DRAFT

Green Lake

Green Lake County, Wisconsin

Aquatic Plant Management Plan

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Official First Draft

Soliciting Agency & Public Comments

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Green Lake APM Planning Committee

Green Lake Sanitary District	Silver Creek Estuary representative	NE Lake / Channel Area representative
Green Lake Association	City Mill Pond representative	SE Lake Area representative
City of Green Lake Parks Committee	Fishing Committee representative	North Shore representative
Beyers Cove representative		

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B. Riparian Stakeholder Survey Response Charts and Comments
C. Aquatic Plant Survey Data
D. Report Comment Response Document – *Included in Finalized Version*

1.0 INTRODUCTION

Green Lake, Green Lake County is an approximate 7,456 acre drainage lake with a maximum depth of 236 feet and a mean depth of 104 feet (Photograph 1.0-1; Map 1). It is the deepest natural inland lake in Wisconsin and the second most voluminous. In addition to Green Lake proper, there are four adjoining estuaries: three inlet basins called Silver Creek (215 acres), Beyers Cove (28 acres), and County K Marsh (269 acres), and one outlet basin called City Millpond (48 acres). These four basins, as well as select areas of Green Lake, are designated as Areas of Special Natural Resource Interest (ASNRI) by the WDNR for having Critical Habitat/Sensitive Area Designations. The lake is fed via eight streams: Dakin Creek, Hill Creek, Roy Creek, Wuerches Creek, White Creek, Silver Creek, Spring Creek, and Assembly Creek. Water flows out of Green Lake into City Millpond and into the Puchyan River. Green Lake's watershed encompasses approximately 107 square miles, of which greater than 50% is comprised of agricultural lands (Sesing 2013).

Green Lake is on the 303(d) impairment list for low dissolved oxygen in stratified layers at specific times of the year. This impairment has been connected to phosphorus loading in the recently completed Diagnostic and Feasibility Study and is discussed in the Upper Fox Wolf Basin Total Maximum Daily Load (TMDL). Sediment cores collected and analyzed from various locations in Green Lake in 1999 and 2016 indicate that the amount of phosphorus entering the lake has doubled since 1930.

Photograph 1.0-1. Green Lake natural shoreline.

In 1951, stakeholders within Green Lake's watershed formed the Green Lake Association with a mission of promoting conservation of Green Lake and its watershed. As members of the Green Lake Association began to notice water quality degradation, they created the Green Lake Sanitary District (GLSD). A *Lake Management Plan (LMP)* was completed for Green Lake in 2013 (Sesing 2013) that covered many aspects of the lake's ecology. The lake management plan outlined a number of objectives and strategies pertaining to the lake's aquatic plant community, and includes reducing user conflicts with aquatic plants through integrated methods (mechanical harvesting, herbicide application, etc.) and protecting the integrity of the native aquatic plant community.

In 2013, the Green Lake Sanitary District successfully applied for a Wisconsin Department of Natural Resources (WDNR) Aquatic Invasive Species (AIS) Established Population Control (EPC) Grant to aid in funding Eurasian water milfoil (*Myriophyllum spicatum*; EWM) and curly-leaf pondweed (*Potamogeton crispus*; CLP) monitoring and control from 2013-2015 within the lake's three inlet basins. Additionally, this project also included a comprehensive assessment of Green Lake's aquatic plant community in 2014.

In 2022, a group of Green Lake stakeholders lead by the Green Lake Association (GLA) and the Green Lake Sanitary District (GLSD) initiated a project to create a *Comprehensive Lake and Watershed Management Plan* (L&WM) for Green Lake. This overarching plan would incorporate the recently approved Nine Key Element Watershed Plan (2022) and provide an update to the outdated Lake Management Plan (2013).

The Wisconsin Department of Natural Resources (WDNR) requires an *Aquatic Plant Management* (APM) Plan to be updated at roughly five-year intervals in order for a lake group to be eligible for certain permits, including a multi-year mechanical harvesting permit (NR109). An APM Plan is one component of the L&WMP which focuses on aquatic plants and related management. With the last Lake Plan being completed over a decade ago, the GLA and GLSD identified the immediate need to update the APM Plan for Green Lake. The APM Plan contained here would become the first phase/module of the L&WMP.

Onterra was contracted in fall 2022 to assist with a series of WDNR grant applications to provide cost share for a project aimed at updating the APM Plan for Green Lake. Both grant applications were successful and the project commenced in March 2023. The APM Planning project presented here also includes an investigation of stakeholder perceptions and preferences through a written stakeholder survey, as well as studies aimed to understand the near-shore watershed of the lake termed *shoreland condition.*

2.0 STAKEHOLDER PARTICIPATION

Stakeholder participation is an important part of any management planning exercise. The objective of this component in the planning process is to accommodate communication between the planners and the project sponsors. The communication is educational in nature, both in terms of the planners educating the stakeholders and vice-versa. The planners educate the lake group 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 a focus group called a *Planning Committee.* For this project, the *Planning Committee* consisted of members of the GLA and GLSD LMPT, as well as representation from key areas around the system.

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

2.1 Strategic Planning Committee Meetings

Planning committee meetings were used to gather comments, create management goals and actions and to deliver study results.

APM Planning Project Info Meeting

On April 4, 2024, Eddie Heath presented at the GLA/GLSD's annual *State of the Lake* gathering. This 45-minute presentation provided a foundational understanding of the Aquatic Plant Management (APM) Planning project, as well as highlights of the 2023 surveys conducted as part of the project. A copy of this presentation is included in Appendix A.

Planning Committee Meeting I

On May 17, 2024, Eddie Heath met with the *APM Planning Committee*. 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. A copy of this presentation is included in Appendix A.

The planning committee meeting attendees were supplied with the draft report sections prior to the meeting and much of the meeting time was utilized to detail the results, discuss the conclusions and initial recommendations, and answer committee questions.

Planning Committee Meeting II

The second planning committee meeting was held on May 17, 2024 and concentrated on the development of management goals and actions that make up the framework of the implementation plan. This meeting had extensive discussions on varying management options, how each technique could be used in reaching potential management goals, and risk assessment of the techniques. Mitigating the impacts of nuisance aquatic plants, duckweed, and sedimentation were key topics discussed at the meeting. This was a discussion-based meeting with no formal presentation materials.

Planning Committee Meeting III

Onterra and representatives from the GLA and GLSD met virtually on March 13, 2025 for approximately 1.5 hours methodically going through each management action contained within the draft Implementation Plan Section (5.0). These discussions integrated perspectives that were brought forth during the Focus Group Listening Sessions, the Riparian Stakeholder Survey, and the overall APM planning process.

2.2 Management Plan Review and Adoption Process

On April 16, 2025, an early draft of the complete Aquatic Plant Management Plan was provided to the *APM Planning Committee* for review. These comments were addressed to result in the Official First Draft.

On April 30, 2025, the Official First Draft of the Aquatic Plant Management Plan for Green Lake was supplied to WDNR (lakes and fisheries programs), partner organizations, and community groups to solicit comments on the Implementation Plan. At that time the Official First Draft was posted to the GLA website for public review, with outreach efforts requesting interested stakeholders to provide comments. The posting remained active past the minimum required 21-day public comment period required.

During the GLA/GLSD's 2025 annual *State of the Lake* gathering, Eddie Heath of Onterra presented the draft Implementation Plan developed by the *APM Planning Committee*, supporting information used to arrive at this plan, and answered questions from the audience. XXXX individuals were present at the meeting, with an additional XXX people viewing the live-stream via the teleconference platform. This meeting further alerted the Green Lake stakeholders of the draft Plan's existence on the web (onscreen QR code during presentation) and the fact that written comments are welcomed at this time.

The public comment period remained active until DATE when the WDNR (Ted Johnson) communicated INSERT COMMENT SUMMARY.

2.3 Riparian Stakeholder Survey

As a part of this project, a stakeholder survey was distributed to Green Lake Association (GLA) and Green Lake Sanitary District (GLSD) members around Green Lake. The survey was designed by Onterra staff and the LMPT and reviewed by a WDNR social scientist which was approved in August of 2023. During October of 2023, the 10-page, 44-question survey was posted online through Survey Monkey for survey-takers to answer electronically. If requested, a hard copy was sent with a self-addressed stamped envelope for returning the survey anonymously. The returned hardcopy surveys were entered into the online version by a third-party for analysis. Thirty percent (30%) of the 925 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 Green Lake. Forty-three percent of respondents indicated that they visit the lake on the weekend, vacation, and/or as a holiday residence, while 29% visit seasonally through the year, 21% are year-round residents, and 3% listed other. Fifty-nine percent of respondents have owned their property for over 11 years, and 42% have owned their property for over 25 years.

The stakeholder survey data is discussed throughout Section 3.0 with respect these particular topics. Figures 2.0-1 to 2.0-3 highlight several baseline stakeholder perceptions discovered within this survey. More than half of survey respondents indicate that they use either a motor boat with greater than 25 hp motor, pontoon, canoe/kayak, or a combination of these three vessels on Green Lake (Figure 2.0-1). Jet skis were also a popular option. On a large lake and popular lake such as Green Lake, the importance of responsible boating activities is increased. The need for responsible boating increases during weekends, holidays, and during times of nice weather or good fishing conditions as well, due to increased traffic on the lake.

Question 17: What types of watercraft do you currently use on Green Lake?

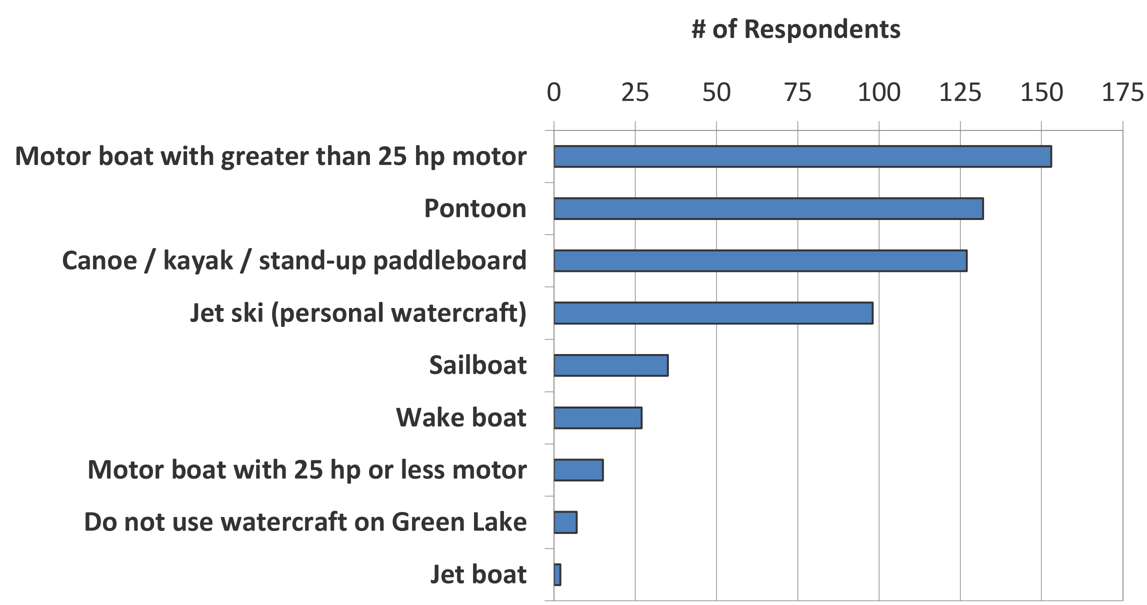


Figure 2.0-1. Select survey responses from the Green Lake stakeholder survey. Additional questions and response charts may be found in Appendix B.

As displayed on Question 16, some of the top recreational activities on the lake involve boat use (Figure 2.0-2). Although boat traffic was listed as a factor potentially impacting Green Lake in a negative manner, it was ranked 6th on a list of stakeholder's top concerns regarding the lake (Figure 2.0-3). Water quality degradation and algal blooms were ranked as the top two concerns of stakeholder survey respondents.

Question 16: Please rank up to three activities that are important reasons for owning your property on or near Green Lake.

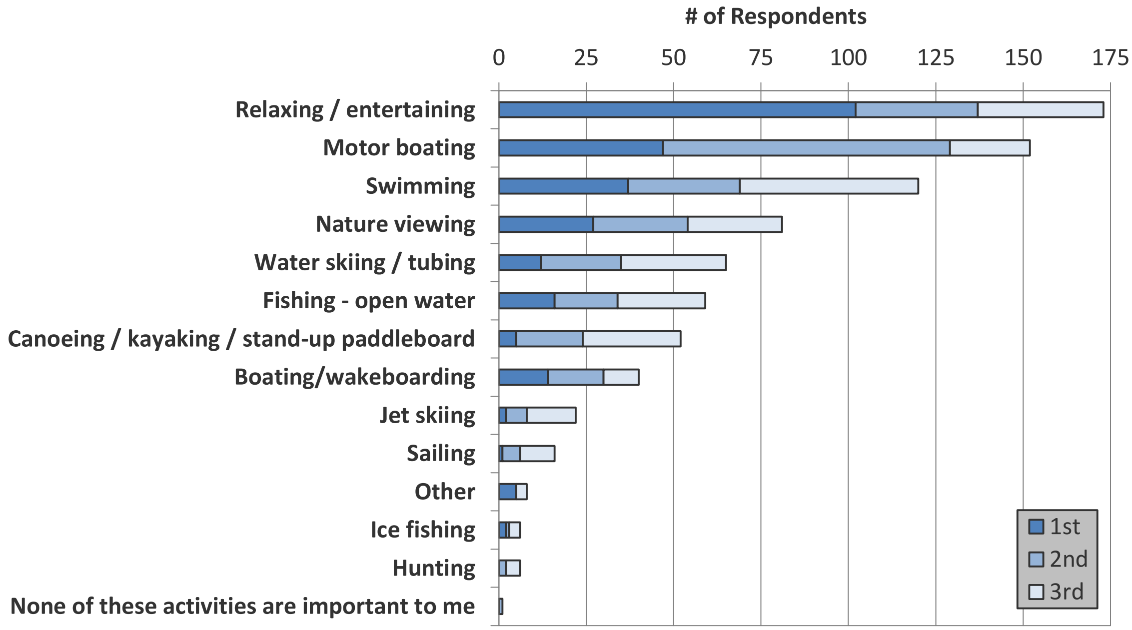


Figure 2.0-2. Select survey responses from the Green Lake stakeholder survey. Additional questions and response charts may be found in Appendix B.

Question 22: From the list below, please rank your top three concerns regarding Green Lake, with the 1st being your top concern.

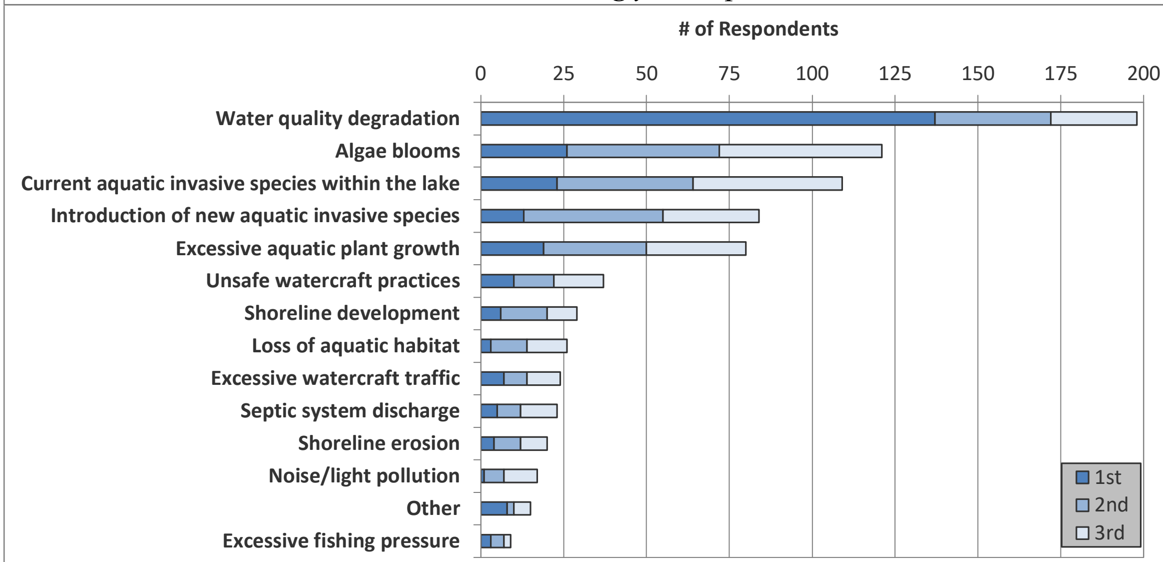


Figure 2.0-3. Select survey responses from the Green Lake stakeholder survey. Additional questions and response charts may be found in Appendix B.

2.4 Focus Group Listening Sessions

As part of the Aquatic Plant Management Plan planning process, the GLA partnered with Blue Door Consulting to conduct 11 segmented focus groups with more than 80 participants. These sessions engaged anglers, farmers, lakeshore property owners (grouped by geography), and government officials to ensure a wide range of local perspectives.

While the focus groups were not designed to quantify frequency of specific viewpoints, the research surfaced strong recurring perceptions around aquatic vegetation as a growing concern. Many participants, especially lakeshore property owners and anglers, described a noticeable increase in nuisance vegetation, including duckweed, filamentous algae, and uprooted plant mats, which they viewed as symptoms of broader water quality degradation.

These perceptions were often attributed to phosphorus loading, commonly understood by participants as entering the lake from multiple sources including farm and lawn runoff. Some participants, particularly anglers and shoreline residents, also expressed concern that wake boats may contribute to sediment disturbance and vegetation uprooting, though no local data was cited to support that claim. It's important to note that while this perception was voiced in multiple groups, it does not represent a confirmed causal relationship.

Participants across segments emphasized that the aquatic plant issue is limiting recreation in certain areas of the lake, making activities like swimming, sailing, and diving less viable than in the past. While they appreciated educational efforts, many expressed a desire for more visible, timely action to address the underlying causes of aquatic vegetation overgrowth, especially phosphorus.

3.0 RESULTS & DISCUSSION

3.1 Shoreland Condition

Primer on Lake Shoreland Zone and its Importance

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

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

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

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

Shoreland Research

Studies conducted on nutrient runoff from Wisconsin lake shorelands have produced interesting results. For example, a USGS study on several Northwoods Wisconsin lakes was conducted to determine the impact of shoreland development on nutrient (phosphorus and nitrogen) export to these lakes (Graczyk et al. 2003). During the study period, water samples were collected from surface runoff and ground water and analyzed for nutrients. These studies were conducted on several developed (lawn covered) and undeveloped (undisturbed forest) areas on each lake. The study found that nutrient yields were greater from lawns than from forested catchments, but also that runoff water volumes were the most important factor in determining whether lawns or wooded catchments contributed more nutrients to the lake. Groundwater inputs to the lake were found to be significant in terms of water flow and nutrient input. Nitrate plus nitrite nitrogen and total phosphorus yields to the ground-water system from a lawn catchment were three or sometimes four times greater than those from wooded catchments.

A separate USGS study was conducted on the Lauderdale Lakes in southern Wisconsin, looking at nutrient runoff from different types of developed shorelands – regular fertilizer application lawns (fertilizer with phosphorus), non-phosphorus fertilizer application sites, and unfertilized sites (Garn 2002). One of the important findings stemming from this study was that the amount of dissolved phosphorus coming off of regular fertilizer application lawns was twice that of lawns with non-phosphorus or no fertilizer. Dissolved phosphorus is a form in which the phosphorus molecule is not bound to a particle of any kind; in this respect, it is readily available to algae. Therefore, these studies show us that it is a developed shoreland that is continuously maintained in an unnatural manner (receiving phosphorus rich fertilizer) that impacts lakes the greatest. This understanding led former Governor Jim Doyle into passing the Wisconsin Zero-Phosphorus Fertilizer Law (Wis Statue 94.643), which restricts the use, sale, and display of lawn and turf fertilizer which contains phosphorus. Certain exceptions apply, but after April 1 2010, use of this type of fertilizer is prohibited on lawns and turf in Wisconsin. The goal of this action is to reduce the impact of developed lawns, and is particularly helpful to developed lawns situated near Wisconsin waterbodies.

Shorelands provide much in terms of nutrient retention and mitigation, but also play an important role in wildlife habitat. Woodford and Meyer found that green frog density was negatively correlated with development density in Wisconsin lakes (Woodford and Meyer 2003). As development increased, the habitat for green frogs decreased and thus populations became significantly lower. Common loons, a bird species notorious for its haunting call that echoes across Wisconsin lakes, are often associated more so with undeveloped lakes than developed lakes (Lindsay et al. 2002). And studies on shoreland development and fish nests show that undeveloped shorelands are preferred as well. In a study conducted on three Minnesota lakes, researchers found that only 74 of 852 black crappie nests were found near shorelines that had any type of dwelling on it (Reed 2001). The remaining nests were all located along undeveloped shoreland.

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

Photograph 3.1-1. Example of coarse woody habitat in a lake.

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

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

National Lakes Assessment

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

Photograph 3.1-2. Example of a bio-log restoration site.

Through the National Lakes Assessment, a number of potential stressors were examined, including nutrient impairment, algal toxins, fish tissue contaminants, physical habitat, and others. The 2007 NLA report states that "*of the stressors examined, poor lakeshore habitat is the biggest problem in the nation's lakes; over one-third exhibit poor shoreline habitat condition*" (USEPA 2009). Furthermore, the report states that "*poor biological health is three times more likely in lakes with poor lakeshore habitat.*" These results indicate that stronger management of shoreline development is absolutely necessary to preserve, protect, and restore lakes. Shoreland protection will become increasingly important as development pressure on lakes continues to grow.

Wisconsin's Healthy Lakes & Rivers Action Plan

Starting in 2014, a program was enacted by the WDNR and UW-Extension to promote riparian landowners to implement relatively straight-forward shoreland restoration activities. This program provides education, guidance, and grant funding to promote installation of best management practices aimed to protect and restore lakes and rivers in Wisconsin. The program has identified five best practices aimed at improving habitat and water quality (Figure 3.1-1).

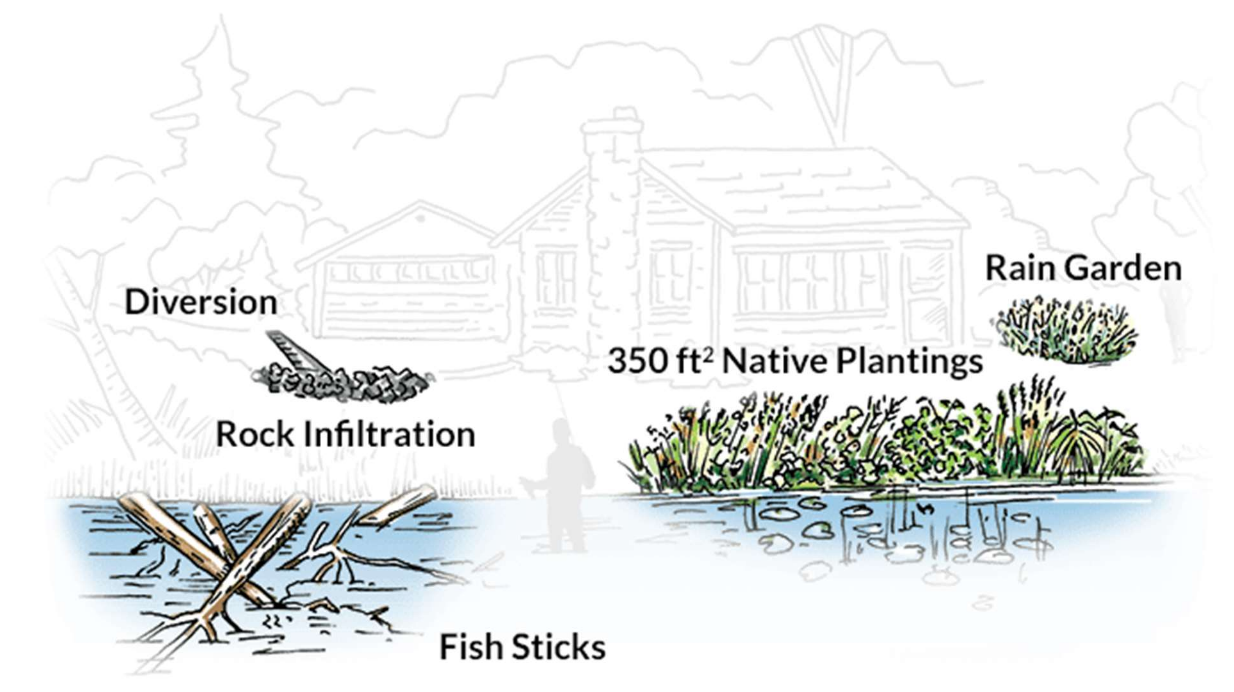


Figure 3.1-1. Healthy Lakes & Rivers 5 Best Practices. Illustration by Karen Engelbretson, extracted from healthylakeswi.com.

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

The Healthy Lakes and Rivers Grant Program allows partial cost coverage for implementing best practices. Competitive grants are available to eligible applicants such as lake associations and lake districts. The program allows a 75% state cost share up to $1,000 per practice. Multiple practices can be included per grant application, with a $25,000 maximum award per year. Eligible projects need to be on shoreland properties within 1,000 feet of a lake or 300 feet from a river. The landowner must sign a Conservation Commitment pledge to leave the practice in place and provide continued maintenance for 10 years. More information on this program can be found here:

https://healthylakeswi.com/

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

Green Lake Shoreland Zone Condition

Shorelands and Shallows

A draft WDNR Lake Shoreland & Shallows Habitat Monitoring Field Protocol (WDNR 2020) was utilized to evaluate the shoreland zone on a parcel-by-parcel basis beginning at the estimated high-water level mark and extending inland 35 feet. The immediate shoreline was surveyed and classified based upon its potential to negatively impact the system due to development and other human impacts. Within the shoreland zone the natural vegetation (canopy cover, shrub/herbaceous) was given an estimate of the percentage per plot (Photo 3.1-3). Human disturbances (impervious surface, manicured lawn, agriculture, number of buildings, boats on shore, piers, boat lifts, sea wall length and other similar categories) were also recorded by number of occurrence or percentage per plot during the survey.

Photograph 3.1-3. Example of canopy, shrub and herbaceous layers.

The entire shoreline of Green Lake was surveyed by Golden Sands Resource Conservation & Development Council, Inc.in the summer of 2017 following the WDNR protocol.

A change in Wisconsin shoreline zoning regulation in 2015 resulted in a boom in boat houses building along the shoreline increasing impervious surface in a zone critical to the lake's health. The LMPT was interested in documenting the effect of the change in the zoning statute on Green Lake, initiating a replicate survey in 2023. The data comparisons will form the basis for discussions with the Green Lake County Land Use and Zoning Department about the impact permitting and enforcement decisions have on the health of the lake. The data will also form the basis of discussions with interested landowners, particular to their property, on the benefits of shoreline restoration and buffers to the health of the lake and the potential for implementing them.

In an effort to increase the flow of information between lake stakeholders and project planners, this project piloted an interactive web map application for the system, allowing users to see the shoreland and shallows survey as it relates to their property or favorite recreation areas. Various layers can be turned on and off, and some layers can be selected and a pop-up window will provide additional information. Access to this interactive map is provided below:

https://onterra.maps.arcgis.com/apps/webappviewer/index.html?id=5ce030a7a3de436d917c66f38c600563

Please note that when investigating the 2017 data, errors in georeferencing were apparent such that the data collected could not be tied to a specific parcel. The compiled data outputs were determined to be sound, but spatial comparisons could not be made. Therefore, the following comparisons investigate are discussed in terms of number of parcels as opposed to length of shoreline frontage.

Canopy cover is defined as the proportion of a parcel's buffer zone that is shaded by trees that are at least 16 feet tall. The survey crew estimates canopy cover in 5% increments from zero to 100%. During the 2023 survey, 39% of the system's shoreline length, or 15.2 miles, was categorized as having a buffer zone with at least 50% canopy coverage (Figure 3.1-2). It is important to note that some undeveloped parcels, such as wetland areas, that naturally do not have a canopy present are also factored into this result (Map 2). In comparison to 2017, only nominal differences in the composition of canopy coverage are noted.

