twin Lakes, particularly South Twin, is currently at relatively low levels. The District has been extremely active in EWM management decision making over the years, embracing changes in technologies, philosophies, and risk assessments. The District continues to be committed to managing for a low EWM population in the system, with the goal being to maintain the low population through manual removal efforts and small-scale herbicide treatments. Based upon their understanding of when EWM populations have reached pivotal levels in the past, the District has created a matrix of size and density thresholds to guide management decision making.

5.0 AQUATIC PLANT IMPLEMENTATION PLAN SECTION

The District's *Comprehensive Management Plan* for the Twin Lakes was finalized and approved by the WDNR in 2018. This *Plan* can be found on the WDNR website located here:

https://apps.dnr.wi.gov/lakes/grants/project.aspx?project=128402234

The Implementation Plan Section of the *2018 Plan* includes the following management goals along with specific management actions developed to help reach those goals.

1. Control Existing and Prevent Further Aquatic Invasive Species Infestations within the Twin Lakes
    - Continue Clean Boats Clean Waters watercraft inspections at critical public access locations
    - Coordinate volunteer monitoring of AIS
    - Coordinate annual professional monitoring of AIS, particularly EWM
    - Conduct EWM Population Control on North Twin Lake Using Hand-Harvesting and Herbicide Spot Treatments
    - Conduct Large-Scale Herbicide Treatment on South Twin Lake
    - Develop Long-Term Contingency Strategy for Rebounding EWM Populations in South Twin Lake
    - Investigate and Study Alternative Management Methodologies
    - Coordinate Periodic Quantitative Vegetation Monitoring
2. Maintain Current Water Quality Conditions
    - Monitor water quality through WDNR Citizens Lake Monitoring Network
3. Increase District'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 NSTLRA's involvement with other entities that have responsibilities in managing (management units) the Twin Lakes
    - Conduct Periodic Riparian Stakeholder Surveys
4. Improve Lake and Fishery Resource of the Twin Lakes
    - Educate Stakeholders on the Importance of Shoreland Condition and Shoreland Restoration
    - Protect natural shoreland zones around the Twin Lakes
    - Coordinate with WDNR and private landowners to expand coarse woody habitat in the Twin Lakes
    - Educate Stakeholders on Swimmers Itch
    - Continue the Loon Watch Program

Figure 5.0-1. District management goals (numbered) and actions developed to assist in reaching the goal. From *North & South Twin Comprehensive Management Plan* (2018)

During this process, the District revisited their Aquatic Plant Management Plan based on the lessons learned during the project and current best management practices (BMPs) for aquatic plant management. The goal of this project was to update Management Goal 1 of the District's *Comprehensive Management Plan* (Figure 5.0-1). Within the following Implementation Plan, Management Goals 1-4 were developed through a collaborative effort of the District Lake Management Team and ecologist/planners from Onterra.

The District also utilized this opportunity to refresh additional aspects of other overall management goals. The subsequent Management Goals 5-10 were constructed and authored solely by the District Lake Management Team, although some text was carried over from the 2018 *Comprehensive Management Plan*.

Within the following management actions, the District Board of Commissioners is listed as the facilitator for all management actions. The District Board of Commissioners will be responsible for deciding whether the formation of sub-committees and/or directors is needed to carry out the various management actions.

The Implementation Plan represents the path the District will follow in order to meet their lake management goals. The goals detailed within the plan are designed to be ambitions, but realistic and achievable considering the capacity of the District. 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 District has a Functioning and Up-to-Date Management Plan

Management Action:	Periodically update lake management plan
Timeframe:	Continuation of current effort; periodic
Facilitator:	The District 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 (CLMP)* 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." 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. Although the District is not pursuing grant for implementing water quality or watershed management activities, they will roughly adhere to the 10-year recommended interval of investigations into these parameters to ensure the health of North and South

Twin Lakes. Likely at the time of the next Aquatic Plant Management (APM) Plan update, as discussed below, the District will consider taking a more comprehensive approach of investigating water quality and other lake parameters.

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 *CLMP* as it relates to the specific management actions being considered.

The District is focused on making sure their management plan is in good standing for grant eligibility and access to APM-related permits. As discussed above, the District is likely to consider commencing a comprehensive planning effort in roughly 2028, which would have an *Aquatic Plant Management Plan* component built into the overall comprehensive plan.

Annual Control & Monitoring Plan

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 District 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 District members for their understanding.

Management Action:	Conduct periodic District member stakeholder surveys
Timeframe:	Periodic: corresponding with management plan updates or when prompted
Facilitator:	The District Board of Commissioners
Description:	Formal riparian stakeholder user surveys have been performed by the association in 2017 and 2022. Likely at the time of a Plan update or prior to a large management effort, an updated stakeholder survey would be distributed to the District 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 2023, 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: Monitor Aquatic Vegetation on Twin Lakes

Management Action:	Periodically monitor the Eurasian watermilfoil population
Timeframe:	Periodic: annually; Timing: during latter part of growing season
Facilitator:	The District 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 North & South Twin Lakes, this survey would likely take place in late-August to the end of September, dependent on the growing conditions of the particular year and occurring after all management activities have ceased. This survey would include a complete or focused, particularly for North Twin Lake, meander survey of the system's littoral zone by professional ecologists and mapping using GPS technology (sub-meter accuracy is preferred). Since 2007, complete or focused late-season EWM mapping surveys occurred on the Twin Lakes using a consistent mapping style and density rating system, largely as a monitoring and planning aspect of the EWM management program. The District will likely continue conducting annual Late-Season EWM Mapping Surveys on both lakes, but may consider a focused approach on North Twin.

Management Action:	Coordinate periodic point-intercept aquatic plant surveys
Timeframe:	Periodic: at least once every 5 years, Timing: during July-August
Facilitator:	The District 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) have been conducted in South Twin Lake annually between 2008-2022 with the exception of 2012 and 2019. The point-intercept survey has been completed on North Twin Lake in 2011, 2016, and 2021. This survey provides quantitative population estimates for all aquatic plant species within the lakes and is designed to allow comparisons with past surveys in the Twin Lakes 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 District will ensure the point-intercept surveys is conducted at least once every five years on each lake to maintain eligibility for WDNR AIS Control Grants, or potentially more frequently if prompted by a specific rationale. For South Twin Lake, it is likely that point-intercept surveys will take more frequently, such as every other year, as an aspect of monitoring the native plant community's response to ongoing management activities. If a whole-lake treatment is to occur on South Twin Lake, the District would ensure pre- and posttreatment whole-lake point-intercept surveys take place.

Management Goal 3: Prevent Establishment of New Aquatic Invasive Species

Management Action:	Monitor Twin Lakes entry points for aquatic invasive species
Timeframe:	Continuation of current effort
Facilitator:	The District Board of Commissioners
Description:	The North and South Twin Lakes 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 District utilizes WDNR grant funding to sponsor watercraft inspections through the WDNR's Clean Boats Clean Waters (CBCW) program at three public boat launches (South Twin Lake Rd Landing, North Twin Lakota Rd Landing, and the North Twin Millerville Rd Landing). The District targets up to 400 hours of combined watercraft inspects at these landings, allocating proportion of hours as the District deems appropriate. *https://dnr.wi.gov/Aid/documents/SurfaceWater/CleanBoatsCleanWatersFactSheet.pdf*

Management Action:	Investigate supplemental aquatic invasive species prevention and containment methods.
Timeframe:	Ongoing
Facilitator:	The District Board of Commissioners
Description:	Based upon modeling by the University of Wisconsin Center for Limnology, North and South Twin Lakes are both listed on the state's top 300 AIS Prevention Priority Waterbodies. This means that North and South Twin Lakes has a high number of boats arriving from lakes that have AIS (receiving) and a high number of boats moving from North and South Twin Lakes 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. The District is currently investigating alternative preventions 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™) for applicability at the landing locations.

Management Action:	Convey updated aquatic plant management information and messaging to District members and interested parties
Timeframe:	Ongoing
Facilitator:	The District Board of Commissioners
Description:	Aquatic Invasive Species are constantly evolving and spreading in our Lake and River resources. The Goal is to be aware of current AIS in the Twins, emerging AIS in other nearby geographic areas in order to prevent, mitigate or reduce the introduction of AIS and/or "control" existing AIS to a level that is established by The District. **STRATEGIES** - Awareness/Education of current or potential AIS which have/may invade the Twins by ; o Attending annual Lakes Conferences o Interaction with other Lake Districts and Associations to understand risks, options and costs to manage or prevent introduction of AIS o Use of consultants, WDNR and other stakeholders in the Twins to assess and implement changing best practices - Utilize The District financial resources in the war against AIS by; o Education of our constituency of AIS risks/alternatives via multiple communication methods o As discussed in the previous management action, consider capital outlays for capital assets such as CD3 or I-Lids to prevent, mitigate entry or spread of AIS on the Twins and other water resources by residents of The District as well as public users of the resource. Evaluate post implementation if the asset is providing expected value proposition. o As outlined above the implementation of CBCW or other riparian volunteer alternatives to assist in gathering data, identifying trends including physical evidence of the existence of AIS in The District in order to effectively plan from a financial and action perspective in the battle against AIS Using all facts gathered from a variety of resources, design annual budgets and activities annually. Present them to The District Board for discussion and approval and presentation in a summary format at the Annual meeting of The District for budget approval by The District members for lake management activities.

Management Goal 4: Actively manage EWM to "Control" the EWM population on the Twin Lakes

Management Action:	Conduct Integrated Pest Management Program towards EWM
Timeframe:	Ongoing
Facilitator:	The District Board of Commissioners
Description:	EWM has been present in the Twins since 2000. The Goal is to diligently monitor EWM and evaluate what management strategies, if any, should be considered and implemented to maintain "control" of EWM on the Twins for boating, fishing and other recreational activities in service to the members of The District and other public users of the Twins resource. Complete eradication of EWM is not deemed realistic but use of Integrated Pest Management activities, in a financially prudent, data driven approach can achieve "control". The District defines "lake-wide control" as being able to keep the EWM population of South Twin Lake below 10% littoral frequency of occurrence (measured by the point-intercept survey), and to hold the EWM population of North Twin Lake to current (2022) or lower levels. Historically the District has observed several occasions where EWM populations exceeded these levels, requiring whole-lake management activities the following year. Additionally, other management activities as outlined in the matrix below may be implemented when EWM populations are below these levels as part of achieving the overall management goal. The District has developed a management matrix to serve as a baseline guide of operations based on EWM colony characteristics (Table 5.0-1). The District strives to keep the EWM population in "control" through manual removal means, with as minimal need for whole lake treatments and herbicide spot treatments as possible.

Table 5.0-1. Updated EWM Management Matrix developed by the District

	Colony Density				
Colony Size	Surface Matting	Highly Dominant	Dominant	Scattered	Highly Scattered
< 1 acre	1,2,3	1,2,3	2,3	2,3,4	4
1 - 5 acres	1,2	1,2	1,2	2,3,4	3,4
5 - 10 acres	1	1,2	1,2	2,4	4
> 10 acres	1	1	1	2	4
Whole Lake > 15% LFOO	5	5	1	1,2	4

Activity

1 Herbicide Spot Treatment
2 Manual: DASH
3 Manual: Hand Pulling
4 No Active Management, Just Monitor
5 Whole Lake Herbicide Treatment

The District understands the importance of the native aquatic plant community, and strives to understand any collateral native plant impacts surrounding any management actions it takes. In order to reach this objective, the District 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, with more specific information contained below.

General IPM Program

- **Manual Removal**
    - ***DASH*** – a good strategy for small, emerging identified plants or to follow up after herbicide treatments to maximize length of time in which "control" or efficacy is achieved.
    - ***Hand Harvest*** – similar to DASH but even on a smaller scale and less dense population of EWM to prevent emergence/spread of new sparse EWM colonies.
- **Herbicide treatment**
    - ***Whole lake*** – can be designed as a whole lake or calculated on whole lake benefit depending on herbicide used, concentration of herbicide and other factors.
    - ***Spot treatment*** – Typically small scale is < 10 acres and large scale > 10 acres. Must also evaluate whole lake concentration of herbicide impacts in the design and monitoring of results. Depending on the size of the spot treatment and herbicide being used, the impact and concentration of the herbicide will be evaluated in the design of the treatment.
- **Mechanical Harvesting** – The District has historically had reservations about contracting mechanical harvesting efforts on the lakes, 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 on harvested native plants and bi-catch, especially small fish. This management tool is inconsistent with the District's goal of population management. Mechanical Harvesting is considered by the District to be a "last resort" activity when control cannot be achieved and mechanical is the only remaining option for effective use of the resource.
- **Do nothing** – if matrix parameters are not met the key activity is continued surveys and trending/analysis of the resource year over year.

IPM Program Details

Herbicide Treatment The District believes that dense areas of EWM that are impacting navigation, recreation, and aesthetics of the system can have these qualities restored for multiple years by conducting ProcellaCOR™ treatments using BMPs for implementation. As outlined in the matrix above, the District would generally consider targeting EWM colonies with herbicide use-patterns when densities are *dominant, highly dominant*, or *surface matting* within the lake.

While the District 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 for spot treatments, or in low exposure and long exposure times for whole-lake treatments.

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

- Early consultation with WDNR would occur. The District strives to work with the WDNR early in their planning stages to be alerted of any concerns that may be resolved or mitigated.
- The preceding annual *EWM Control & Monitoring Report(s)*, produced in Jan-March would outline the preliminary control and monitoring strategy for the upcoming season, potentially evolving based upon the result of a pretreatment survey and subsequent investigations and discussions.
- EWM efficacy would occur by comparing annual late-summer EWM mapping surveys. Specifically, these would be conducted during the *year prior to treatment*, *year of treatment*, and the *year after treatment*. Successful herbicide treatments would be those that result in almost no EWM within the application area during the *year of treatment* and little rebound during the *year after treatment.* Large EWM rebounds during the *year after treatment* would be considered seasonal suppression and not "control."
- If grant funds are being used, large areas are being targeted, and/or new-to-the-region herbicide strategies are being considered, the District will cooperate with WDNR to conduct a quantitative evaluation monitoring plan be constructed that is consistent with the *Draft Aquatic Plant Treatment Evaluation Protocol (October 1, 2016):*

  https://dnrx.wisconsin.gov/swims/downloadDocument.do?id=158140137

  This generally consists of collecting quantitative point-intercept data the *late-summer prior to treatment* (pre) and the summers following the treatment (*year of treatment and year after treatment*) within the application area – called sub-sample point-intercept survey. Whole-lake treatments on South Twin Lake would be monitored by using whole-lake point-intercept data.
- Herbicide concentration monitoring may also occur surrounding the treatment if grant funds are being used or the District believes important information would be gained from the effort. The District believes after numerous years of conducting this form of monitoring, it has reservations about the future utility of this data considering the large costs to ship and analyze these samples.
- 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.
- The District would work with the WVIC and the WDNR to possibly adjust the outflow at the dam surrounding the treatment in an effort to hold herbicide concentrations and exposure times in South Twin Lake. The District

	understands the limitations of these possible adjustments based upon many factors including precipitation. • 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, like walleye, have outgrown their most-sensitive life stage to herbicide exposure (first 14 days after hatching). 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. ***Manual Removal*** The District has implemented large amounts of manual removal efforts in the past, especially using DASH efforts following herbicide treatments. The District understands the role of size and density in determining if manual removal efforts are scale-appropriate for management. Areas appliable for hand-harvesting include EWM mapped with point-based methods such as *single or few plants*, *clumps of plants*, and *small plant colonies*. Low-density and smaller areas of EWM mapped with polygon-based methods may also be applicable to a hand-harvesting strategy as outlined in the matrix above (Table 5.0-1). • If a Diver Assisted Suction Harvest (DASH) component is utilized, the District 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. • Manual removal 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. • EWM efficacy would be determined by comparing annual late-summer EWM mapping surveys during the *year prior to treatment* to the *year of treatment*. Successful manual removal operations will at least maintain current levels of EWM between the two annual surveys.

Management Goal 5: Maintain Water Quality Conditions

Management Action:	Monitor water quality through WDNR Citizens Lake Monitoring Network.
Timeframe:	Continuation of current effort.
Facilitator:	The District Board of Commissioners
Description:	Monitoring water quality is an important aspect of every lake management planning activity. Collection of water quality data at regular intervals aids in the management of 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. Water quality data is collected by the Wisconsin Valley Improvement Corporation (WVIC) for a 3-year period, once every 10 years. The next sampling period will be conducted in 2030-2033. Volunteer water quality monitoring is taking place regularly by District volunteers through the Citizen Lake Monitoring Network (CLMN). The CLMN is a WDNR program in which volunteers are trained to collect water quality information on our lakes. The District sought enrollment and found several members willing to be trained in these activities. Training was conducted by WDNR specialist Sandra Wickman. Chemistry sampling is being collected (chlorophyll and total phosphorous) by District members under the CLMN on a minimum of three times throughout ice off conditions. The months, times of the month, and the areas on the lake of collection, are governed by the WDNR each year. These samples are sent to Madison for analysis and entry into the Surface Water Integrated Monitoring System (SWIMS). The District members under the CLMN are also monitoring Secchi Disk (clarity) readings in each lake twice per month. In addition, water temperatures are being collected using a supplied temperature probe by the WDNR. Secchi Disk and temperature readings are collected in pre-selected spots on the Lakes given out by the WDNR during ice off conditions, and are entered into the SWIMS database. All equipment and training are received and conducted by the WDNR. Sandra Wickman (715 365 8951) of the WDNR is the current contact person with this program. It is important to note that the data collected (water temperature, and Secchi readings) are entered into the WDNR SWIMS database by the volunteer. In addition to the CLMN program current efforts, additional water sampling will be completed by volunteers trained in chemistry sampling to monitor chlorophyll, phosphorus, and chlorine on additional stations (minimum of three) on North Twin, created by the WDNR considering the Lake Districts recommendations. Along with the additional water testing, monitoring vegetation growth around the testing points will also be conducted, and matched to the water testing data.

Management Goal 6: Reduce the incidents of Swimmer's Itch experienced by North & South Twin Lakes District members by 90% from previously reported levels, restoring full enjoyment of lake activities with lower risk of experiencing the debilitating Swimmer's Itch condition; to protect property values; and to support the economic sustainability of resorts and businesses on the Twin Lakes

Management Action:	Explore and investigate possible actions that can be implemented to reduce the incidents on swimmers itch on North & South Twin Lakes
Timeframe:	Continuation of current effort.
Facilitator:	The District Board of Commissioners
Description:	The 2022 LMP Stakeholders Survey completed by members of the District identified swimmers itch as the number 1 problem for the Twin Lakes. Through their feedback they are demanding the Lake District Commission take action to address this problem. The Commission has a responsibility to respond to the expectations of our constituency. The District will take the following action steps: • Educate Lake District members about the life cycle of swimmers itch, how swimmers itch is passed to humans, and preventive actions that can be taken by swimmers. • Track the incidents of swimmers itch experienced in the District using a third-party website accessible through the District web page. • Continue to research and explore possible strategies and actions that may result in the mitigation of swimmers itch.

Management Goal 7: Management of natural shoreland zones around the Twin Lakes

Management Action:	Educate Lake District members about the importance of shoreline conditions and shoreland restoration, and monitor resulting actions
Timeframe:	Continuation of current effort.
Facilitator:	The District Board of Commissioners
Description:	Approximately 7.4 miles (51%) of the Twin Lake's shoreline was found to be in either a *natural* or *developed-natural* state. It is therefore very important that owners of these properties become educated on the benefits their shoreland is providing to the Twin, and that these shorelands remain in a natural state. Since property owners may have little experience with or be uncertain about restoring a shoreland to its natural state, the District has decided to take the following actions: 1. Educate District members about the importance of healthy and natural shorelands.

	2. Solicit 3-5 District members to allow shoreland restoration and storm water runoff designs for their property. 3. The District will work with Vilas County Land & Water Conservation Department personnel or a private entity to create design work. Small scale WDNR grants may be sought to offset design costs. 4. Designs to be shared with the District members to provide further education of shoreland restoration projects. 5. Move forward with implementing shoreland restoration per the designs that were developed for those riparians that desire to carry out the project. Project funding would partially be available through the WDNR's Healthy Lakes program. 6. The District's goal would be to have up to three (3) shoreland restoration sites to serve as demonstrations sites to encourage other riparians to follow the same path of shoreland restoration. 7. The District's goal would be to have 5-10 formal shoreland enhancement activities within the next 5 years. 8. Additional information may be sent directly to riparians via e-mail and brochures that highlight these restoration projects. Additional printed information to be disseminated at the District's Annual Meeting. 9. The District website: nstlakedistrict.com to be used to document and showcase shoreland projects implemented by fellow riparians. 10. Consider formation of a Shoreland Restoration Sub-committee.

Management Action:	Coordinate with local and WDNR resources to expand implementation of WDNR's Healthy Lakes Program.
Timeframe:	2023 through 2028
Facilitator:	The District Board of Commissioners
Description:	Healthy Lakes is a state-wide initiative that helps improve the health of our lakes by increasing property owner participation in habitat restoration and runoff and erosion control projects that are eligible for cost-sharing funding: The District will take the following action steps: 1. Educate District members about the (5) five healthy lakes best practices. a. Fish Sticks – Creates fish & wildlife habitat. b. Native Plantings – Improves wildlife habitat, improves natural beauty, privacy & slows runoff. c. Diversion – Prevents runoff from flowing into the lake. d. Rock Infiltration – Captures and cleans runoff. e. Rain Gardens – Creates wildlife habitat & natural beauty while capturing and leaning runoff 2. Utilize The District website: nstlakedistrict.com to share program details and resources. 3. Showcase riparian properties who have implemented Healthy Lakes best practices on The District website.

	4. Consider the formation of a Shoreland Restoration Sub-Committee whose responsibilities would consist of coordinating education through informative, how-to meetings, mailings and online communications aimed at encouraging implementation of the Healthy Lakes best practices. 5. Provide access to subject matter experts who can offer additional professional expertise needed to navigate the process and program requirements.