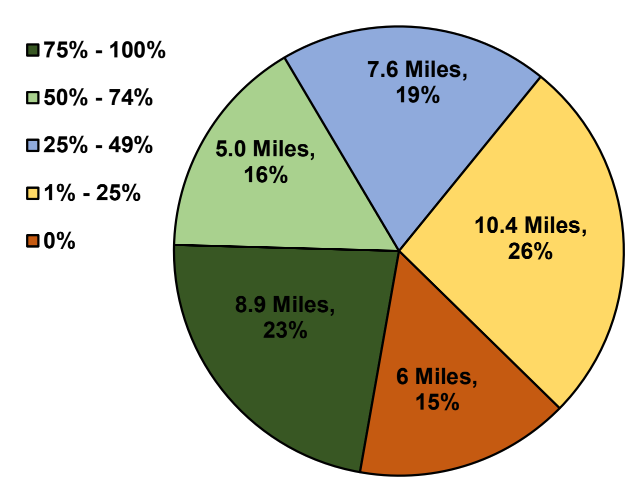


Figure 3.1-2. 2023 canopy cover percentage. Based upon length of shoreline

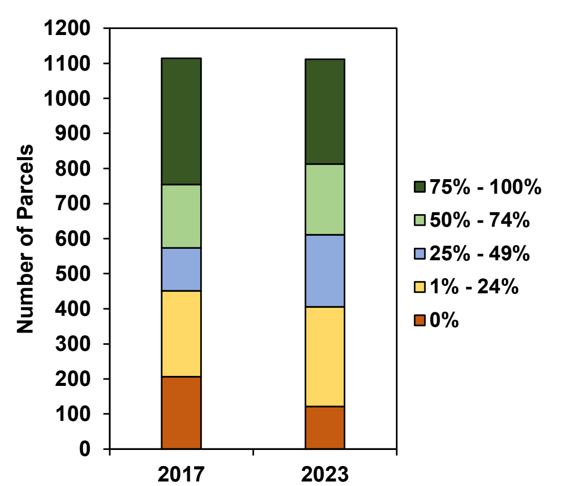


Figure 3.1-3. 2017-2023 percent canopy cover comparison. Based upon number of parcels

During the surveys, the proportion of various ground layers of a parcel's buffer zone were also estimated in 5% increments. The sum of all "ground layers" (shrub/herbaceous plants, impervious surface, manicured lawn, agriculture, and other) must equal 100%.

Shrub and herbaceous layers were defined as small trees and plants less than 16 feet tall. As discussed in the primer section above, this is one of the most important layers to buffering nutrients and pollutants into the lake. The 2023 survey recorded approximately 12.7 miles, or 35% Green Lake's shoreline length to have at least 50% shrub and herbaceous cover (Figure 3.1-4, Map 3). The study also indicates that 16.3 miles or 42% of the shoreline length has no shrub/herbaceous layer present. This means that the ground layer of these parcels is completely comprised of manicured lawn or impervious surfaces.

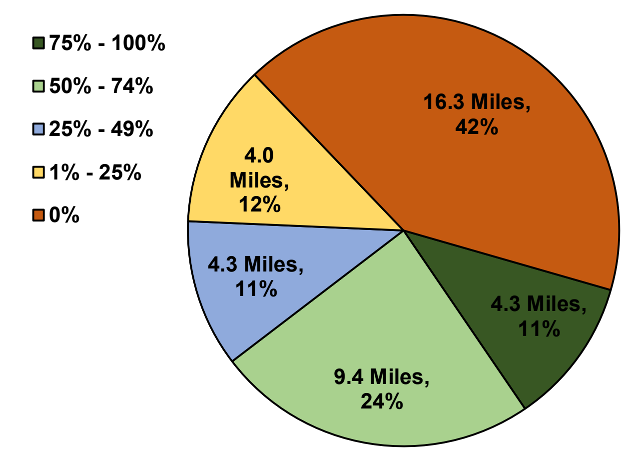


Figure 3.1-4. 2023 shrub & herbaceous layer percentage. Based upon length of shoreline

Please note that on the following figures for manicured lawn and impervious surface coverage, the color scheme has been reversed. The lower coverage categories are depicted as shades of green, as they are beneficial for the lake. One of the primary mechanisms shrub/herbaceous layers are able to buffer nutrients in lakes is their extensive and deep roots facilitate the nutrients dissolved in water to infiltrate into the ground. While manicured lawns are a dense network of plants, their shallow root systems offer little in assistance for water to soak into the ground. In 2023, one third of the nearshore buffer zone of the greater Green Lake system was comprised of parcels that were at least half manicured lawn. Comparing the data from 2017 and 2023, a reduction in parcels with no manicured lawn was recorded. These data also indicate a positive shift in parcels that are at least half covered with a manicured lawn, with less parcels having over 75% lawn coverage.

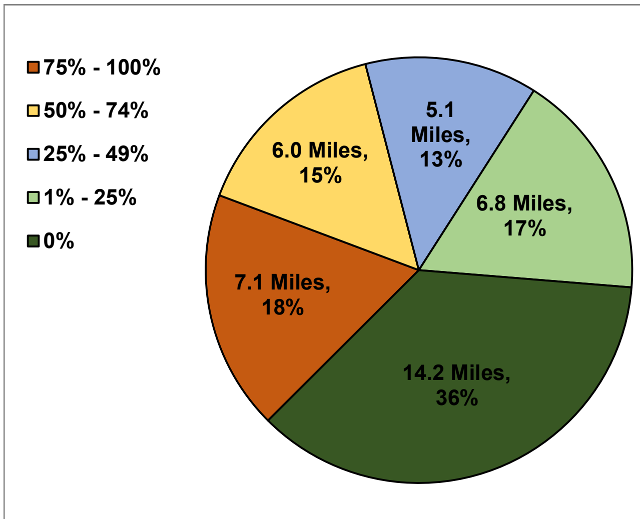


Figure 3.1-5. 2023 manicured lawn cover percentage. Based upon length of shoreline

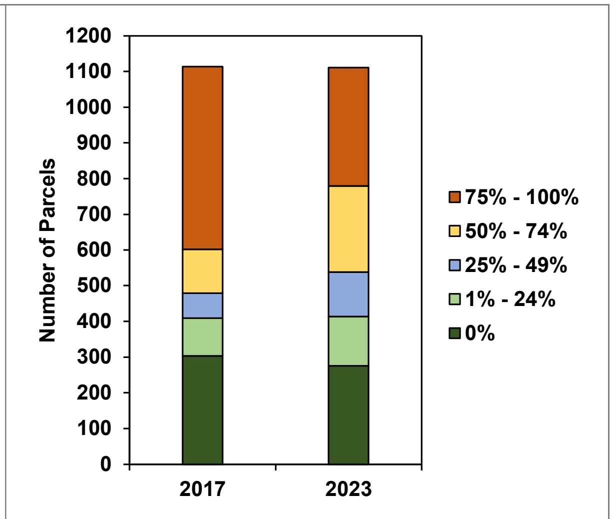


Figure 3.1-6. 2017-2023 percent manicured lawn cover comparison. Based upon number of parcels

Impervious surfaces are those that do not allow water to infiltrate into the ground at all, such as rooftops, roads, driveways, walkways, boulders, concrete stairs, etc. over 85% of the length of shoreline buffers on Green Lake have less than 25% coverage of impervious surfaces (Figure 3.1-

7). This equated to 913 parcels in 2023, which is lower than 1,045 parcels in 2017 and indicating a shift of increased impervious surfaces in the Green Lake buffer zone (Figure 3.1-8)

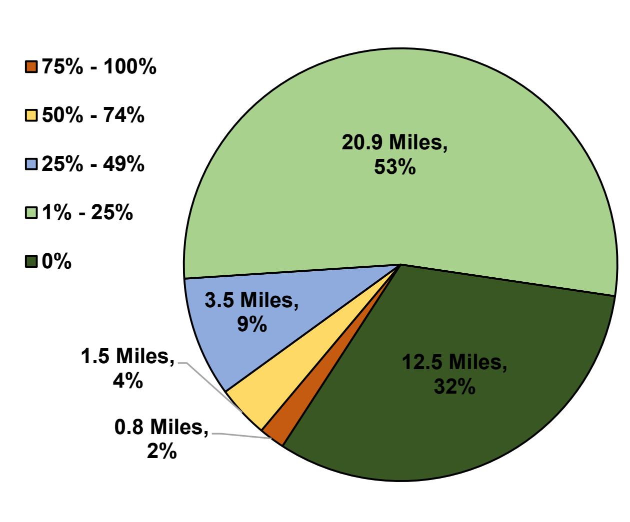


Figure 3.1-7. 2023 impervious surface cover percentage. Based upon length of shoreline

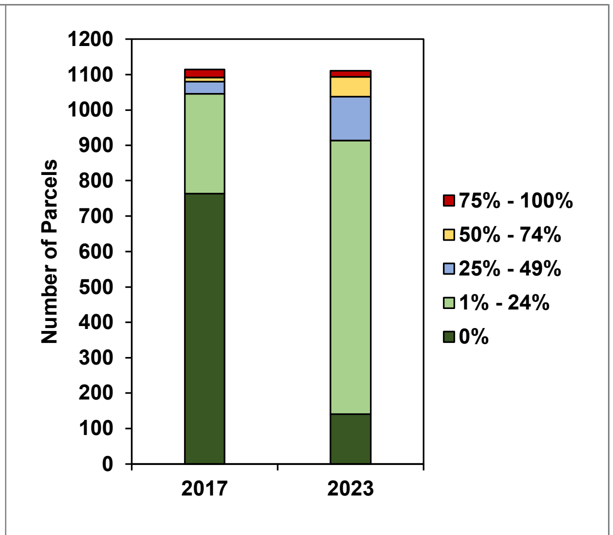


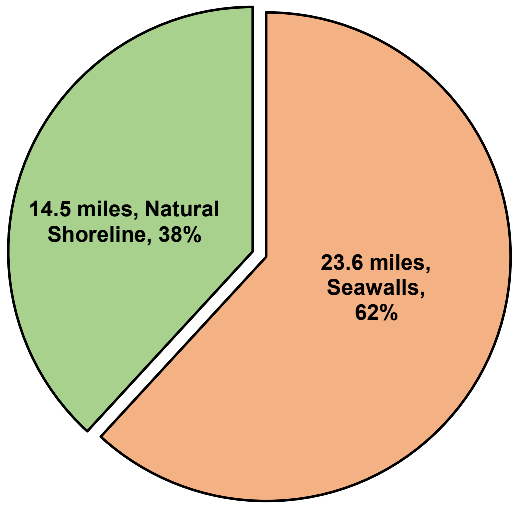
Figure 3.1-8. 2017-2023 percent impervious surface cover comparison. Based upon number of parcels

Human-modified Shoreland Practices Assessment

The importance of the shoreland zone of a lake is well discussed above. It is important to also acknowledge that natural shorelines are dynamic and are naturally altered over time from shoreland erosion and impacts from ice shoves. While the impacted shorelines continue to provide valuable wildlife habitat, the changes are undesired by the property owners. Seawalls are commonly constructed to reduce shoreline erosion and protect adjacent upland properties from wave action and winter ice shoves. However, these structures reduce the natural complexity of the nearshore habitat and reduce biodiversity. Therefore, these artificial shoreland modification practices are generally discouraged.

On large lakes like Green Lake, erosion and ice shoves can be extremely damaging to valuable shoreline properties. Water levels above the ordinary high-water level can also cause damage, particularly when coupled with wave action. When a circumstance justifies the need for shoreland modifications to protect property, the WDNR favors properly implemented rip-rap/rock or bio-logs. These structures mimic a type of native shoreline, providing a level of environmental benefit in addition to shoreland stabilization.

The Green Lake PMT sponsored a supplemental survey of the Green Lake system's shoreline, to determine the extent and type of seawalls on the lake. Seawalls were delineated with submeter accuracy and classified in five different categories (masonry, metal, riprap/rock, wood, or other). Seawalls are commonly installed to protect the shoreline from erosion due to large wave action. During this survey, 23.6 total miles of seawall were observed along 40.4 miles of shoreline (Map 6). Most of the seawall was classified as riprap/rock, followed by masonry, and other (Figure 3.1-9).



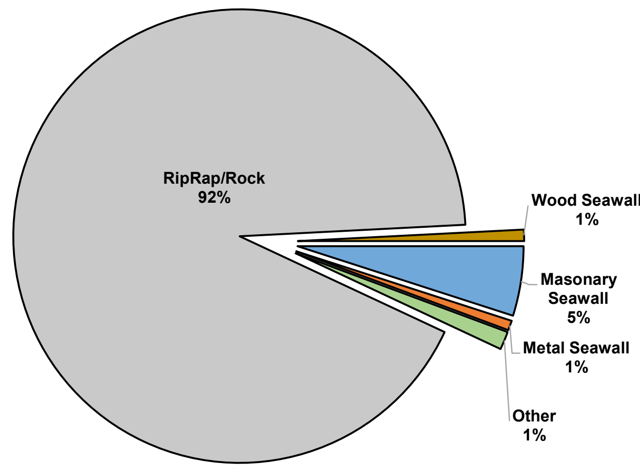


Figure 3.1-9. Green Lake seawall survey results. Percentage seawalls vs. natural shoreline (Left) and Percentage of seawall categories (Right).

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. Figure 3.1-10 displays the responses of members of Green Lake stakeholder property and their seawall type. The vast majority (73%) of stakeholders reported having a seawall made of rip-rap. Green Lake riparians were also asked what *changes do you hope to see for the Green Lake Shoreline*, with 56% of respondents stating *more natural shoreline* would be preferred (Appendix B, Question #27).

Question #11. What type of seawall do you have on your property?

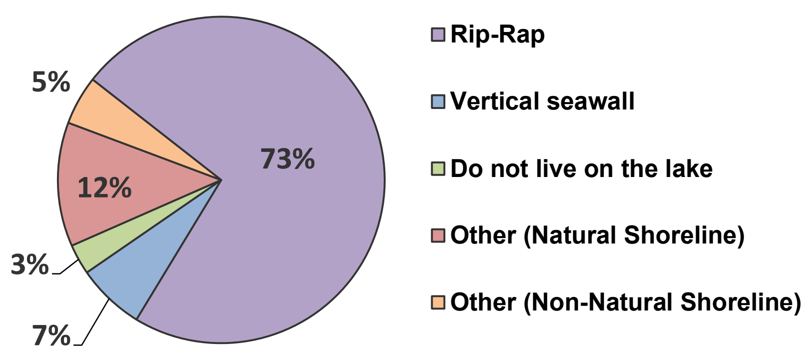


Figure 3.1-10. Stakeholder survey response Question #11: What type of seawall do you have on your property?

Buffer Zone Boathouses & Structures Assessment

The WDNR Shorelands & Shallows Protocol does include the collection of "boathouse" information, but the surveyor is instructed to only record boathouses that are over the water. During the supplemental shoreline seawall survey discussed above, the Green Lake PMT also sponsored a supplemental survey to accurately map the location so all structures in the 35-foot buffer zone. All structures were identified and classified in three different location categories (at water's edge, over water, and set back within 35ft). If a boathouse was identified, it was further classified as a single or multiple stalls. During this survey, 168 total boathouses were observed and 63 other structures were observed along 40.4 miles of shoreline (Map 7, Figure 3.1-11). Most of the boathouses were single stall and were set back within 35 feet of the shoreline. Some of the other structures observed were primarily sheds or a dwelling located within the 35-foot buffer zone.

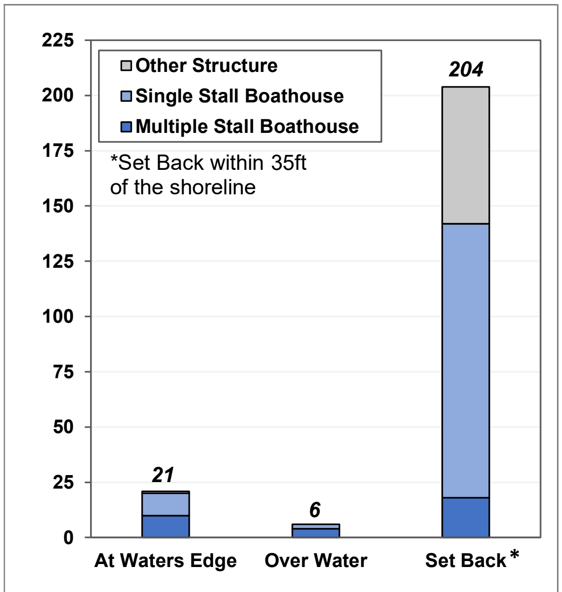


Figure 3.1-11. Structures within a 35-foot shoreline buffer zone survey results.

Figure 3.1-12 displays the responses of members of Green Lake stakeholders to their perceptions regarding boathouses on Green Lake. Most of the survey respondents believe boathouses have no impact or a small impact on Green Lake's water quality and natural beauty/aesthetics. Even though most believed boathouses have little to no impact on Green Lake, most survey respondents would be in favor of stricter ordinances with regards to placement and size of boathouses.

How much of a negative impact, if any, do you feel boathouses have on Green Lake's - *Question 6: water quality?* - *Question 7: natural beauty and aesthetics?*	*Question 8: How much would you support or oppose stricter ordinances for Green Lake County to restrict the placement and size of boathouses?*

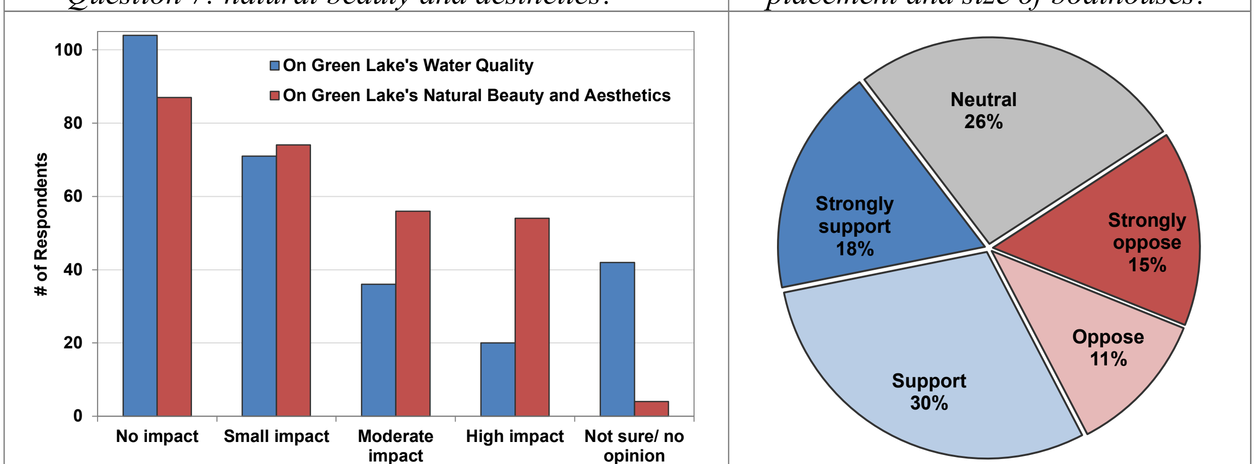


Figure 3.1-12. Survey responses from the Green Lake Stakeholder Survey. Additional questions and response charts may be found in Appendix B.

3.2 Aquatic Plants

3.2.1 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 Green Lake and the adjoining basins periodically since 2007. Map 8 displays these sampling locations, in addition to the table outlining sampling resolution and total number of sampling locations. At each point-intercept location within the *littoral zone*, information regarding the depth, substrate type (soft sediment, sand, or rock), and the plant species sampled along with their relative abundance on the sampling rake was recorded.

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

Species List

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

Frequency of Occurrence

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

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

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 (LFOO)*. 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 Green Lake to be compared to other lakes within the region and state.

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

Green Lake falls within the Southeastern Wisconsin Till Plains (SWTP) *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.

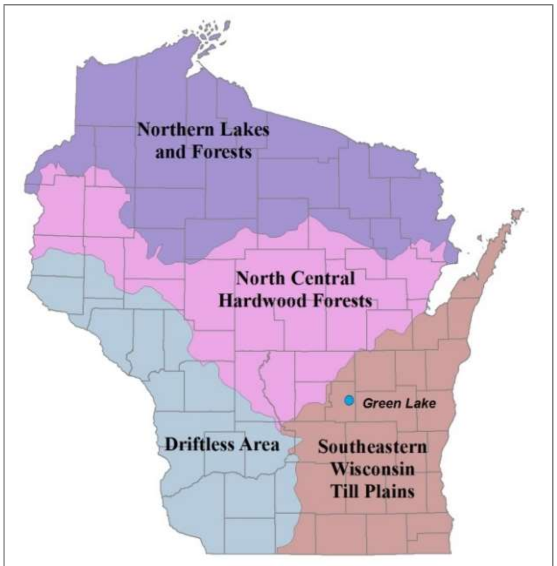


Figure 3.2.1-1. Location of Green Lake within the ecoregions of Wisconsin. After (Nichols 1999).

Species Diversity

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

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

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

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

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

If a lake has a diversity index value of 0.90, it means that if two plants were randomly sampled from the lake there is a 90% probability that the two individuals would be of a different species. The Simpson's Diversity Index value from Green Lake is compared to data collected by Onterra and the WDNR Science Services on 392 lakes throughout Wisconsin.

3.2.2 System Wide Aquatic Plant Community

Aquatic plant surveys were conducted on Green Lake and its four adjacent waterbody basins in 2023. This section will investigate the overall vegetation condition of the system, with subsequent sections providing more specific information for a given waterbody.

Aquatic Plant Species Assessments

Approximately a total of 46 aquatic plant species were recorded in Green Lake and estuaries during the 2023 point-intercept surveys. Of these 46 species, coontail (*Ceratophyllum demersum*), wild celery (*Vallisneria americana*), and muskgrasses (*Chara* spp.) were the most frequently encountered native plant species (Photograph 3.2.2-1).

Coontail *(Ceratophyllum demersum)*	Muskgrasses (*Chara* spp.)	Wild celery (*Vallisineria americana*)
		

Photograph 3.2.2-1. Common aquatic plant species found within the Green Lake system. Photograph credit Onterra.

Table 3.2.2-1 displays all of the 46 species that were documented during the 2023 point-intercept surveys on the Green Lake system. Table 3.2.2-1 is organized by growth form which separates out species based on whether they are emergent species, floating-leaf species, submergent species, or free-floating species. Species with an "X" on the table indicate that the species was physically encountered on the rake during the point-intercept survey. Additional species ("I" on table) may have been identified as a part of another survey, such as the floating-leaf and emergent community mapping survey, or were visually noticed during the point-intercept survey but were not found at any location on the rake sampler. Common examples of incidental species include those growing on the shoreline of the lake such as purple loosestrife or iris species, or species in low abundance.

Table 3.2.2-1. List of aquatic plant species in 2023 point-intercept and community mapping surveys.

Growth Form	Scientific Name	Common Name	WI State Status	Coefficient of Conservatism	Green Lake	Beyers Cove	City Mill Pond	Silver Creek	County K Marsh
Emergent	*Eleocharis palustris*	Creeping spikerush	Native	6				I	
	Iris spp. (sterile)	Iris spp. (sterile)	Unknown (Sterile)	N/A		I			
	Iris pseudacorus	Pale-yellow iris	Non-Native - Invasive	N/A					I
	Lythrum salicaria	Purple loosestrife	Non-Native - Invasive	N/A			I		I
	Phalaris arundinacea	Reed canary grass	Non-Native - Invasive	N/A		I		I	I
	Phragmites australis subsp. americanus	Common reed	Native	5					I
	Schoenoplectus acutus	Hardstem bulrush	Native	5	I				
	Schoenoplectus tabernaemontani	Softstem bulrush	Native	4	I		I	I	
	Sparganium eurycarpum	Common bur-reed	Native	5	I	I	I	I	
	Typha latifolia	Broad-leaved cattail	Native	1	I	I	I		I
	Typha spp.	Cattail spp.	Unknown (Sterile)	N/A			I	I	I
FL	*Nuphar variegata*	Spatterdock	Native	6					I
	Nymphaea odorata	White water lily	Native	6	X	X	X	X	X
Submergent	*Ceratophyllum demersum*	Coontail	Native	3	X	X	X	X	
	Chara spp.	Muskgrasses	Native	7	X	X			
	Elatine minima	Waterwort	Native	9	X				
	Elodea canadensis	Common waterweed	Native	3	X	X		X	
	Heteranthera dubia	Water stargrass	Native	6	X	X	X	X	
	Myriophyllum sibiricum	Northern watermilfoil	Native	7	X				
	Myriophyllum spicatum	Eurasian watermilfoil	Non-Native - Invasive	N/A	X	X	X	X	
	Najas flexilis	Slender naiad	Native	6	X	X			
	Najas guadalupensis	Southern naiad	Native	7	X	X		X	
	Nitella spp.	Stoneworts	Native	7	X				
	Potamogeton berchtoldii	Slender pondweed	Native	7	X				
	Potamogeton crispus	Curly-leaf pondweed	Non-Native - Invasive	N/A	X	X	X	X	I
	Potamogeton foliosus	Leafy pondweed	Native	6	X				
	Potamogeton friesii	Fries' pondweed	Native	8	X		X	X	
	Potamogeton gramineus	Variable-leaf pondweed	Native	7	X				
	Potamogeton illinoensis	Illinois pondweed	Native	6	X				
	Potamogeton nodosus	Long-leaf pondweed	Native	5	X		X		
	Potamogeton praelongus	White-stem pondweed	Native	8	X	X			
	Potamogeton pusillus	Small pondweed	Native	7	X	X			
	Potamogeton richardsonii	Clasping-leaf pondweed	Native	5	X	X	X	X	
	Potamogeton robbinsii	Fern-leaf pondweed	Native	8	X	X			
	Potamogeton strictifolius	Stiff pondweed	Native	8	X				
	Potamogeton zosteriformis	Flat-stem pondweed	Native	6	X		X	X	
	Ranunculus aquatilis	White water crowfoot	Native	8	X	X	X	X	
	Sagittaria sp. (rosette)	Arrowhead sp. (rosette)	Native	N/A	I				
	Stuckenia pectinata	Sago pondweed	Native	3	X	X	X	X	I
	Vallisneria americana	Wild celery	Native	6	X	X	X	X	
	Zannichellia palustris	Horned pondweed	Native	7	X	X			
S/E	*Eleocharis acicularis*	Needle spikerush	Native	5	X				
FF	*Lemna minor*	Lesser duckweed	Native	5	X	X		X	
	Lemna trisulca	Forked duckweed	Native	6	X	X	X		
	Lemna turionifera	Turion duckweed	Native	2	X		X		
	Spirodela polyrhiza	Greater duckweed	Native	5	X	X	X		
	Wolffia spp.	Watermeal spp.	Native	N/A	X	X	X	X	

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

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).

The most common plant species in the Green Lake system is coontail (Figure 3.2.2-1). Coontail has whorls of leaves which fork into two to three segments, providing lots of surface area for the growth of periphyton and habitat for invertebrates. Unlike most of the submersed plants found in Wisconsin, coontail does not produce true roots and is often found growing entangled amongst other aquatic plants or matted at the surface. Since it lacks true roots, coontail derives most of its nutrients directly from the water (Gross et al. 2003). This ability in combination with a tolerance for low-light conditions allows coontail to become more abundant in eutrophic waterbodies with higher nutrients and low water clarity. Coontail has the capacity to form dense beds that can float and mat on the water's surface.