Management Goal 8: Sustain Current Walleye and Muskellunge Fisheries and Improve North and South Twin Lakes Fisheries as a Whole

Management Action:	Collaborate with the WDNR and interested parties to conduct and gather research that aid in maintaining North and South Twin Lakes as a premier fishery by addressing the input received from The District's Riparian Survey.
Timeframe:	Initiate 2023-2028
Facilitator:	The District Board of Commissioners
Description:	The goal is to provide optimum use and enjoyment of aquatic resources. A healthy and diverse environment is essential to meet this goal and shall be promoted through management programs. Management programs shall be "integrated" - close working relationship among functions of the Lake District, WDNR, other governmental agencies, federally recognized Tribal Nations, and the public. The District will keep interested parties informed as necessary of policies, plans and management. The District needs adequate information to set attainable management objectives, evaluate attainment of those objectives, and make recommendations on required fishing regulations, stocking quotas, and habitat restoration and improvements. All decisions (stocking, habitat, fishing regulations) are based on a population's status relative to the objectives. **Action Steps: Walleye** Walleye are considered sustained in North and South Twin Lakes by natural reproduction. They are the most targeted fish per the riparian surveys, and represent a significant attraction to the lakes. *District Objectives:* 1. Insure there is a minimum of 3 or more adult walleye per acre and total harvest is less than 35% of the adult population to protect spawning adults. 2. 25% of all adult walleye are 15" or larger. 3. Conduct surveys every five years to determine target objective(s) starting in 2024. 4. Implement a walleye management plan by 2028 **Action Steps: Muskellunge** Muskellunge are found in lakes occupying areas with abundant submerged aquatic plants. Nearly 90% of muskellunge waters occur in the Northern Region where North and South Twin Lakes are located. North and South Twin Lakes is Classified as a Class "A" Musky lake. Which is defined as "able to support good muskellunge

	populations and provide the best muskellunge fishing". Continue to conduct research to gain a better understanding of muskellunge population dynamics and population variability in North and South twin Lakes. September 20th 2022 saw a stocking of 280 Muskellunge fingerlings into North Twin and 70 fingerlings into South Twin lakes. Permit was granted by the WDNR based on research conducted by them in conjunction with the Lake District. *District Objectives:* 1. 30% of all adult muskies are 40" or larger. 2. Conduct surveys every five years to determine target objective(s) starting in 2024. 3. Completion of Muskie management plan by 2028. **Action Steps: Bass** North and South Twin Lakes are home to both largemouth and small mouth bass. The popularity of bass fishing has increased in the past 6 years as both a recreation and competitive sport. As such has been indicated on the riparian surveys as a pursued fish of choice. *District Objectives:* 1. 30% of all adult bass (largemouth and smallmouth) are 14" or larger 2. Conduct surveys on each species every five years to determine target objective(s) starting 2025. 3. Implement management plan(s) per results of survey(s) conducted. **Action Steps: Panfish** Panfish: Bluegill, Crappies, Yellow Perch Our most popular fish to catch occur throughout the state and anglers enjoy catching them throughout the year. *District Objectives:* 1. 30% of panfish are 9" or larger. 2. Conduct surveys on each species every five years to determine target objective(s) starting 2025. <u>Overall District Action Steps</u>: • Contact WDNR departments to gather current data on all species in the Twin Lakes. • Contact Tribal communities to gather current data (if any) on current species in the Twin Lakes and communicate management goal • Contact Brian Sloss Professor of Fisheries and Water Resources brian.sloss@uwsp.edu

Management Goal 9: **Continue the Loon Watch Program**

Management Action:	Continue the Loon Watch Program
Timeframe:	Continuation of current effort
Facilitator:	The District Board of Commissioners
Description:	The District has formed a Loon Watch Committee to monitor the Twin Lakes for loon activity. The Loon Watch program is operated through the Sigurd Olson Environmental Institute from Northland College. The purpose of the program is to provide a picture of common loon reproduction and population trends on northern Wisconsin lakes. Loon watch volunteers send in a yearly report on sightings of any loon activity, number counts, chicks observed and markings on a lake map where loons were seen. The Twin Lakes have been considered non- producing by Northland College. Although a few chick sightings have been reported, there is no verification of successful survival till fall migration. No nesting sites have been discovered on either lake. The District will continue this program, providing information and education to its membership at the District's annual meetings.

Management Goal 10: **Expand and Strengthen the District's partnership with its members and Facilitate partnerships with other governmental and management entities through education, communication and data collection**

Management Action:	Educate members and other stakeholders with respect to conditions and activities that effect lake protection and enjoyment.
Timeframe:	Continuation of current effort
Facilitator:	The District Board of Commissioners
Description:	The District educates and informs it's members and other stakeholders through a variety of means such as meetings, appearing as guest speakers at local events, maintaining a web site, and digital communications. It is a priority to not only provide information and data but to facilitate understanding of lake issues, implementation of activities that address said issues and the intended outcome of those actions. The means by which the District facilitates understanding of pertinent information is by consulting resources such as lake consultants, the WDNR, local lake management associations and districts; Town Lakes Committees and membership input.

Management Action:	Improve efforts to communicate Information and Activities through written, electronic and in person sharing.
Timeframe:	Continuation of current effort
Facilitator:	The District Board of Commissioners
Description:	1. The District communicates with members and stakeholders through its website, nstlakedistrict.com and email. The District plans to update its website interface to make it more user friendly for current users. The website is the primary way to communicate information to the stakeholders; as part of the technology update the District will prominently feature its email address to enable its members and stakeholders to reach out to the District with questions and concerns. 2. The District will survey members periodically (but no less than every 5 years) to determine how effectively the District is addressing the members concerns and priorities. 3. The District has become aware of a significant increase in the number of short-term rental properties on the lakes. This increase results is in more usage by persons unfamiliar with the topography and ecosystem of the lakes. The District will extend its communication efforts to these users by preparing and distributing written materials containing important information about the lakes that will result enhance their lake experience and alert them to areas or activities of concern.

Management Action:	Ensure that data collected through lake resources that is used to support decisions made by the District (whether for action/inaction) is communicated with clarity, context, and simplicity.
Timeframe:	Continuation of current effort
Facilitator:	The District Board of Commissioners
Description:	Summarize scientific data for presentation to members and stakeholders in an easily understood manner ,either written, or through in person presentations.

6.0 LITERATURE CITED

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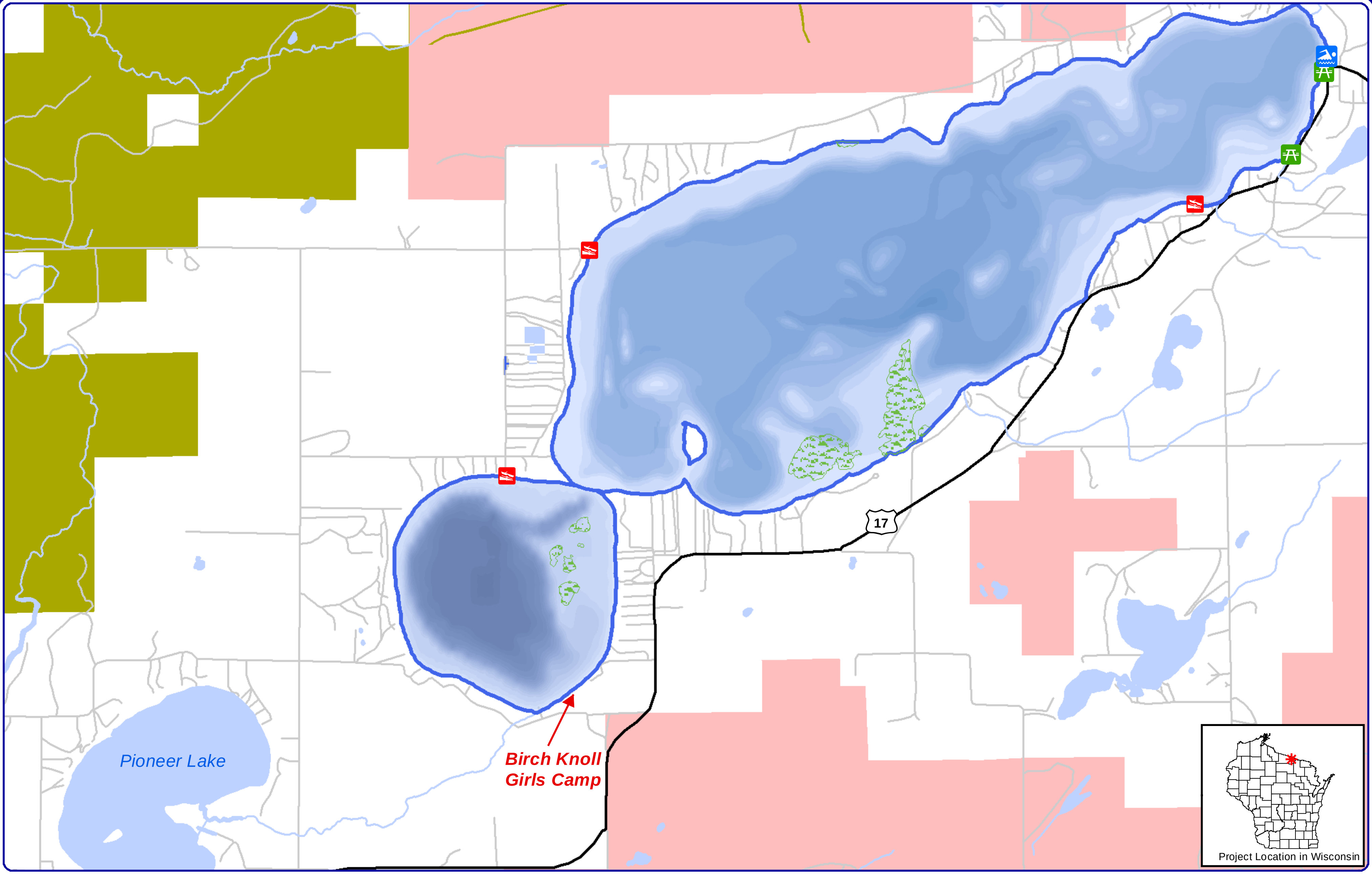


N W E S

4,300

Feet

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

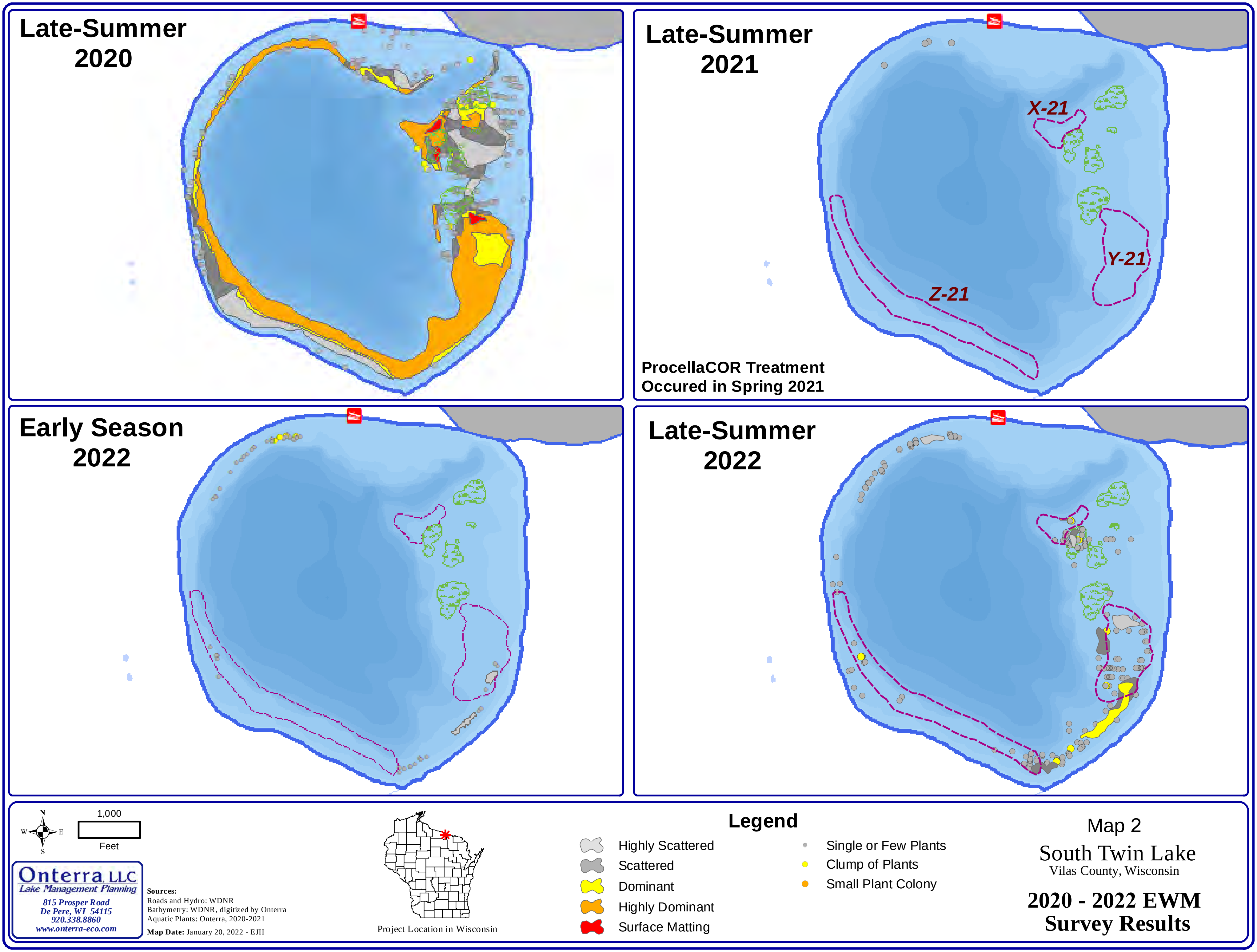
Sources:
Roads and Hydro: WDNR
Map Date: November 3, 2015
Filename: NSTwin_Location_proposal.mxd

Legend

- North and South Twin Lake ~ 3,516 acres
  Onterra Definition
- National Forest Land
- County Forest
- Public Access
- Public Park
- Public Beach

Map 1
North and South Twin Lakes
Vilas County, Wisconsin

Project Location
& Lake Boundaries



Onterra, LLC
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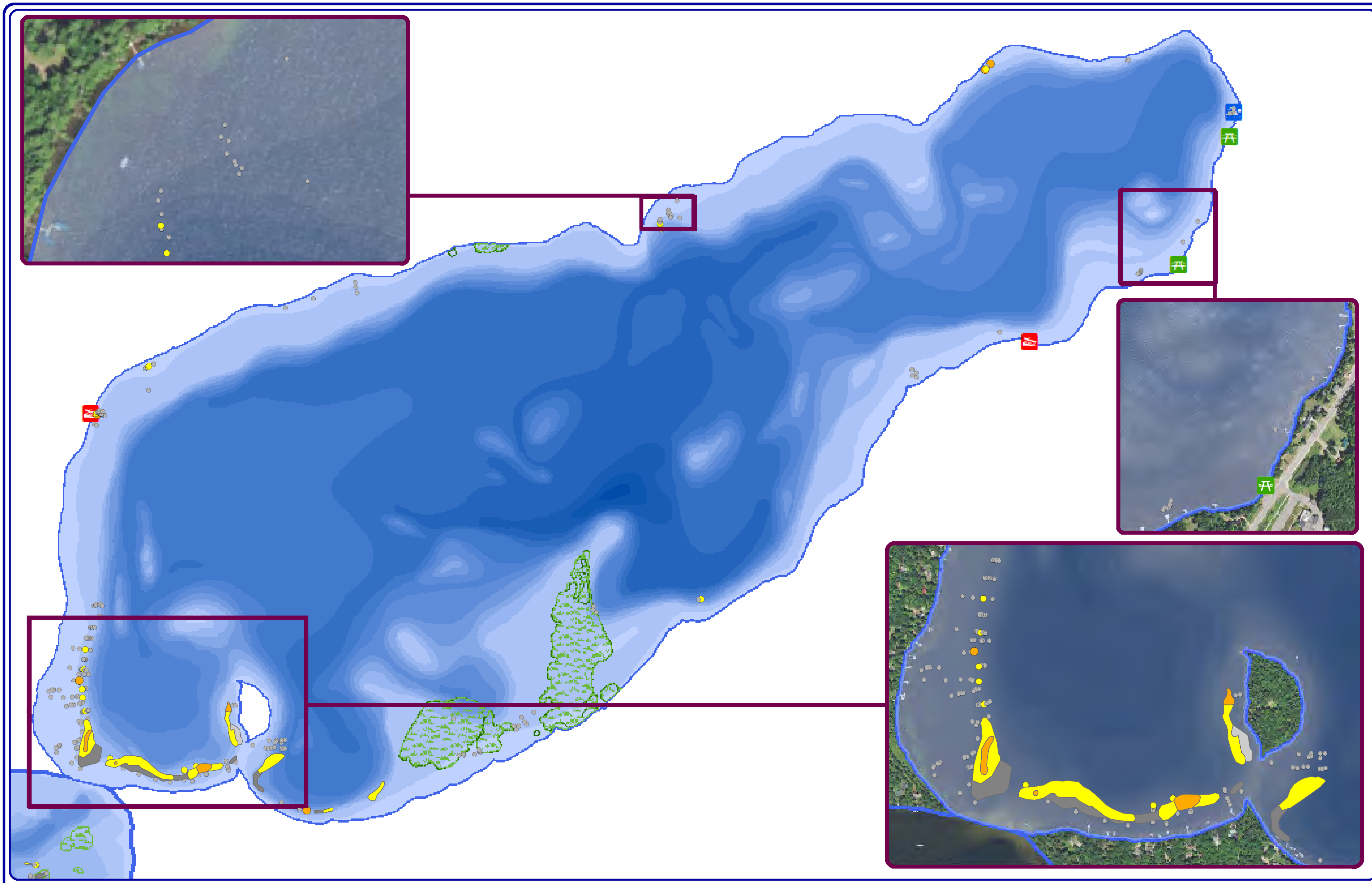
920.338.8860
www.onterra-eco.com

Sources:
Roads and Hydro: WDNR
Bathymetry: WDNR, digitized by Onterra
Aquatic Plants: Onterra, 2020-2021
Map Date: January 20, 2022 - EJH

Map 2
South Twin Lake
Vilas County, Wisconsin
2020 - 2022 EWM Survey Results



Legend

EWM Survey Results *(August 24-25, 2022)*

- Highly Scattered
- Scattered
- Dominant
- Highly Dominant
- Surface Matting
- Single or Few Plants
- Clump of Plants
- Small Plant Colony
- Bullrush Community *(Summer 2016)*

N
W E
S

2,000
Feet

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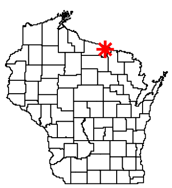
De Pere, WI 54115
920.338.8860
www.onterra-eco.com

Sources:
Roads and Hydro: WDNR
Bathymetry: WDNR, digitized by Onterra
Orthophotograph: NAIP, 2020
Aquatic Plants: Onterra, 2022
Map Date: January 20, 2023 - EJH



Project Location in Wisconsin

Map 3
North Twin Lake
Vilas County, Wisconsin

August 2022 EWM Survey Results

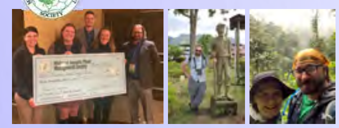
A

APPENDIX A

Public Participation Materials

Onterra, LLC

- Founded in 2005, HQ in De Pere, WI
- Staff
  - Three full-time ecologists
  - One part-time paleoecologist
  - Four full-time field technicians
  - Five summer interns
- Services
  - Science and planning
- Philosophy
  - Promote realistic planning
  - Assist, not direct



Onterra LLC

Presentation Outline

- Lake Management Planning
- Aquatic Plants
- Non-Native Aquatic Plants
  - 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

Onterra LLC

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.

Onterra LLC

What is a Lake Management Plan?