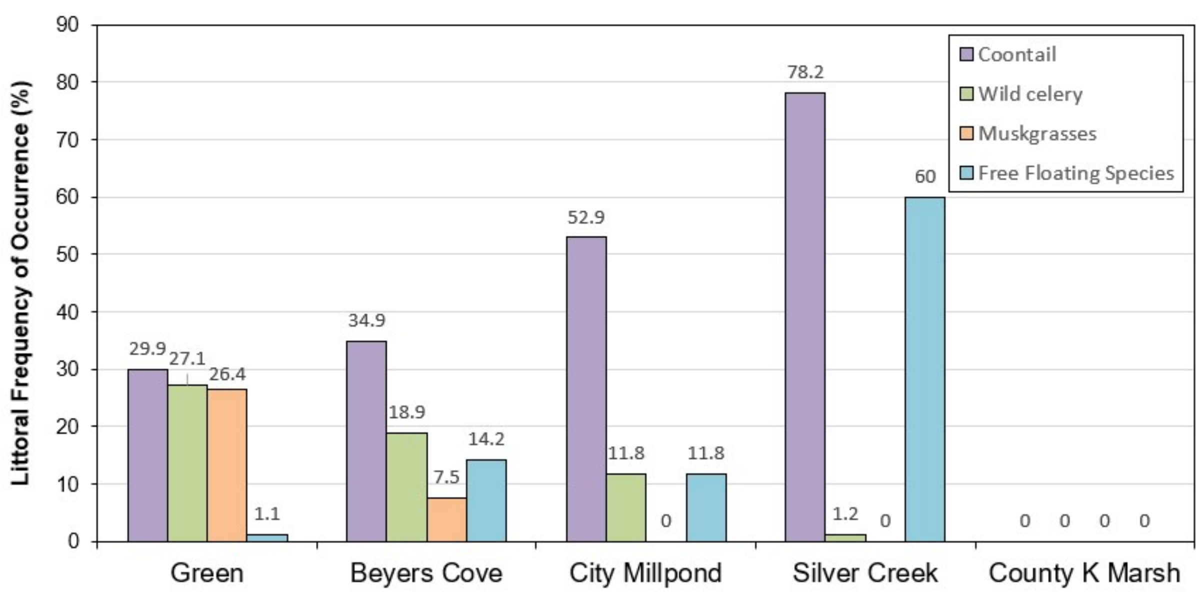
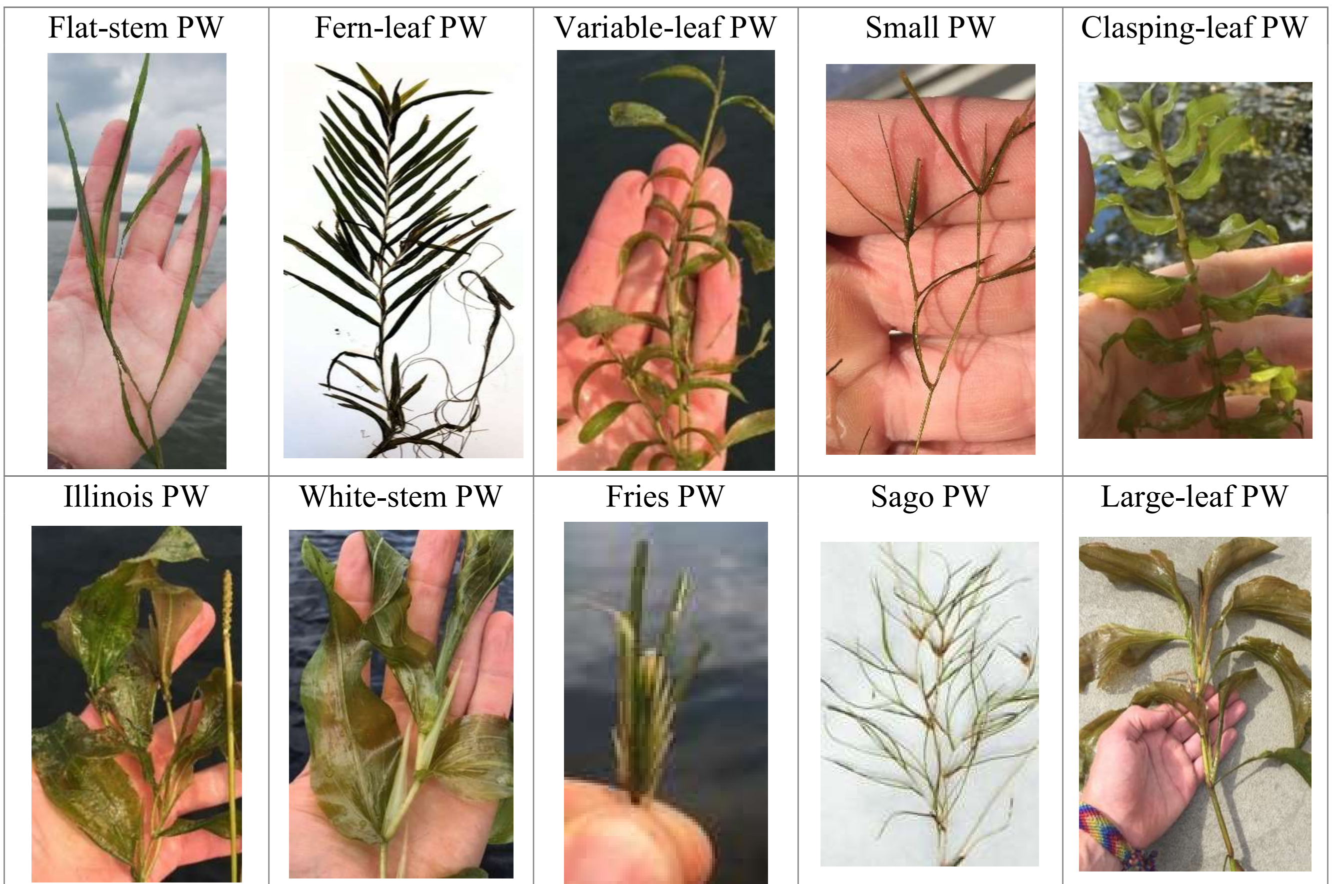


Figure 3.2.2-1. LFOO of common native aquatic plant species. LFOO = littoral frequency of occurrence. Free-floating species = Lesser duckweed, greater duckweed, forked duckweed, turion duckweed, and watermeal spp.

The second-most abundant plant in the Geen Lake system is wild celery. Wild celery contains a basal rosette, which means that the long, grass-like leaves extend in a circular fashion from the base of the plant located at the sediment-water interface. To keep the leaves standing in the water column, lacunar cells in the leaves trap air and gasses making them more buoyant. Towards the late-summer when water celery is at its peak growth stage, it is easily uprooted by wind and wave activity. The wild celery can then pile up on shorelines depending on the predominant wind direction. This occurs periodically on Green Lake, and is common on other large waterbodies around the state.

The third-most abundant macrophyte in Green Lake. Muskgrasses are not a true plant but a genus of macroalgae, of which there are ten documented species that occur in Wisconsin. Dominance of the aquatic plant community by muskgrasses is common in hardwater lakes and these macroalgae have been found to be more competitive against vascular plants (e.g., pondweeds, milfoils, etc.) in lakes with higher concentrations of calcium carbonate in the sediment (Kufel and Kufel 2002); (Wetzel 2001). Muskgrasses require lakes with good water clarity, and their large beds stabilize bottom sediments. Studies have also shown that muskgrasses sequester phosphorus in the calcium carbonate encrustations which form on these plants, aiding in improving water quality by making the phosphorus unavailable to phytoplankton (Coops 2002). Muskgrasses can be easily identified by their strong skunk-like odor. As well as providing a food source for waterfowl, muskgrasses often serves as a sanctuary for small fish and other aquatic organisms.

Plant species from the family Potamogetonaceae are referred to as the pondweeds. The Green system is known to contain about a dozen different pondweed species and possibly some hybrid varieties (Photograph 3.2.2-2). Pondweeds leaves and forms come in a variety of sizes, like large-leave pondweed with leaves a few inches wide to small pondweed with leaves a few millimeters wide. Pondweeds are favored by many anglers, as they provide enough habitat to provide cover for fish, but not too much that the fish cannot see the bait or lure at the end of the line.



Photograph 3.2.2-2. Common Potamogetonaceae species in Green Lake. PW = Pondweed. Photo credit Onterra.

Large populations of free-floating vegetation have been documented at times on Silver Creek including during the 2017 and 2023 Onterra surveys. The free-floating plants are made up largely of lesser duckweed (*Lemna minor*), turion duckweed (*Lemna turionifera*) and watermeal species (*Wolffia* spp.); with lesser amounts of forked duckweed (*Lemna trisulca*) and greater duckweed (*Spirodela polyrhiza*). These species can vary in abundance at any given time and are influenced by flow or wind driven water movement since they are not rooted in the sediment. More information on duckweed in Green Lake will be discussed at the end of this section.

The Green Lake system is known to harbor two non-native submersed aquatic plant species, Eurasian watermilfoil (EWM) and curly-leaf pondweed (CLP) (Photography 3.2.2-3). Both of these plant species are native to Europe and Asia and can thrive in some Wisconsin waterways to levels that can impact navigation and recreation as well as alter the way the ecosystem functions. In some lakes, these species can integrate into the overall aquatic plant community and only provide minor negative attributes.

Photograph 3.2.2-3. Eurasian watermilfoil (left) and curly-leaf pondweed (right) from Green Lake. Photo credit Onterra.

EWM was first documented in Green Lake in 1969. In 2010, DNA analysis revealed that the plants in Green Lake were hybrid water milfoil (HWM), a cross between EWM and the indigenous northern water milfoil. Onterra ecologists sent in additional milfoil samples in 2013, and these were also confirmed as HWM. HWM can grow faster, become more invasive, and be less susceptible to chemical control strategies than pure-strain EWM. Unless specifically indicated, this report will use the term "EWM" to refer to the combined population of EWM and HWM within Green Lake.

Map 9 shows the locations of EWM from the 2023 point-intercept surveys on Green Lake and the adjacent basins. While EWM continues to be prevalent in the Green Lake system, populations are overall lower than the previous assessments during 2014. 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.

CLP was first officially discovered in Green Lake in 1971. Like some of Wisconsin's native pondweeds, CLP's primary method of propagation is through the production of numerous asexual reproductive structures called turions. Once mature, these turions break free from the parent plant and may float for some time before settling and overwintering on the lake bottom. Once favorable growing conditions return (i.e., spring), new plants emerge and grow from these turions. Many of the turions produced by CLP begin to sprout in the fall and overwinter as small plants under the ice. Immediately following ice-out, these plants grow rapidly giving them a competitive advantage over native vegetation. CLP typically reaches its peak biomass by mid-June, and following the production of turions, most of the CLP will naturally senesce (die back) by mid-July.

The senescence of curly-leaf pondweed populations has been shown to release a significant amount of phosphorus into the water from decomposing plant tissues (James et al. 2002). Because CLP dies back by the beginning of July, the impact to navigation and recreation do not overlap with the majority of the recreation season. In instances where a large turion base may have already built up, lake managers and regulators question whether the repetitive annual herbicide strategies may be imparting more strain on the environment than the existence of the invasive species.

Because CLP dies back in early July, the mid-summer point-intercept surveys are not a good way to document these populations. The conditions of Beyers Cove have favored dense and impactful CLP populations in the past, so a properly timed June point-intercept survey occurred on this waterbody to understand the population of CLP. This will be discussed in the subsequent waterbody-specific section.

Aquatic Plant Community Metrics

The previous sections focused on understanding the aquatic plant population of Green Lake, including the abundance of individual species. The following waterbody-specific section will also investigate trend analysis of individual species populations over time. Lake managers also use a variety of aquatic plant metrics to understand the overall aquatic plant community of a system.

Map 10 shows the number of native aquatic species present at each sampling point during the 2023 point-intercept surveys. In some lakes, the higher the aquatic plants present can indicate higher value areas of the lake. However, disturbed conditions can also favor a high number of disturbance-tolerant species. Lake managers largely look at the stability of this metric over time to understand changes in the overall aquatic plant community.

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.

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 within Section 3.2.1). This assessment allows the aquatic plant community of Green Lake to be compared to other lakes within the region and state.

The species richness, average conservatism, and floristic quality values for Green Lake and each estuary are listed below in Figure 3.2.2-2. These values can be compared to the Southeast Wisconsin Till Plains (SWTP) and Wisconsin State means (blue bars on Figure 3.2.2-2). Using the species richness and average conservatism to calculate the Floristic Quality Index for Green

Lake system reveals exceptionally high values for Green Lake system (Figure 3.2.2-2). The FQI of Green Lake system of 44.2 and 39.7, respectively, is well above the ecoregion median and state median. A comparison of these metrics to previous surveys on a lake-by-lake basis are discussed below within each waterbody's individual report section.

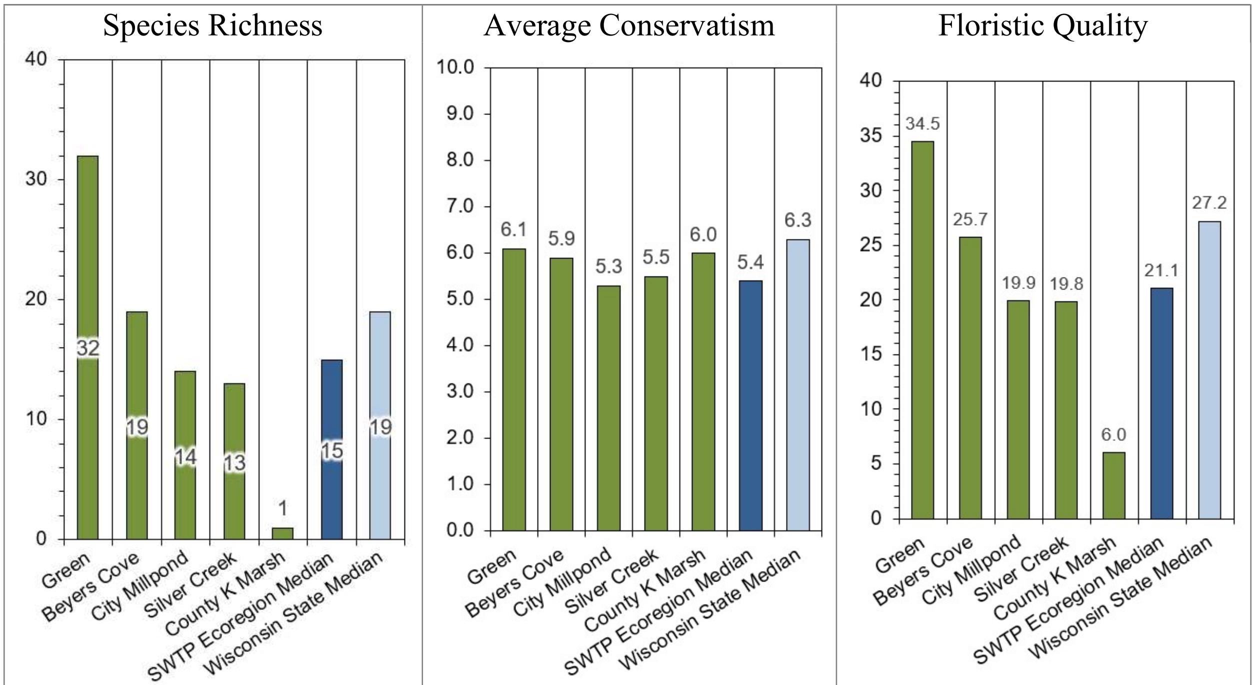


Figure 3.2.2-2. Floristic Quality Index attributes from 2023. Analysis follows (Nichols 1999).

Species diversity is often confused with species richness. While species diversity utilizes species richness, it also takes into account evenness or the variation in abundance of the individual species within the community. 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.

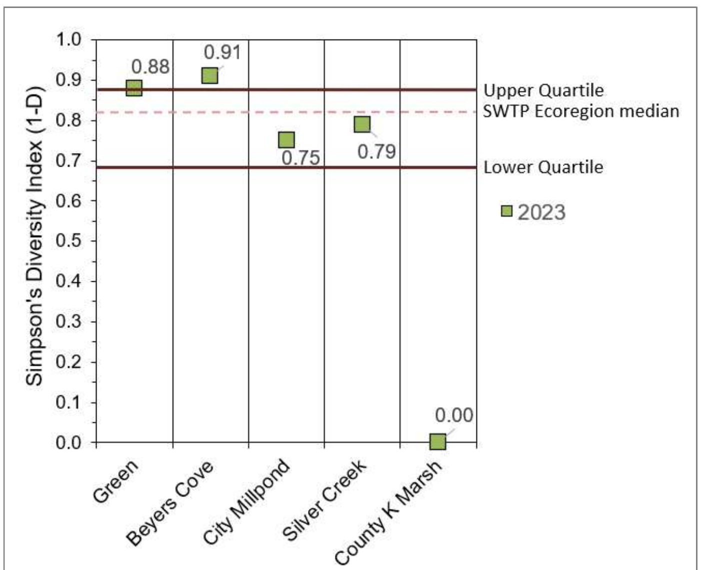


Figure 3.2.2-3. Simpson's Diversity Index from 2023.

Figure 3.2.2-3 displays the diversity metrics from the Green Lake system compared to data collected by Onterra and the WDNR Science Services on 77 lakes within the Southeast Wisconsin Till Plain ecoregion. Green Lake proper and Beyers Cove have diversity values at or above the 75th percentile of lakes in this ecoregion. City Millpond and Silver Creek have values lighly below the ecoregion median (50th percentiel).

Total Rake Fullness (TRF) values are recorded at each sampling location as a part of the point-intercept survey methodology, essentially documenting the abundance of aquatic plant biomass within the lake regardless of what species it is (Figure 3.2.2-4, Map 11). Beyers Cove and Silver Creek contain aquatic plants in over 90% of their respective littoral zones. City Millpond had aquatic plants at 71% of sampling locations, with almost all locations containing the lowest density rating of aquatic plants present. Please note that most of the dense lily pad region of this outlet basin are not factored into this figure, mostly representing the area available for recreational use. Green Lake proper has aquatic plants in three-quarters of its littoral zone, with a mix of dense (rake-fullness of 3) and low-density (rake-fullness of 1) plant communities.

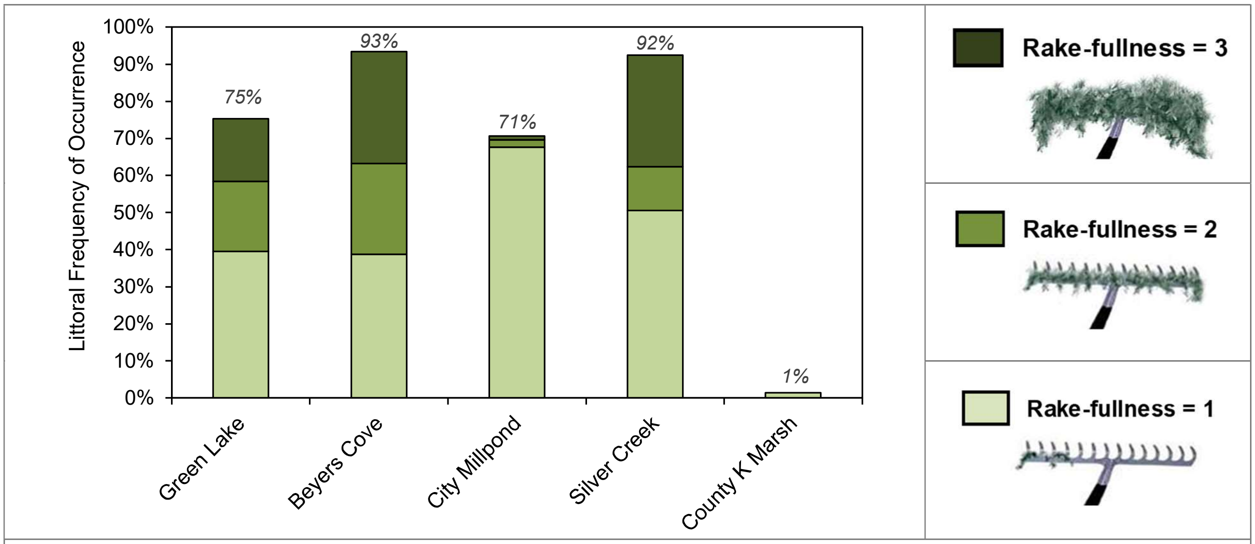


Figure 3.2.2-4. Total rake fullness data from 2023 point-intercept surveys.

Critical Habitat Areas

While the name has changed from *sensitive area designations* to *critical habitat designation*, the goal remains to ensure important areas of the waterbody are protected from human activity and disturbances. These areas are designated through a formal process by the WNDR, and give regulators stronger ability to deny certain permits that may threatened the intrinsic value of these areas. For Green Lake, the areas chosen have been found to contain the mechanisms that protect the water quality of Green Lake, harbor high quality aquatic plant communities, and other essential habitat to support wildlife and fish life cycles (WDNR, Designation of Sensitive Areas in Green Lake, Green Lake County 2006). There are eight critical habitat areas identified on Green Lake and its estuaries (Map 1, Table 3.2.2-2) which all together total 903.8 acres. These areas are located throughout the system and contain emergent, floating-leaf, and wetland plant communities. More details on the critical habitat areas on Green Lake can be found interactively online:

Table 3.2.2-2. WDNR Critical Habitat Designation.

WDNR Name	Acres
Green Lake - 1 (County Park Marsh)	524.0
Green Lake - 2 (Blackbird Point Bay)	8.4
Green Lake - 3 (Beyers Cove)	26.3
Green Lake - 4 (West Norwegian Bay)	71.3
Green Lake - 5 (Green Lake Millpond)	47.4
Green Lake - 6 (East Shore Dartford	7.0
Green Lake - 7 (Carver Islands)	5.1
Green Lake - 8 (Silver Creek Marsh)	214.3
	903.8

https://apps.dnr.wi.gov/lakes/criticalhabitat/Project.aspx?project=10419304

Community Mapping Surveys

A key component of any aquatic plant community assessment is the delineation of the emergent and floating-leaf aquatic plant communities within each lake as these plants are often underrepresented during the point-intercept survey. Many of these areas have been designated as *critical habitat areas*. The emergent and floating-leaf community mapping survey (often referred to as *community mapping survey*) creates a snapshot of these important communities within each lake as they existed during the survey and is valuable in the development of the management plan and in comparisons with future surveys. Examples of emergent plants include cattails, rushes, sedges, grasses, bur-reeds, and arrowheads, while examples of floating-leaf species include the water lilies.

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

The emergent and floating-leaf aquatic plant communities in Green Lake were mapped using a Trimble Global Positioning System (GPS) with sub-meter accuracy. These aquatic plant communities are displayed on Maps 13-17 and are also visible on the Green Lake Interactive Shoreland Condition interactive web map:

https://onterra.maps.arcgis.com/apps/webappviewer/index.html?id=5ce030a7a3de436d917c66f38c600563

Please note that small colonies, those less than approximately 40-ft in width, are mapped with point-based methods. The margins of larger colonies are delineated with area-based methods, essentially a polygon defining the colonies footprint. The footprint of these colonies can be measured with acreage, whereas point-based occurrences cannot.

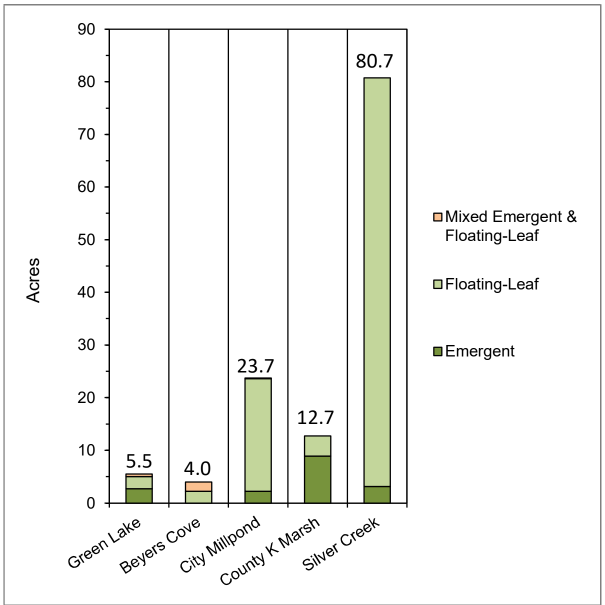


Figure 3.2.2-5. Community map acres from 2023.

The 2023 community mapping survey delineated a total of almost 127 acres of floating-leaf and emergent plant communities within the ordinary high water mark of the Green Lake system (Figure 3.2.2-5). It is important to note that many valuable wetland communities also exist in adjacent areas to these communities that were not assessed as part of this survey. Floating-leaf and emergent plant communities have been found to fluctuate over time. Changes in these species are often associated with differences in water levels and watercraft traffic compared to changes in submersed aquatic plants being primarily related to water clarity and aquatic plant management activities. Trends in these aquatic plant communities will be explored in the individual basin-specific sections.

Carp Management

A 1998 survey of Silver Creek indicated this system was in a turbid state with almost no submersed aquatic plant growth (9E Plan, 2022). The County K Marsh was in a similar state. Green Lake resource managers recognized the impact carp were having on Green Lake's ecosystem particularly within the estuaries where turbidity was high and aquatic vegetation was sparse. In the mid-2000s, a "bubble barrier" was installed underneath County Highway A between Silver Creek Estuary and Green Lake to keep carp from migrating into this estuary from Green Lake proper during the spring spawning season (Photograph 3.2.2-4, left frame).

Photograph 3.2.2-4. Bubble barrier and fencing exclosures. Barriers shown from Silver Creek (left) and County Hwy K Marsh (right). Photo credit Onterra

The seasonally operated bubble barrier appears to be an effective deterrent for carp that want to move into the Silver Creek Estuary from Green Lake. Aggressive commercial carp removal within the Silver Creek Estuary was also conducted to remove carp that were trapped within this upstream estuary, as well as from Green Lake itself. Aquatic plant surveys of the Silver Creek Estuary following the installation of the barrier indicated aquatic plant growth had increased greatly. A carp barrier was also installed between the County Highway K Marsh and Green Lake but has not yielded the same results as for the Silver Creek Estuary (Photograph 3.2.2-4, right frame).

Duckweed Population

The free-floating plants are made up largely of lesser duckweed (*Lemna minor*), turion duckweed (*Lemna turionifera*) and watermeal species (*Wolffia* spp.); with lesser amounts of forked duckweed (*Lemna trisulca*) and greater duckweed (*Spirodela polyrhiza*). These species can vary in abundance at any given time and are influenced by flow or wind driven water movement since they are not rooted in the sediment. Reliable anecdotal reports indicate sizeable duckweed populations originating in Silver Creek started appearing after the carp management program was initiated. An official plant survey conducted in 2007 documented a high population of duckweed in Silver Creek. Photograph 3.2.2-5 shows the current condition of Silver Creek as it relates to duckweed coverage.

Photograph 3.2.2-5. Duckweed in Silver Creek Estuary. Photograph credit Phil Burkart.

Unlike most other aquatic plants, duckweed and watermeal obtain all of their nutrients directly from the water (Huebert and Shay 1991). While these plants are flowering plants, they mainly reproduce vegetatively via budding. Under optimal conditions, they can double their population every 16 hours (Hasan and Chakrabarti 2009), allowing them to completely cover areas of waterbodies in a very short time. These plants cannot grow and reproduce in fast-moving water and require areas of still or slow-moving water that is relatively protected from wind.

According to Hasan and Chakrabarti (2009), only a minimal amount of phosphorus within the water is required to support duckweed growth, and once this level has been reached, the concentration of nitrogen, specifically ammonia nitrogen, is the main nutrient controlling the growth of duckweeds. Sources of ammonia nitrogen to lakes include fertilizers and animal wastes. If adequate nutrients and light are present, the remaining important factor in determining the growth rate of duckweeds is temperature (Van der Heide et al. 2006). The growth rate of duckweeds is positively correlated with water temperature, and their maximum growth rate is achieved when water temperature is at 78.8°F (Van der Heide et al. 2006). However, if their density or the thickness of the mat becomes too great, their growth rates decline due to self-shading (Driever et al. 2005).

As will be discussed within the subsequent Silver Creek Section (3.2.6), duckweed populations negatively impact navigation, recreation, and aesthetics in this part of the system. In 2023, riparian property owners and GLA members were asked about how various aquatic plants impacted access to the lake. Duckweed was identified as the most impactful plant, with 55% of respondents indicating duckweed negatively impacted their access (Figure 3.2.2-6).