- Many organizations have plans for managing waterbodies that include Twin Lakes
- This would be the local lake organization's *Plan* for managing Twin Lakes
  - Based upon their capacity
  - Addressing their concerns
  - Complimentary to other *Plans*

Onterra LLC

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

Onterra LLC

Management Planning Project Overview

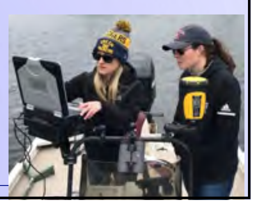
- Foster holistic understanding of ecosystem
- Collect & analyze data
  - Technical & sociological
- Construct long-term & useable plan
  - Living plan subject to revision over time
- Onterra's role is to provide technical direction
  - Not really recommendations

Onterra LLC

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 Twin Lakes Aquatic Plant Survey Results
  - 3.3 Eurasian watermilfoil
- 4.0 Summary & Conclusions
- 5.0 Implementation Plan
- 6.0 Literature Cited

2022 District Survey
- 436 Sent, 182 returned = 42%
- >60% = statistically valid representation of population sampled

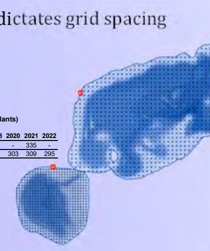


Onterra LLC

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

	Point Spacing (meters)	Total Sampling Locations	Littoral Sample Locations (≤ max depth of plants) 2008	2009	2010	2011	2013	2014	2015	2016	2017	2018	2020	2021	2022
North Twin Lake	100	1164	-	-	-	368	-	-	-	353	-	-	-	335	-
South Twin Lake	63	622	304	303	309	304	311	302	305	295	307	304	303	309	295



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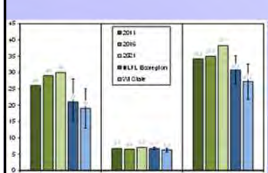
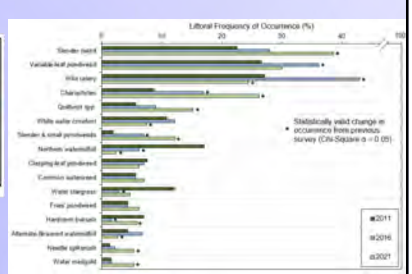
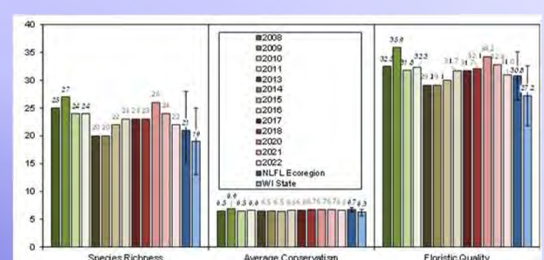
Highlights of North Twin





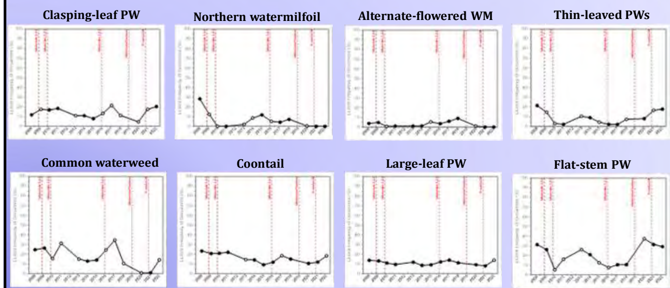
Onterra LLC

Highlights of South Twin



Onterra LLC

Highlights of South Twin



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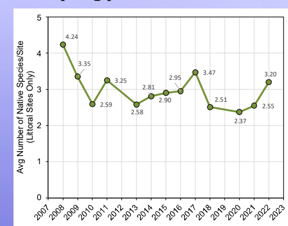
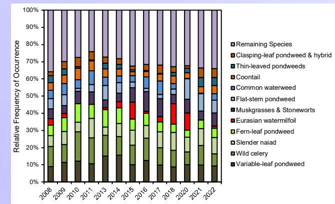
Comparative Metrics

- Ave Native Species Per Littoral sampling point



- Relative Frequency of occurrence



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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

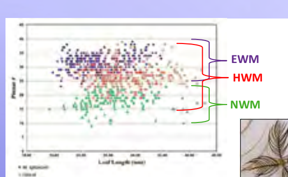
Onterra LLC

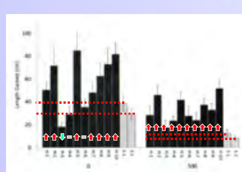
Non-Native Aquatic Plants

Eurasian Watermilfoil

- **First "officially" documented *in 2001***
- **DNA analysis has only been pure-strain EWM to date**

Science on Invasive Watermilfoil Hybridity





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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

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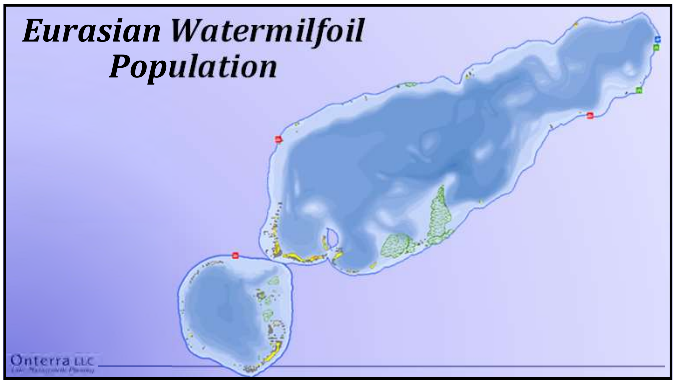
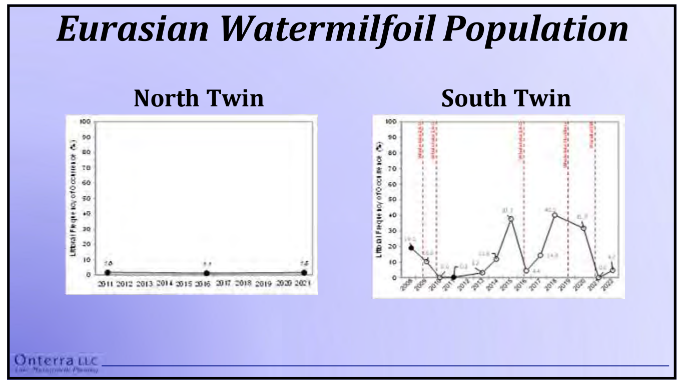
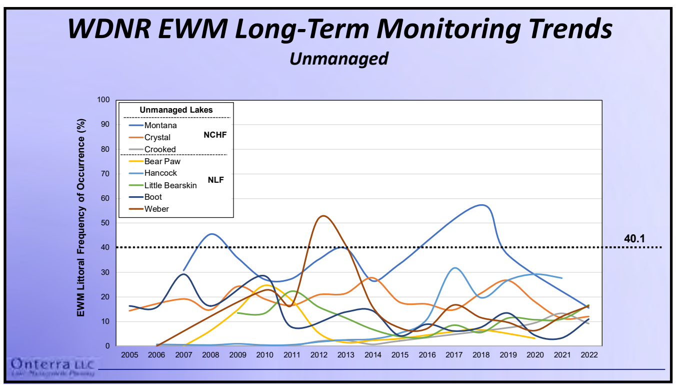
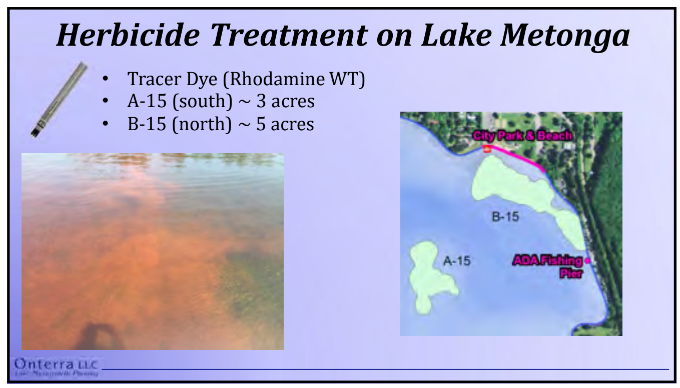
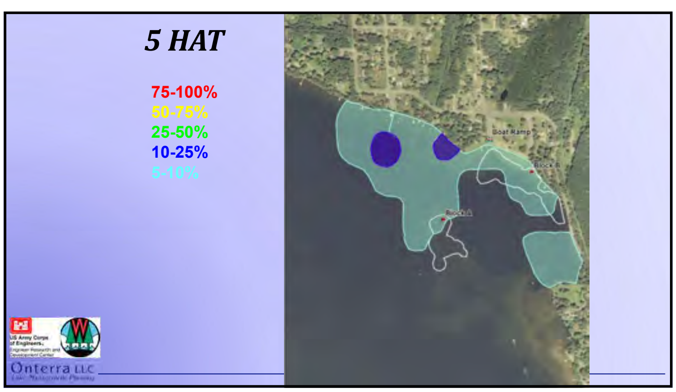
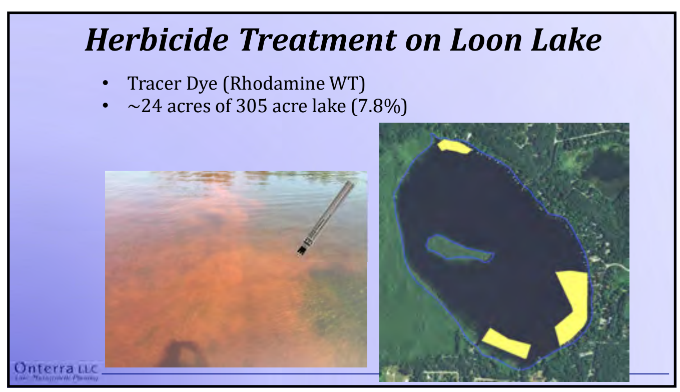

Eurasian Watermilfoil Population
Onterra LLC


Eurasian Watermilfoil Population
North Twin
South Twin
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
40.1
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022
Onterra LLC

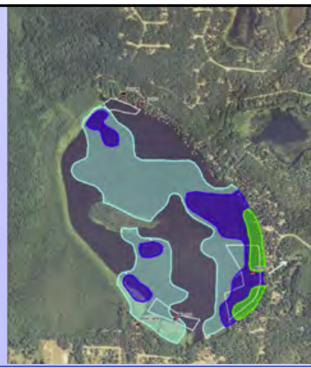

Herbicide Treatment on Lake Metonga
Tracer Dye (Rhodamine WT)
A-15 (south) ~ 3 acres
B-15 (north) ~ 5 acres
City Park & Beach
B-15
A-15
ADA Fishing Pier
Onterra LLC


5 HAT
75-100%
50-75%
25-50%
10-25%
5-10%
Onterra LLC


Herbicide Treatment on Loon Lake
Tracer Dye (Rhodamine WT)
~24 acres of 305 acre lake (7.8%)
Onterra LLC

6 HAT

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



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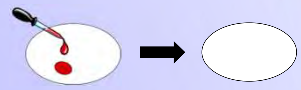
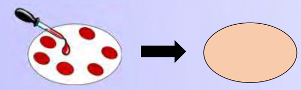
Ecological Definitions of Herbicide Treatment

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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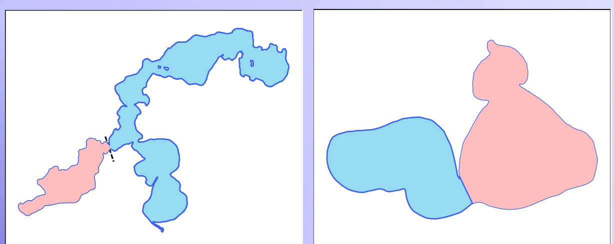
Area of Potential Impact (AOPI)

- Mixing area, reaches equilibrium - basin or bay of a lake



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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!

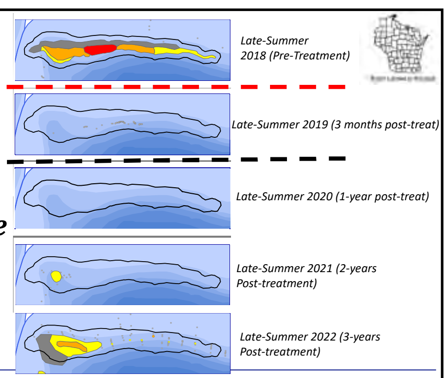
Onterra LLC

Florpyrauxifen-benzyl (ProcellaCOR™)

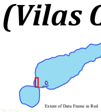
- New class of synthetic auxin hormone mimics
  - Much different binding affinity than other auxins
  - Use at PPB rate vs PPM
- Shorter contact exposure time (CET) requirement
- Short environmental fate of active ingredient (mainly photolysis)
- Acid metabolite has activity as an herbicide (longer environmental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

Onterra LLC

EWM



North Twin Lake (Vilas Co.)



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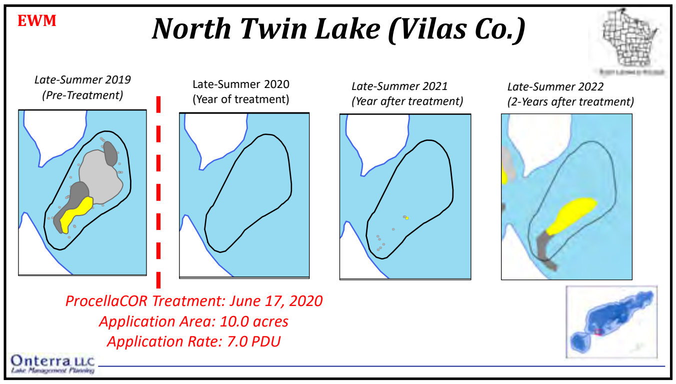
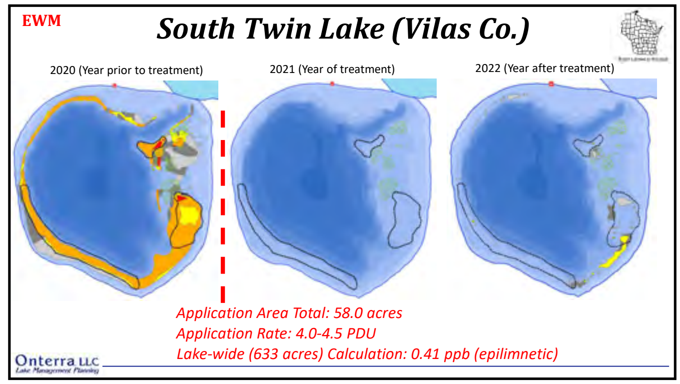
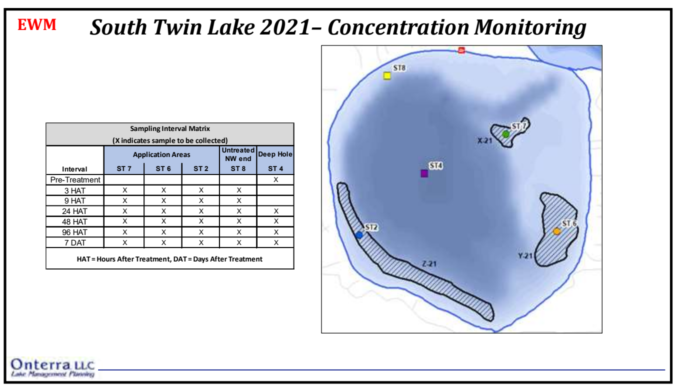


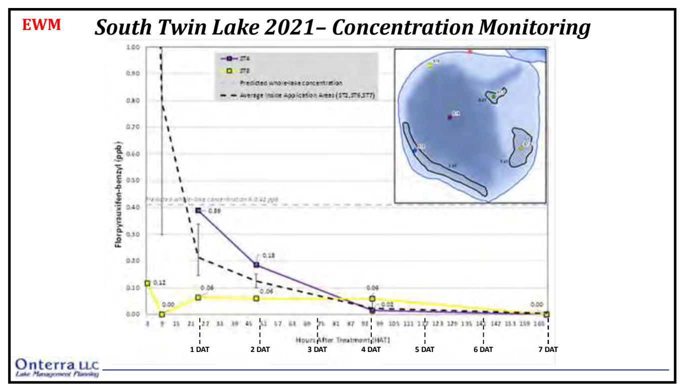


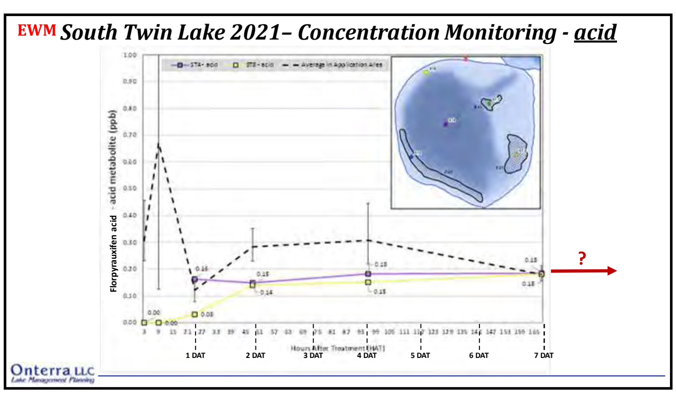


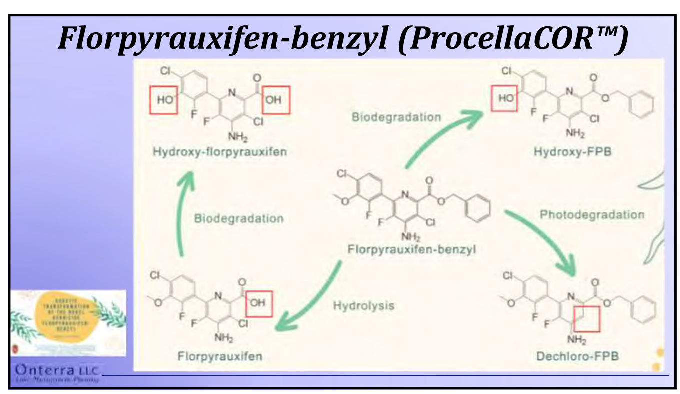
Sampling Interval Matrix (X indicates sample to be collected)

Interval	Application Areas ST 7	Application Areas ST 6	Application Areas ST 2	Untreated NW end ST 8	Deep Hole ST 4
Pre-Treatment					X
3 HAT	X	X	X	X	
9 HAT	X	X	X	X	
24 HAT	X	X	X	X	X
48 HAT	X	X	X	X	X
96 HAT	X	X	X	X	X
7 DAT	X	X	X	X	X

HAT = Hours After Treatment, DAT = Days After Treatment







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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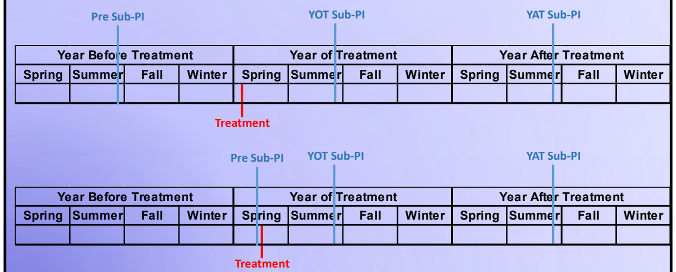
Sub-Sample Point-Intercept Survey



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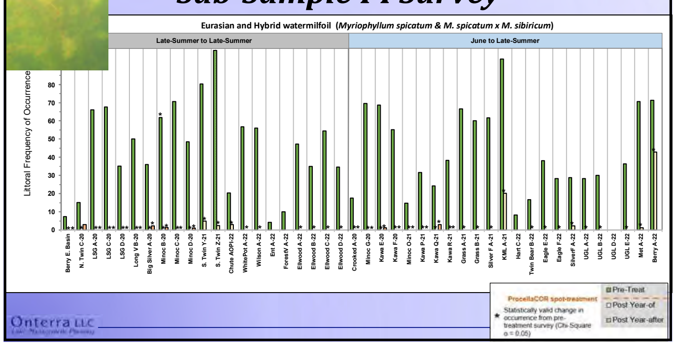
Sub-Sample PI Survey



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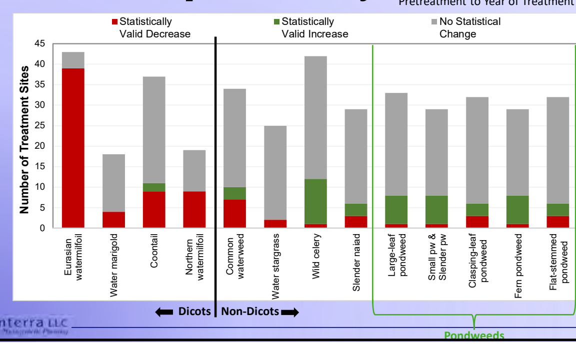
Sub-Sample PI Survey – Pre to YOT



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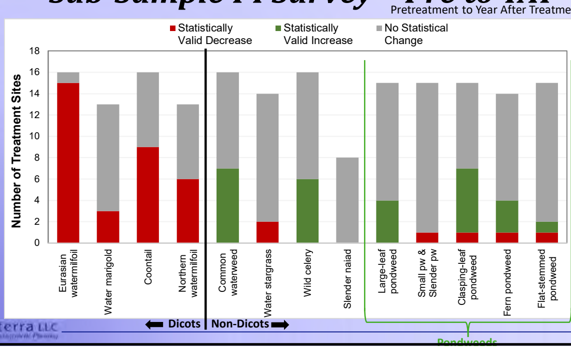
Sub-Sample PI Survey – Pre to YAT



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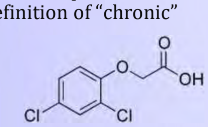
2.4-D Impacts on Fish Early Life Stages

- 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"



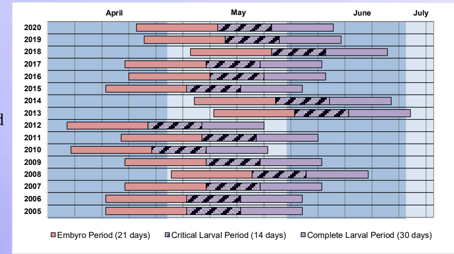
Onterra LLC

Dehnert et al. 2021

Onterra LLC

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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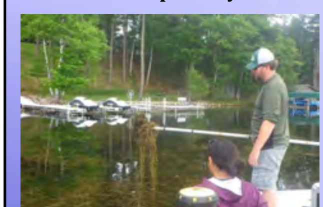
Integrated Pest Management (IPM)

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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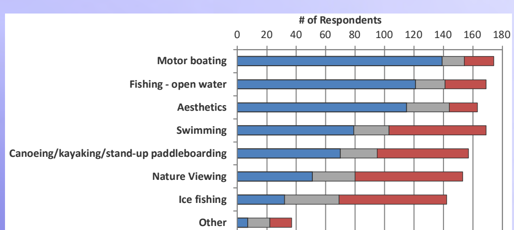
Stakeholder Perceptions of EWM Management

42% Response Rate

Has the Eurasian watermilfoil population ever had a negative impact on your enjoyment of Twin Lakes?



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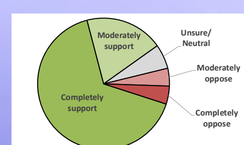
Stakeholder Perceptions of EWM Management

42% Response Rate

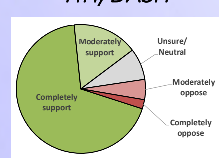
What is your level of support for the future use of the following EWM management techniques?

Herbicide



Support	86%
Not Support	8%
Unsure/Neutral	6%

HH/DASH



Support	85%
Not Support	7%
Unsure/Neutral	8%

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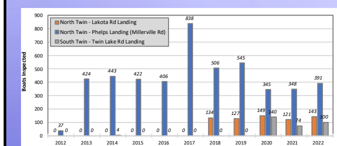
AIS Prevention & Containment

Clean Boats Clean Waters

- 200hrs at Phelps
- 100hrs at Lakota
- 100hrs at South Twin



Supplemental?