Queston 30: Have duckweed populations had a negative impact on your access of Green Lake?

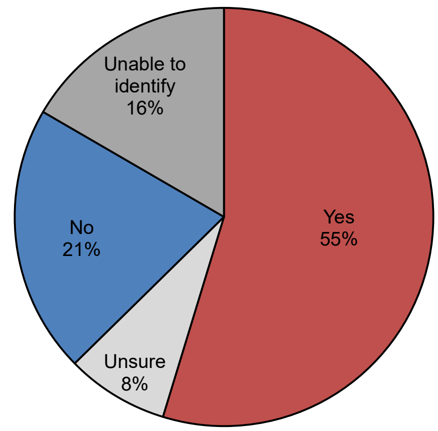


Figure 3.2.2-6. Duckweed-related survey responses from the Green Lake stakeholder survey. Additional questions and response charts may be found in Appendix B.

In addition to the navigation impediment duckweed causes, concerns exist about the nutrient loading potential to Green Lake, proper from duckweed produced in Silver Creek and upstream waters. During the summer of 2022, Onterra facilitated a study to estimate the load of phosphorus entering Green Lake via duckweed from Silver Creek Estuary. The intent was to complete several field collections of duckweed entering the lake during the summer and relate the results of those field collections with varying levels of duckweed flow determined visually. Essentially calibrate daily visual estimates of flow into categories from none to heavy and then use the field collection results to extrapolate the wet weight of duckweed entering the lake. Ultimately, the methodology failed to allow for a reasonably accurate estimate of how much duckweed entered the lake during the 2022 growing season. However, the field data results can be used to generate a basic understanding of the amount of phosphorus entering in the form of duckweed from the estuary.

In July 2022, both ends of a 100-ft long flexible, floating boom was secured on the lake side adjacent to one of the bridge abutments at the Silver Creek Estuary. One end was detached, moved across the entrance, and secured near the opposite abutment. Once full, the ends of the boom were brought together and the boom closed (Photograph 3.2.2-6). It took 3 minutes for the boom to fill. The entirety of the duckweed catch was removed from the boom by repeatedly filling a pre-weighed wash bucket and placing the spoils in a trailer. The wash bucket has a screen at the bottom that allowed much of the water to drain out of the sample. Before dumping the contents in the trailer, the bucket was weighed. Fifty-nine bucket loads were required to remove the captured duckweed from the boom resulting in a wet weight of approximately 770 lbs. Three grab samples were taken from the trailer and sent to the UW Forage Lab for analysis.

Photograph 3.2.2-6. Duckweed nutrient study. Photo credit: Onterra.

The boom was deployed and emptied of duckweed in Aug and in September of the same year with grab samples being sent to the UW Forage Lab as well. Nine samples in total were collected over the 3 field sampling events. The lab results indicated an average of 7.11% dry matter with a minimum of 5.86% and a maximum of 8.54%. Phosphorus results ranged from 0.37-0.47% dry matter as phosphorus, with an average of 0.41%. Using this average and the first sampling date as an example, 257 lbs of dry matter entered the boom each minute. This means that at the time of sampling, an average of 0.076 lbs of phosphorus was entering Green Lake from Silver Creek Estuary in the form of duckweed each minute.

The duckweed does not flow at a constant rate from the Silver Creek Estuary into Green Lake; instead, it enters the lake in pulses throughout the summer. Assuming the flow on July 22, 2022 was relatively moderate and using the rate of 0.076 lbs of phosphorus/minute, some broad estimates can be made. Considering a growing season from June 15 to September 15 (93 days), and the percentage of the time during the growing season the flow was approximately the same as July 22, 2022, the amount of phosphorus entering Green Lake via Silver Creek duckweed can be estimated. If the duckweed flow rate occurs 10, 20, or 30% of the time, the estimated phosphorus contributions would be 1012, 2024, and 3035 lbs, respectively. The USGS estimates Green Lake's annual external to be approximately 33,820 lbs. It must be noted that the potential phosphorus load entering the via duckweed is not in addition to the USGS estimate, but actually a part of the estimate. This is because the duckweed utilize the nutrients, including phosphorus, entering the estuary from Silver Creek to build biomass and then those nutrients enter the lake in the form of duckweed.

Starting in 2024, the US Geological Survey (USGS) began a pilot project to document the quantity of duckweed enter Green Lake under the County Highway A bridge. This project will use video images and other measurements to quantify duckweed, and couple that with nutrient analysis from physical samples to extrapolate loading amounts.

The GLSD currently manages duckweed from Silver Creek to improve navigation, recreation and aesthetics using its mechanical harvester. The harvesting equipment is not efficient at picking up these species for a number of factors discussed within the Implementation Plan (Section 5.0). When up against the harvester, these duckweed rafts simply are pushed around by the equipment. This is analogous to picking up dirt on a floor with just a dustpan, lacking a broom to provide resistance to direct the dust onto the dustpan. Modified conveyor mesh may help more duckweed to be extracted using a mechanical harvester, but will still present challenges. Harvested duckweed is heavy, causing the mechanical harvester to sit lower in already shallow water. Therefore the harvester has to unload more frequently in order to maintain sufficient draft to operate.

Alternative duckweed management strategies are utilized on other waterbodies in Wisconsin and around the globe. In some instances, containment booms and jetties are used to retain duckweed in an area and are periodically harvested with mechanical harvesters or skimming machines. This also allows a fixed structure for the mechanical harvester to push the duckweed up against to be more efficiently captured by its conveyor system. On Delavan Lake, a person-operated suction/siphon system was considered a few years ago. With blue-green algae (BGA) populations being mixed in duckweed populations, this strategy was ultimately not initiated for the inability of finding masks/respirators that would provide adequate protection for the operating crews. Other lakes have considered automated infrastructure that would use jets or bubbles to direct duckweed populations into a fixed extraction pipe or catch basin, but concern for collateral uptake of fish and invertebrates have been regulatory roadblocks to implementation. Herbicide management is utilized on some systems, but these activities only provide temporary relief. When herbicides are used, the dead and decaying duckweed can use up the majority of oxygen in the water column, as well as releasing nutrients back into the water column, which both have substantial negative collateral impacts.

Aquatic Plant Management

The GLSD has been conducting a nuisance control strategy towards aquatic plants utilizing aquatic herbicides and mechanical harvesting form many years. The goal of these activities has been solely to provide increased navigational abilities within select areas of the system. The GLSD primarily relies on the use of a mechanical harvester to cut and remove aquatic plants from the system. As shown on Map 12, the mechanical harvesting is permitted around the lake starting at the pier-face (i.e. end of docks) and extending 30-ft out. Of the 134.5 acres available to harvest, the GLSD estimates only 10-15% of the area actually gets cut. The GLSD has a program where riparians can signal for extra harvesting effort in their recreational footprint for a fee. The permit also allows the collection of floating and non-rooted aquatic plants like duckweed and coontail.

Figure 3.2.2-7 shows the amount of mechanical harvesting that has occurred since 1979, with the average being 370 loads per year. Harvest amounts have been similar to this average in recent years (2019-2024), down from extremely high amounts of removed material in 2012-2018. In 2023, 410 loads of harvested aquatic plant material were removed from the Green Lake system. As displayed on the embedded table on Map 12, over one-third of the 2023 harvest was from Dartford Bay and City Millpond. A similar amount of harvesting occurred from County Road A and Silver Creek Estuary.

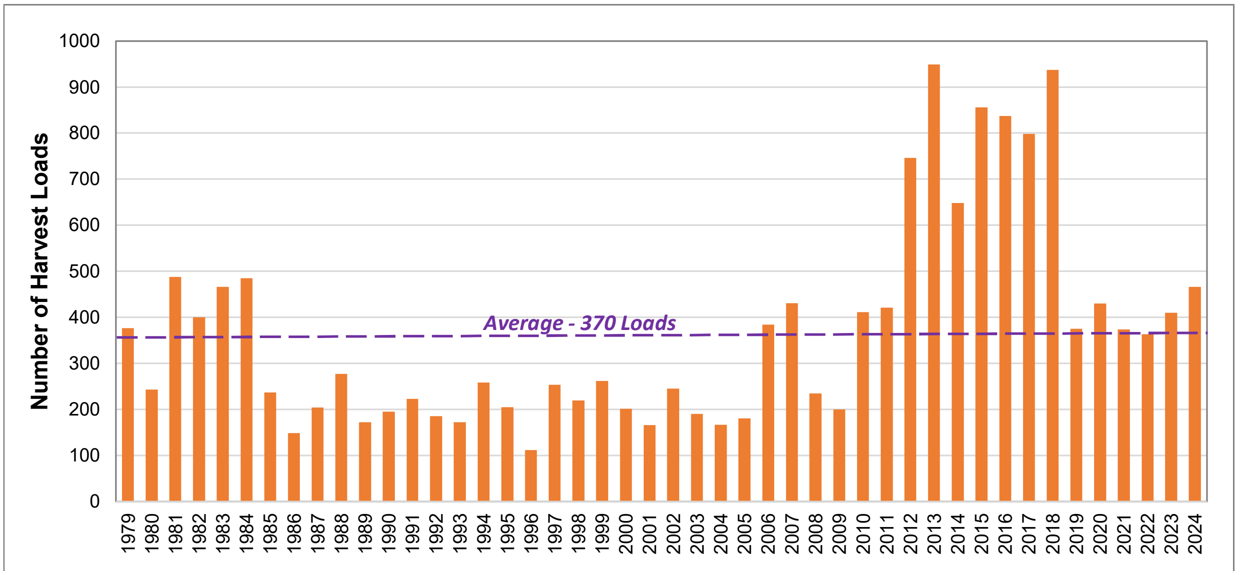


Figure 3.2.2-7. Mechanical harvesting history on Green Lake.

When plants are removed from a lake as part of a mechanical harvesting program, nutrients are also removed. The nutrient composition of extracted plants varies greatly by species, but also can vary by productivity of the lake and time of year. The GLSD estimates each of their harvest load is about 3,000 lbs of wet material, with quite a bit of variability based upon species composition.

Combining the mass of plant material removed annually with phosphorus content coefficients of harvested material from three different literature examples (models), a potential range of phosphorus removal from mechanical harvesting can be calculated (Figure 3.2.2-8).

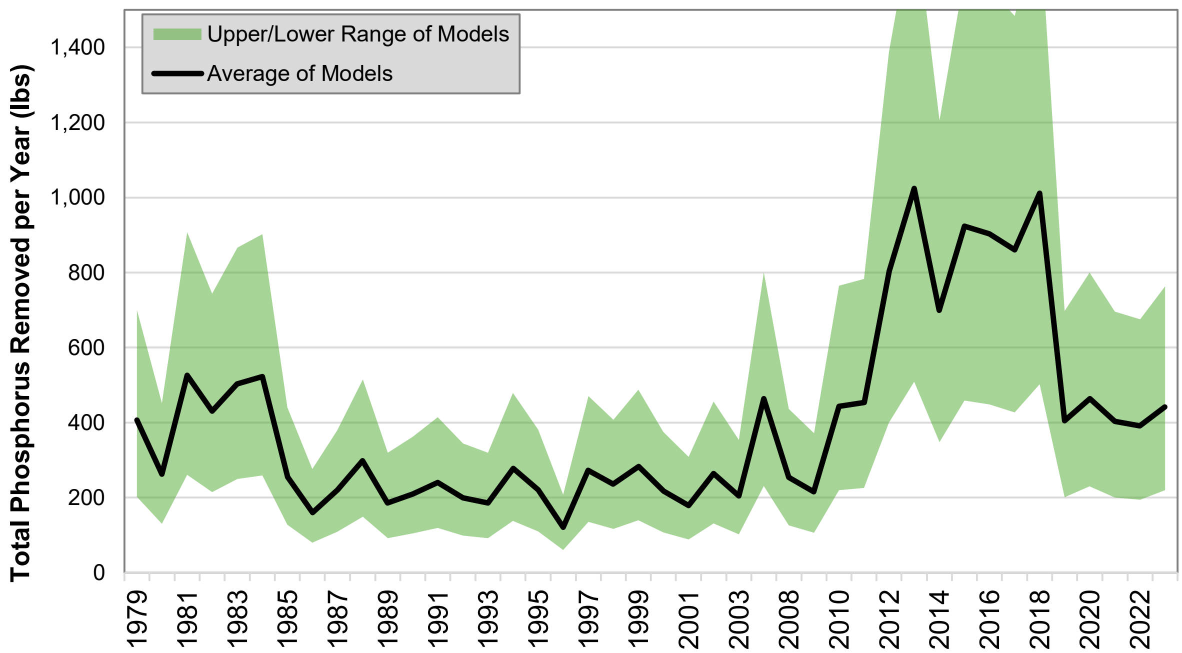


Figure 3.2.2-8. Potential phosphorus removed by mechanical harvesting. Total phosphorus content in vegetated material using a 2009 study on Pewaukee Lake, WI (Ebeling et al. 2011), a 1991 study on Whitewater-Rice Lakes, WI (Goddard and Field 1994), and Lake Sallie, MN (Peterson et al. 1974).

Based upon this modeling exercise, about 300 lbs of phosphorus are removed from Green Lake annually. For perspective the annual phosphorus load of Green Lake is estimated to be over 33,000 lbs. It is important to note that the source of phosphorus in aquatic plants comes from a combination of 1) uptake from the water column and 2) root-mined from the sediments, depending on the type of plants removed. Phosphorus from rooted plants like EWM and water celery largely originate from legacy phosphorus in the sediment, whereas the phosphorus of free-floating plants like duckweeds is derived from the water column. Therefore, the phosphorus removed from mechanical harvesting originates from a combination of watershed loading and internal legacy nutrient sources. These models suggest that over 13,000 lbs of phosphorus has been removed from Green Lake during 1979-2023 through mechanical harvesting. However, all lakes act as nutrient sinks as a part of their aging process (eutrophication), so that cumulation must be compared to the massive and unknow amount of phosphorus that has accumulated in the lake since its creation 12,000 years ago.

Table 3.2.2-3 shows the herbicide treatment record of the Green Lake system over the past two decades. Herbicide treatments in 2013 to 2017 primarily targeted EWM and CLP populations within the adjacent basins. From 2020 to current, herbicide treatments have been used to minimize nuisance plants and algae in the system.

In situ herbicide concentration monitoring surrounding the herbicide treatments in 2014-2017 indicate that sufficient herbicide concentration and exposure times were met for multi-year CLP and EWM control to be achieved on Beyers Cove. However, the high water exchange in City Millpond was insufficient for long-term EWM control but marginally sufficient for CLP control.

The accidental introduction of the common carp (*Cyprinus carpio*) has likely also had adverse impacts to Green Lake's ecosystem. Direct foraging and uprooting of aquatic plants by common carp not only alters aquatic plant community structure, but they also resuspend bottom sediments and nutrients which increases turbidity and decreases water clarity (Fischer and Krogman 2013).

Table 3.2.2-3. Herbicide treatment record.

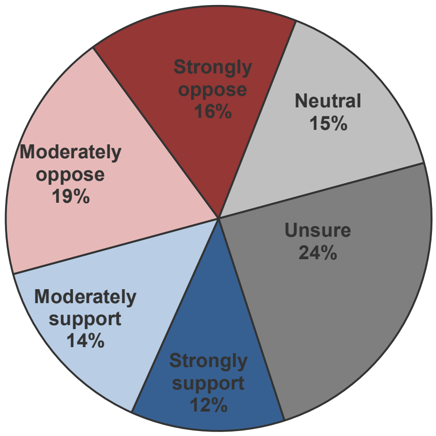
Date	Acreage	Chemical	Amount	Location
5/14/2013	13.6	DMA 4 IVM	130 gallons	Silver Creek
5/21/2014	75.1	Aquathol K DMA 4 IVM	186 gallons 69 gallons	Beyers Cove and Millpond
5/31/2014	4.0	DMA 4 IVM Reward	68 gallons 2 gallons	Green Lake Conference Center
5/15/2015	47.7	Aquathol K DMA 4 IVM	135.7 gallons 50.5 gallons	Millpond
5/15/2015	27.4	Aquathol K DMA 4 IVM	50.2 gallons 18.6 gallons	Beyers Cove
6/4/2015	4.0	DMA 4 IVM	67.5 gallons	Green Lake Conference Center
5/9/2016	27.4	Aquathol K	50.25 gallons	Beyers Cove
5/15/2017	47.7	Aquathol K	135.8 gallons	Millpond
6/2/2020	5.8	Captain (algaecide) Clipper SC Tribune	5.75 gallons 1.625 gallons 5.75 gallons	Beyers Cove
7/18/2019	0.7	Tribune Clipper SC Captain (algaecide)	26 ounces 0.75 gallons 0.75 gallons	South Shore Terrace Marina
6/19/2020	0.7	Captain (algaecide) Clipper SC Tribune	0.75 gallons 35 ounces 0.75 gallons	South Shore Terrace Marina
5/20/2021	3.6	Captain (algaecide) Clipper SC Tribune	3.5 gallons 0.9 gallons 3.5 gallons	Beyers Cove
6/18/2021	0.7	Clipper SC Captain (algaecide) Tribune	26 ounces 0.75 gallons 0.75 gallons	South Shore Terrace Marina
5/23/2022	5.0	Tribune Captain (algaecide) Flumigard SC	5 gallons 5 gallons 1.25 gallons	Beyers Cove
6/1/2022	0.4	Captain (algaecide) Tribune Flumigard SC	0.75 gallons 0.75 gallons 0.2 gallons	South Shore Terrace Marina
9/9/2022	0.2	Tribune Captain (algaecide) Cutrine-Plus granular	0.2 gallons 0.5 gallons 10 lbs	Hatti Sherwood Park Lagoon
5/18/2023	5.0	Captain (algaecide) Tribune Flumigard SC	5 gallons 5 gallons 1.25 gallons	Beyers Cove
5/18/2023	0.7	Flumioxazin 51% WD Tribune Captain (algaecide)	0.2 gallons 0.75 gallons 0.75 gallons	South Shore Terrace Marina

In 2023, riparian property owners and GLA members were asked about their support or opposition for various aquatic plant management techniques. Twenty-six percent (48%) of stakeholder respondents indicated they were supportive (pooled *highly supportive* and *moderately supportive* responses) of using herbicides on Green Lake, whereas 35% were unsupportive (pooled *not supportive* and *moderately un-supportive* responses) (Figure 3.2.2-9). The largest response category for the use of herbicides to manage aquatic plants was *unsure* or *neutral*, indicated by almost 40% of stakeholder respondents.

Higher support was garnered by respondents for the use of mechanical harvesting to manage aquatic plants, with 87% supporting that methodology (pooled *strongly supportive* and *moderately supportive* responses) with only 4% being unsupportive (pooled *not supportive* and *moderately un-supportive* responses).

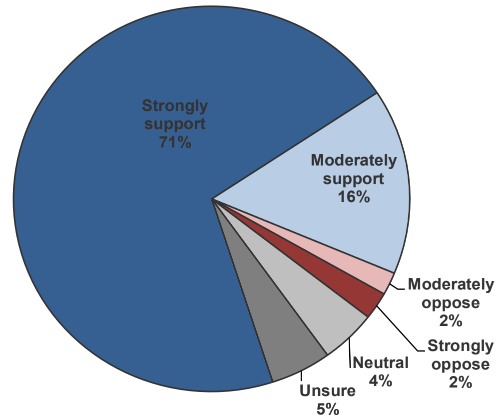
Queston 33: Aquatic plants can be controlled using many techniques. What is your level of support for the use of the following management techniques in Green Lake?

Herbicide Control



Support	26%
Not Support	35%
Unsure/Neutral	39%

Mechanical Harvest (i.e. weed cutter)



Support	87%
Not Support	4%
Unsure/Neutral	9%

Figure 3.2.2-9. Aquatic plant management-related stakeholder survey responses. Additional questions and response charts may be found in Appendix B.

Blue-Green Algae Monitoring Summary

Blue-green algae blooms have been periodically noted on Green Lake. Understanding algae dynamics in lakes can be complicated since so many factors control growth rates of algae, such as light availability, nutrient levels, water temperatures, zooplankton populations, and interactions between algal species themselves. The complexity is compounded in large systems like Green Lake.

Photograph 3.2.2-7. Blue-green algae bloom on a Wisconsin lake. Photo credit: Onterra.

Like 'true' algae, cyanobacteria or blue-green algae are able to convert sunlight into energy through the process of photosynthesis (Photograph 3.2.2-7). Many species of blue-green algae can naturally be found in Wisconsin waters, some of which can produce toxins potentially dangerous to people and animals. Exposure to these toxins can be from ingestion of water, skin contact, or by inhaling aerosolized water droplets.

The largest risk of exposure consists of swallowing water containing the toxins, usually during water-sporting activities. Symptoms include nausea, vomiting, diarrhea and in severe cases, liver failure or paralysis. Skin contact with algae can produced blistering of the exposed skin. Allergy-like symptoms including coughing, watery eyes, and nose/throat irritation are most commonly associated when wind and motor boat activity cause the toxins to become aerosolized.

The GLA launched a blue green algae (BGA) monitoring program in 2022 including having BGA species identified by the WI State Lab of Hygiene which will occur on a five-year rotation. Concurrently, GLA also started a weekly beach toxin screening in 2022 through the use of microcystin dipsticks which was continued in 2023. This program samples five locations every week beginning in June until early September. These locations contain four public areas, one private property, and can be viewed on Google Maps here:

https://www.google.com/maps/d/viewer?mid=1WUpT3f_Ty89Sl7kfVKu9D-Bi-Y1i2Do&ll=43.808580586974166%2C-88.99792780555556&z=13

The 2023 results did not yield any BGA densities warranting beach closures. The BGA with the highest concentration was located in County K Marsh but was not elevated high enough for a closure.

During 2024, the GLA further enhanced their BGA monitoring program utilizing BloomOptix technology to more rapidly detect BGA presence through the use of specialized microscopes.

On August 1, 2024, confirmed BGA blooms positive for microcystin toxins resulted in closure of select beaches by the Green Lake County Health Department (Photograph 3.2.2-8). All advisories and closures were lifted within 6 days.

Photograph 3.2.2-8. 2024 BGA Bloom on County K Marsh. Photo credit: GLA 7/31/2024.

3.2.3 Green Lake Aquatic Plant Community

Green Lake, proper, encompasses the majority of the project location and is the primary area recreationalists utilize on the system. Point-intercept surveys have been completed on the lake in 2007, 2014, and 2023. An important component of the point-intercept survey is defining the littoral zone, or the zone at which aquatic plants can grow. On all the adjoining waterbody basins, the entire open water is within the plant growing range, so all the sampling points represent the littoral zone. But on Green Lake, the water depth is too deep for macrophytes to grow in much of the lake. Therefore, it is important to establish the maximum depth that aquatic plants grow. The maximum depth of plant growth is almost exclusively influenced by water clarity. In general, aquatic plants grow to a depth of two to three times the average summer Secchi disk depth. Mean annual growing season Secchi disk depths recorded at the deep hole sampling location have ranged from a minimum of 10.7 feet in 2017 to a maximum of 18.7 feet in 2013 and averaged 15.2 feet.

For Green Lake, one may expect aquatic plants to grow out to about 25-30 feet based upon this relationship. However, the point-intercept surveys only confirmed aquatic plants growing out to 21 feet in 2007, 23 feet in 2014, and 18 feet in 2023. This may be a function of the steep drop off in the lake and the course nature of the point-intercept sampling grid (100 meter spacing). For reference, Onterra sampled 371 sampling locations between 18 and 30 feet deep in 2023, not locating aquatic plants on any of them. Figure 3.2.3-1 shows the aquatic plant growth distribution by depth on Green Lake. The small dip between 8-11 feet in each survey is likely a function of a reduced quantity of sampling locations at those depths, not a lower frequency of plants.

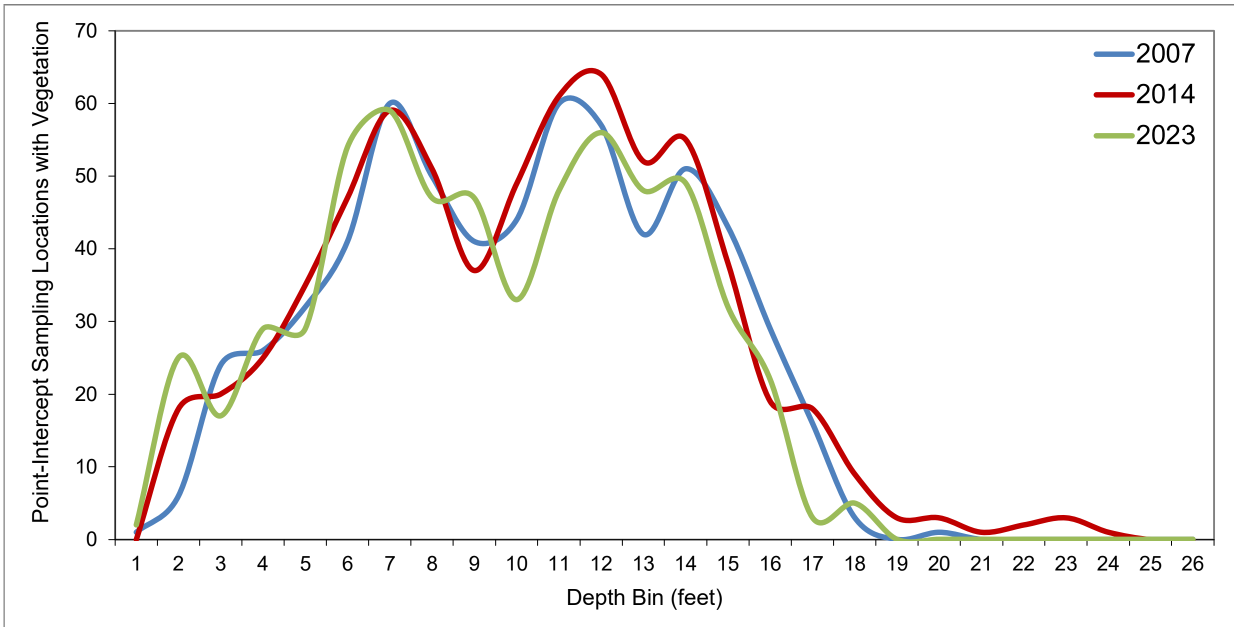


Figure 3.2.3-1. Green Lake aquatic plant distribution by depth from available point-intercept surveys.

Total rake fullness values from the point-intercept surveys are displayed on Figure 3.2.3-2. These data represent the aquatic plant biomass at each sampling location and does not differentiate between native or non-native vegetation. Aquatic plant growth has been between 70-79% of the littoral zone, a relatively constant metric. The proportion of various rake fullness ratings also appears relatively consistent over time. The greatest amounts of plant biomass in the 2023 survey was found along the east shore near County Highway A, the northeast end of Dartford Bay, and the inside of Norwegian Bay (Map 11).