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

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EWM Management Plan

Comp Mgmt Plan

Manual

- Where spot treatments are not anticipated to be effective but control of target areas is still sought (as opposed to just monitoring them)

Spot Treatment

- colonized areas where a sufficiently large treatment area can be constructed to hold concentration and exposure times (preference to *dominant* or greater density AIS populations)

Whole-Lake Treatment (STwn)

- populations exceeded 10%, *highly dominant* and *surface matted* conditions started becoming apparent. As these colonies become more one dimensional (i.e. EWM monoculture), native plant diversity declines and an alteration in the lakescape become apparent

Plan Addendum

Colony Size	Surface Matting	Highly Dominant	Dominant	Scattered	Highly Scattered
< 1 acre	1,2,3	1,2,3	2,3,	2,3,4	4
1 - 5 acres	1,2	1,2	1,2	2,3,4	3,4
5 - 10 acres	1	1,2	1,2	2,4	4
> 10 acres	1	1	1	2	4

Activity

1 Herbicide spot treatment
2 DASH
3 Hand Pulling
4 No active just monitor

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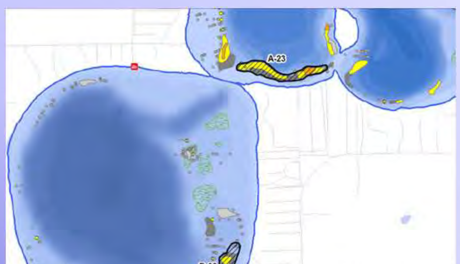
2022 Herbicide Treatment Plan



2023 Preliminary EWM Management Strategy
ProcellaCOR Spot Treatment

Site	Acres	Avg Depth (ft)	Volume (acre-ft)	PDU Rate (per acre-ft)	PDU Total
A-23	9.8	8.0	78.4	5.5	431.2
B-23	9.1	8.0	72.8	5.0	364.0
Total	18.9		151.2		795.2

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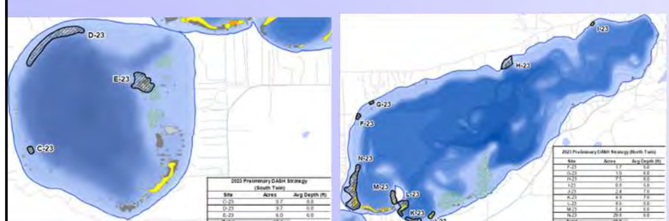
2022 Manual Removal Plan



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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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B

APPENDIX B

District Stakeholder Survey Response Charts & Comments

North and South Twin Lakes - Anonymous Stakeholder Survey

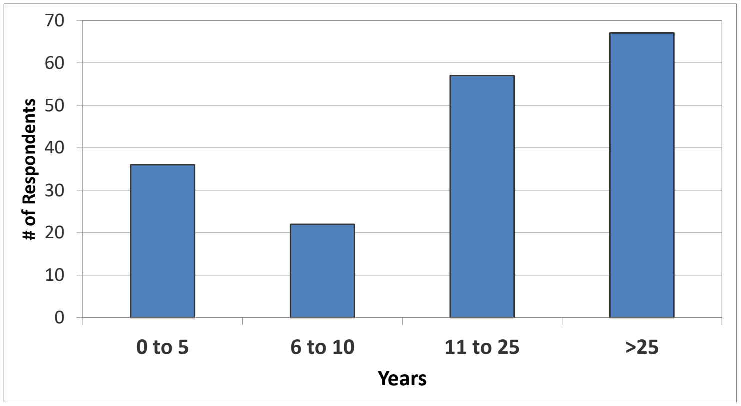
Surveys Distributed:	*436*
Surveys Returned:	*182*
Response Rate:	*42%*

North and South Twin Lakes Property

1. How many years have you owned your property on North and South Twin Lakes?

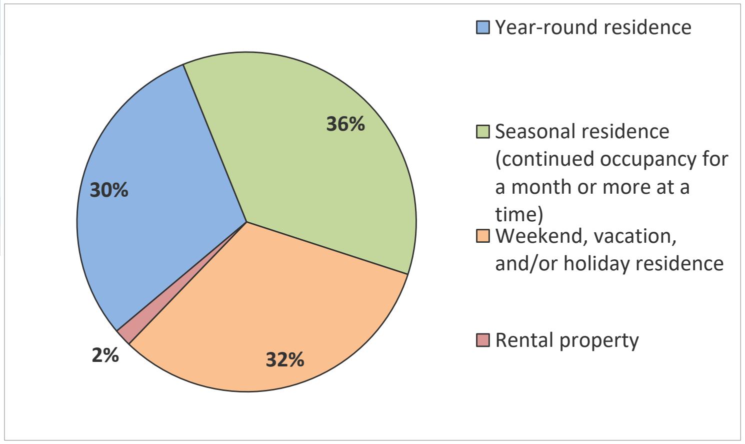
Answer Options	Response Count
	182
answered question	**182**
skipped question	**0**

Category (# of years)	Responses	% Response
0 to 5	**36**	**20%**
6 to 10	**22**	**12%**
11 to 25	**57**	**31%**
>25	**67**	**37%**



2. How is your property on North and South Twin Lakes used?

Answer Options	Response Percent	Response Count
Year-round residence	30.0%	54
Seasonal residence (continued occupancy for a month or more at a time)	36.1%	65
Weekend, vacation, and/or holiday residence	32.2%	58
Rental property	1.7%	3
	answered question	**180**
	skipped question	**2**

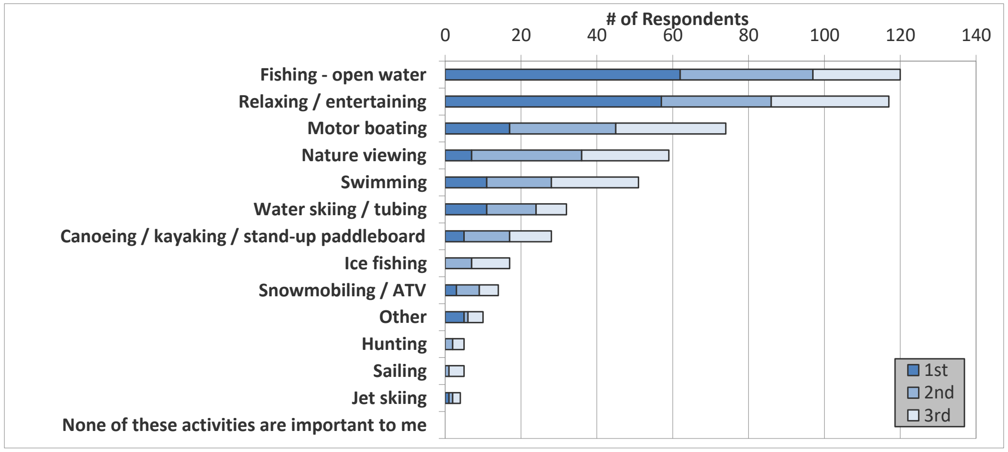


Recreational Activity on North and South Twin Lakes

3. Please rank up to three reasons why you own your property, with the 1st being most important.

Answer Options	1st	2nd	3rd	Rating Average	Response Count
Fishing - open water	62	35	23	1.68	120
Relaxing / entertaining	57	29	31	1.78	117
Motor boating	17	28	29	2.16	74
Nature viewing	7	29	23	2.27	59
Swimming	11	17	23	2.24	51
Water skiing / tubing	11	13	8	1.91	32
Canoeing / kayaking / stand-up paddleboard	5	12	11	2.21	28
Ice fishing	0	7	10	2.59	17
Snowmobiling / ATV	3	6	5	2.14	14
Other	5	1	4	1.9	10
Hunting	0	2	3	2.6	5
Sailing	0	1	4	2.8	5
Jet skiing	1	1	2	2.25	4
None of these activities are important to me	0	0	0	0	0
				answered question	**181**
				skipped question	**1**

Number	"Other" responses
1	Own a resort business on the lake
2	Family legacy
3	FAMILY TIME
4	Swimming
5	Vacation get-away
6	Retirement residence
7	Family owned property in the area
8	resale value
9	can't swim because of swimmers itch
10	Peace and quiet
11	Love the lake, anything on the water to include many items above but limited to 3, nature, relaxing, escape to the "northwoods" & most importantly family being there as well.
12	cross country skiing

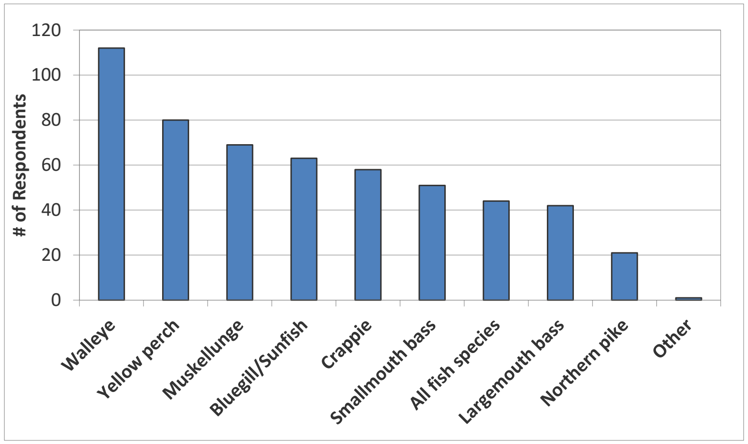


4. Have you personally fished on North and South Twin Lakes in the past three years?

Answer Options	Response Percent	Response Count
Yes	84.4%	152
No	15.6%	28
	answered question	**180**
	skipped question	**2**

5. What species of fish do you try to catch on North and South Twin Lakes?

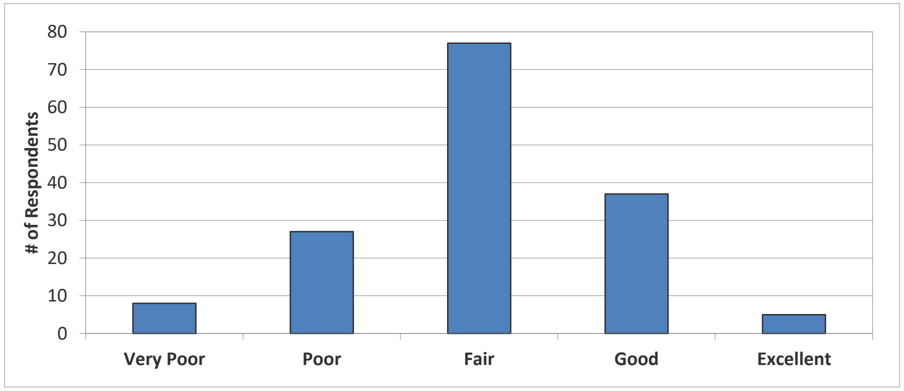
Answer Options	Response Percent	Response Count
Walleye	72.7%	112
Yellow perch	52.0%	80
Muskellunge	44.8%	69
Bluegill/Sunfish	40.9%	63
Crappie	37.7%	58
Smallmouth bass	33.1%	51
All fish species	28.6%	44
Largemouth bass	27.3%	42
Northern pike	13.6%	21
Other	0.7%	1
	answered question	**154**
	skipped question	**28**



Number	"Other" responses
1	Greatly depends on who in the family is doing the fishing. Don't fish as much as we used to but still enjoy it

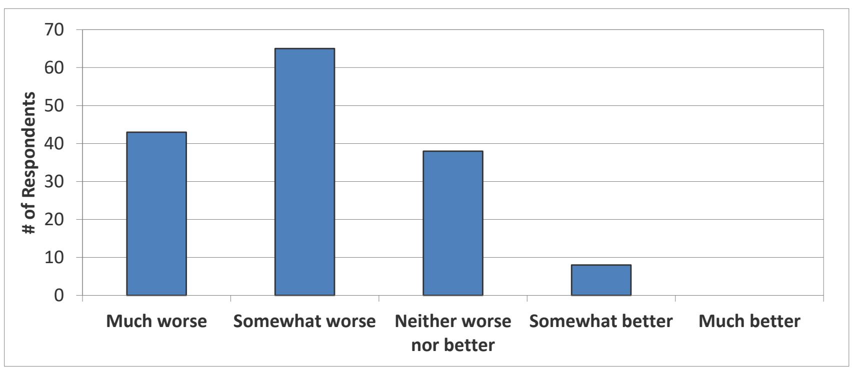
6. How would you describe the current quality of fishing on North and South Twin Lakes?

Answer Options	Very Poor	Poor	Fair	Good	Excellent	Response Count
	8	27	77	37	5	154
					answered question	**154**
					skipped question	**28**



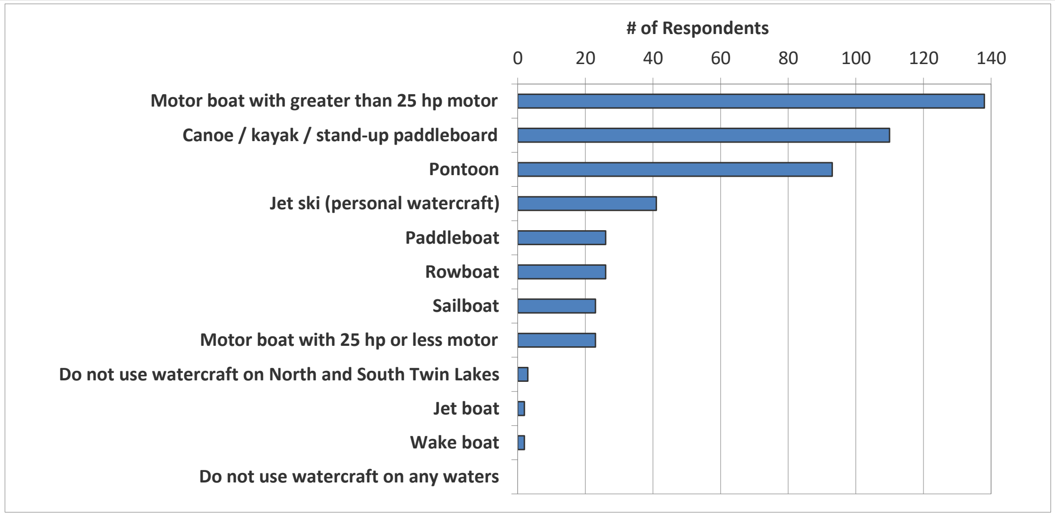
7. How has the quality of fishing changed on North and South Twin Lakes since you have started fishing the lake?

Answer Options	Much worse	Somewhat worse	Neither worse nor better	Somewhat better	Much better	Response Count
	43	65	38	8	0	154
					answered question	**154**
					skipped question	**28**



8. What types of watercraft do you currently use on North and South Twin Lakes?

Answer Options	Response Percent	Response Count
Motor boat with greater than 25 hp motor	75.8%	138
Canoe / kayak / stand-up paddleboard	60.4%	110
Pontoon	51.1%	93
Jet ski (personal watercraft)	22.5%	41
Paddleboat	14.3%	26
Rowboat	14.3%	26
Sailboat	12.6%	23
Motor boat with 25 hp or less motor	12.6%	23
Do not use watercraft on North and South Twin Lakes	1.7%	3
Jet boat	1.1%	2
Wake boat	1.1%	2
Do not use watercraft on any waters	0.0%	0
	answered question	**182**
	skipped question	**0**



9. Do you use your watercraft on waters other than North and South Twin Lakes?

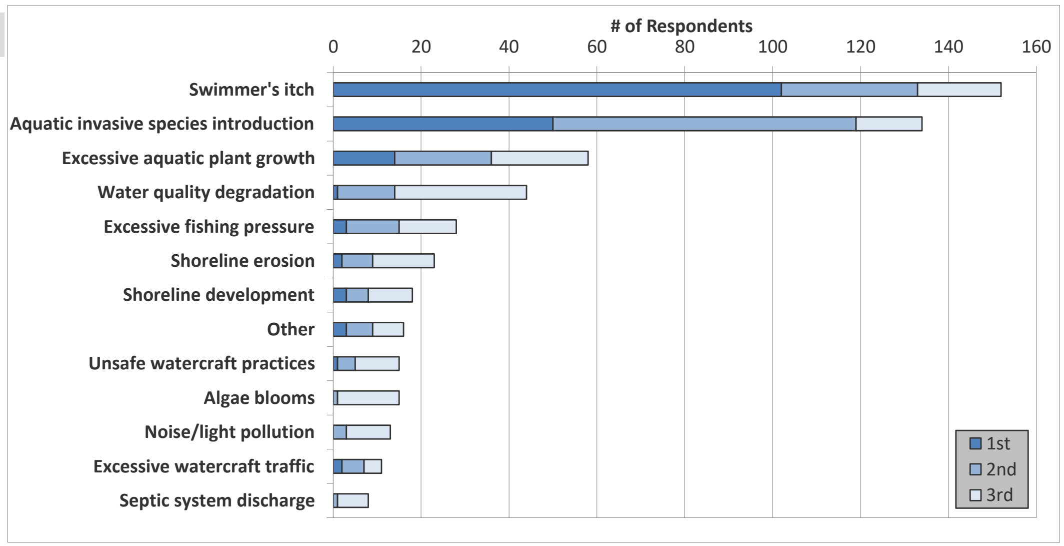
Answer Options	Response Percent	Response Count
Yes	32.6%	58
No	67.4%	120
	answered question	**178**
	skipped question	**4**

North and South Twin Lakes Current and Historic Condition, Health and Management

10. From the list below, please rank your top three concerns regarding North and South Twin Lakes, with the 1st being your top concern.

Answer Options	1st	2nd	3rd	Response Count
Swimmer's itch	102	31	19	152
Aquatic invasive species introduction	50	69	15	134
Excessive aquatic plant growth	14	22	22	58
Water quality degradation	1	13	30	44
Excessive fishing pressure	3	12	13	28
Shoreline erosion	2	7	14	23
Shoreline development	3	5	10	18
Other	3	6	7	16
Unsafe watercraft practices	1	4	10	15
Algae blooms	0	1	14	15
Noise/light pollution	0	3	10	13
Excessive watercraft traffic	2	5	4	11
Septic system discharge	0	1	7	8
			answered question	**181**
			skipped question	**1**

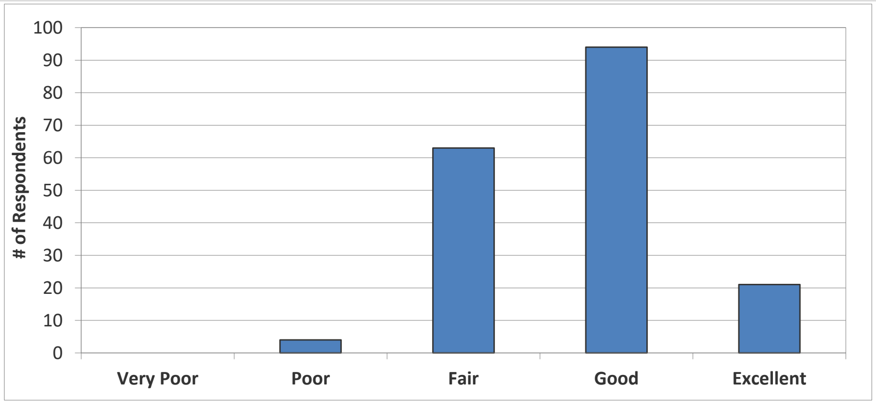
Number	"Other" responses
1	Motor trolling for fishing
2	Algae, excessive spearing!
3	Lack of aquatic vegetation to hold any kind of fish
4	over spearing
5	# 1 concern existing millfoil control
6	Spearfishing
7	Concerned about the decline in fishing species I have seen since owning my property on North Twin
8	Barren areas with no aquatic plant growth
9	Indian Spearing
10	Need to restock fish
11	To many LM Bass not enough Musky
12	Water depth
13	Swimmer's Itch--it was horrendous last year. It gets #1 and 2 for us.
14	Milfoil on South Twin
15	ice fishing has taken a major tole on the fish population
16	Many boats do not use lights at night, Need Warden action
17	spearing is #1 in hurting fish population



18	Impact of native american walleye spearing harvests
Question 10	**continued…**
19	Lack of vegetation
20	Decrease of cabbage weed growth over the years
21	Water level
22	tribal spearing has taken 1000+ Spawning walleyes annually for too many years and no restocking program. Bull--- to DNR's assessment to naturally reproduction is sufficient.
23	spearing
24	lake district and over harvest of fish
25	Our family has owned property on the Twins since 1930, all of the concerns listed within your survey are legitimate concerns and all have merit and should be monitored, addressed and appropriate measures taken. Water quality over my sixty some years has obviously eroded. Glad to hear that some measures are in the works relative to swimmers itch. A beautiful lake and recreational opportunities with family and friends afraid to go in the water because of swimmers itch. This being after preventative measures being taken and still getting it. Thanks for all of the efforts, planning and implementation of measures to improve the quality of the Twins. All of the line item concerns mentioned are important and ultimately can affect property values not to mention ongoing pleasurable use of the lakes. Education as to care and good stewardship by users is also important.

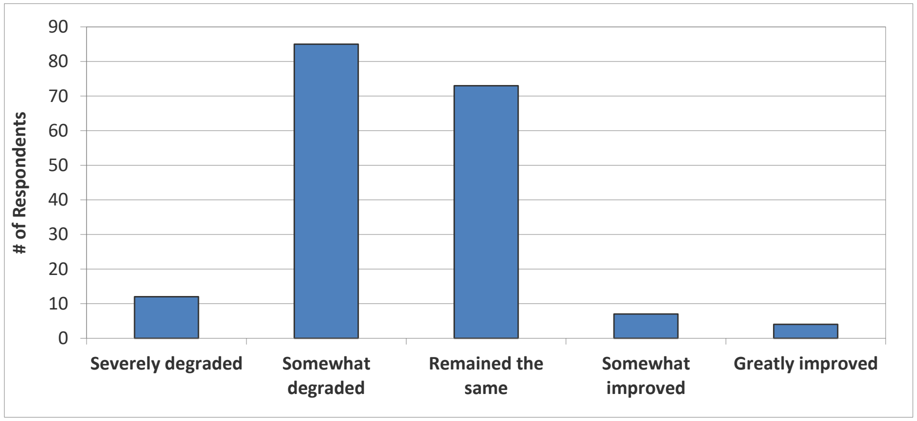
11. How would you describe the overall current water quality of North and South Twin Lakes?

Answer Options	Very Poor	Poor	Fair	Good	Excellent	Response Count
	0	4	63	94	21	182
					answered question	**182**
					skipped question	**0**



12. How has the overall water quality changed in North and South Twin Lakes since you first visited the lake?

Answer Options	Severely degraded	Somewhat degraded	Remained the same	Somewhat improved	Greatly improved	Response Count
	12	85	73	7	4	181
					answered question	**181**
					skipped question	**1**

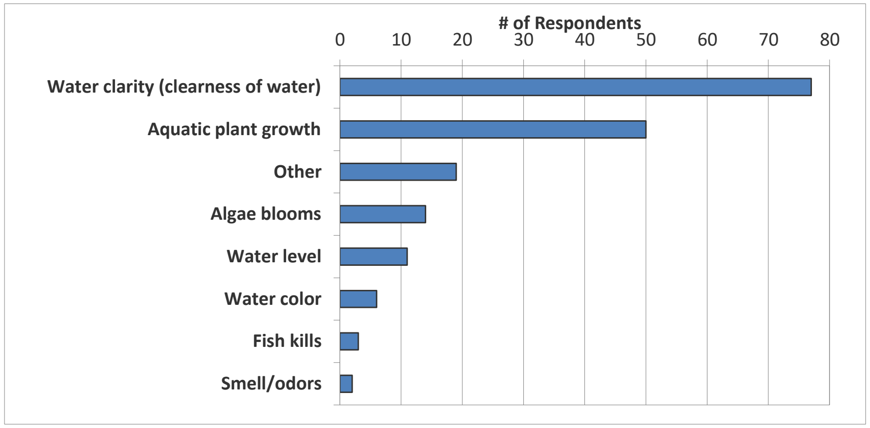


13. Which of the following would you say is the single most important aspect when considering water quality?

Answer Options	Response Percent	Response Count
Water clarity (clearness of water)	42.3%	77
Aquatic plant growth	27.5%	50
Other	10.4%	19
Algae blooms	7.7%	14
Water level	6.0%	11
Water color	3.3%	6
Fish kills	1.7%	3
Smell/odors	1.1%	2
	answered question	**182**
	skipped question	**0**

Question 13 continued...

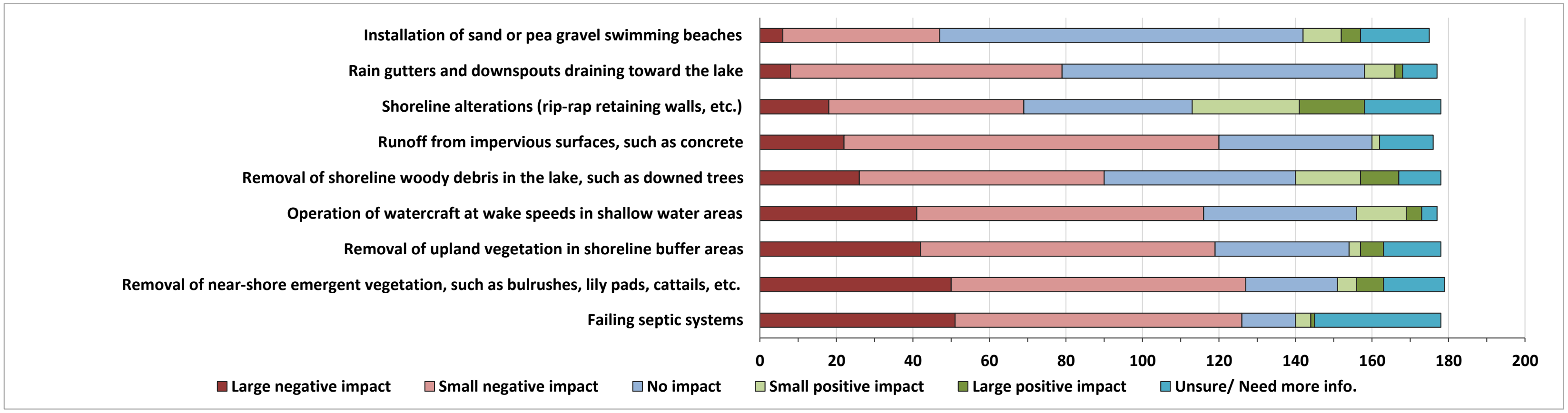
Number	"Other" responses
1	Swimmers itch has made impossible for swimming and enjoying our lake
2	Algae, water clarity
3	swimmers itch organisms
4	swimmer's itch
5	swimmers itch
6	swimmers itch
7	Swimmer's itch
8	We get water in our basement when it's too high.
9	Itch
10	Swimmers itch
11	Swimmers itch
12	swimmers itch
13	Swimmer's Itch
14	Milfoil
15	swimmers itch
16	Unable to swim off dock or put feet in water, kids can't swim off dock related to itch!😕😢😒
17	increasing muck at shorelines
18	All of the listed aspects are factors. The volume of algae and discoloration of items that are in the water has greatly increased along with the population of crayfish and snails.
19	Swimmers itch



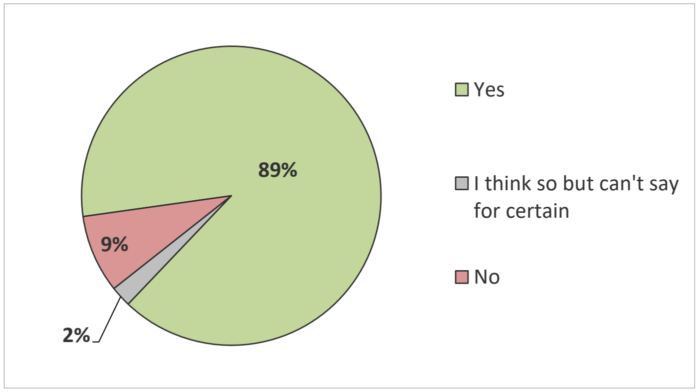
14. Using the following scale, what impact, if any, do you believe each of the following practices have on the water quality of North and South Twin Lakes?

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	51	75	14	4	1	33	178
Removal of near-shore emergent vegetation, such as bulrushes, lily pads, cattails, etc.	50	77	24	5	7	16	179
Removal of upland vegetation in shoreline buffer areas	42	77	35	3	6	15	178
Operation of watercraft at wake speeds in shallow water areas	41	75	40	13	4	4	177
Removal of shoreline woody debris in the lake, such as downed trees	26	64	50	17	10	11	178
Runoff from impervious surfaces, such as concrete	22	98	40	2	0	14	176
Shoreline alterations (rip-rap retaining walls, etc.)	18	51	44	28	17	20	178
Rain gutters and downspouts draining toward the lake	8	71	79	8	2	9	177
Installation of sand or pea gravel swimming beaches	6	41	95	10	5	18	175
						answered question	**179**
						skipped question	**3**

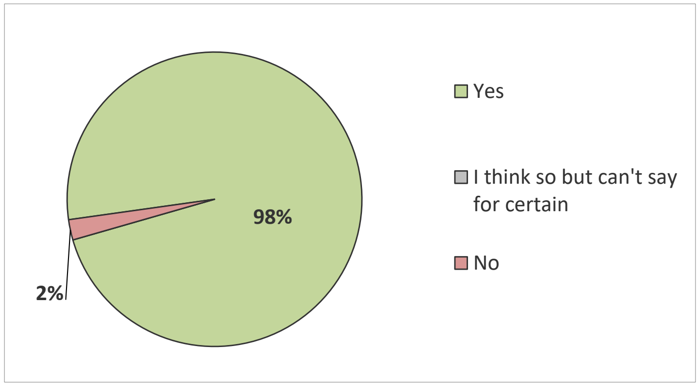
Question 14 continued…



15. Have you, anyone from your household, or a guest experienced swimmer's itch as a result of participating in water activities on North and South Twin Lakes?		
Answer Options	Response Percent	Response Count
Yes	89.3%	159
I think so but can't say for certain	2.3%	4
No	8.4%	15
	answered question	178
	skipped question	4

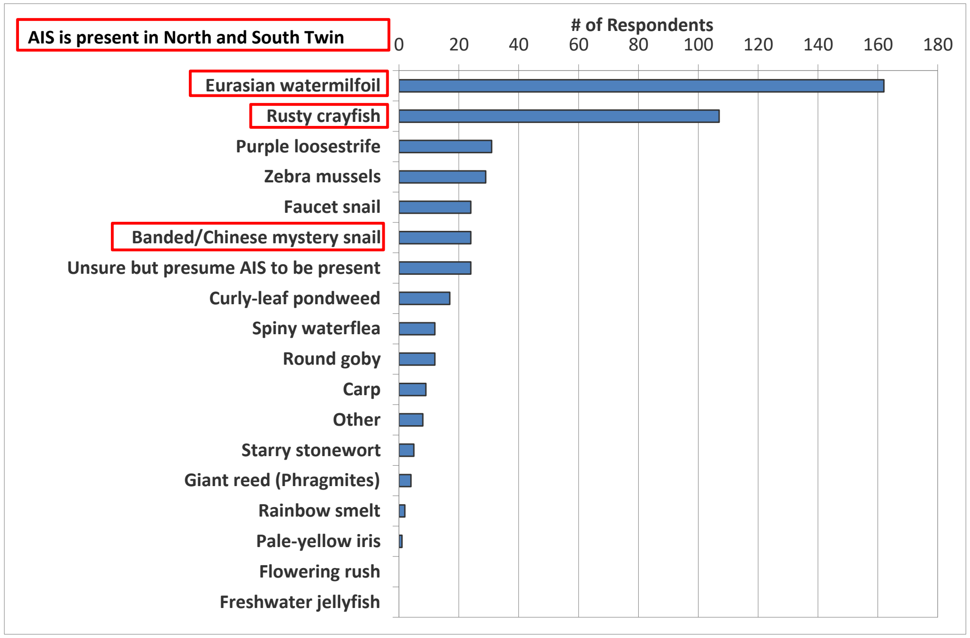


16. Do you believe aquatic invasive species are present within North and South Twin Lakes?		
Answer Options	Response Percent	Response Count
Yes	97.8%	175
I think so but can't say for certain	0.0%	0
No	2.2%	4
	answered question	179
	skipped question	3



17. Which aquatic invasive species do you believe are present in or immediately around North and South Twin Lakes?

Answer Options	Response Percent	Response Count
Eurasian watermilfoil	92.1%	162
Rusty crayfish	60.8%	107
Purple loosestrife	17.6%	31
Zebra mussels	16.5%	29
Faucet snail	13.6%	24
Banded/Chinese mystery snail	13.6%	24
Unsure but presume AIS to be present	13.6%	24
Curly-leaf pondweed	9.7%	17
Spiny waterflea	6.8%	12
Round goby	6.8%	12
Carp	5.1%	9
Other	4.6%	8
Starry stonewort	2.8%	5
Giant reed (Phragmites)	2.3%	4
Rainbow smelt	1.1%	2
Pale-yellow iris	0.6%	1
Flowering rush	0.0%	0
Freshwater jellyfish	0.0%	0
	answered question	**176**
	skipped question	**6**

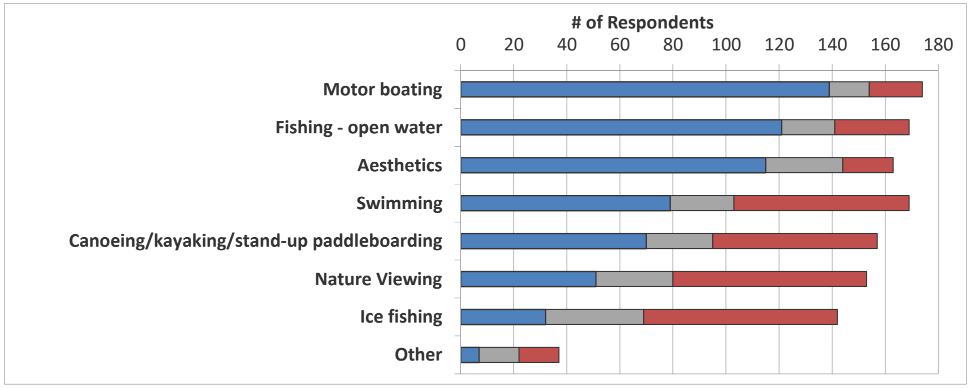


Number	"Other" responses
1	Large snails, don't know their name, NEVER present in North Twin in the 1970s -90s. They are prolific now and I'm sure are an invasive species. We have always had small snails and lots of clams around naturally. I don't know when this other species began to become so dominant but it's been at least 15 or 20 years and continously getting worse.
2	the newspaper says there is
3	not familiar with the others listed above
4	Great number of snails, don't know species
5	Large snails that cause swimmers itch
6	Snails
7	I know there are a variety of invasive species plants in the area but not great with identifying by name.
8	Small snails but unsure of name

18. Has the Eurasian watermilfoil (EWM) population ever had a negative impact on your enjoyment of North and South Twin Lakes?

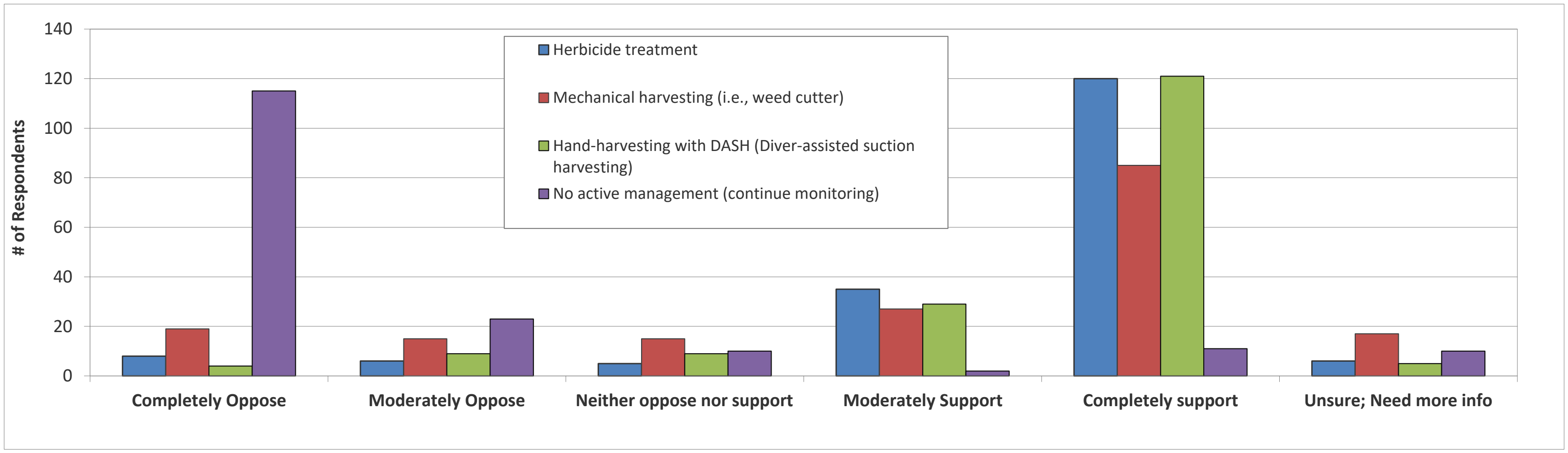
Answer Options	Yes	Unsure	No	Response Count
Motor boating	139	15	20	174
Fishing - open water	121	20	28	169
Aesthetics	115	29	19	163
Swimming	79	24	66	169
Canoeing/kayaking/stand-up paddleboarding	70	25	62	157
Nature Viewing	51	29	73	153
Ice fishing	32	37	73	142
Other	7	15	15	37
			answered question	**178**
			skipped question	**4**

Number	"Other" responses
1	Cleaning up the shoreline
2	I will not boat, swim or fish in South Twin when the Milfoil is extreme
3	Sailing
4	Not enough knowledge to make an informed reply
5	When management was out there with their boat trying to remove milfoil from the middle of the lake A lot of the cut pieces floated towards the shoreline and started planting themselves at our shoreline.
6	Swimmers itch
7	property value
8	Some weed beds are to thick to fish
9	EVERYTHING in our sw corner of South Twin
10	Property value



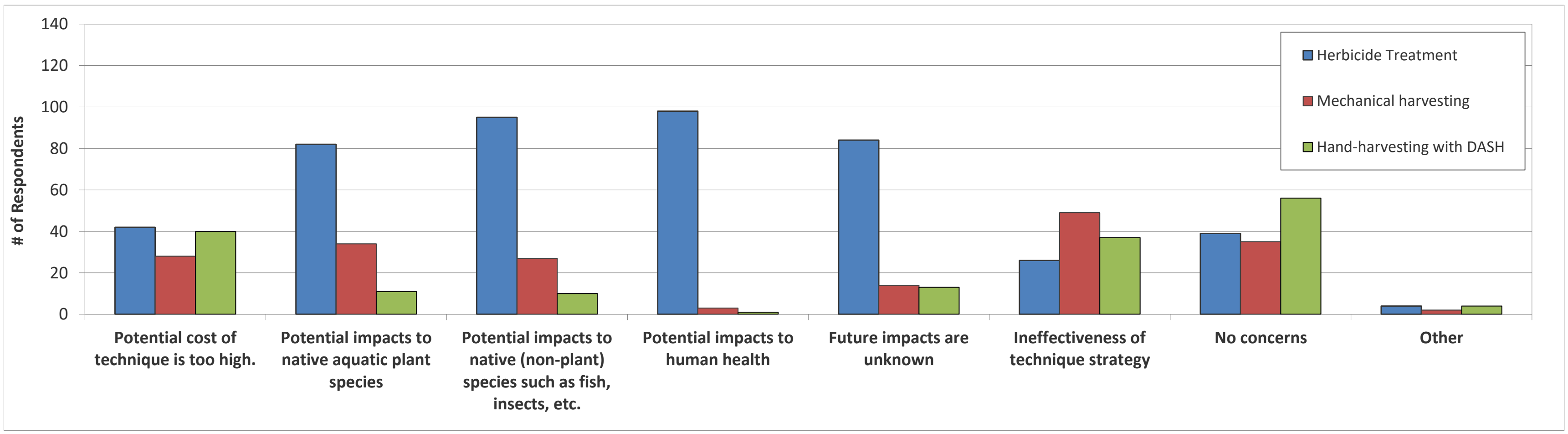
19. What is your level of support for the use of the following EWM management techniques in North and South Twin Lakes?

Answer Options	Completely Oppose	Moderately Oppose	Neither oppose nor support	Moderately Support	Completely support	Unsure; Need more info	Response Count
Herbicide treatment	8	6	5	35	120	6	180
Mechanical harvesting (i.e., weed cutter)	19	15	15	27	85	17	178
Hand-harvesting with DASH (Diver-assisted suction harvesting)	4	9	9	29	121	5	177
No active management (continue monitoring)	115	23	10	2	11	10	171
						answered question	**180**
						skipped question	**2**



20. Do you have any concerns for the future use of aquatic herbicide treatments, DASH/hand-harvesting, and/or mechanical harvesting to target EWM in North and South Twin Lakes?

Answer Options	Herbicide Treatment	Mechanical harvesting	Hand-harvesting with DASH	Response Count
Potential cost of technique is too high.	42	28	40	77
Potential impacts to native aquatic plant species	82	34	11	106
Potential impacts to native (non-plant) species such as fish, insects, etc.	95	27	10	109
Potential impacts to human health	98	3	1	99
Future impacts are unknown	84	14	13	91
Ineffectiveness of technique strategy	26	49	37	83
No concerns	39	35	56	66
Other	4	2	4	6
			answered question	**168**
			skipped question	**14**

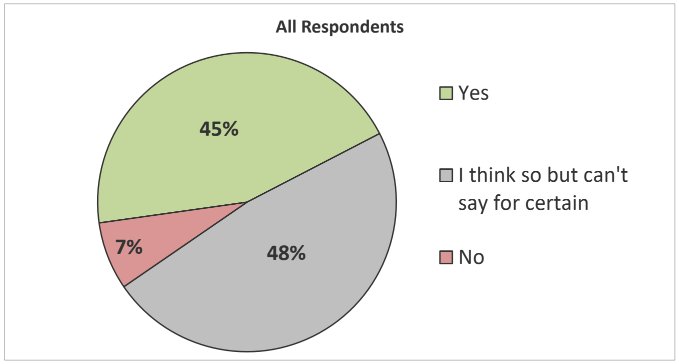


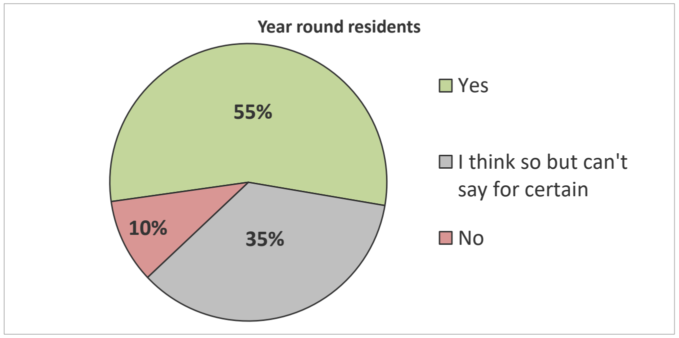
Question 20 continued…

Number	"Other" responses
1	Don't know enough about each technique but want EWM and swimmers itch dealt with in an effective way that keeps water safe for native flora/fauna.
2	no comment
3	above are unfamiliar to me
4	Not knowledgeable enough to choose any of these.
5	As long as it is safe for the lake in humans and it shows improvement than there would be no concerns.
6	Mechanical n hand spread it to much.
7	It's already impacting summer fun! Kids can't swim if front of cottage!😒
8	this question does not make sense and should be re worded
9	My understanding is we are try to manage, thus use what is needed to control. Preference is method with least risk to environment.
10	Naturally the safety of some form of herbicide treatment is always a concern, along with the effectiveness of all types/forms of measures to target and control or eradicate.
11	I do not feel competent to access the long term impact of these methods. I trust the science to make sound decisions based on the evidence.

21. In 2019 and 2020 on North Twin and 2021 on South Twin, the lakes spot treatments were conducted with the herbicide ProcellaCOR to manage EWM. Do you believe these treatments have been effective?