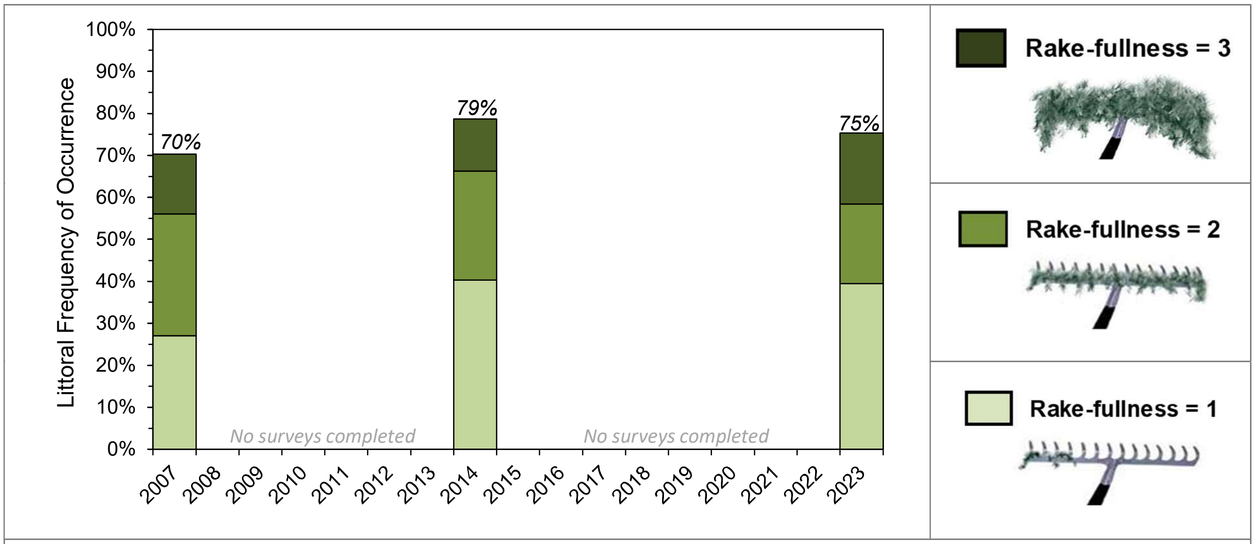


Figure 3.2.3-2. Green Lake total rake fullness data available point-intercept surveys.

Table 3.2.3-1 displays all the 46 species that were documented during the 2007, 2014, and 2023 point-intercept surveys on Green Lake. Table 3.2.3-1 is organized by growth form which separates out species based on whether they are emergent species, floating-leaf species, submergent species, or free-floating species.

Approximately a total of 33 native aquatic plant species were sampled during the 2023 point-intercept survey in Green Lake with coontail (29.9%), wild celery (27.1%), and muskgrasses (26.4%), being the most commonly encountered native species (Figure 3.2.3-2). EWM was one of the most frequently encountered species within the lake with an occurrence of 28% in 2023. Curly-leaf pondweed was very low with occurrences of 1.5%, however, curly-leaf pondweed peaks in biomass early summer when the point-intercept survey occurred midsummer. 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. Due to this, the littoral occurrences of the following morphologically-similar species were combined for this analysis: small pondweed (*Potamogeton pusillus*) and slender pondweed (*P. berchtoldii*).

Table 3.2.3-1. Green Lake aquatic plant species list.

Growth Form	Scientific Name	Common Name	Status in Wisconsin	Coefficient of Conservatism	2007	2014	2023
Emergent	*Carex comosa*	Bristly sedge	Native	5		I	
	Lythrum salicaria	Purple loosestrife	Non-Native - Invasive	N/A		I	I
	Phalaris arundinacea	Reed canary grass	Non-Native - Invasive	N/A		I	I
	Schoenoplectus acutus	Hardstem bulrush	Native	5	X	X	I
	Schoenoplectus tabernaemontani	Softstem bulrush	Native	4		I	I
	Sparganium eurycarpum	Common bur-reed	Native	5		I	I
	Typha latifolia	Broad-leaved cattail	Native	1			I
	Typha spp.	Cattail spp.	Unknown (Sterile)	N/A		I	I
FL	*Nymphaea odorata*	White water lily	Native	6		X	X
Submergent	*Ceratophyllum demersum*	Coontail	Native	3	X	X	X
	Chara spp.	Muskgrasses	Native	7	X	X	X
	Elatine minima	Waterwort	Native	9			X
	Elodea canadensis	Common waterweed	Native	3	X	X	X
	Heteranthera dubia	Water stargrass	Native	6	X	X	X
	Myriophyllum sibiricum	Northern watermilfoil	Native	7	X	X	X
	Myriophyllum sibiricum X spicatum	Hybrid watermilfoil	Non-Native - Invasive	N/A	X	X	X
	Najas flexilis	Slender naiad	Native	6	X	X	X
	Najas marina	Spiny naiad	Non-Native - Potentially Invasive	N/A	X		
	Nitella spp.	Stoneworts	Native	7	X	X	X
	Potamogeton amplifolius	Large-leaf pondweed	Native	7	X		
	Potamogeton berchtoldii	Slender pondweed	Native	7		X	X
	Potamogeton berchtoldii & Potamogeton pusillus	Slender pondweed and Small pondweed	Native	N/A		X	X
	Potamogeton crispus	Curly-leaf pondweed	Non-Native - Invasive	N/A	X	X	X
	Potamogeton foliosus	Leafy pondweed	Native	6	X	X	X
	Potamogeton friesii	Fries' pondweed	Native	8		X	X
	Potamogeton gramineus	Variable-leaf pondweed	Native	7	X		X
	Potamogeton illinoensis	Illinois pondweed	Native	6	X	X	X
	Potamogeton nodosus	Long-leaf pondweed	Native	5	X	X	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 strictifolius	Stiff pondweed	Native	8		X	X
	Potamogeton zosteriformis	Flat-stem pondweed	Native	6	X	X	X
	Ranunculus aquatilis	White water crowfoot	Native	8	X	X	X
	Ruppia cirrhosa	Spiral ditch-grass	Native	8	X	X	
	Sagittaria sp. (rosette)	Arrowhead sp. (rosette)	Native	N/A			I
	Stuckenia pectinata	Sago pondweed	Native	3	X	X	X
	Vallisneria americana	Wild celery	Native	6	X	X	X
	Zannichellia palustris	Horned pondweed	Native	7	X	X	X
S/E	*Eleocharis acicularis*	Needle spikerush	Native	5		X	X
	Sagittaria graminea	Grass-leaved arrowhead	Native	9			I
FF	*Lemna minor*	Lesser duckweed	Native	5			X
	Lemna trisulca	Forked duckweed	Native	6			X
	Lemna turionifera	Turion duckweed	Native	2			X
	Spirodela polyrhiza	Greater duckweed	Native	5			X
	Wolffia spp.	Watermeal spp.	Native	N/A			X

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 and/or Emergent; FF = Free-floating

Figure 3.2.3-3 compares the littoral frequency of select occurrence of aquatic plant species in Green Lake from each of the three point-intercept surveys. A statistically valid change in occurrence from one survey to the next is indicated by an asterisk on the figure. Many species saw statistically valid changes in occurrence between the 2014 and 2023 surveys. The top native species, coontail, saw a valid decreases in occurrence while wild celery and muskgrasses saw a valid increase from 2014 to 2023. The occurrence of EWM decreased from roughly 45% occurrence in 2014 and 2017 to 28% in 2023.

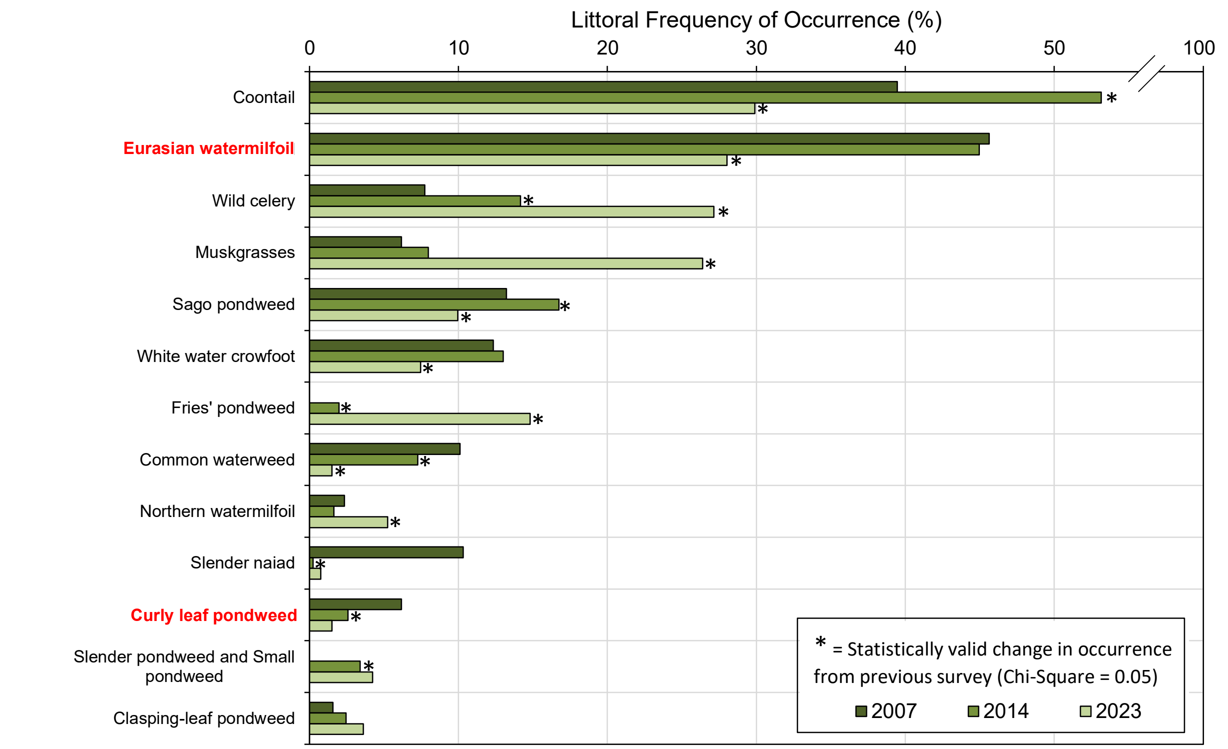


Figure 3.2.3-3. Green Lake 2007, 2014, and 2023 LFOO. LFOO = littoral frequency of occurrence.

A comparison of the available point-intercept surveys allows for detecting changes in the aquatic plant community over time. Map 2 shows the number of native species per sampling location and Figure 3.2.3-3 shows the average of these values from each survey. This metric was the greatest in 2007 at 1.82 species per sampling point. The 2023 survey found 1.39 species per site which was relatively the same as the 1.32 species documented in the 2014 survey (Figure 3.2.3-4).

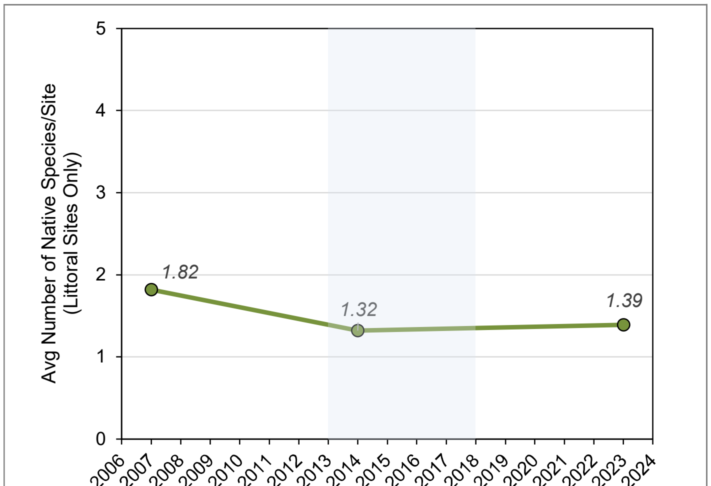


Figure 3.2.3-4. Green Lake average native species per sampling location.

One way to visualize the diversity of a lake's plant community is to examine the relative frequency of occurrence of aquatic plant species. Relative frequency of occurrence is used to evaluate how often each plant species is encountered in relation to all the other species found. Figure 3.2.3-5 displays the relative frequency of occurrence of aquatic plant species from each of the three point-intercept surveys in Green Lake. These data indicate that some species such as coontail and EWM comprised higher portions of the relative frequency in previous years as compared to 2023.

Wild celery accounted for 4.3% of the relative frequency in the 2007 survey and has expanded to account for 15.7% in 2023. EWM accounted for as much as 24.6% of the relative frequency in 2014 and in the 2023 survey it decreased to 16.2%.

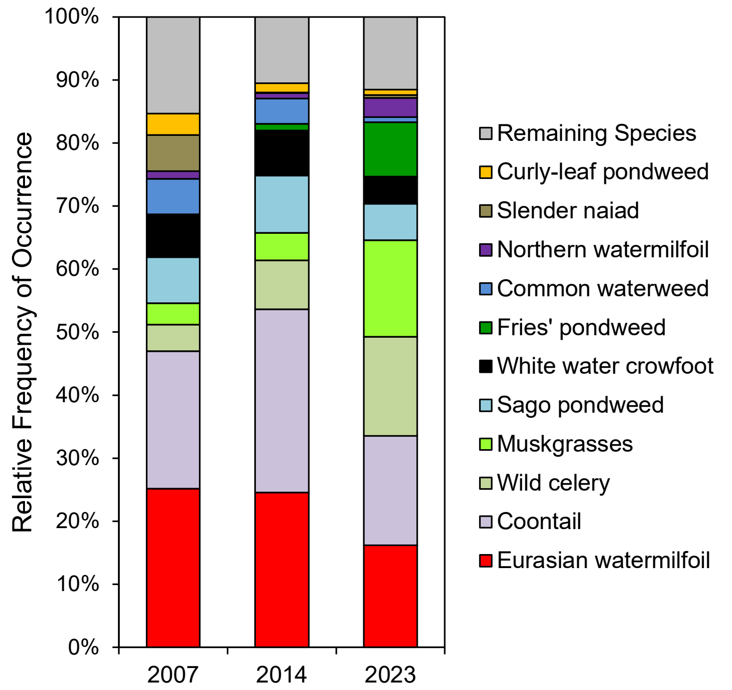


Figure 3.2.3-5. Green Lake relative frequency of occurrence.

A comparison of the species richness, average conservatism, and floristic quality from each of the three point-intercept surveys in Green Lake is displayed on Figure 3.2.3-6. In the 2023 point-intercept survey, the total richness was 30 compared to 24 in 2014 and 32 in 2007. Average conservatism values varied from 6.0 in 2023 to 6.2 in 2014. The floristic quality in Green Lake has varied as well from 30.4 in 2014 to 32.9 in the 2023 survey. The species richness and floristic quality values from the 2023 survey are above the ecoregion and state median values. The average conservatism is nearly in line with the state median values and slightly above the ecoregion median values.

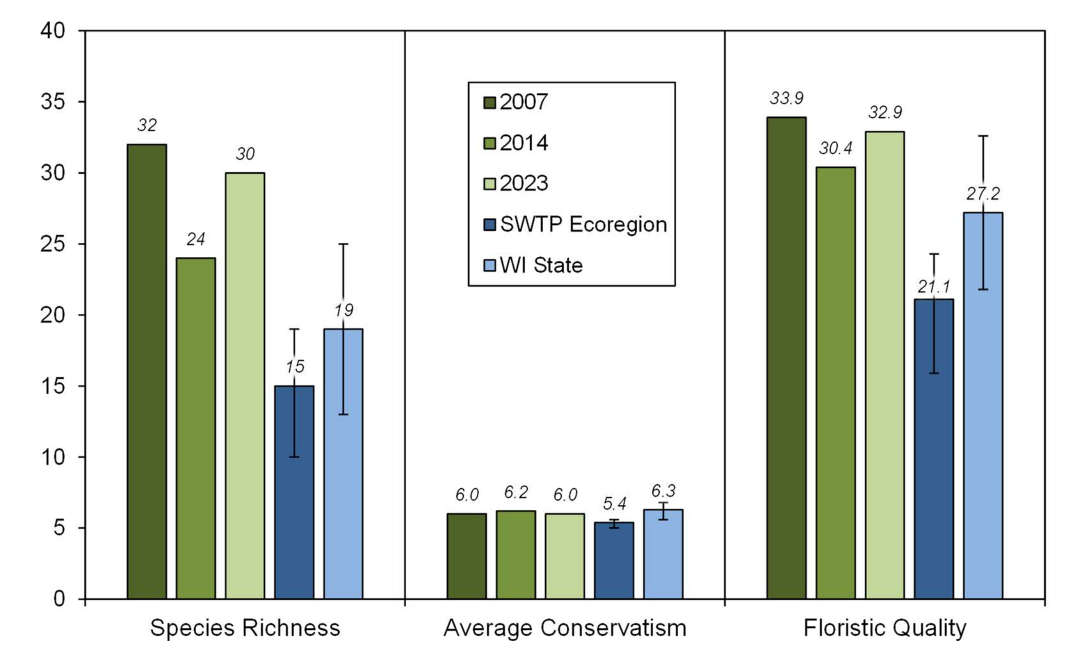


Figure 3.2.3-6. Green Lake Floristic Quality Index. Analysis follows (Nichols 1999). Error bars indicate interquartile range (25th percentile to 75th percentile). Median = 50th percentile.

In 2023, Onterra ecologists also conducted a survey aimed at mapping emergent and floating-leaved plant communities in Green Lake. In 2014, approximately 7.4 acres of emergent and floating-leaf aquatic plant communities were delineated in Green Lake proper compared to 5.5 in 2023 (Figure 3.2.3-7 and Map 13).

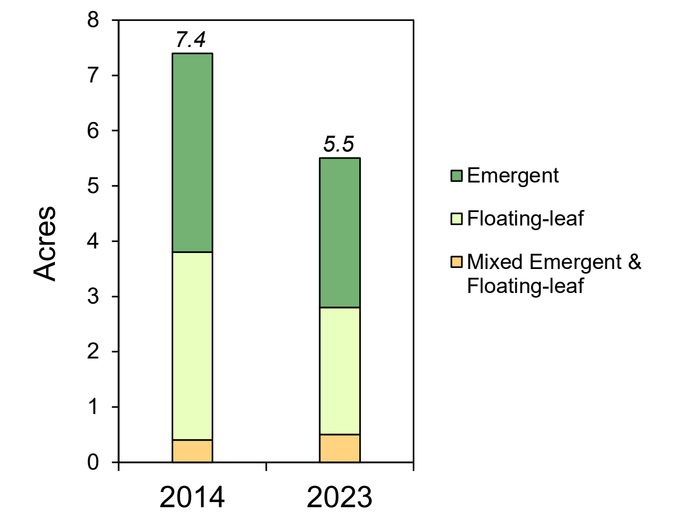


Figure 3.2.3-7. Acres of floating-leaf and emergent plant communities on Green Lake. Data from 2014 and 2023 community mapping surveys conducted by Onterra.

Figure 3.2.3-8 shows a summary of the community mapping footprint analysis of Green Lake proper from 2013/2014 to 2023. This decline in acreage appears to be in communities that were located near Blackbird Point and in the channel off of Norwegian Bay, both areas listed as WDNR Critical Habitat Areas. The vast majority of emergent and floating-leaf aquatic plant communities are within the estuaries and will be detailed further in the subsequent sections.

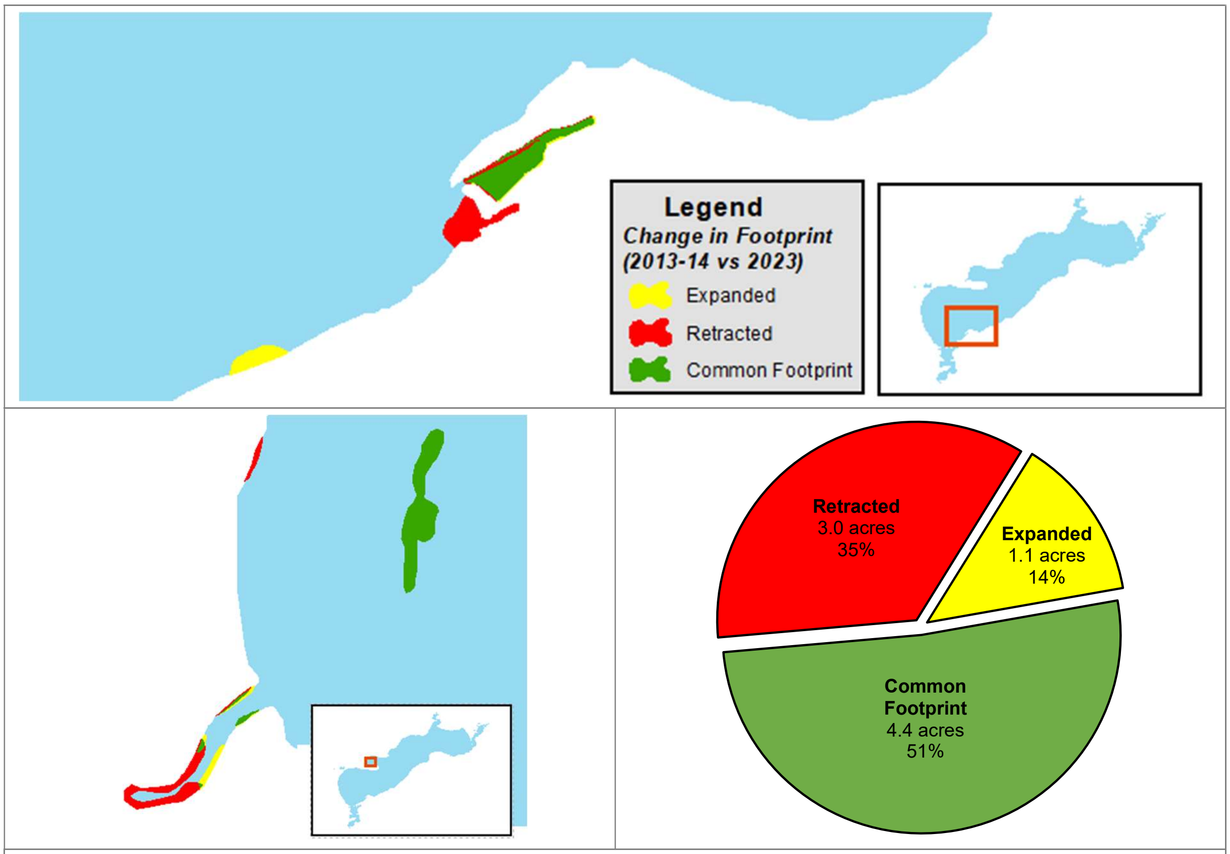


Figure 3.2.3-8. Green Lake community map footprint analysis. Data from 2013/2014 and 2023 floating-leaf and emergent plant community mapping surveys conducted by Onterra.

Emergent and floating-leaf plant communities often recede or expand in response to changes in water levels. In general, fluctuating water levels is healthy for a lake. The artificial stabilization of water levels has decreased floating-leaf and emergent plant communities on many lakes throughout the world.

Figure 3.2.3-9 shows water levels within Green Lake near the inlet of the County K Marsh estuary. In the summer of 2023, there is an evident decrease in water levels, with the lowest of the year occurring on September 9, 2023 with a gage height of 5.8 ft. The average water level gage height from 2018-2023 was 6.37 ft. Water level impacts on the east part of the system such as City Millpond were reported as more extreme.

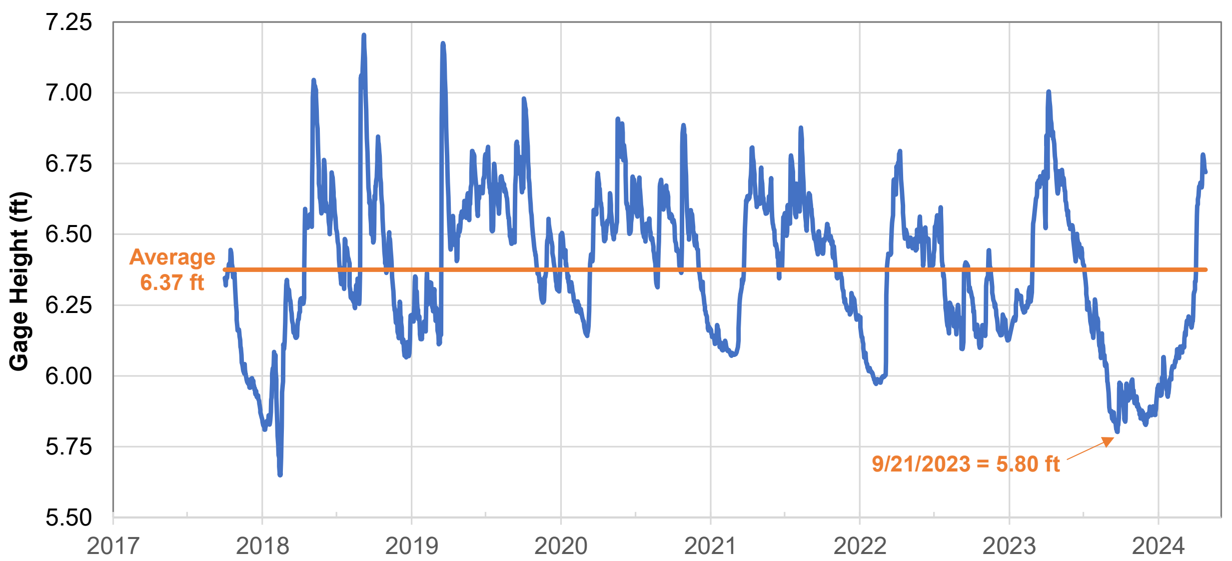


Figure 3.2.3-9. Green Lake water levels from 2018-2024. Source: U.S. Geological Survey at SW Inlet @ CT Highwy K NR Green Lake,Wi – 040734605.

3.2.4 Beyers Cove Aquatic Plant Community

Beyers Cove is one of the four estuaries located to the northwest of Green Lake (Map 1). Table 3.2.4-1 displays all of the 31 species that were documented during the 2013-2018 and 2023 point-intercept surveys on the Beyers Cove. Table 3.2.4-1 is organized by growth form which separates out species based on whether they are emergent species, floating-leaf species, submergent species, or free-floating species.

Table 3.2.4-1. Beyers Cove aquatic plant species list.

Growth Form	Scientific Name	Common Name	Status in Wisconsin	Coefficient of Conservatism	2013	2014	2015	2016	2017	2018	June 2023	July 2023
Emergent	*Iris spp. (sterile)*	Iris spp. (sterile)	Unknown (Sterile)	N/A							I	
	Phalaris arundinacea	Reed canary grass	Non-Native - Invasive	N/A							I	
	Sparganium eurycarpum	Common bur-reed	Native	5							I	
	Typha latifolia	Broad-leaved cattail	Native	1							I	
FL	*Nuphar variegata*	Spatterdock	Native	6	X				X			
	Nymphaea odorata	White water lily	Native	6	X	X	X	X	X	X	X	X
Submergent	*Ceratophyllum demersum*	Coontail	Native	3	X	X	X	X	X	X	X	X
	Chara spp.	Muskgrasses	Native	7						X	X	X
	Elodea canadensis	Common waterweed	Native	3	X	X		X	X	X	X	X
	Heteranthera dubia	Water stargrass	Native	6				X			X	X
	Myriophyllum sibiricum	Northern watermilfoil	Native	7		X	X					
	Myriophyllum spicatum	Eurasian watermilfoil	Non-Native - Invasive	N/A	X	X	X	X	X	X	X	X
	Najas flexilis	Slender naiad	Native	6				X			X	X
	Najas guadalupensis	Southern naiad	Native	7			X		X	X		X
	Potamogeton berchtoldii	Slender pondweed	Native	7								X
	Potamogeton crispus	Curly-leaf pondweed	Non-Native - Invasive	N/A	X		X	X			X	X
	Potamogeton friesii	Fries' pondweed	Native	8				X				
	Potamogeton praelongus	White-stem pondweed	Native	8	X							X
	Potamogeton pusillus	Small pondweed	Native	7				X			X	
	Potamogeton richardsonii	Clasping-leaf pondweed	Native	5	X					X	X	X
	Potamogeton robbinsii	Fern-leaf pondweed	Native	8								X
	Ranunculus aquatilis	White water crowfoot	Native	8	X		X				X	X
	Stuckenia pectinata	Sago pondweed	Native	3	X		X	X	X		X	X
	Vallisneria americana	Wild celery	Native	6				X	X	X	X	X
S/E	*Eleocharis acicularis*	Needle spikerush	Native	5							X	
FF	*Lemna minor*	Lesser duckweed	Native	5					X		X	X
	Lemna trisulca	Forked duckweed	Native	6								X
	Lemna turionifera	Turion duckweed	Native	2	X							
	Spirodela polyrhiza	Greater duckweed	Native	5								X
	Wolffia spp.	Watermeal spp.	Native	N/A								X

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

Total rake fullness values from the 2013-2018, and June and July of 2023 point-intercept surveys are displayed on Figure 3.2.4-1. Two point-intercept surveys in 2023 were collected to collect data on curly-leaf pondweed which peaks in June and a later season survey in July when other native plants begin to peak in biomass but curly-leaf pondweed senesces. The July survey would serve as a comparison to the system wide point-intercept survey on Green Lake and other estuaries. Primary focus will be given to the July 2023 survey unless otherwise specified. These data represent the aquatic plant biomass at each sampling location and does not differentiate between native or non-native vegetation. One of the greatest amounts of plant biomass in the July 2023 survey was found in the center of the lake as well as in floating-leaf and emergent plant communities.