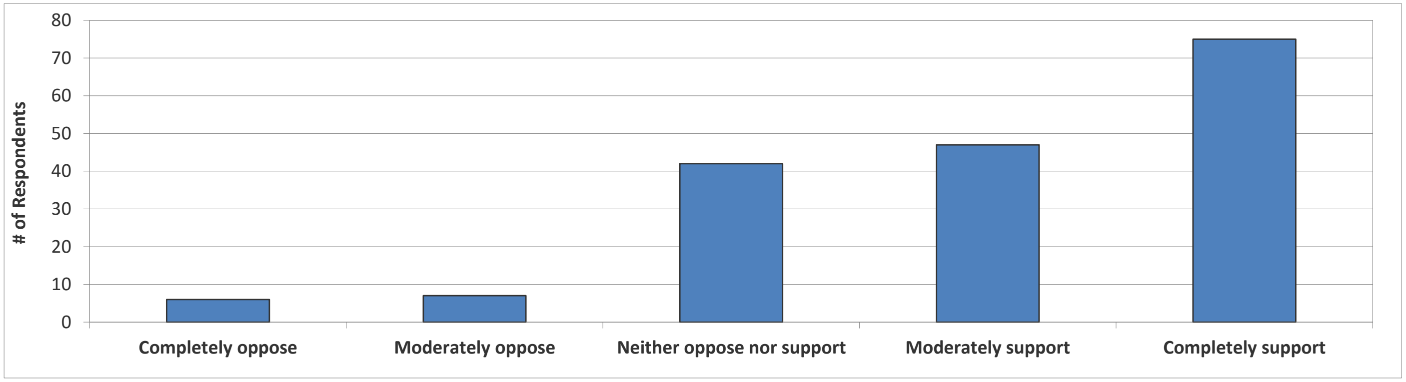
Answer Options	Response Percent	Response Count
Yes	44.6%	79
I think so but can't say for certain	48.0%	85
No	7.3%	13
	answered question	**177**
	skipped question	**5**
Answer results from year round residents (Q2)	**Response Percent**	**Response Count**
Yes	54.9%	28
I think so but can't say for certain	35.3%	18
No	9.8%	5
	answered question	**51**
	skipped question	**131**





22. Would you support or oppose using ProcellaCOR in future treatments to manage EWM?

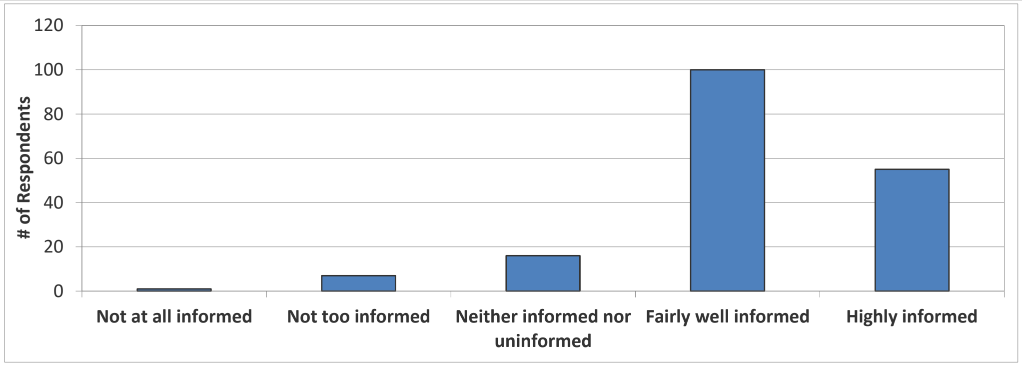
Answer Options	Completely oppose	Moderately oppose	Neither oppose nor support	Moderately support	Completely support	Rating Average	Response Count
	6	7	42	47	75	4.01	177
						answered question	**177**
						skipped question	**5**



North and South Twin Lake District

23. How informed have you been by the Lake District via email, website, annual meetings or other actions regarding lake management activities?

Answer Options	Not at all informed	Not too informed	Neither informed nor uninformed	Fairly well informed	Highly informed	Response Count
	1	7	16	100	55	179
					answered question	**179**
					skipped question	**3**

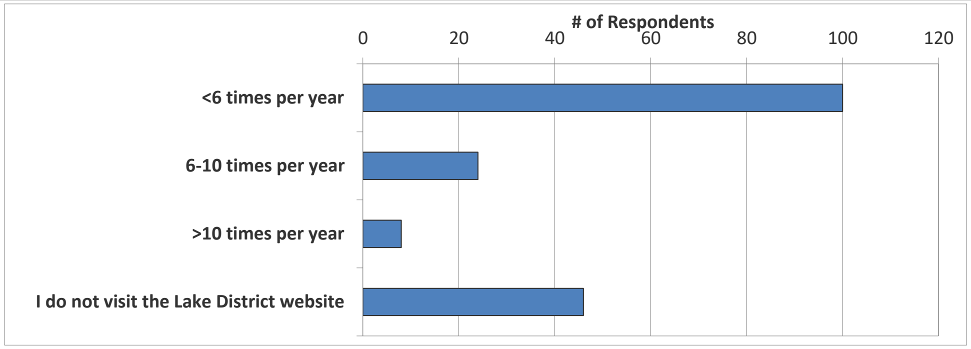


24. Do you believe that the Lake District has had a positive impact on the quality of management activities being performed on North and South Twin Lakes?

Answer Options	Response Percent	Response Count
Yes	80.0%	144
No	5.6%	10
Unsure	14.4%	26
	answered question	**180**
	skipped question	**2**

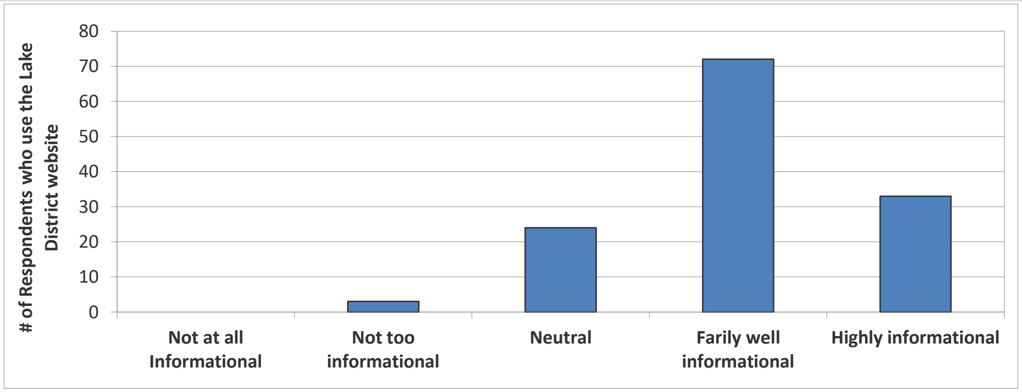
25. Have you visited the Lake District website (www.nstlakedistrict.com) in the past few years and if yes, how often?

Answer Options	Response Percent	Response Count
<6 times per year	56.2%	100
6-10 times per year	13.5%	24
>10 times per year	4.5%	8
I do not visit the Lake District website	25.8%	46
	answered question	**178**
	skipped question	**4**



26. Does the Lake District website provide adequate information for riparians of North and South Twin Lakes?

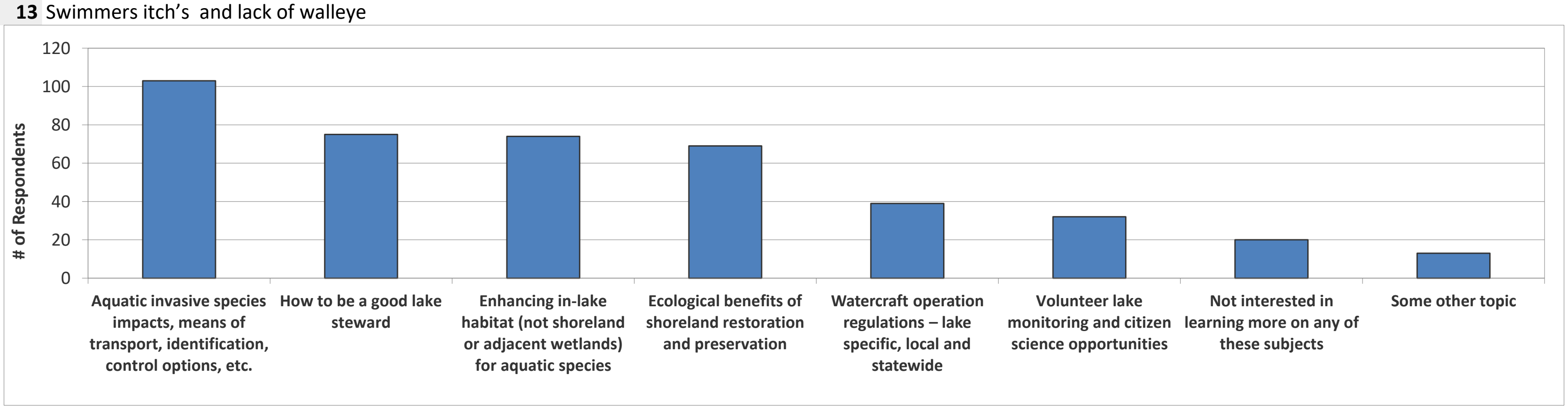
Answer Options	Not at all Informational	Not too informational	Neutral	Farily well informational	Highly informational	Rating Average	Response Count
	0	3	24	72	33	3.93	132
						answered question	**132**
						skipped question	**50**



31. 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.	59.2%	103
How to be a good lake steward	43.1%	75
Enhancing in-lake habitat (not shoreland or adjacent wetlands) for aquatic species	42.5%	74
Ecological benefits of shoreland restoration and preservation	39.7%	69
Watercraft operation regulations – lake specific, local and statewide	22.4%	39
Volunteer lake monitoring and citizen science opportunities	18.4%	32
Not interested in learning more on any of these subjects	11.5%	20
Some other topic	7.5%	13
	answered question	**174**
	skipped question	**8**

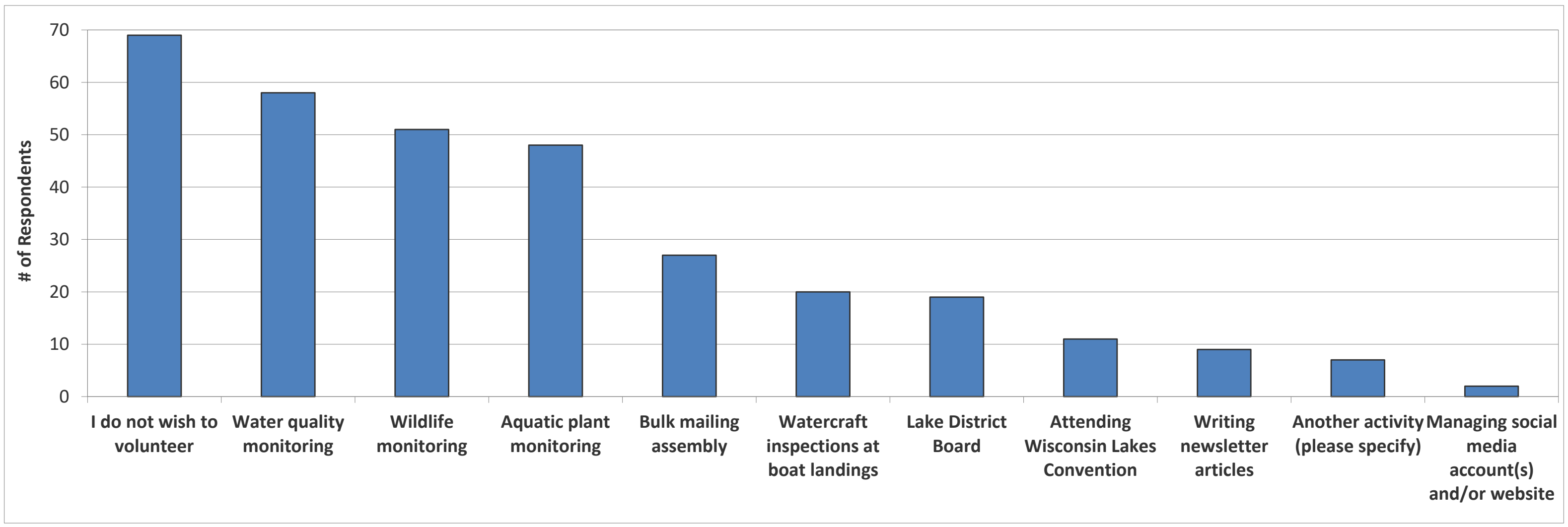
Number	"Some other topic" responses
1	Proactive Prevention of Swimer's Itch Issues
2	Swimmers itch
3	Fish stocking programs
4	Swimmers itch eradication
5	the future of Musky population
6	Getting rid of swimmers itch
7	no more rules. Thats what makes this lake good. NO speed or wake rules
8	Get rid of itch please!
9	would introduction of wild rice be beneficial?
10	swimmers itch
11	I believe all of these communicated on a regular basis to the public lake users in general as well as lake property owners is great.
12	Swimmers itch
13	Swimmers itch's and lack of walleye



28.The effective management of North and South Twin Lakes will require the cooperative efforts of numerous volunteers. Please select the activities you would be willing to participate in if the Lake District requires additional assistance.

Answer Options	Response Percent	Response Count
I do not wish to volunteer	41.3%	69
Water quality monitoring	34.7%	58
Wildlife monitoring	30.5%	51
Aquatic plant monitoring	28.7%	48
Bulk mailing assembly	16.2%	27
Watercraft inspections at boat landings	12.0%	20
Lake District Board	11.4%	19
Attending Wisconsin Lakes Convention	6.6%	11
Writing newsletter articles	5.4%	9
Another activity (please specify)	4.2%	7
Managing social media account(s) and/or website	1.2%	2
answered question		167
skipped question		15

Number	"Another activity" responses
1	Unable to volunteer at this time.
2	Sorry I can't help, but would be willing to offer monetary help.
3	we are only visit there for occasional weekends
4	require vehicles that launch boats to pay permit to offset costs
5	Lake activities
6	Right now with commitment to work and family I have little time to devote to outside involvement. Not getting to the "Northwoods" enough to effectively become involved at this time. Sorry!
7	Age, Health limit active participation



29. Please feel free to provide any additional comments concerning North and South Twin Lakes.

Answer Options	Response Count
	87
answered question	**87**
skipped question	**95**

Number	Response Text
1	Swimmers itch is a BIG DEAL hurting businesses on the lake (in addition to residents' enjoyment). Ask for any and all options for treatment to be explored.
2	Totally against gas motor trolling for walleye & muskies - has negative impact on water quality and fishing. With current technology- use electric motor and cast. What are your thoughts?
3	The Maganzer duck has been identified as the main carrier in relation to swimmers itch, hopefully something has been proposed to deal with them
4	Boat landing yearly maintenance.
5	Just a word of thanks for the management of Milfoil on our Lakes. This is extremely important and we are pleased that it is continually being addressed. I would like to see the lake treated or find some remediation to control/remove the excessive snail population. I believe our swimmers itch problem would lessen and quality of our Lakes greatly improve. This is a property value concern as well.
6	Thanks to all the people who who work to keep the lakes clean and usable!
7	We need to get the swimmers itch controlled.
8	Thank you for taking the time to keep our lake beautiful and healthy.
9	Been a NSTLRA member since 1995 and past Chairman for 5+. Am proud of work our current leaders are doing. They do a fantastic job. Keep up the great work.Thanks for all your time and help.
10	Thank you for your time and effort and please keep up the good work.
11	There are no weeds at all on my shore/pier area. Though I don't want to see a lot of weeds some would be good to hold fish as there is not a weed in sight.
12	Duck itch Very Important
13	I appreciate all the committee does for our twin lakes.
14	Thank you current Board members and volunteers for all the work you do to ensure North and South Twin Lakes remain quality lakes.
15	For all Lake District property owners swimmers itch I believe continues to be the most pressing issue with respect to water activities and property values.
16	Thanks for the great Job.
17	Great lake, would love if we did not have a problem with swimmers itch.
18	Main problem is swimmers itch
19	The 2021 milfoil treatment was very effective and improved the lake greatly.
20	We need to invest in further treatment(s) or actions of the on-going swimmers itch issues on North and South Twin Lake. Enough talk... Lets actually start doing something about it!!!!
21	we sold the property in fall of 2021

22	Moved here in 2001 have been up here since 1979 vacationing and SI is very aggravating for us and visitors.
23	It is imperative to maintain resources for future generations and am willing to support where ever I am able.
24	You should consider including all properties in the N & S Twin Lake watershed in the lake district as in done in many other communities in WI. Those properties impact the lake also and including them would provide more money and assistance in preserving this important asset.
25	Keep up your good work.
26	Greatly appreciate the efforts of the Lake District members and hope to be able to participate more after retirement.
27	Watercraftbtraffic..more HP on boats, wake board boats are dangerous, these boats operating near shore cause problesm. big boats cut good weeds and let bad weeds grow, Jet skis should have limited time on the lake, they show no respect for fishermen.
28	Some stocking northern pike would be nice.. I've not seen any small northern or musky in these lakes in 10 years. I don't believe they are reproducing at all. At least northern you can catch and keep and they're delicious.
29	Thanks for letting us have input and thanks for all that you do!
30	Thank you
31	We had a snail population explosion on South Twin2 0rm 3 summers ago. Does anybody Know why? I have my own. thoughts.
32	The fishing quality has declined. Are there plans to stock more walleye and musky into the lakes.
33	Plant more fish in the lake.
34	I think that the board is doing a great job. Many thanks for their efforts and the time they spend working to improve the lakeshore owners experience.
35	Lake was much better last year
36	Swimmers itch is my primary concern. We have grandkids that enjoy water activities and it is difficult to impossible to do with swimmers itch
37	Swimmer's itch is growing concern. It needs to be a top priority in the future.
38	I've fished Musky and walleye on N Twin lake since 1989. We bought our place on N Twin to enjoy the Musky and walleye fishing in my golden years. Unfortunately the fishing hasn't been so golden. Until the LM Bass population (weed dweller) and weed growth get under control, the LM Bass will continue to consume more Musky and Walleye fry than anglers will ever catch. Please, continue the weed management and remove limits on the invasive Large Mouth Bass.
39	Our family supports the efforts to improve Lake conditions, and we think overall situation has improved over the past few years. Somewhat concerned about long term viability of some management techniques such as herbicide treatments and possible unforseen consequences, but see good overall vigilance in watching for changes. All need to accept that not all lake issues can be managed away. We agree that swimmers itch is an annoyance but don’t support aggressive mitigation (such as poisoning ducks or snails). Swimmers itch is a natural seasonal phenomenon and agressive efforts to eliminate it will likely be futile.
40	Please do something to get rid of swimmers itch.
41	Please make eliminating swimmers itch a priority.
42	My main concerns are Swimmers Itch, Mill foil, and boat launching maintenance.
43	ban loud rap music form boats at all hours
44	I'd be willing to donate to a fish stocking fund if the DNR thought it could be helpful. Any way the Lake Association could negotiate with the Native Americans to exempt our lake from spearing for say 5 years to see if that improves walleye or muskie populations?
45	Thank you for all that you do to preserve our lakes! For our family, the Swimmer's itch problem is the number 1 issue that will determine whether we keep our North Twin property in perpetuity or whether we move on. We have little kids. They got absolutely destroyed by Swimmer's itch multiple times last year, even as late as mid-October. Anything we can do to help the problem, we would support, including considering additional personal financial support. Thanks again for all of your efforts.
46	Thank you for all you do for us!

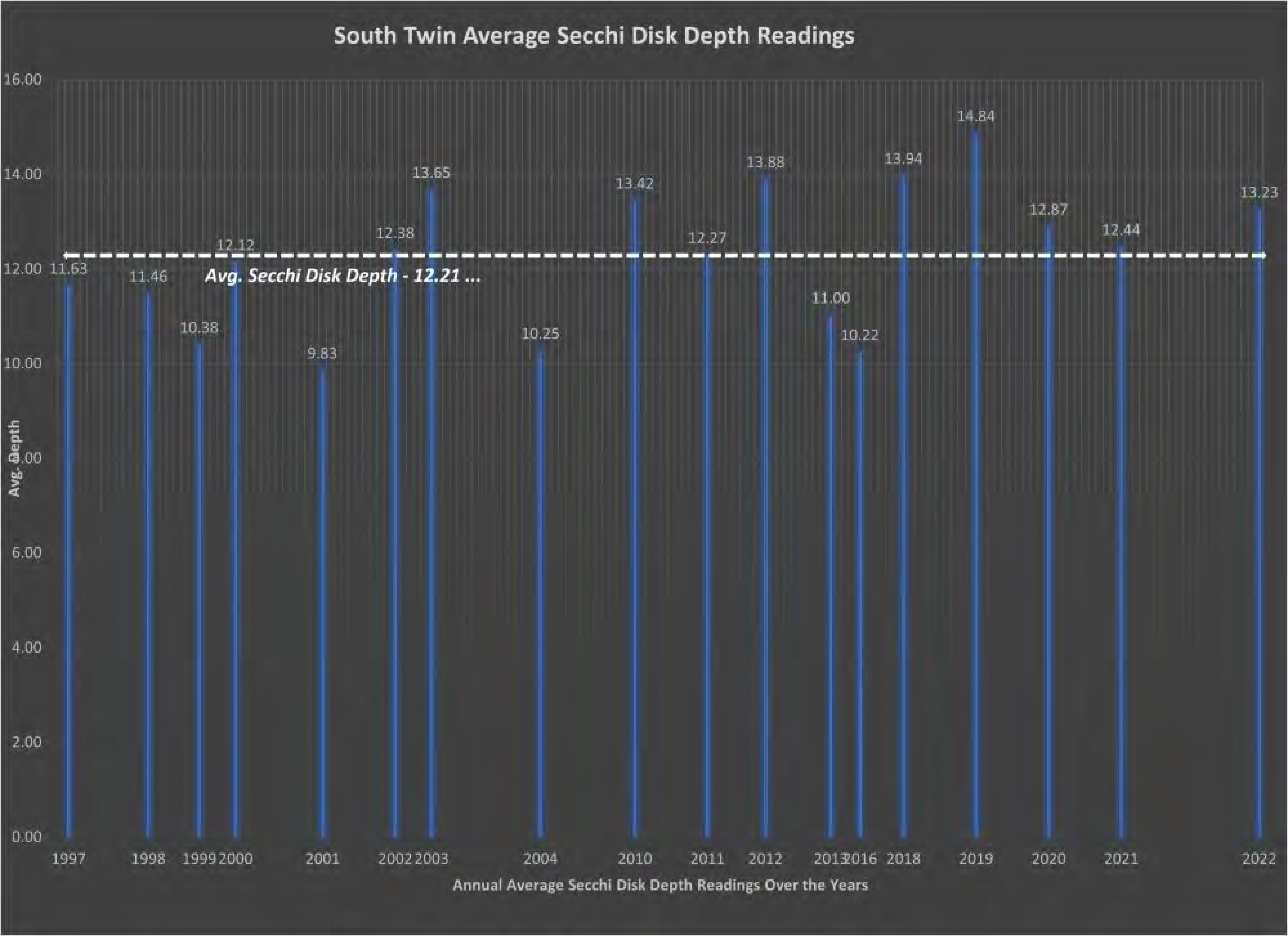
47	Some people that use the lakes may not know rules on the lake. They tend to speed by too close to the shoreline in Docks.
48	Water quality and control of AIS is top concern by far. The milfoil treatment in 2021 on south twin did a great job. Surprised how much native plants came back and fishing was great. Concerned on how quick it comes back and eventual tolerance to most commonly used herbisides
49	Thank you for the time and effort you have generously donated to help maintain the beauty of our lakes!
50	Thank you for this important work!
51	The invasive issues on the Twin Lakes are significantly caused by users who do not live on or own property on the lakes, need to get financial support from them, such as Boat Landing fees.
52	We are new in the area and live away also. We are interested in anything that will improve the lake condition.
53	Lake District is doing a great job.
54	I feel there should be a mandatory fee for parking your trailer at boat landings. This would help with taking care of the lake that they are using.
55	Let's keep up the good work and save N and S Twin from invasive species!!
56	Kind of bummed….Looking to sell related to swimmers itch! This should be high priority.
57	Get a handle on swimmers itch! Get transient users (guides, etc.) of lake to monetarily participate in cleaning up of aquatic issues. Most lake homeowners put watercraft in at spring time and take out in fall. The guides and lake hoppers don't have any skin in the game and are the logical reason we have an issue. Let's make them pay for usage!
58	We are in favor of continued treatment with chemicals to get rid of AIS as long as it is working and not harmful. We dont want to be choked off by weeds.
59	Keep up the good work!
60	would introduction of wild rice be beneficial?
61	I firmly believe swimmers itch is caused more from already infected snails that pass it on to their offspring. Yes, the ducks introduced the parasite but they are not the sole source of the continued problem. It makes no sense that two dozen ducks can infect 3500 acres every year. I have many thousands of snails on my shoreline yet seldom see ducks particularly mergansers. I said all this before yet no research as been done to eliminate the snails as a more significant ongoing cause of swimmers itch.
62	Would like to see enforcement and fines given to individuals dumping grass clippings and leaves into the lake. Also having structures lakeside being used as permanent storage buildings.
63	I think the follow-up EWM treatment on S Twin in June 2021 had a great impact. I hope we can continue to manage the problem with herbicide and divers. So far so good and thanks.
64	Swimmers itch is a major concern for myself and family and most of my neighbors. Unfortunately, I think it has gotten progressively worse and causes us not to use the lake property as intended.
65	Excited to see the significant improvement in Milfoil over the past 3 years. Lets hope we can keep it this way going forward.
66	I've from the beginning been opposed to the lake district and I'm still opposed. Kurt G. Allison
67	Swimmers itch is a big concern. When we first owned the cottage in 2002 there wasn't any evidence of it. Now no one wants to go into the water.
68	I'm an avid fisherman on both of the lakes. I see a need for some musky stocking as it hasn't been done in years as the population seems down and per the DNR surveys. Also be interested in rejuvenating a fish crib program as the cribs from the 6o's are no longer there or depleted
69	appreciate the knowledge and dedication of the board
70	Website needs to be updated more frequently. I don't consider plant growth and presence as a component of water quality. But it does correlate with key water quality factors such as N, P, and transparency. Otherwise, a good survey.
71	When we purchased and built on the lake lot the fishing in the lake was much better. There was also less swimmers itch and less Eurasian watermilfoil. My boat is placed in the lake in the spring and taken out in the fall, it never goes to a different lake. The problem is the water enthusiasts that travel to different lakes. There should be a paid permit to launch a boat. That would help offset the cost of the cleanup caused by the boaters who bring the invasive species. If this is not considered an option the problem is not being taken seriously.

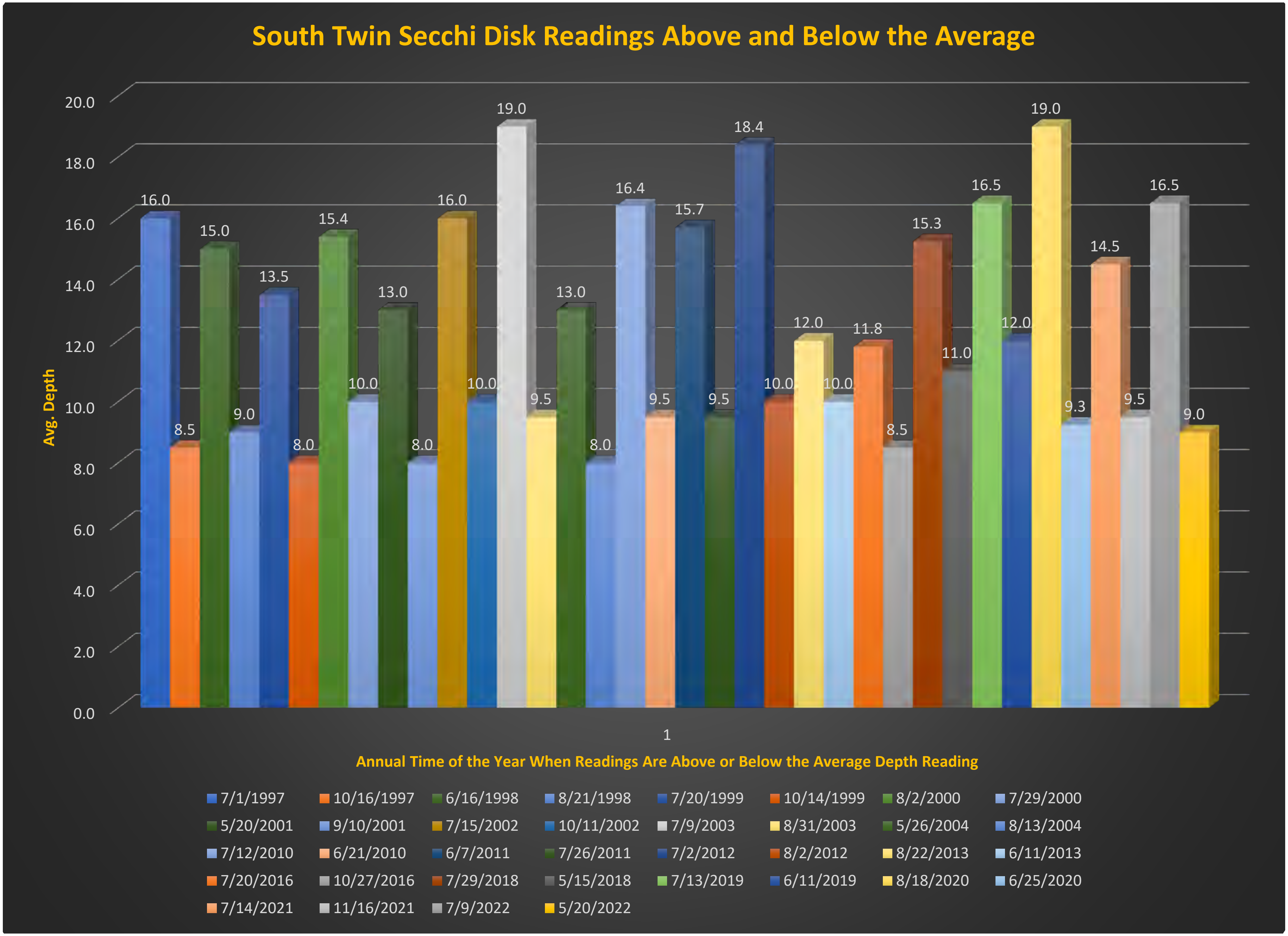
72	Love our lakes and fully appreciate the admirable efforts being made by our board members, reps, and volunteers. If I was younger and more able I would be proud to participate more.
73	SOME OF THE BOARD MEMBERS THINK THEY ARE WARDENS ON THE LAKE AND TRY AND TELL PEOPLE WHAT TO DO AND I DONT LIKE IT
74	Do your best to solve swimmers itch problem. Don't assume a regulatory posture.
75	Restock fishery
76	more pressure on the WDNR re: musky planting
77	We do not go on South Twin after Spring because of the extreme EWM !!!
78	Keep up good work. The plan and budget should address what is needed short & long term.
79	Thanks for doing a good job. Keep up the good work!
80	Please, please, please get swimmers itch under control!!!
81	These are PUBLIC waters and all remediation efforts should be financed by the PUBLIC, not just riparian owners!!
82	It's great that folks are working together to preserve, protect and improve our beautiful natural resources. Thank you for the efforts in doing so. Along with that it takes education of and cooperation of the individuals who are using our lakes for recreational purposes. Thanks for all of the efforts!!!!! What's done now will make a difference for years and generations to come! Being a fourth generation user on the Twins I fully understand that and look to the future with our fifth generation adding for us a grandchild for which the sixth generation of family is enjoying the "Twins" and the beautiful "Northwoods" known as God's Country! :)
83	We need an effective plan to resolve the swimmers itch problem. There has been insufficient communication or action on this. IT MUST BE ONE OF THE TWO TOP PRIORITIES WITH MILFOIL. Shore line improvement and water quality are fine but if the top two are not addressed the lakes will become undesirable
84	Excessive gas-powered watercraft activity
85	swimmers itch and the need for stocking the lake.
86	Keep up the good work.
87	Thank you for gathering this information.

C

APPENDIX C

District Water Quality Figures


South Twin Average Secchi Disk Depth Readings
Avg. Depth
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
11.63
11.46
10.38
12.12
9.83
12.38
13.65
10.25
13.42
12.27
13.88
11.00
10.22
13.94
14.84
12.87
12.44
13.23
Avg. Secchi Disk Depth - 12.21 ...
1997
1998
1999
2000
2001
2002
2003
2004
2010
2011
2012
2013
2016
2018
2019
2020
2021
2022
Annual Average Secchi Disk Depth Readings Over the Years

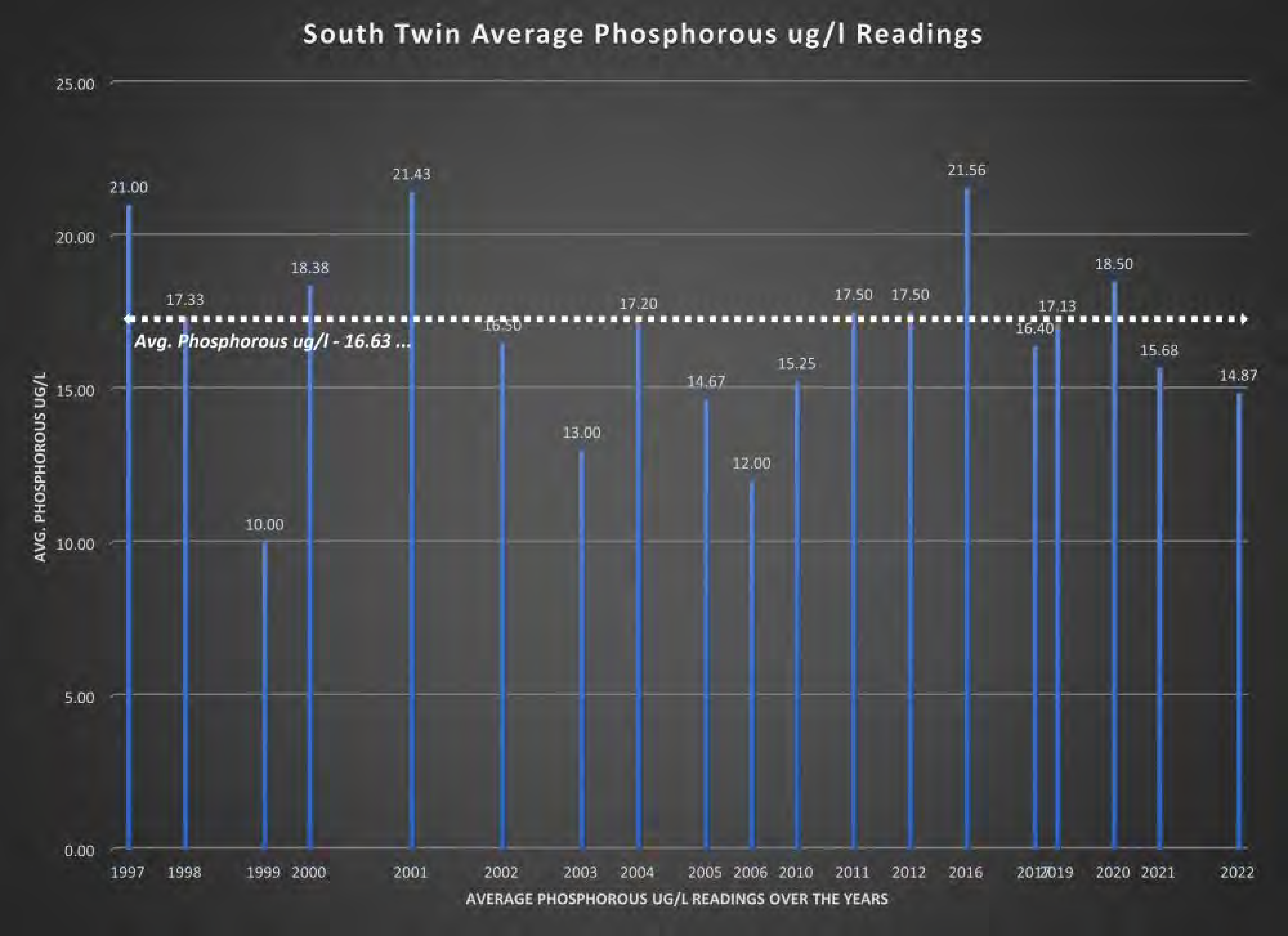


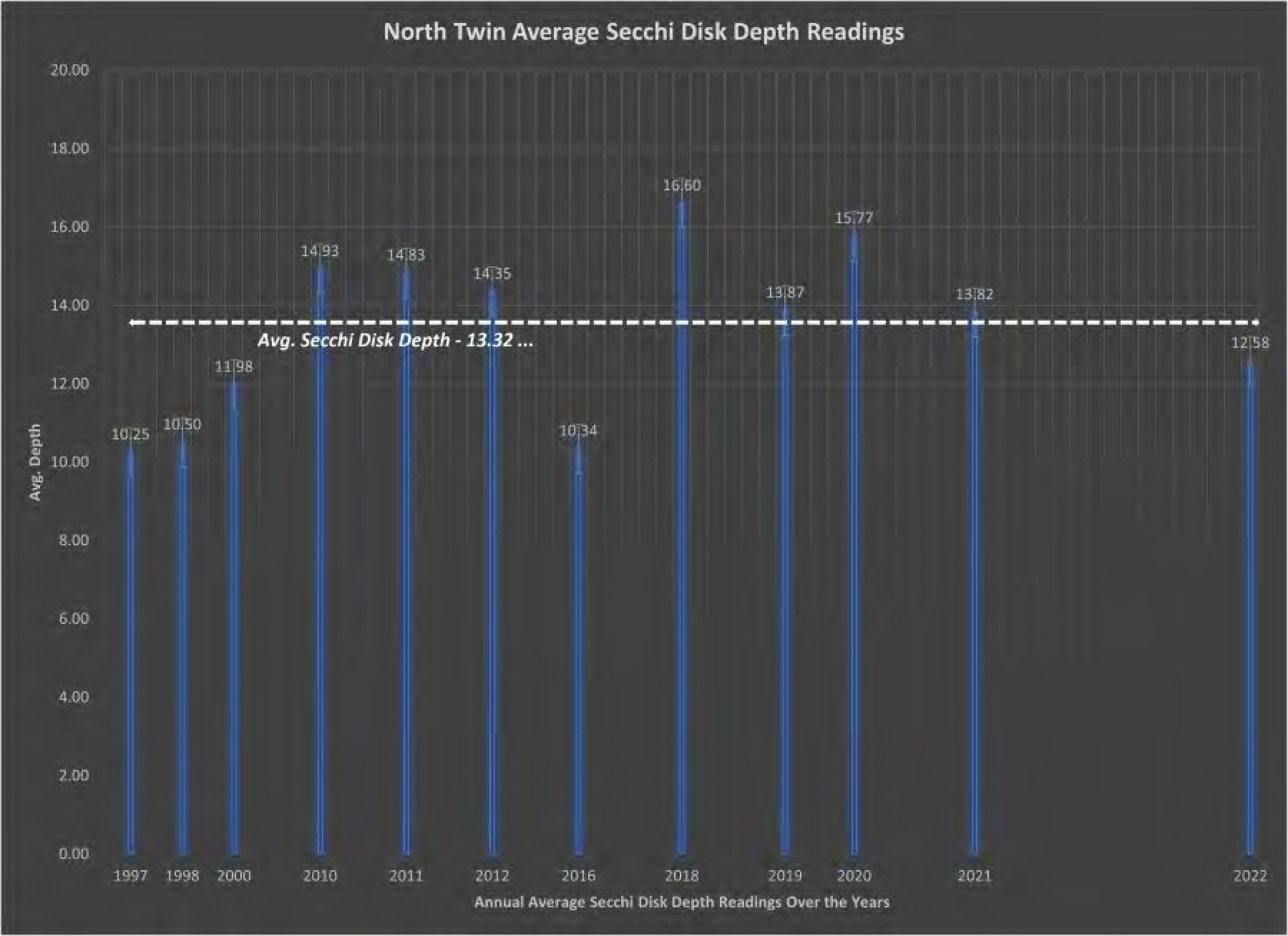
South Twin Secchi Disk Readings Above and Below the Average
Avg. Depth
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
16.0
8.5
15.0
9.0
13.5
8.0
15.4
10.0
13.0
8.0
16.0
10.0
19.0
9.5
13.0
8.0
16.4
9.5
15.7
9.5
18.4
10.0
12.0
10.0
11.8
8.5
15.3
11.0
16.5
12.0
19.0
9.3
14.5
9.5
16.5
9.0
1
Annual Time of the Year When Readings Are Above or Below the Average Depth Reading
7/1/1997
10/16/1997
6/16/1998
8/21/1998
7/20/1999
10/14/1999
8/2/2000
7/29/2000
5/20/2001
9/10/2001
7/15/2002
10/11/2002
7/9/2003
8/31/2003
5/26/2004
8/13/2004
7/12/2010
6/21/2010
6/7/2011
7/26/2011
7/2/2012
8/2/2012
8/22/2013
6/11/2013
7/20/2016
10/27/2016
7/29/2018
5/15/2018
7/13/2019
6/11/2019
8/18/2020
6/25/2020
7/14/2021
11/16/2021
7/9/2022
5/20/2022

Phosphorous ug/l Impact …

When phosphorus increases, that means there is more food available for algae, so algal concentrations increase. When algal concentrations increase, the water becomes less transparent and the Secchi depth decreases.

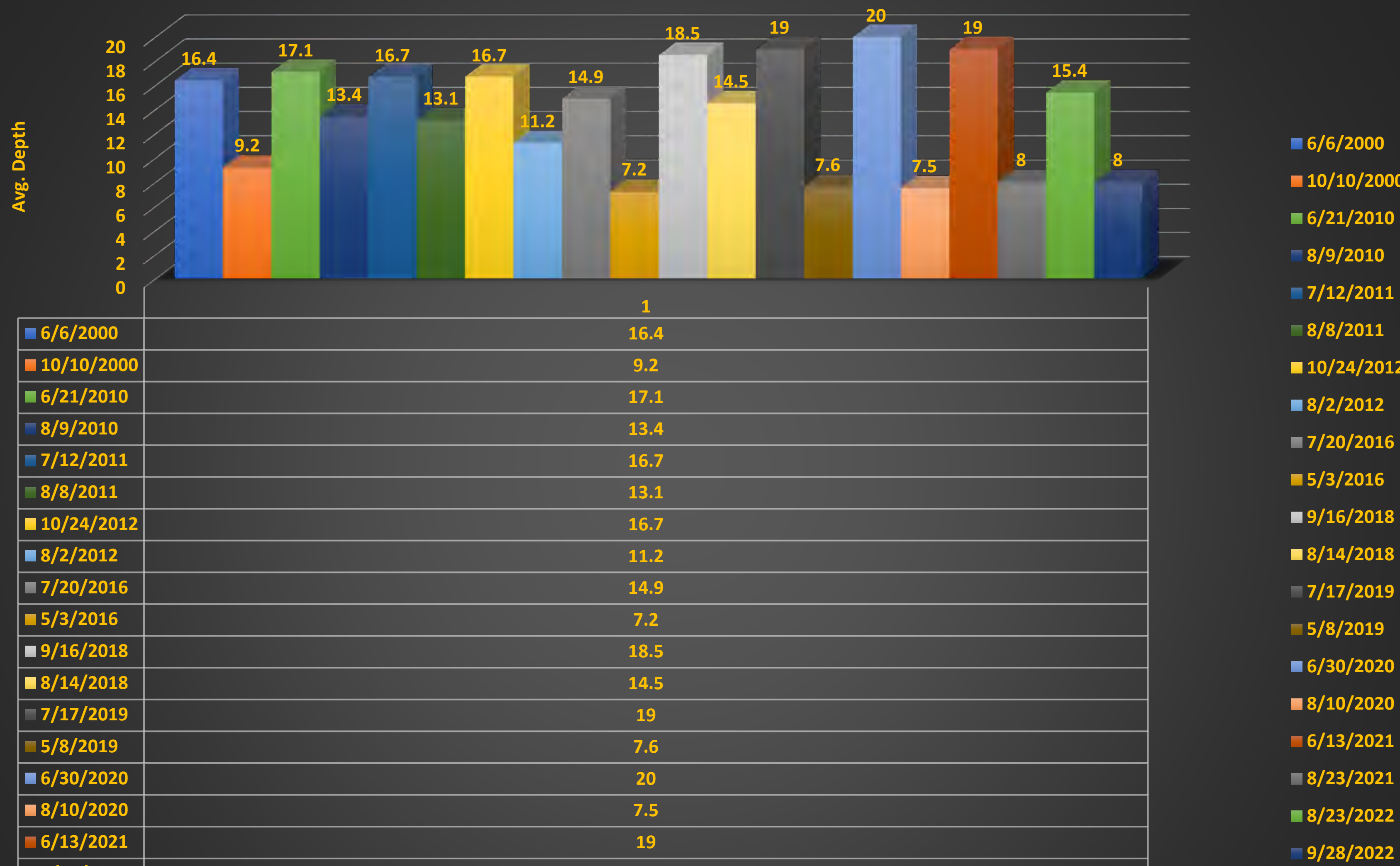
TP (ug/L)	Attributes
<6	**Oligotrophy:** Clear water, oxygen throughout the year at the bottom of the lake, very deep cold water.
6-12	Bottom of shallower lakes may become anoxic (no oxygen).
12-24	**Mesotrophy:** Water moderately clear most of the summer. May be "greener" in late summer.
24-48	**Eutrophy:** Algae and aquatic plant problems possible. "Green" water most of the year.
48-96	Blue-green algae dominate, algal scums and aquatic plant problems.
96-192	**Hypereutrophy:** (light limited productivity). Dense algae and macrophytes.
192-384	Algal scums, few aquatic plants