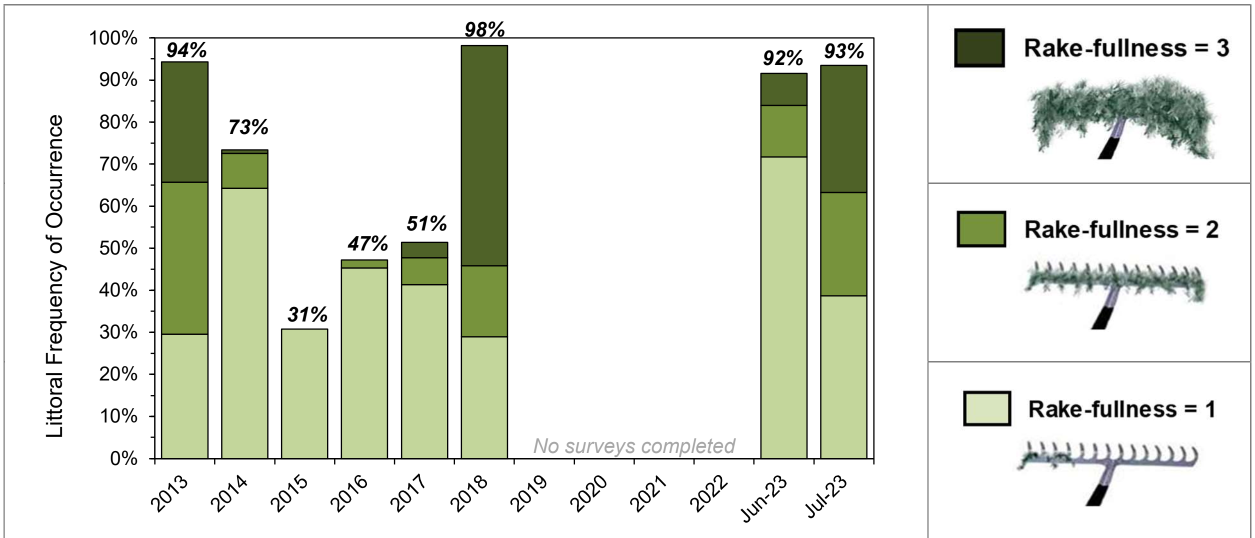


Figure 3.2.4-1. Beyers Cove total rake fullness data available point-intercept surveys.

Approximately a total of 21 native aquatic plant species were sampled during the July 2023 point-intercept survey in Beyers Cove with water stargrass (51.9%), coontail (34.9%), and southern naiad (28.3%), being the most commonly encountered native species (Figure 3.2.4-2). Eurasian watermilfoil was also a frequently encountered species within the lake with an occurrence of 17% in 2023. Curly-leaf pondweed was 15.1%, however, it was 34.9% during the June 2023 survey which is a more accurate representation since curly-leaf pondweed peaks in biomass earlier than most native plant species (Figure 3.2.4-3).

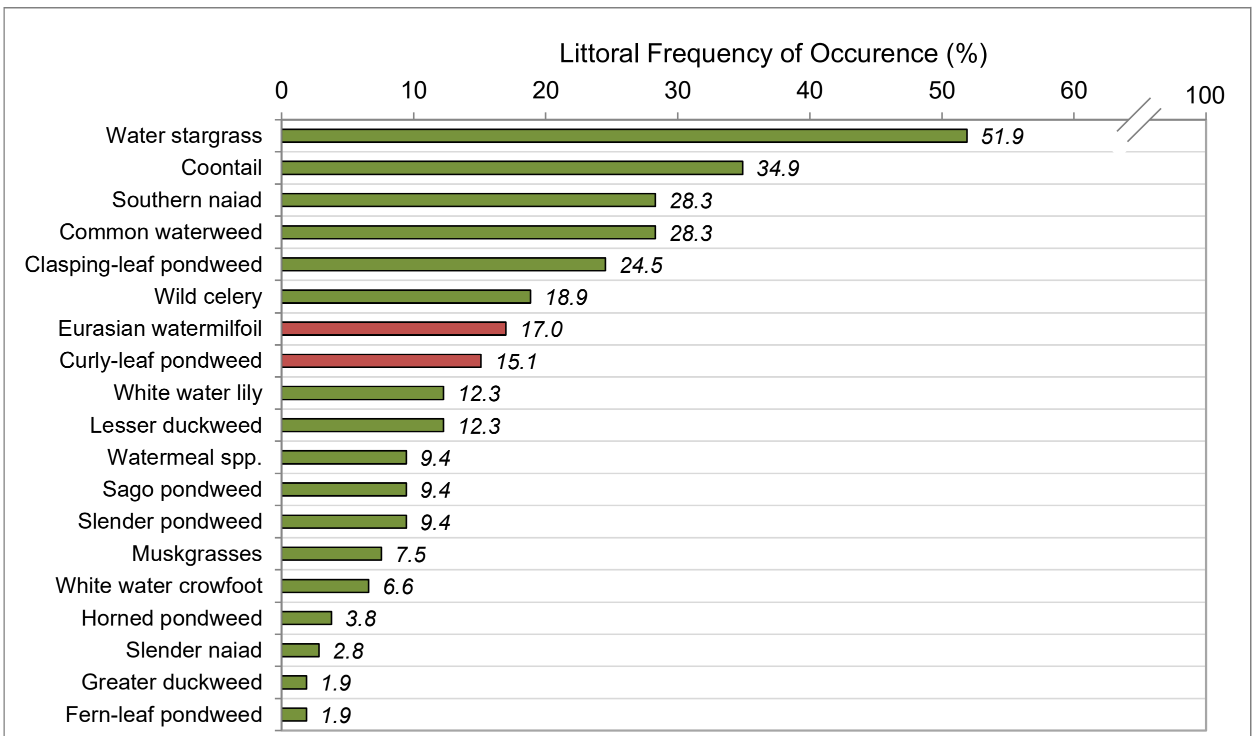


Figure 3.2.4-2. Beyers Cove summer 2023 LOO. LFOO = littoral frequency of occurrence. Species with greater than 1.0% LFOO shown.

Beyers Cove has been treated with aquatic herbicides from 2014-2018 with the goal of reducing EWM and CLP populations. These treatments met expectations of reducing target populations, but also reduced populations of some native species (Figure 3.2.4-4). Interestingly, some aquatic plant species not found in Beyers Cove even before herbicide treatments began like water stargrass, southern naiad, and wild celery are all thriving in 2023.

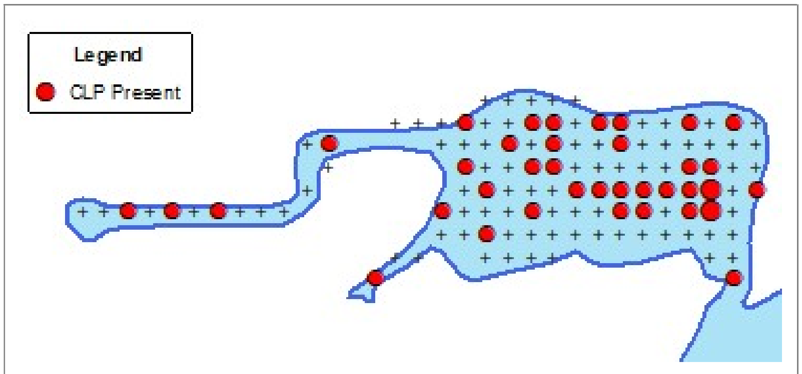


Figure 3.2.4-3. Beyers Cove June 2023 curly-leaf pondweed locations.

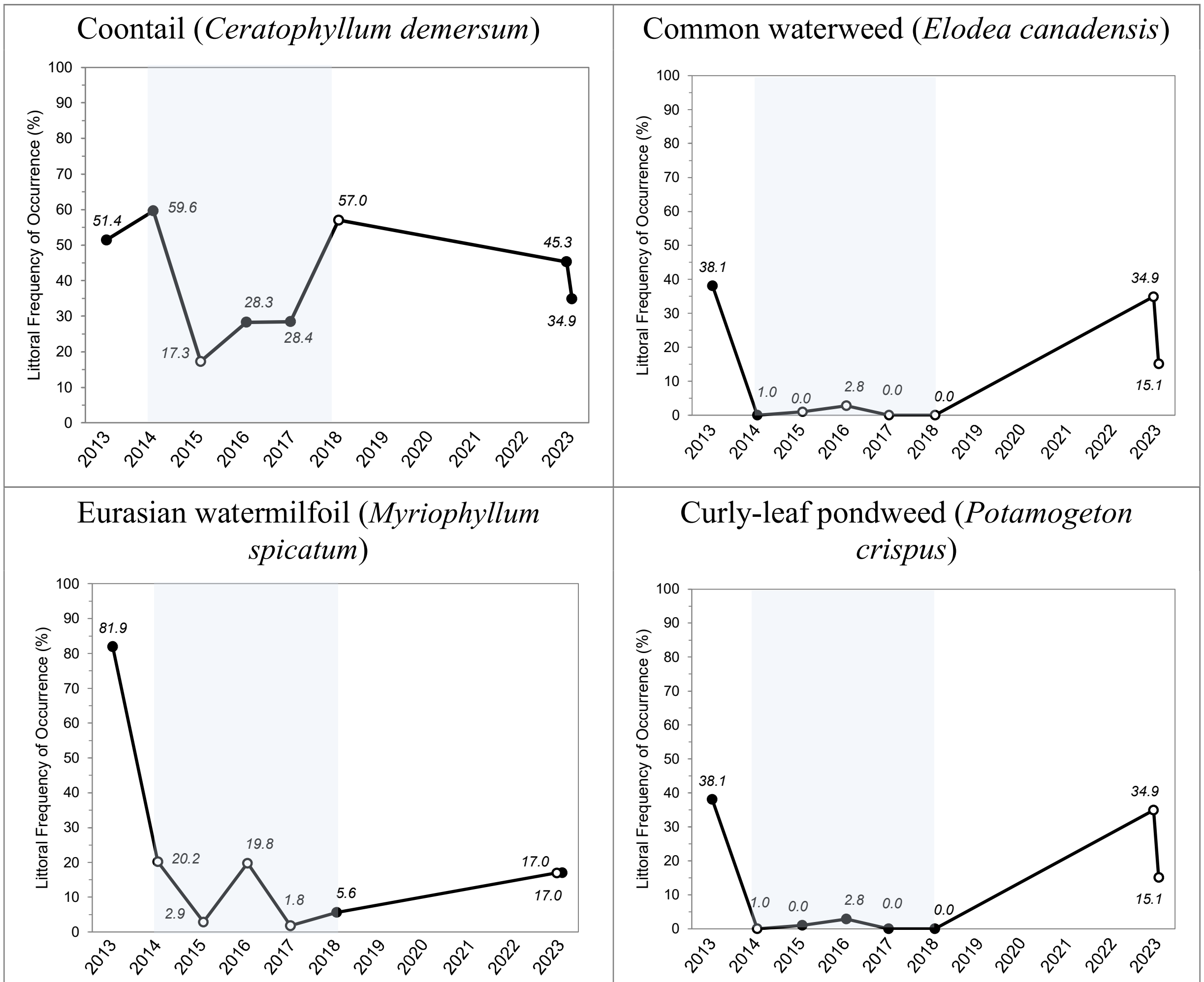


Figure 3.2.4-4. Beyers Cove 2013-2018, & 2023 LFOO. LFOO = littoral frequency of occurrence.

Figure 3.2.4-5 shows the average number of native species per sampling location from each survey. This metric was the greatest in 2023 at 2.65 species per sampling point and lowest in 2017 at 0.66 species per sampling location. The 2023 species richness data are shown on Map 10.

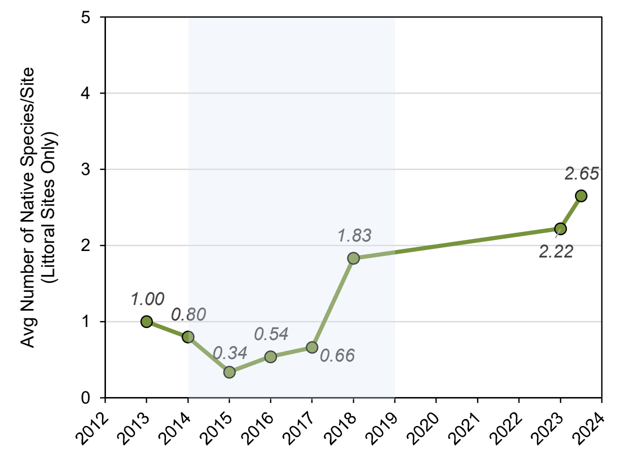


Figure 3.2.4-5. Beyers Cove average native species per sampling location.

One way to visualize the diversity of a lake's plant community is to examine the relative frequency of occurrence of aquatic plant species. Relative frequency of occurrence is used to evaluate how often each plant species is encountered in relation to all the other species found. Figure 3.2.4-6 displays the relative frequency of occurrence of aquatic plant species from each of the eight point-intercept surveys in Beyers Cove. These data indicate that some species such as common waterweed, coontail, and Eurasian watermilfoil comprised higher portions of the relative frequency in previous years as compared to 2023. Coontail and common waterweed collectively accounted for 80.7% in 2018 but in July of 2023 accounted for 21.2% of the relative frequency. Eurasian watermilfoil accounted for as much as 37.2% of the relative frequency in 2013 and in the 2023 survey it decreased to 5.7%. July of 2023 was the most evenly distributed years of aquatic plant relative frequency of abundance over the survey time frame.

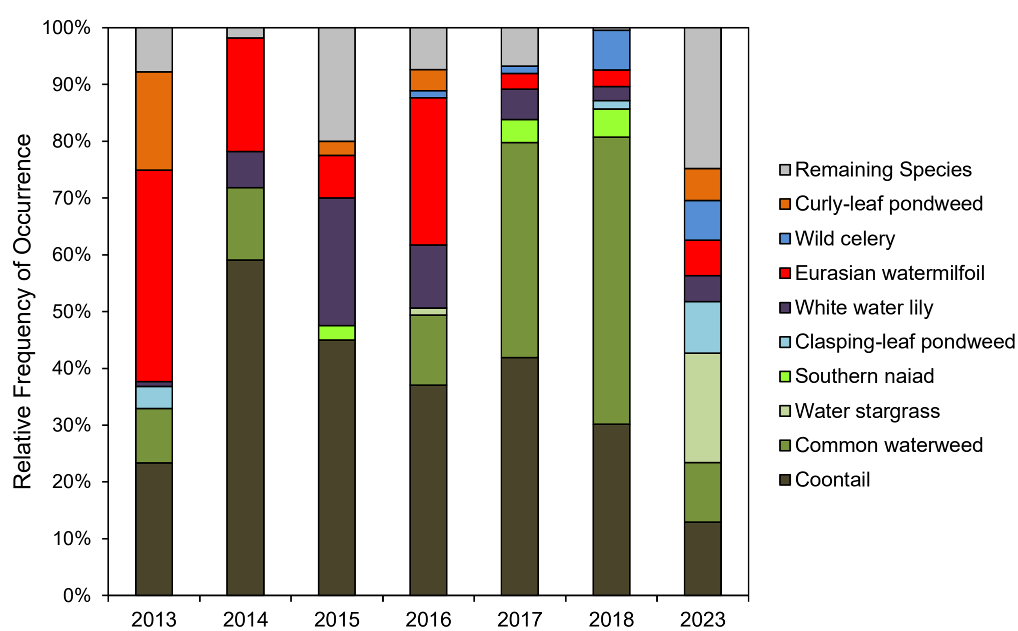


Figure 3.2.4-6. Beyers Cove relative frequency of occurrence.

A comparison of the species richness, average conservatism, and floristic quality from each of the eight point-intercept surveys in Beyers Cove is displayed on Figure 3.2.4-5. In the July 2023 point-intercept survey, the total richness was 19 compared to 5-9 in any previous year. The June and July 2023 surveys nearly doubled in species richness values compared to previous years. Average conservatism value in the July 2023 survey was also the highest recording at 5.9. The floristic quality in Beyers Cove increased as well from 14.0 in 2018 to 25.7 in the July 2023 survey. All of the July 2023 survey values are above the state median values and near the Southwestern Till Plains Ecoregion median values. The rise in plant diversity observed in Beyers Cove is likely a result of the absence of annual endothall and 2,4-D herbicide treatments which occurred in the estuary from 2013 to 2018. The native plant community has demonstrated remarkable resilience, recovering effectively from the impact of these treatments.

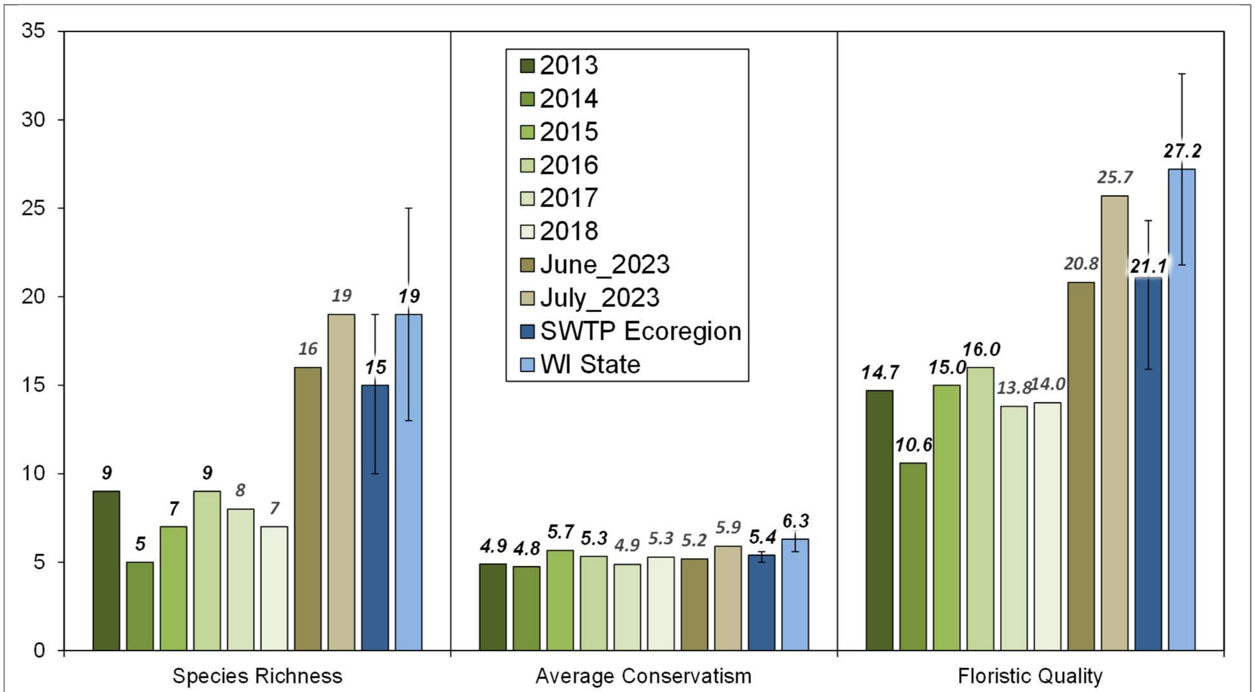


Figure 3.2.4-7. Beyers Cove Floristic Quality Index. Analysis follows (Nichols 1999). Error bars indicate interquartile range (25th percentile to 75th percentile). Median = 50th percentile.

In 2023, Onterra ecologists also conducted a survey aimed at re-mapping emergent and floating-leaved plant communities in Beyers Cove. In 2013, approximately 7.7 acres of emergent and floating-leaf aquatic plant communities were delineated in Beyers Cove compared to 4.0 in 2023 (Map 14, Figure 3.2.4-8).

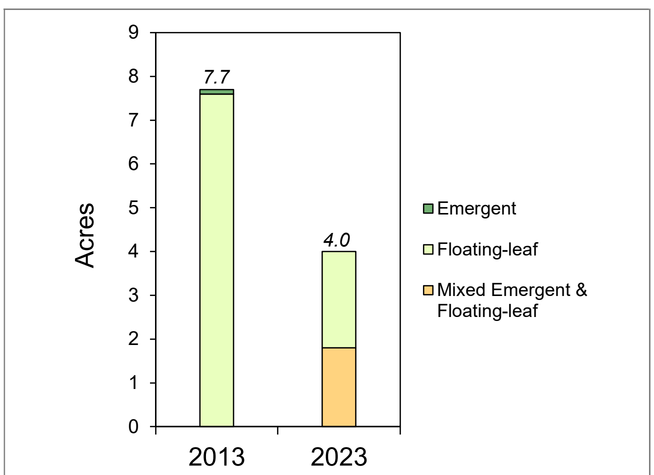


Figure 3.2.4-8. Acres of floating-leaf and emergent plant communities on Beyers Cove. Data from 2013 and 2023 community mapping surveys conducted by Onterra.

Figure 3.2.4-7 displays further on the retraction and expansion of emergent and floating-leaf plant communities in Beyers Cove. Aquatic plant communities have noticeably retracted in the corridor leading out from the boat landing. Expansion of white-water lily in deeper part of the bay have been documented over this time period.

Figure 3.2.4-9. Beyers Cove community map footprint analysis. Data from 2013/2014 and 2023 floating-leaf and emergent community mapping surveys conducted by Onterra.

3.2.5 City Millpond Aquatic Plant Community

City Millpond is the outlet basin of Green Lake (Map 1). Point-intercept surveys have been completed on the lake from 2013 – 2018, and 2023. Total rake fullness values from these years are displayed on Figure 3.2.5-1. Aquatic plants were found at about 70% of reachable point-intercept sampling locations in 2023, down from 85% or greater frequency from 2013-2018.

These rake fullness data represent the aquatic plant biomass at each sampling location and does not differentiate between native or non-native vegetation. Of the vegetation located in 2023, the majority of it was of the lowest density designation (rake-fullness = 1). Map 11 spatially displays the rake fullness data for City Millpond.

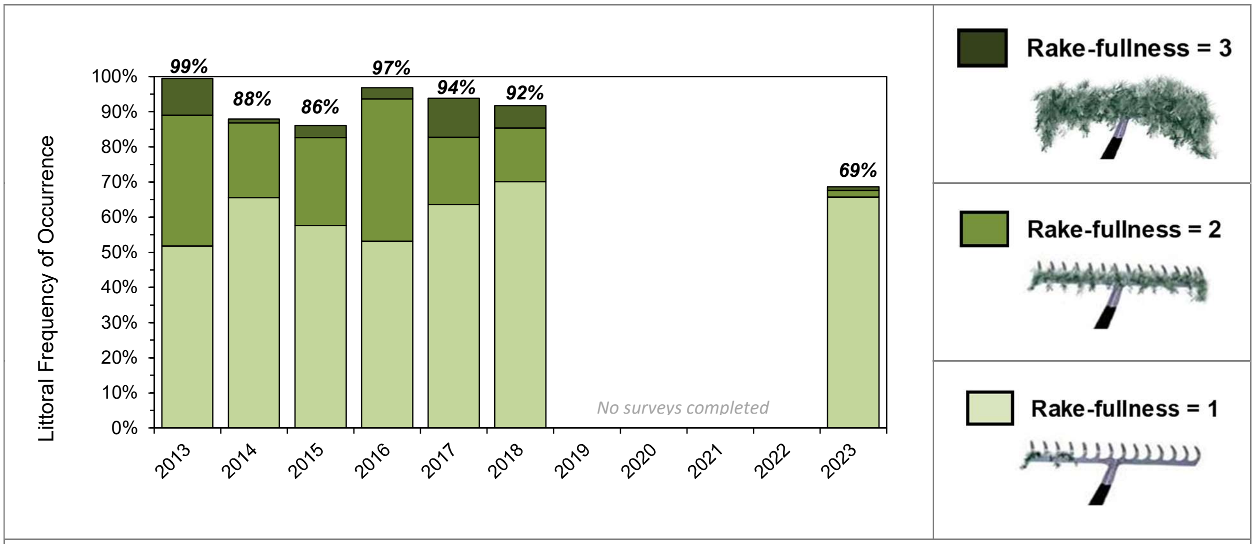


Figure 3.2.5-1. City Millpond total rake fullness data available point-intercept surveys.

Approximately a total of 16 native aquatic plant species were sampled during the 2023 point-intercept survey in City Millpond with coontail (53.9%), wild celery (11.8%), and white water lily (7.8%), being the most commonly encountered native species (Figure 3.2.5-2). Eurasian watermilfoil was also observed with an occurrence of 3.9% in 2023. Curly-leaf pondweed was very low as well with an occurrence of 1.0%, however, curly-leaf pondweed peaks in biomass early summer when the point-intercept survey occurred midsummer. Table 3.2.5-1 displays all of the 35 species that were documented during the 2013-2018 and 2023 point-intercept surveys on the City Millpond. Table 3.2.5-1 is organized by growth form which separates out species based on whether they are emergent species, floating-leaf species, submergent species, or free-floating species.

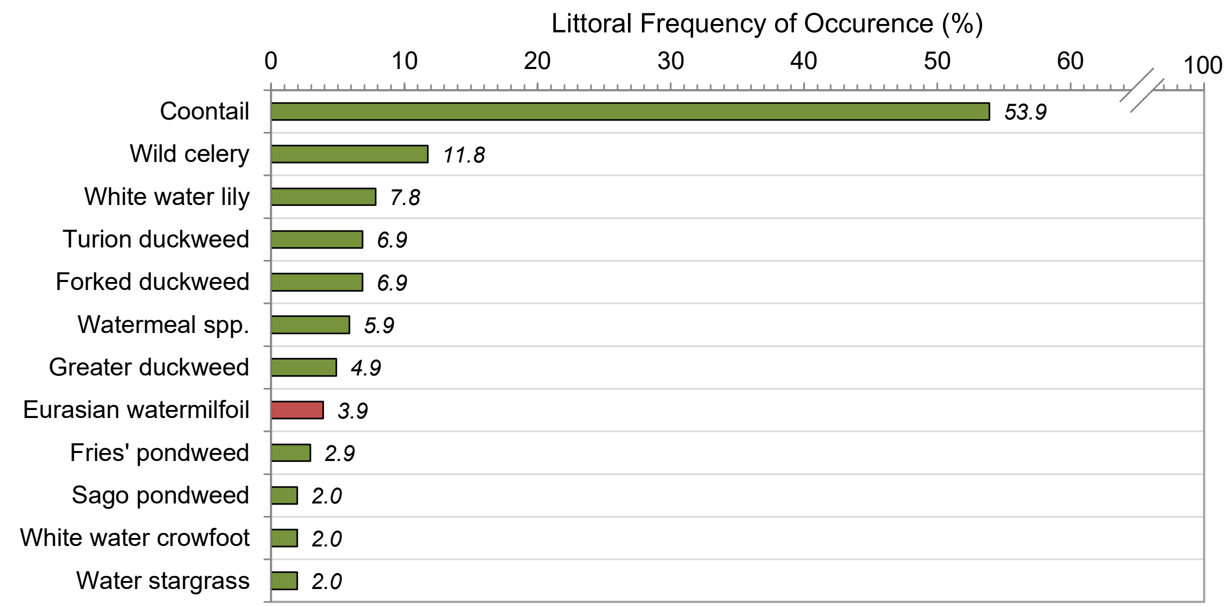


Figure 3.2.5-2. City Millpond 2023 LOO. LFOO = littoral frequency of occurrence**.** Species with greater than 2.0% LFOO shown.

Table 3.2.5-1. City Millpond aquatic plant species list.

Growth Form	Scientific Name	Common Name	Status in Wisconsin	Coefficient of Conservatism	2013	2014	2015	2016	2017	2018	2023
E	*Sparganium eurycarpum*	Common bur-reed	Native	5			X		X		
FL	*Nuphar variegata*	Spatterdock	Native	6					X		
FL	*Nymphaea odorata*	White water lily	Native	6	X	X	X	X	X	X	X
Submergent	*Ceratophyllum demersum*	Coontail	Native	3	X	X	X	X	X	X	X
Submergent	*Chara spp.*	Muskgrasses	Native	7	X	X	X	X		X	
Submergent	*Elodea canadensis*	Common waterweed	Native	3	X	X	X	X	X	X	
Submergent	*Heteranthera dubia*	Water stargrass	Native	6	X	X	X	X	X	X	X
Submergent	*Myriophyllum sibiricum*	Northern watermilfoil	Native	7		X	X				
Submergent	*Myriophyllum spicatum*	Eurasian watermilfoil	Non-Native - Invasive	N/A	X	X	X	X	X	X	X
Submergent	*Najas guadalupensis*	Southern naiad	Native	7	X		X				
Submergent	*Potamogeton crispus*	Curly-leaf pondweed	Non-Native - Invasive	N/A	X	X	X	X	X	X	X
Submergent	*Potamogeton friesii*	Fries' pondweed	Native	8	X	X		X	X	X	X
Submergent	*Potamogeton nodosus*	Long-leaf pondweed	Native	5	X						X
Submergent	*Potamogeton richardsonii*	Clasping-leaf pondweed	Native	5	X	X	X	X	X	X	X
Submergent	*Potamogeton strictifolius*	Stiff pondweed	Native	8	X		X			X	
Submergent	*Potamogeton zosteriformis*	Flat-stem pondweed	Native	6	X	X		X	X	X	X
Submergent	*Ranunculus aquatilis*	White water crowfoot	Native	8	X	X	X	X	X	X	X
Submergent	*Stuckenia pectinata*	Sago pondweed	Native	3	X	X	X	X	X	X	X
Submergent	*Vallisneria americana*	Wild celery	Native	6	X	X	X	X	X	X	X
Submergent	*Zannichellia palustris*	Horned pondweed	Native	7	X						
S/E	*Eleocharis acicularis*	Needle spikerush	Native	5						X	
FF	*Lemna minor*	Lesser duckweed	Native	5			X	X	X	X	
FF	*Lemna trisulca*	Forked duckweed	Native	6	X	X	X	X	X	X	X
FF	*Lemna turionifera*	Turion duckweed	Native	2	X	X					X
FF	*Spirodela polyrhiza*	Greater duckweed	Native	5	X	X	X	X			X
FF	*Wolffia spp.*	Watermeal spp.	Native	N/A	X	X	X	X	X		X

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

City Millpond has been treated with aquatic herbicides from 2014-2017 with the goal of reducing EWM and CLP populations. EWM control was found to be short-lived, rebounding within a year of treatment. The CLP treatments appeared to be more effective, although assessing the treatment of an annual plant like CLP is more complex than for a perennial like EWM.

Figure 3.2.5-3 compares the littoral frequency of occurrence of select aquatic plant species in City Millpond from each of seven point-intercept surveys. A statistically valid change in occurrence from one survey to the next is indicated by an open circle on the figure. Many species saw statistically valid changes in occurrence between the timeframe but a particularly large decline was consistently observed from 2018 to 2023 in absence of coordinated herbicide management.

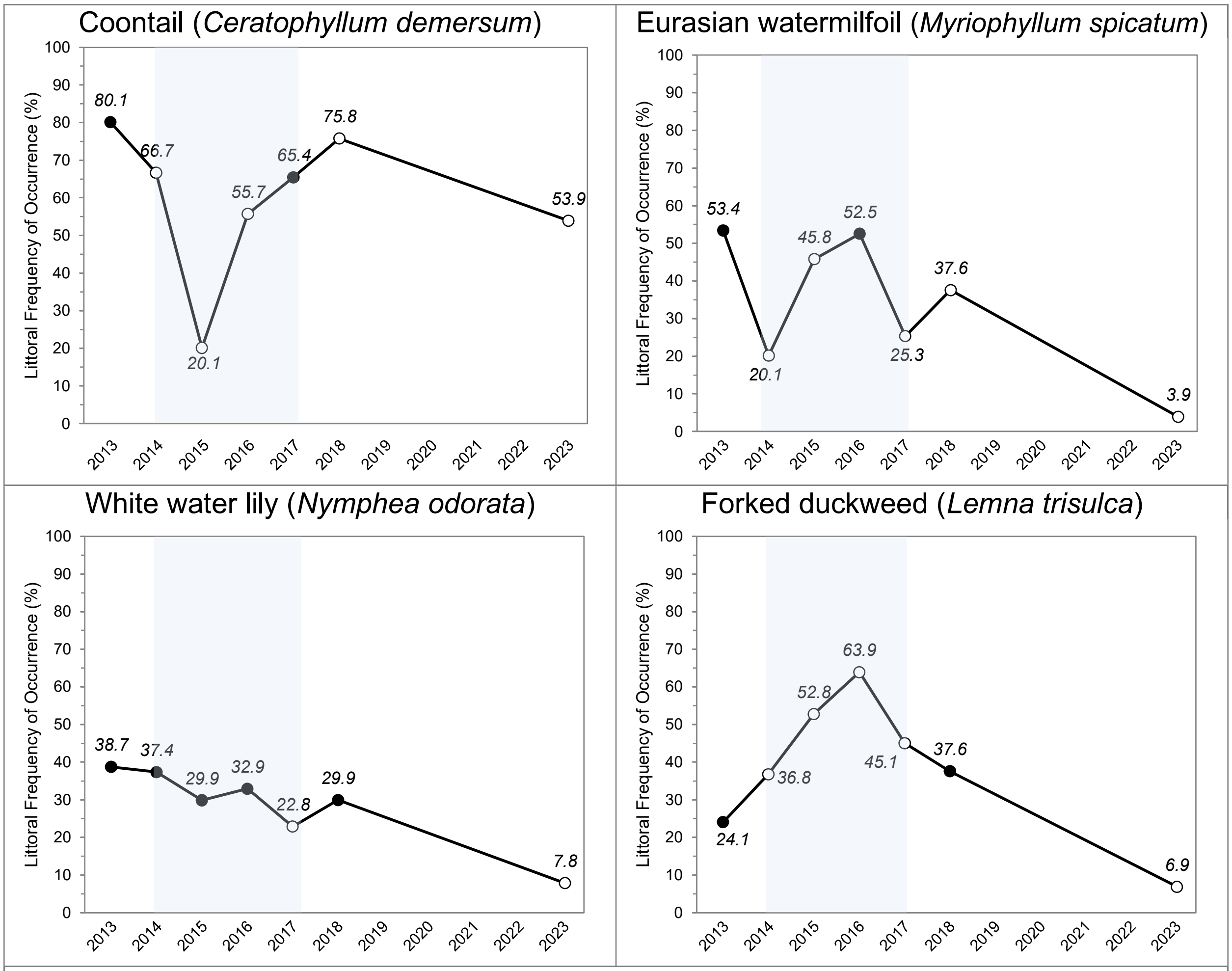


Figure 3.2.5-3. Littoral frequency of occurrence of select native aquatic plant species. Open circle indicates a statistically valid change in occurrence from the previous survey (Chi-Square α = 0.05).

A comparison of the available point-intercept surveys allows for detecting changes in the aquatic plant community over time. Figure 3.2.5-3 shows the average of these values from each survey. This metric was the highest in 2015 and 2017 at 2.69 species per sampling point. The 2023 survey found 1.09 species per site which is a decrease from the previous surveys and is the lowest recorded during the timeframe (Figure 3.2.5-4). Coupled with the data above, most of these locations are coontail, a non-rooted plant subject to moving around the system. The 2023 species richness data are shown on Map 10.

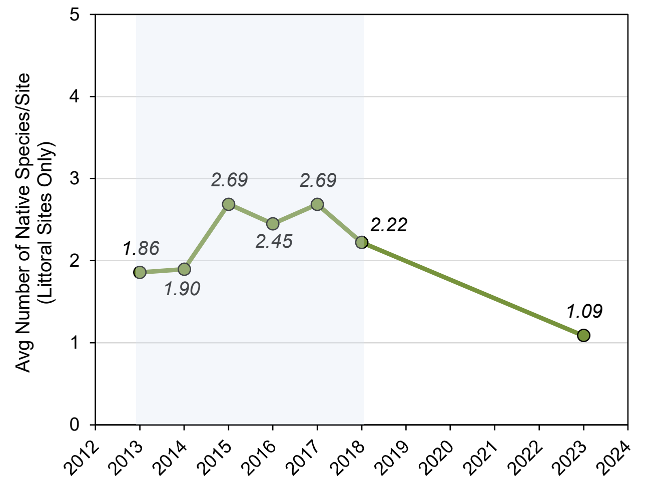


Figure 3.2.5-4. City Millpond average native species per sampling location.

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 3.2.5-5). Relative frequency of occurrence is used to evaluate how often each plant species is encountered in relation to all the other species found. Figure 3.2.5-4 displays the relative frequency of occurrence of aquatic plant species from each of the point-intercept surveys in City Millpond. These data indicate that some species such as coontail, lesser duckweed, and Eurasian watermilfoil have varied quite a bit over time in relative frequency. Coontail, for example, accounted for 6.4% of the relative frequency in the 2015 survey and has expanded to account for 47.0% in 2023. Eurasian watermilfoil accounted for as much as 20.1% of the relative frequency in 2013 and in the 2023 survey it decreased to 3.4%.

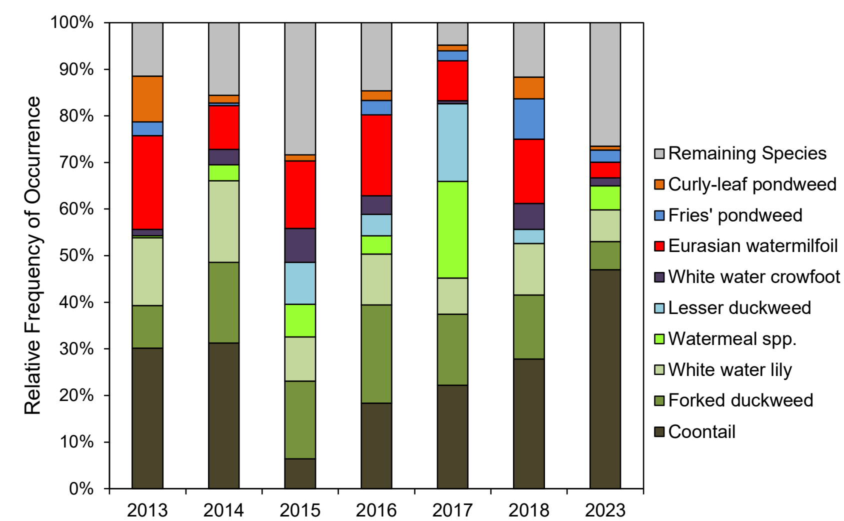


Figure 3.2.5-5. City Millpond relative frequency of occurrence.

A comparison of the species richness, average conservatism, and floristic quality from each of the four point-intercept surveys in the City Millpond is displayed on Figure 3.2.5-6. In the 2023 point-intercept survey, the total richness was 14 compared to 15 to 19 in previous years. Average conservatism values varied from 5.3 in 2023 to 5.7 in 2018. The floristic quality in the City Millpond has varied as well from 19.8 in 2023 to 24.5 in the 2013 survey. The species richness and floristic quality values from the 2023 survey are below the ecoregion and state median values, indicating that the aquatic plant community in the City Millpond is fair to poor in quality and a decline over this time period of study.

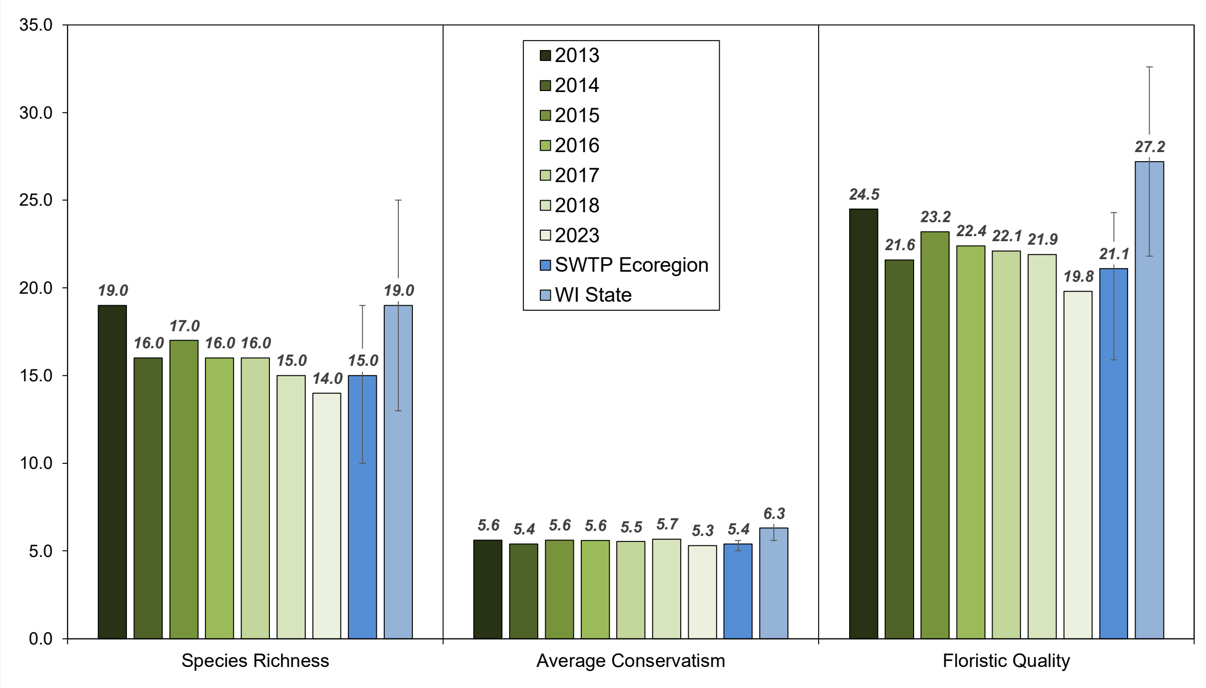


Figure 3.2.5-6. City Millpond Floristic Quality Index. Analysis follows (Nichols 1999). Error bars indicate interquartile range (25th percentile to 75th percentile). Median = 50th percentile.

In 2023, Onterra ecologists also conducted a survey aimed at mapping emergent and floating-leaved plant communities in City Millpond. In 2013, approximately 24.5 acres of emergent and floating-leaf aquatic plant communities were delineated in the City Millpond compared to 23.7 in 2023 (Map 15, Figure 3.2.5-7). Based on the data collected, quantity of emergent and floating leaf communities have largely remained in the same areas with a few changes. Figure 3.2.5-8 shows a footprint analysis of the 2013 vs 2023 community mapping surveys. Nearshore areas of human habitation correspond with areas of vegetation communities lost, mostly populations of white water lily. The center "island" of white water lilies expanded in some areas and retracted in others, possibly a result of differing boating patterns in this area.

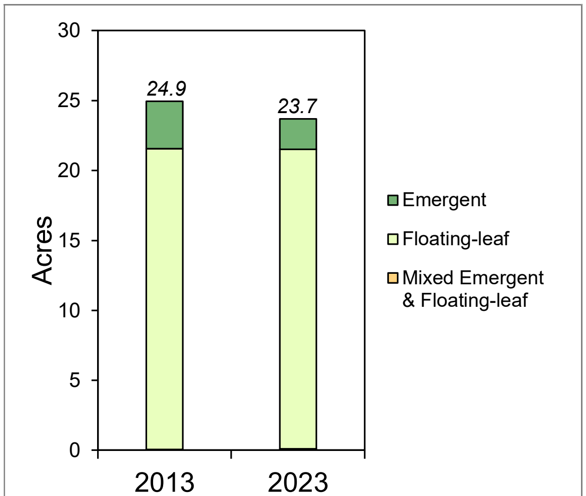


Figure 3.2.5-7. Acres of floating-leaf and emergent plant communities on City Millpond. Data from 2013 and 2023 community mapping surveys conducted by Onterra.

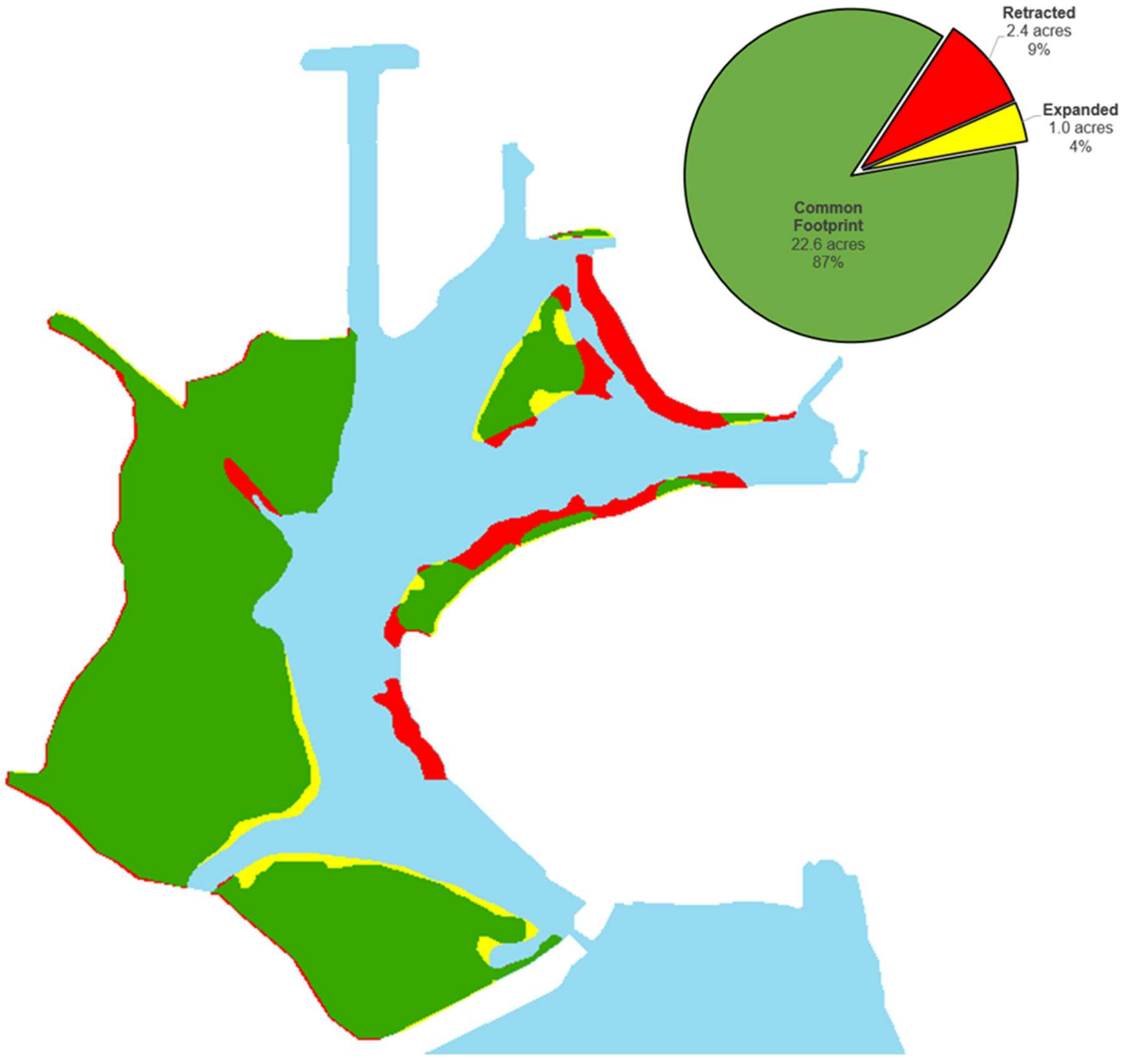


Figure 3.2.5-8. City Millpond community map footprint analysis. Data from 2013/2014 and 2023 floating-leaf and emergent community mapping surveys conducted by Onterra.

3.2.6 Silver Creek Aquatic Plant Community

Silver Creek is one of the three inlet estuaries on Green Lake (Map 1). This basin reportedly had low amounts of aquatic plants for many decades and as recently as a survey conducted in 1998. With the installation of the carp barrier in the mid-2000s and extensive carp harvesting efforts, large increases in submersed macrophytes established themselves. EWM was one of the primary initial colonizers, being found at 75% of the sampling locations in 2007.

Total rake fullness values from the 2007, 2013-2018, and 2023 point-intercept surveys are displayed on Figure 3.2.6-1. Aquatic plants have inhabited a similar amount of the littoral zone over time. These rake-fullness data represent the aquatic plant biomass at each sampling location and does not differentiate between native or non-native vegetation. Denser vegetation was observed in 2016, with other years having a similar proportion of rake-fullness ratings.

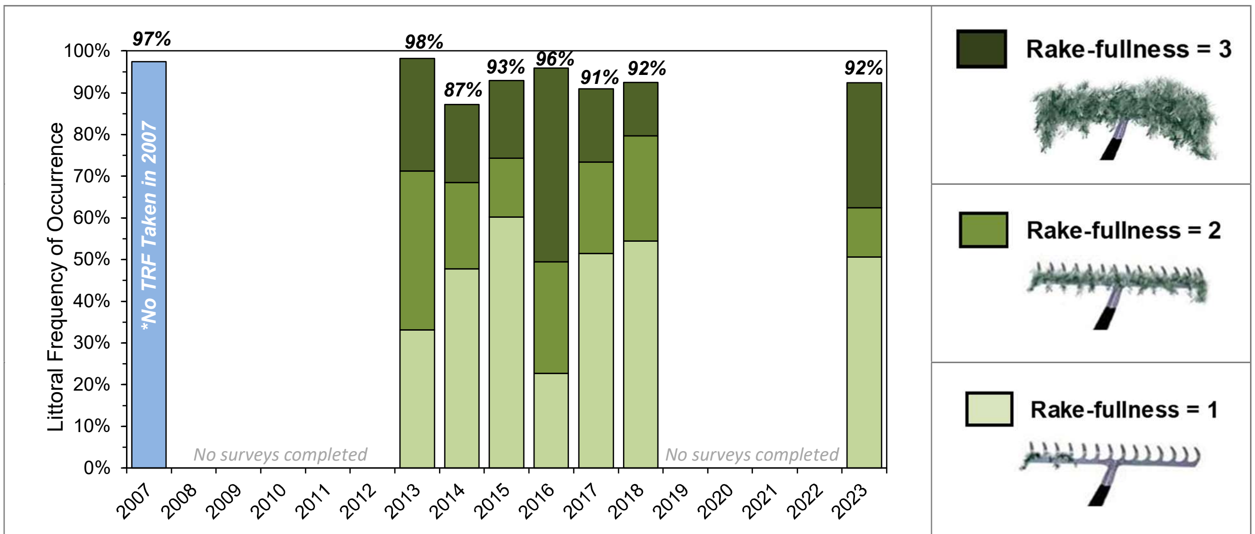


Figure 3.2.6-1. Silver Creek total rake fullness data available point-intercept surveys.

Approximately total of 15 native aquatic plant species were sampled during the 2023 point-intercept survey in Silver Creek with coontail (78.2%), lesser and turion duckweed (55.9%), and common waterweed (52.4%), being the most commonly encountered native species (Figure 3.2.6-2). Eurasian watermilfoil was another frequently encountered species within the estuary with an occurrence of 10% in 2023. Curly-leaf pondweed was observed as well but at a very low occurrence of 5.3%, however, curly-leaf pondweed peaks in biomass early summer when the point-intercept survey occurred midsummer. 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. Due to this, the littoral occurrences of the following morphologically-similar species were combined for this analysis: lesser duckweed (*Lemna minor*) and turion duckweed (*L. turionifera*). Table 3.2.6-1 displays all of the 35 species that were documented during the 2007, 2013-2018, and 2023 point-intercept surveys on Silver Creek. Table 3.2.6-1 is organized by growth form which separates out species based on whether they are emergent species, floating-leaf species, submergent species, or free-floating species.

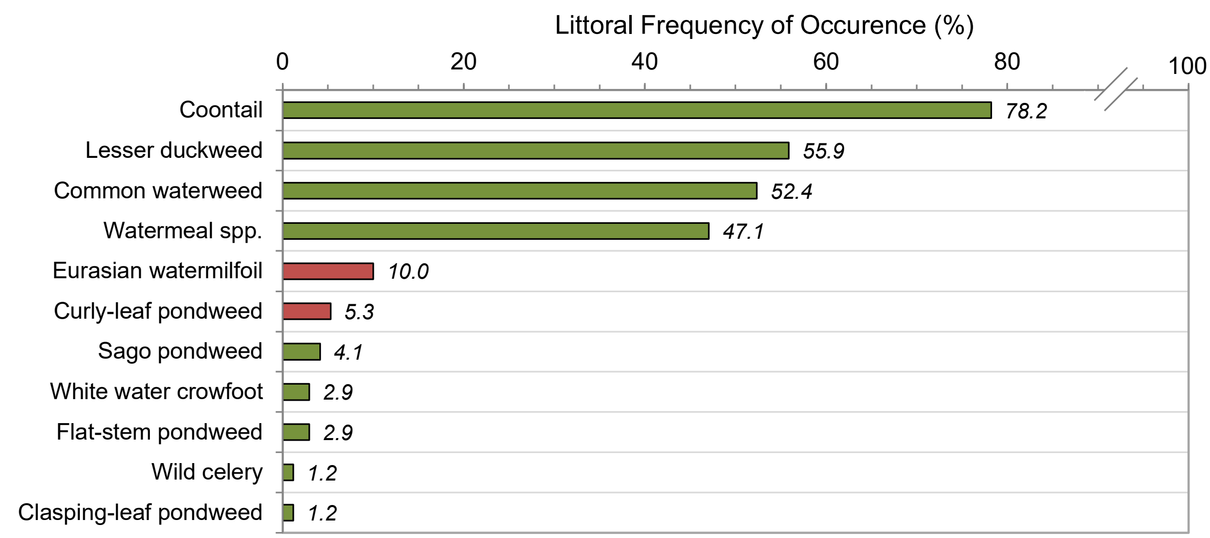


Figure 3.2.6-2. Silver Creek 2023 LOO. LFOO = littoral frequency of occurrence**.** Species with greater than 1.0% LFOO shown.

Table 3.2.6-1. Silver Creek aquatic plant species list.