South Twin Average Phosphorous ug/l Readings
25.00
20.00
15.00
10.00
5.00
0.00
AVG. PHOSPHOROUS UG/L
Avg. Phosphorous ug/l - 16.63 ...
21.00
17.33
10.00
18.38
21.43
16.50
13.00
17.20
14.67
12.00
15.25
17.50
17.50
21.56
16.40
17.13
18.50
15.68
14.87
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2010
2011
2012
2016
2017
2019
2020
2021
2022
AVERAGE PHOSPHOROUS UG/L READINGS OVER THE YEARS



North Twin Average Secchi Disk Depth Readings
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Avg. Depth
10.25
10.50
11.98
14.93
14.83
14.35
10.34
16.60
13.87
15.77
13.82
12.58
Avg. Secchi Disk Depth - 13.32 ...
1997
1998
2000
2010
2011
2012
2016
2018
2019
2020
2021
2022
Annual Average Secchi Disk Depth Readings Over the Years

North Twin Secchi Disk Depth Readings Above and Below the Average



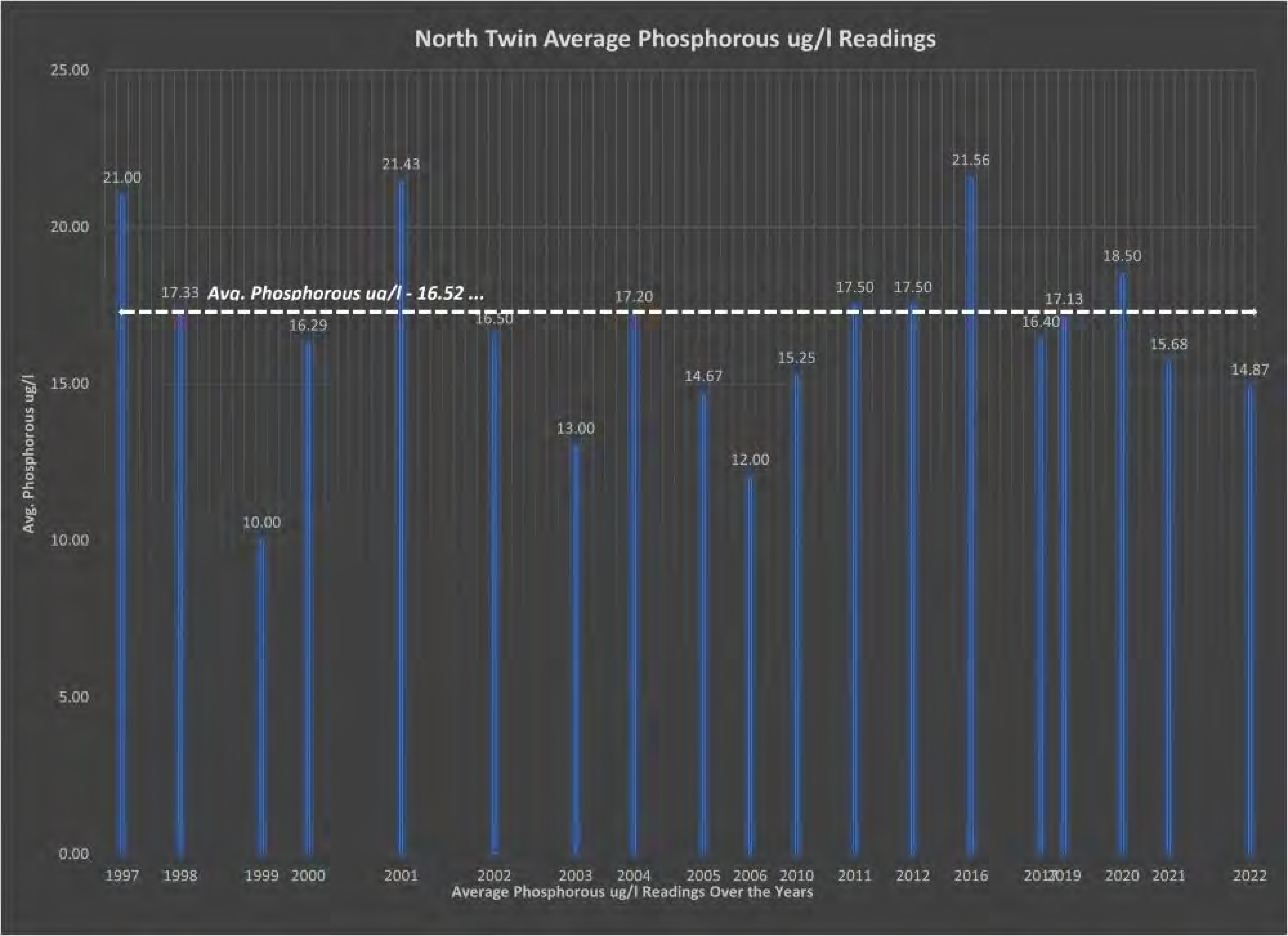
	1
6/6/2000	16.4
10/10/2000	9.2
6/21/2010	17.1
8/9/2010	13.4
7/12/2011	16.7
8/8/2011	13.1
10/24/2012	16.7
8/2/2012	11.2
7/20/2016	14.9
5/3/2016	7.2
9/16/2018	18.5
8/14/2018	14.5
7/17/2019	19
5/8/2019	7.6
6/30/2020	20
8/10/2020	7.5
6/13/2021	19
8/23/2021	8
8/23/2022	15.4
9/28/2022	8

Annual Time of the Year When Readings Are Above or Below the Average Depth Reading

Phosphorous ug/l Impact …

When phosphorus increases, that means there is more food available for algae, so algal concentrations increase. When algal concentrations increase, the water becomes less transparent and the Secchi depth decreases.

TP (ug/L)	Attributes
<6	**Oligotrophy:** Clear water, oxygen throughout the year at the bottom of the lake, very deep cold water.
6-12	Bottom of shallower lakes may become anoxic (no oxygen).
12-24	**Mesotrophy:** Water moderately clear most of the summer. May be "greener" in late summer.
24-48	**Eutrophy:** Algae and aquatic plant problems possible. "Green" water most of the year.
48-96	Blue-green algae dominate, algal scums and aquatic plant problems.
96-192	**Hypereutrophy:** (light limited productivity). Dense algae and macrophytes.
192-384	Algal scums, few aquatic plants


North Twin Average Phosphorous ug/l Readings
Avg. Phosphorous ug/l
Avg. Phosphorous ug/l - 16.52 ...
25.00
20.00
15.00
10.00
5.00
0.00
21.00
17.33
10.00
16.29
21.43
16.50
13.00
17.20
14.67
12.00
15.25
17.50
17.50
21.56
16.40
17.13
18.50
15.68
14.87
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2010
2011
2012
2016
2017
2019
2020
2021
2022
Average Phosphorous ug/l Readings Over the Years

D

APPENDIX D

Aquatic Plant Point-Intercept Survey Data Matrix

South Twin Lake

Point-Intercept Survey Data Matrix

Scientific Name	Common Name	LFOO (%)													2021-2022	
		2008	2009	2010	2011	2013	2014	2015	2016	2017	2018	2020	2021	2022	% Change	Direction
Vallisneria americana	Wild celery	60.9	43.2	53.7	58.2	37.3	36.8	43.6	47.8	45.0	33.2	23.8	35.3	27.1	-23.1	▼
Potamogeton gramineus	Variable-leaf pondweed	46.7	46.5	37.5	40.5	46.6	52.6	38.4	46.1	44.3	29.6	31.4	30.7	36.3	18.0	▲
Najas flexilis	Slender naiad	33.2	31.4	17.2	43.4	14.8	25.8	33.4	27.8	40.7	35.2	26.4	30.7	35.9	16.9	▲
Chara & Nitella spp.	Muskgrasses & Stoneworts	30.3	18.8	22.7	27.6	14.5	17.2	32.1	42.0	46.6	18.8	25.1	16.2	29.5	82.3	▲
Potamogeton robbinsii	Fern-leaf pondweed	31.3	32.7	33.7	31.6	30.9	30.8	24.9	26.1	25.7	16.4	12.9	15.9	21.0	32.5	▲
Chara spp.	Muskgrasses	29.3	17.2	22.3	25.3	14.5	16.9	32.1	40.3	40.7	13.8	24.8	14.6	29.2	100.2	▲
Potamogeton zosteriformis	Flat-stem pondweed	31.3	26.1	5.2	16.1	26.0	20.9	12.5	7.5	10.4	10.5	37.3	31.4	29.2	-7.1	▼
Elodea canadensis	Common waterweed	24.7	26.4	15.5	31.3	15.1	12.9	14.1	24.4	34.5	10.5	0.7	1.0	14.2	1366.4	▲
Ceratophyllum demersum	Coontail	23.4	20.8	21.0	22.0	14.5	14.2	9.2	11.9	18.6	15.1	10.6	12.0	18.3	52.9	▲
Potamogeton richardsonii & Pot. hybrid	Clasping-leaf pondweed & hybrid	11.8	17.5	16.8	18.4	10.9	10.9	7.9	13.2	21.5	11.2	4.6	17.5	20.3	16.4	▲
Potamogeton richardsonii	Clasping-leaf pondweed	11.5	17.5	16.8	18.1	10.9	8.9	7.9	13.2	21.5	11.2	4.6	17.5	20.3	16.4	▲
Myriophyllum spicatum	Eurasian watermilfoil	19.1	10.2	0.0	0.3	3.2	11.9	37.7	4.4	14.3	40.1	31.7	0.0	4.7		▲
Heteranthera dubia	Water stargrass	22.4	8.9	4.2	8.6	9.6	13.6	16.1	10.2	11.7	9.2	16.5	11.0	9.2	-16.8	▼
P. amplifolius, P. praelongus, & Pot. hybrid	Large-leaf, white-stem, and hybrid pondweeds	13.8	13.2	11.0	9.5	11.9	8.6	9.2	12.2	14.0	11.2	9.2	8.1	13.9	71.8	▲
P. pusillus, P. berchtoldii, Pot. spp., P. friesii, & P. strictifolius	Thin-leaved pondweeds	21.4	14.5	2.9	2.0	10.3	8.9	4.3	2.0	2.0	7.2	7.9	16.5	17.6	6.8	▲
Potamogeton praelongus	White-stem pondweed	10.5	9.9	10.4	7.6	10.3	5.6	7.9	10.2	9.8	8.2	5.6	4.2	7.8	85.3	▲
Potamogeton pusillus	Small pondweed	3.9	12.5	2.6	1.6	10.3	8.9	4.3	2.0	2.0	6.6	6.3	12.9	13.6	4.7	▲
Eleocharis acicularis	Needle spikerush	5.9	4.0	5.5	1.6	3.2	7.0	9.8	4.4	5.2	6.3	9.2	12.6	8.8	-30.2	▼
Isoetes spp.	Quillwort spp.	3.9	2.6	5.5	3.3	0.6	1.3	6.9	6.1	10.4	8.6	10.6	9.1	11.2	23.5	▲
Myriophyllum sibiricum	Northern watermilfoil	28.3	12.2	0.0	0.0	1.9	8.6	11.8	5.1	4.2	7.2	0.3	0.0	0.0		-
Bidens beckii	Water marigold	14.1	5.9	0.6	2.3	3.9	6.6	6.6	2.7	2.0	7.2	0.0	0.6	0.3	-47.6	▼
Myriophyllum alterniflorum	Alternate-flowered watermilfoil	3.6	4.6	0.6	1.0	1.0	1.0	5.2	3.4	5.9	8.9	1.0	0.0	0.0		-
Potamogeton amplifolius	Large-leaf pondweed	3.6	3.6	0.6	0.7	1.0	0.3	0.0	2.4	2.3	0.3	2.0	3.6	7.1	100.0	▲
Schoenoplectus acutus	Hardstem bulrush	1.0	3.0	2.9	3.0	2.3	1.0	3.9	0.3	1.6	3.3	2.0	0.6	3.1	371.4	▲
Nitella spp.	Stoneworts	2.3	2.6	0.6	2.6	0.0	0.7	0.0	2.0	7.5	5.3	0.3	2.3	0.3	-85.0	▼
Potamogeton friesii	Fries' pondweed	9.2	3.0	0.6	0.3	0.0	0.0	0.0	0.0	0.0	0.7	2.3	3.2	3.7	15.2	▲
Potamogeton spp.	Small pondweed sp.	17.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		-
Potamogeton amplifolius x P. praelongus	Large-leaf x White-stem pondweed hybrid	0.0	0.0	0.0	2.6	1.9	3.6	1.3	0.0	2.0	3.3	1.7	0.6	0.0	-100.0	▼
Potamogeton strictifolius	Stiff pondweed	0.0	0.3	0.3	2.6	0.6	0.0	0.7	1.0	0.7	0.0	2.3	0.3	0.0	-100.0	▼
Ranunculus aquatilis	White water crowfoot	0.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	2.3	1.3	0.7	-47.6	▼
Sagittaria sp. (rosette)	Arrowhead sp. (rosette)	2.6	0.7	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.3	0.0	0.0		-
Potamogeton berchtoldii	Slender pondweed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	1.0	-55.1	▼
Potamogeton richardsonii hybrid	Clasping-leaf pondweed hybrid	0.7	0.0	0.0	0.3	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0		-
Juncus pelocarpus	Brown-fruited rush	0.0	0.0	0.3	1.6	0.0	0.0	0.7	0.3	0.0	0.0	0.0	0.0	0.0		-
Potamogeton perfoliatus	Perfoliate pondweed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		-
Myriophyllum tenellum	Dwarf watermilfoil	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.7		▲
Stuckenia pectinata	Sago pondweed	0.0	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0		-
Sparganium sp.	Bur-reed sp.	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		-
Potamogeton illinoensis	Illinois pondweed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0		-
Sagittaria graminea	Grass-leaved arrowhead	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		-
Eriocaulon aquaticum	Pipewort	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		-
Elatine minima	Waterwort	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		-

▲ or ▼ = Change Statistically Valid (Chi-square; α = 0.05)

▲ or ▼ = Change Not Statistically Valid (Chi-square; α = 0.05)

Littoral frequency of occurrence of aquatic plants from whole - la k e point-intercept surveys in North Twin Lake from 2011-2021.

	Scientific Name	Common Name	LFOO (%) 2011	2016	2021
Dicots	*Ranunculus aquatilis*	White w ater crow foot	10.9	12.2	7.5
	Myriophyllum sibiricum	Northern w atermilfoil	17.1	6.2	2.4
	Myriophyllum alterniflorum	Alternate-flow ered w atermilfoil	4.3	6.8	2.7
	Bidens beckii	Water marigold	1.6	1.7	5.4
	Ceratophyllum demersum	Coontail	4.1	1.7	2.7
	Myriophyllum spicatum	Eurasian w atermilfoil	1.6	1.1	1.5
	Myriophyllum tenellum	Dw arf w atermilfoil	0.0	0.0	0.6
	Utricularia vulgaris	Common bladderw ort	0.0	0.3	0.0
Non-dicots	*Najas flexilis*	Slender naiad	22.6	28.0	38.5
	Potamogeton gramineus	Variable-leaf pondw eed	26.6	36.3	30.1
	Vallisneria americana	Wild celery	27.2	43.1	24.5
	Chara & Nitella	Charophytes	8.7	17.0	26.3
	Chara spp.	Muskgrasses	7.6	16.7	21.2
	Isoetes spp.	Quillw ort spp.	5.7	9.1	15.2
	Potamogeton berchtoldii & P. pusillus	Slender & small pondw eeds	1.9	7.1	12.2
	Potamogeton richardsonii	Clasping-leaf pondw eed	7.6	7.1	6.3
	Elodea canadensis	Common w aterw eed	5.7	5.7	7.2
	Heteranthera dubia	Water stargrass	12.2	2.8	4.8
	Potamogeton friesii	Fries' pondw eed	4.3	4.2	6.3
	Schoenoplectus acutus	Hardstem bulrush	7.1	1.7	6.0
	Potamogeton pusillus	Small pondw eed	1.9	0.0	8.4
	Potamogeton berchtoldii	Slender pondw eed	0.0	7.1	4.2
	Nitella spp.	Stonew orts	1.1	0.3	7.2
	Eleocharis acicularis	Needle spikerush	1.4	2.3	5.4
	Potamogeton zosteriformis	Flat-stem pondw eed	4.3	1.7	3.6
	Potamogeton strictifolius	Stiff pondw eed	1.4	1.7	1.2
	Potamogeton robbinsii	Fern-leaf pondw eed	1.1	0.8	1.2
	Eleocharis palustris	Creeping spikerush	0.8	0.8	1.2
	Sagittaria sp. (rosette)	Arrow head sp. (rosette)	1.1	0.8	0.9
	Potamogeton amplifolius x P. praelong	Large-leaf x w hite-stem pondw eed hybrid	0.0	0.0	1.2
	Potamogeton amplifolius	Large-leaf pondw eed	1.6	0.3	0.0
	Potamogeton praelongus	White-stem pondw eed	0.3	0.8	0.3
	Potamogeton perfoliatus	Perfoliate pondw eed	0.0	0.0	0.6
	Schoenoplectus tabernaemontani	Softstem bulrush	0.0	0.8	0.0
	Sagittaria cristata	Crested arrow head	0.0	0.3	0.3
	Juncus pelocarpus	Brow n-fruited rush	0.8	0.0	0.0
	Fissidens spp. & Fontinalis spp.	Aquatic Moss	0.3	0.0	0.3
	Potamogeton spirillus	Spiral-fruited pondw eed	0.0	0.0	0.3
	Stuckenia pectinata	Sago pondw eed	0.0	0.3	0.0

E

APPENDIX E

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.

Toxicology

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).

Species Susceptibility

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.

Species Susceptibility

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.

<u>Toxicology</u>

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).

<u>Ecological Impacts of Manual and Mechanical Cutting</u>

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).

Ecological Impacts of Benthic Barriers

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.

Ecological effects of Dredging

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).

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APPENDIX F

Comment-Response Document for the Official First Draft

North and South Twin Lake Draft Aquatic Plant Management Plan

Official First Daft: July 31, 2023

Response Comments by District in blue

WDNR Comments from Ty Krajewski (Water Resources Management Specialist), 9/26/2023

- Management Goal 4 Page 52 paragraph 2. How did the lake group arrive at the threshold of 10% LFOO for South twin Lake, and why is there not a threshold for North twin lake? Historical LFOO data on S Twin has in 3 separate cycles shown that once EWM population exceeds 10% in the littoral zone that explosion of EWM to 30%-40% can be expected in 1-2 years. Thus, when LFOO exceeds 10% strategic decisions must be made to determine IPM strategy necessary to mitigate loss of control of EWM and its impact on native plants, recreation, fishing and other aspects of the resource.

  Regarding N Twin, the structure of the littoral zone is much less than that on S Twin as a % of total acreage. Thus, the potential for explosion and its impact is less as well as we have not ever seen historical patterns to rely on to create a threshold. Today, EWM control on N Twin uses in part the matrix developed and included in our LMP. We wish to never allow N Twin to get out of control on EWM as the cost and extent of a whole lake treatment would be very challenging. Thus, we believe a LFOO threshold is not logical today for N Twin management strategies.
  No modifications to the text were made.

- The Matrix is a good approach to managing EWM. Though the department would not consider any of the approaches outlined within as metrics at which we would allow or not allow the certain technique. The permitting process and department review would still happen and a determination would be made. The District believes it is a good guide to use as a broad factor as it evaluates IPM strategies to implement given a multiple of factors. The matrix may change/evolve as we gather more information on the Twins and other lakes regarding management activities. It is a guide and not an absolute. The matrix is a decision-making guide for the District's Lake management Team. We understand a permitting process is still required.
  No modifications to the text were made.

- Page 44 paragraph it seems a little confusing to say that the lake group is using harvest and small-scale management to keep EWM at low levels when within the past couple years large scale treatments have taken place. The District has only used large scale or whole lake activities to gain "control" of EWM, specifically on S Twin. Now that we believe we have achieved "control" based on fall 2023 survey, we can be more targeted with smaller scope management activities. The District has used aggressive DASH activities every year from 2019 – 2023 to either 1) mop up after herbicide treatments to suppress EWM expansion and postpone future herbicide treatments, 2) actively evaluate the cost and benefit of DASH vs small scale herbicide treatments in existing colonies. The 2019 herbicide treatment on N Twin was compared to a 3-year DASH activity on separate areas on N Twin. The result was that the cost of the 3-year DASH

treatment on a 10 acre polygon was at least 4x the cost of a herbicide treatment and less effective. The area we used DASH on for years 2019 – 2022 required a small-scale treatment in 2023 because "control" using DASH was not achieving desired results. This historical data was then used in development of the matrix.
No modifications to the text were made.

- Page 57 Management goal 6. To have a 90% reduction there needs to be pre data to compare to. Will this data be collected through the mentioned 3rd party website. There are not many options for active management of swimmers itch that would be permissible within a lake. will the third party site also track where and when the occurrences happen? This may allow for early response and prevention tactics. Yes, we have actively been compiling historical data for the past 3 years of incidence of swimmers itch on the Twins of where and when it occurs. We intend to continue this data collection so we can track and monitor in the future. This is critical to assess success of activities to mitigate SI and hopefully achieve targeted goals. This goal is based on available studies in Michigan as well as what we believe to be a reasonable standard of success to enable Twin lakes riparians the opportunity to enjoy recreating in the water.
No modifications to the text were made.

- It is encouraging to see a push towards shoreline improvement and protection practices within the next couple years. We encourage and attempt to educate riparians in hopes they adopt helpful practices to maintain shoreline. Township of Phelps project this summer via rip rap repair in the public park is one example.
No modifications to the text were made.

LDF Comments from Celeste Hockings (Natural Resource Director), 9/7/2023

- I would consider us a stakeholder, but I don't feel that we were treated as such, as we didn't receive a stakeholder survey, so we couldn't logistically be able to correctly document our concerns.
  1. You could have sent us one survey for our Council to fill out in order to cover my concern. Per the requirements of a user survey, a defined population needs to be outlined to understand factors like response rate. This user survey population was the District, and referred to as the District Stakeholder Survey. Stakeholder input from agency entities was directly solicited by requesting input to the document during the review process.

  2. We do not support the use of any pesticide/herbicide use, which your plan supports; so we do not want the readers of this document to assume that we are in support of your use of herbicide within the lakes.
  Position acknowledged, no modifications to the text were made.

Summary of Comments received from Public Comment Period

Two stakeholders provided comments on the Swimmers Itch Section (3.4) of the APM Plan. These sentiments have been incorporated into the final version of the APM Plan.