Growth Form	Scientific Name	Common Name	Status in Wisconsin	Coefficient of Conservatism	2007	2013	2014	2015	2016	2017	2018	2023
Emergent	*Acorus americanus*	Sweetflag	Native	7					X			
	Eleocharis erythropoda	Bald spikerush	Native	3		I						
	Eleocharis palustris	Creeping spikerush	Native	6								I
	Lythrum salicaria	Purple loosestrife	Non-Native - Invasive	N/A		I						
	Phalaris arundinacea	Reed canary grass	Non-Native - Invasive	N/A		I						I
	Phragmites australis subsp. Australis	Giant reed	Non-Native - Invasive	N/A		I						
	Schoenoplectus acutus	Hardstem bulrush	Native	5		I						
	Schoenoplectus tabernaemontani	Softstem bulrush	Native	4		I						I
	Sparganium eurycarpum	Common bur-reed	Native	5		I						I
	Typha spp.	Cattail spp.	Unknown (Sterile)	N/A		I						I
FL	*Nuphar variegata*	Spatterdock	Native	6							I	
	Nymphaea odorata	White water lily	Native	6	X	X	X	X	X	X	X	X
FL/E	*Sparganium sp.*	Bur-reed sp.	Native	N/A								I
Submergent	*Ceratophyllum demersum*	Coontail	Native	3	X	X	X	X	X	X	X	X
	Elodea canadensis	Common waterweed	Native	3		X	X	X	X	X	X	X
	Heteranthera dubia	Water stargrass	Native	6					X		X	X
	Myriophyllum sibiricum	Northern watermilfoil	Native	7				X				
	Myriophyllum spicatum	Eurasian watermilfoil	Non-Native - Invasive	N/A	X	X	X	X	X	X	X	X
	Najas guadalupensis	Southern naiad	Native	7					X			X
	Potamogeton crispus	Curly-leaf pondweed	Non-Native - Invasive	N/A	X	X	X	X	X	X	X	X
	Potamogeton foliosus	Leafy pondweed	Native	6					X			
	Potamogeton friesii	Fries' pondweed	Native	8		X						X
	Potamogeton nodosus	Long-leaf pondweed	Native	5					X	X	I	
	Potamogeton richardsonii	Clasping-leaf pondweed	Native	5			X	X			X	X
	Potamogeton strictifolius	Stiff pondweed	Native	8						X	X	
	Potamogeton zosteriformis	Flat-stem pondweed	Native	6		X	X	X	X	X	X	X
	Ranunculus aquatilis	White water crowfoot	Native	8		X	X	X	X	X	X	X
	Stuckenia pectinata	Sago pondweed	Native	3	X	X	X	X	X	X	X	X
	Vallisneria americana	Wild celery	Native	6				X	X		X	X
S/E	*Eleocharis acicularis*	Needle spikerush	Native	5			X		X			
FF	*Lemna minor*	Lesser duckweed	Native	5	X				X	X	X	X
	Lemna trisulca	Forked duckweed	Native	6			X					
	Lemna turionifera	Turion duckweed	Native	2		X	X	X				
	Spirodela polyrhiza	Greater duckweed	Native	5		X						
	Wolffia spp.	Watermeal spp.	Native	N/A	X	X	X	X	X	X	X	X

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

Figure 3.2.6-3 compares the littoral frequency of occurrence of select aquatic plant species in Silver Creek from each of the eight point-intercept surveys. A statistically valid change in occurrence from one survey to the next is indicated by an open circle in the figure. The occurrence of EWM has continued to decrease from 74.4% occurrence in 2007 to 10.0% in 2023. As a pioneering species, EWM may have been an early colonizer of Silver Creek. As native species became established, the EWM population appears to have been outcompeted.

Coontail and duckweed populations dipped in 2014-2015. These populations were largely unimpacted following the spring 2013 herbicide spot treatment targeting EWM, declining in subsequent years. During the planning process, knowledgeable stakeholders indicated that duckweed populations historically were not an issue in Silver Creek. However, these data that indicate that high populations of duckweed existed at least back to 2007 when the bubble barrier was added.

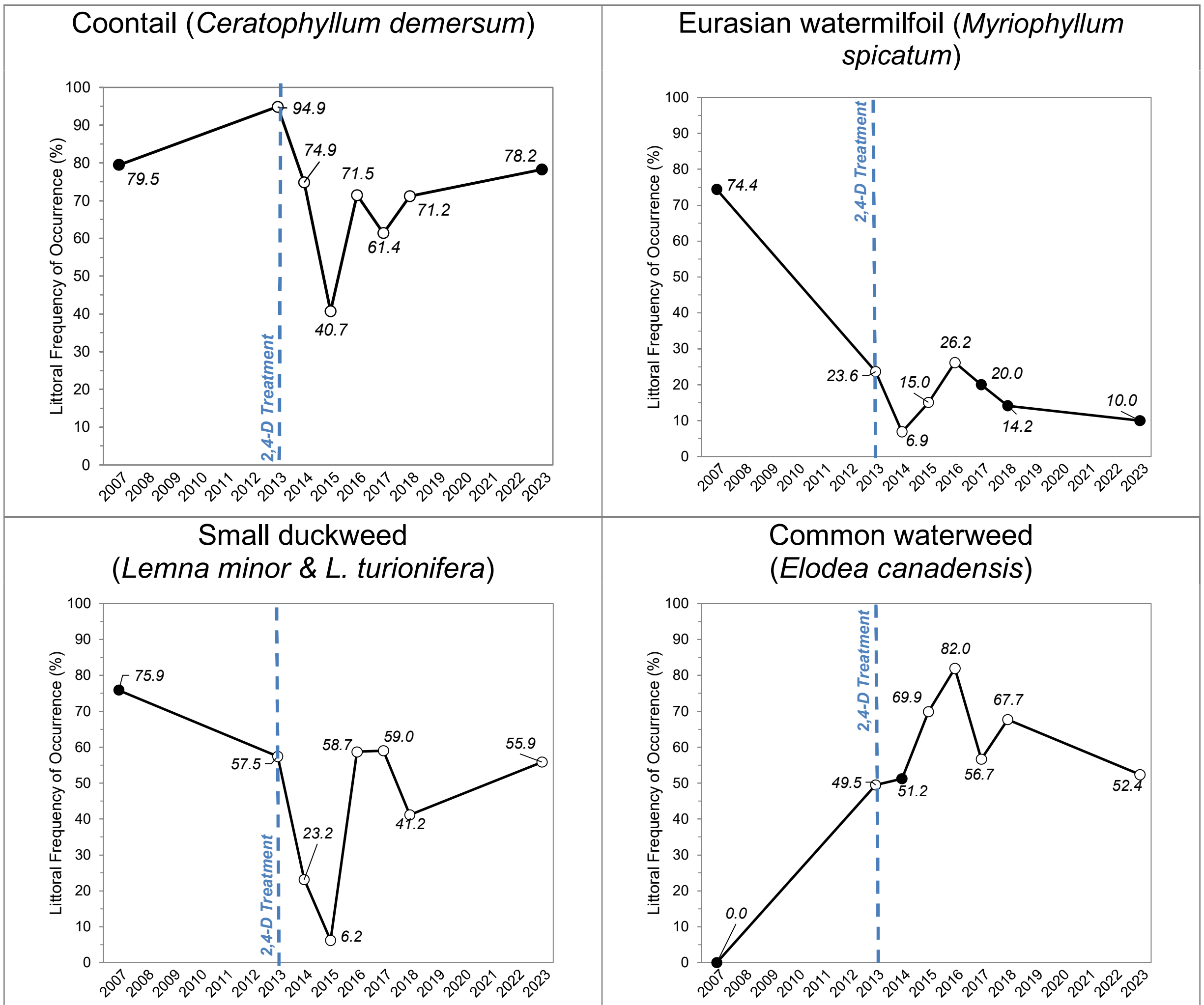


Figure 3.2.6-3. Littoral frequency of occurrence of select native aquatic plant species. Open circle indicates a statistically valid change in occurrence from the previous survey (Chi-Square α = 0.05).

A comparison of the available point-intercept surveys allows for detecting changes in the aquatic plant community over time. Figure 3.2.6-4 shows the average of native species per sampling location from each survey. This metric was at 3.1 during the summer of 2013, a few months following a spring 2,4-D herbicide treatment. The following two years had relatively large reductions in the number of species per point, likely as a result of less duckweed and coontail during this time period. This metric rebounded and was the highest in 2016. The stability of this metric from 2017-2023 is interesting in light of the shifting abundance of some aquatic plant species. This indicates a healthy and diverse system, as one species decreases, another species increases.

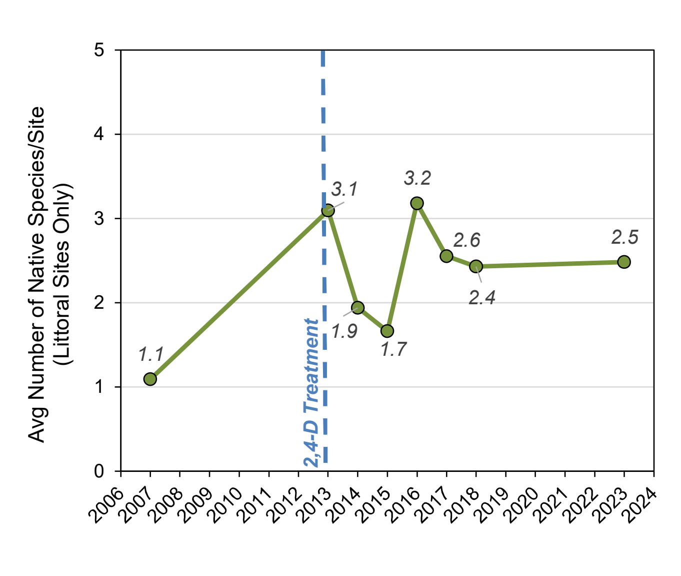


Figure 3.2.6-4. Silver Creek average native species per sampling location.

One way to visualize the diversity of a lake's plant community is to examine the relative frequency of occurrence of aquatic plant species. Relative frequency of occurrence is used to evaluate how often each plant species is encountered in relation to all the other species found. Figure 3.2.6-5 displays the relative frequency of occurrence of aquatic plant species from each of the eight point-intercept surveys in Silver Creek. Common waterweed and coontail are the primary aquatic plants in this estuary. Together their populations were just under 40% of the overall vegetation in 2007, peaked at 55% in 2014-2015, and subsided back to 40% in 2023.

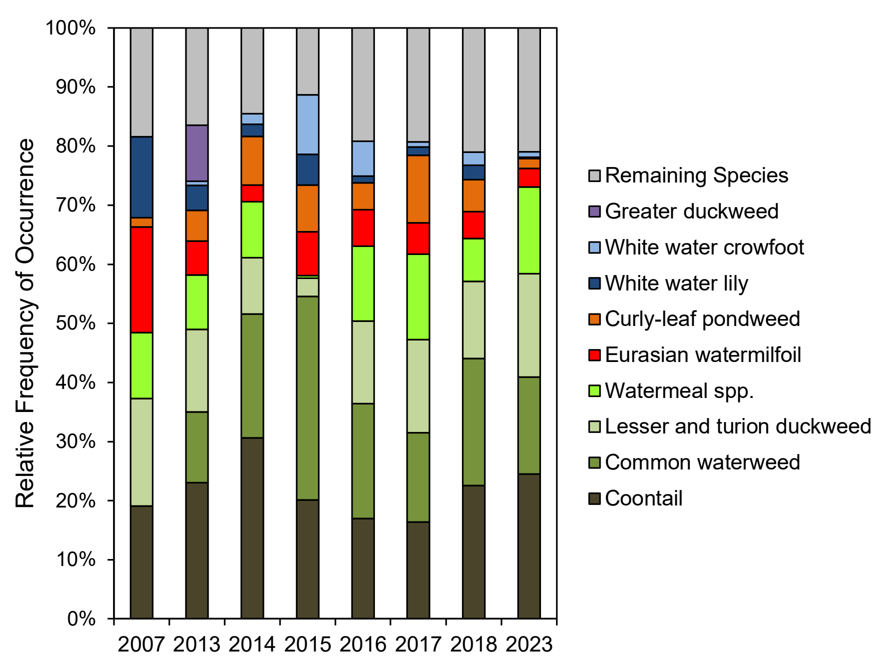


Figure 3.2.6-5. Silver Creek relative frequency of occurrence.

A comparison of the species richness, average conservatism, and floristic quality from each of the four point-intercept surveys in Silver Creek is displayed on Figure 3.2.6-6. In the 2023 point-intercept survey, the total richness was 13 which is about average compared to previous survey years. Average conservatism values varied from 4.3 in 2007 to 5.5 in 2016 and 2023. The floristic quality in Silver Creek has varied as well from 10.4 in 2007 to 22.8 in the 2016 survey. The species richness and floristic quality values from the 2023 survey are below the ecoregion and state median values with the exception of the conservatism value which is slightly above the SWTP ecoregion value.

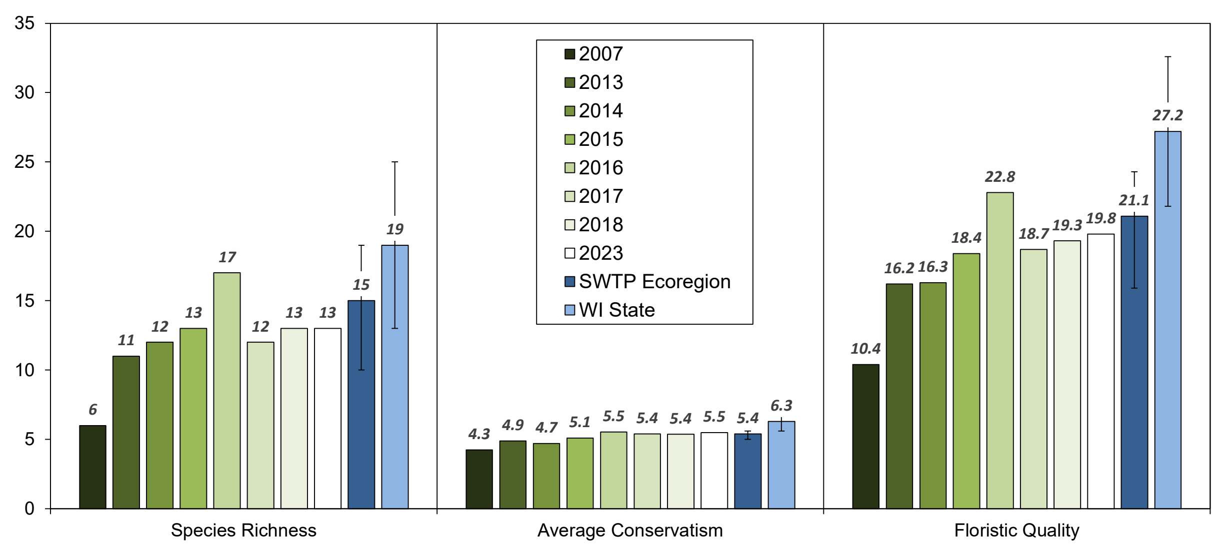
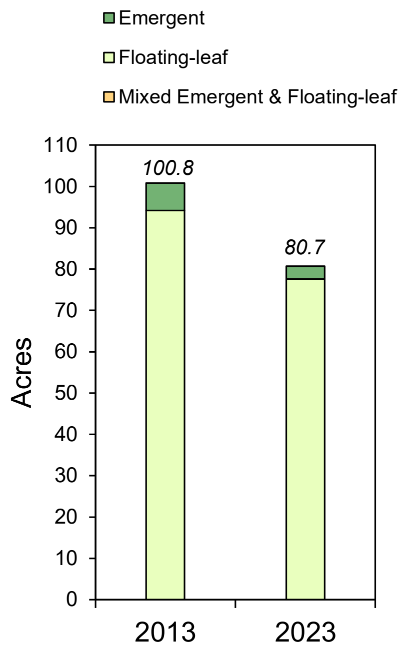


Figure 3.2.6-6. Silver Creek Floristic Quality Index. Analysis follows (Nichols 1999). Error bars indicate interquartile range (25th percentile to 75th percentile). Median = 50th percentile.

In 2023, Onterra ecologists also conducted a survey aimed at mapping emergent and floating-leaved plant communities in Silver Creek. In 2013, approximately 100.8 acres of emergent and floating-leaf aquatic plant communities were delineated in Silver Creek compared to 80.7 in 2023 (Figure 3.2.6-7 and Map 16).

Figure 3.2.6-8 summarizes the footprint analysis of emergent and floating-leaf communities within Silver Creek. This decline in acreage appears to be in communities that were located along the northwestern shoreline and the eastern most shoreline. Onterra staff in 2023 noted it was inaccessible via boat in the northern most area of Silver Creek which was mapped in 2013 (i.e. too shallow). While this data cannot be used as a direct compare, it is evident these aquatic plant communities have increased and decreased in multiple areas throughout Silver Creek. Emergent and floating-leaf plant communities often recede or expand in response to changes in water levels. As water levels rise, these communities retract as water at their lakeward extent becomes too deep. In contrast, these communities often expand during periods of lower water levels.



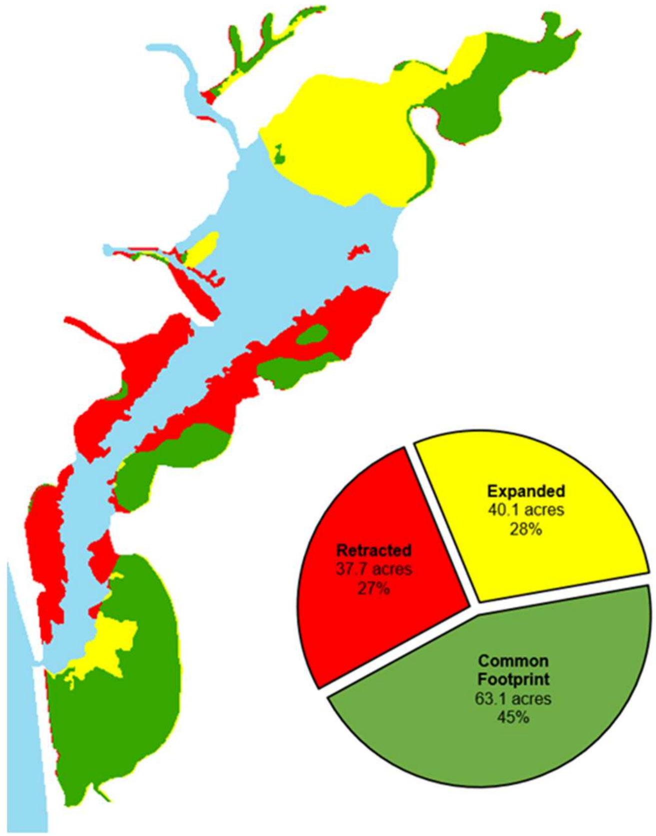


Figure 3.2.6-7. Acres of floating-leaf and emergent plant communities on Silver Creek.

Figure 3.2.6-8. Silver Creek community map footprint analysis. Data from 2013/2014 and 2023 floating-leaf and emergent community mapping surveys conducted by Onterra.

3.2.7 County K Marsh Aquatic Plant Community

County K Marsh is one of four estuaries connected to Green Lake and is located to the southwest of the system (Map 1). During each of the point-intercept surveys, only a point or two contained aquatic plants. During this period of study, no reach change in aquatic plant abundance was observed.

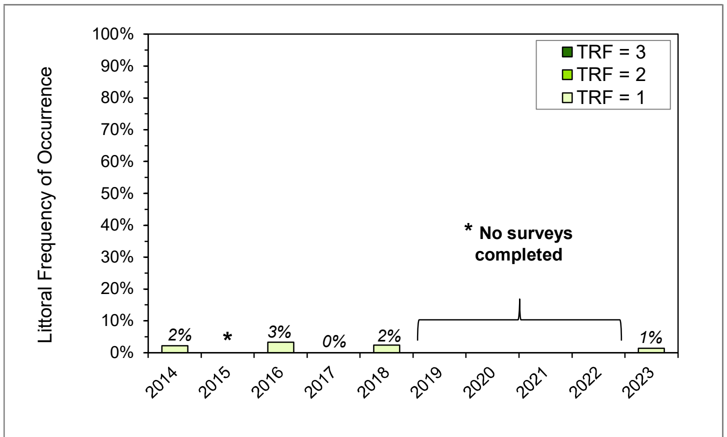


Figure 3.2.7-1. County K Marsh total rake fullness ratings.

Table 3.2.7-1 displays all of the 20 species that were documented during the 2014-2018, and 2023 point-intercept surveys on the County K Marsh. Many of the plant species noted in the 2014 survey are emergent wetland species not likely to have been inside the high-water line of the lake. While coontail, the most abundant plant in Green Lake, is tolerant of low-light conditions and can thrive in degraded environments, the conditions present in County Marsh are too turbid to support coontail or other populations of submersed aquatic plants.

Table 3.2.7-1. County K Marsh aquatic plant species list.

Growth Form	Scientific Name	Common Name	Status in Wisconsin	Coefficient of Conservatism	2014	2016	2017	2018	2023
Emergent	*Bolboschoenus fluviatilis*	River bulrush	Native	5	I				
	Calamagrostis canadensis	Bluejoint grass	Native	5	I				
	Carex comosa	Bristly sedge	Native	5	I				
	Eleocharis erythropoda	Bald spikerush	Native	3	I				
	Iris versicolor	Northern blue flag	Native	5	I				
	Lythrum salicaria	Purple loosestrife	Non-Native - Invasive	N/A					I
	Phalaris arundinacea	Reed canary grass	Non-Native - Invasive	N/A	I				
	Phragmites australis subsp. americanus	Common reed	Native	5	I				
	Sagittaria latifolia	Common arrowhead	Native	3	I				
	Typha spp.	Cattail spp.	Unknown (Sterile)	N/A	I				I
FL	*Nuphar variegata*	Spatterdock	Native	6	I				
	Nymphaea odorata	White water lily	Native	6	X	X	I		X
Submergent	*Ceratophyllum demersum*	Coontail	Native	3	X	X			
	Najas flexilis	Slender naiad	Native	6		I			
	Potamogeton crispus	Curly-leaf pondweed	Non-Native - Invasive	N/A			I	X	I
	Potamogeton foliosus	Leafy pondweed	Native	6		I			
	Ranunculus aquatilis	White water crowfoot	Native	8		I			
	Stuckenia pectinata	Sago pondweed	Native	3		X		X	I
	Vallisneria americana	Wild celery	Native	6		I			
	Zannichellia palustris	Horned pondweed	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; F/L = Floating-leaf & Emergent; S/E = Submergent and/or Emergent; FF = Free-floating

The GLSD has made attempts to understand the factors limiting vegetation growth in County K Marsh. Water celery and sago pondweed were planted within fenced carp exclosures in this system. While the vegetation grew prolifically during the summer, especially sago pondweed (Photograph 3.2.7-1), these plants did not survive the winter and did not regrow the following year.

Photograph 3.2.7-1. Sago pondweed in carp exclosure from County K Marsh. Photograph credit Onterra, 7/3/2018

In 2023, Onterra ecologists also conducted a survey aimed at mapping emergent and floating-leaved plant communities in County K Marsh. The adjacent margins of this basin are cattail and native phragmites grass marshes. These surveys only delineated the communities within the high-water mark, which was a difficult task with lower water levels in 2023. In 2013, approximately 10.2 acres of emergent and floating-leaf aquatic plant communities were delineated in County K Marsh compared to 12.7 in 2023 (Figure 3.2.7-2 and Map 17), indicating stability of these populations.

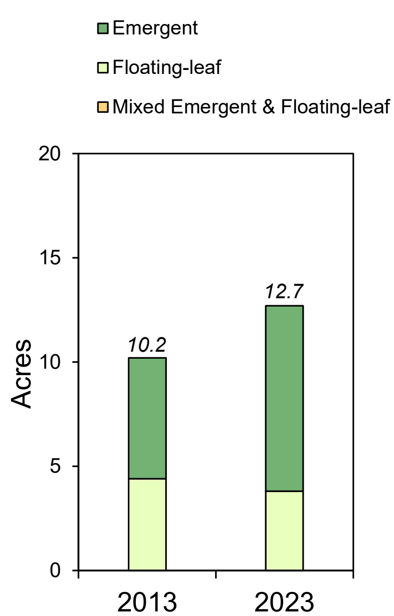


Figure 3.2.7-2. Acres of floating-leaf and emergent plant communities on County Highway K Marsh.

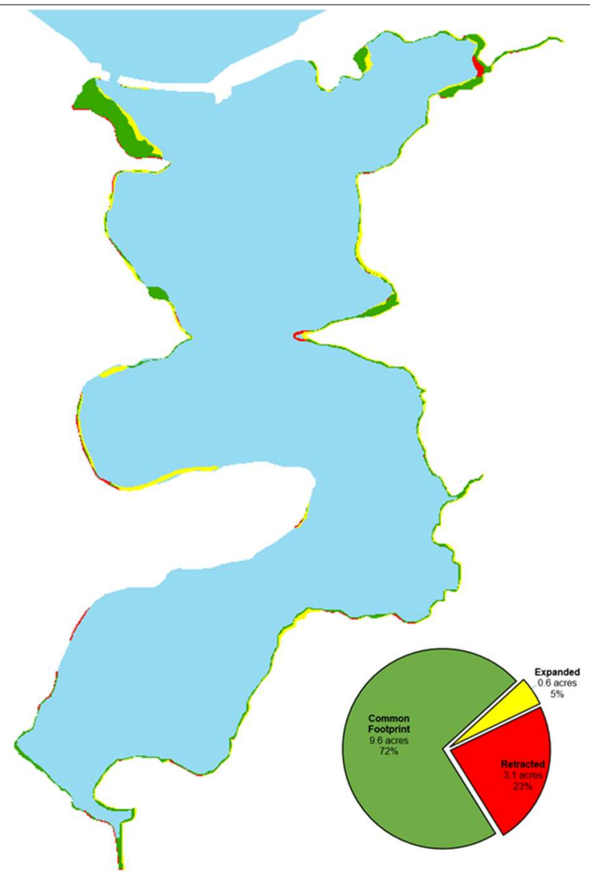


Figure 3.2.7-3. County K Marsh community map footprint analysis. Data from 2013/2014 and 2023 floating-leaf and emergent community mapping surveys conducted by Onterra.

The northern part of this basin is were the largest changes in community abundance was detected during the footprint analysis (Figure 3.2.7-3). Expansion of white-water lily was observed in some areas and contracted in others.

Stakeholders of Green Lake have expressed concerns about the expansion of cattails in County K Marsh. In Photograph 3.2.7-2, a 1938 aerial photograph of County K Marsh is compared with the most recent aerial photograph from 2022. The comparative aerial photographs clearly show a more defined lake-wetland interface in 2022 compared to 1938. The emergent and floating-leaf communities have significantly receded since 1938. Additionally, the 1938 photo reveals small ponds and lakes to the west of County K Marsh, which are now either unrecognizable due to algae and duckweed or have been filled in for agricultural or residential purposes.

The reduction in emergent and floating-leaf communities is attributed to increased nutrient input from the watershed and the introduction of common carp. The 1938 photo showcases these changes, and continued monitoring of the estuary is essential to assess if cattails and other aquatic plant communities are expanding into previously inhabited areas.

1938 **2022**

Photograph 3.2.7-2. Historical photograph of the County K Marsh. 1938 aerial photograph from Wisconsin State Cartographer's Office Historical Aerial Image Finder (WHAIFinder). 2022 aerial photograph from the National Agriculture Imagery Program (NAIP). Pink hashed outline is 2022 open water extents digitizing the 2022 NAIP photo – overlaid on both photos.

3.2.8 Historical Aquatic Plant Dataset Discussion

In 1921, H. W. Rickett conducted a study of aquatic plants in Green Lake for the Geological and Natural History Survey. Fifty years later, Mary Jane Bumby replicated the survey methodology in 1971 as part of her master's thesis from the University of Wisconsin-Milwaukee. Bumby continued to conduct a similar survey every ten years from 1971 to 2001. In 2021, at 90 years old, she funded a repeat of the original study for its 100th anniversary. The species lists from the major surveys are provided in Table 3.2.8-1, in addition to the now standardized point-intercept data collected in 2023.

Table 3.2.8-1. Historical Green Lake aquatic plant species list.

Growth Form	Scientific Name	Common Name	Status in Wisconsin	1921 (Rickett)	1971 (Bumby)	2022 (Pillsbury & Budrick)	2023 (Onterra)
Emergent	*Carex sp.*	Sedge sp.	N/A	X			
	Sagittaria rigida	Stiff arrowhead	Native	X			
	Schoenoplectus acutus	Hardstem bulrush	Native				I
	Schoenoplectus sp.	Bulrush sp.	Native	X			
	Typha spp.	Cattail spp.	Unknown (Sterile)	X			I
	Zizania sp.	Wild rice sp.	Native	X			
FL	*Nymphaea odorata*	White water lily	Native	X			X
Submergent	*Bidens beckii*	Water marigold	Native	X			
	Ceratophyllum demersum	Coontail	Native	X	X	X	X
	Chara spp.	Muskgrasses	Native	X	X	X	X
	Drepanocladus sp.	Aquatic moss sp.	Native	X	X		
	Elatine minima	Waterwort	Native				X
	Elodea canadensis	Common waterweed	Native	X	X	X	X
	Heteranthera dubia	Water stargrass	Native	X	X	X	X
	Myriophyllum sibiricum	Northern watermilfoil	Native			X	X
	Myriophyllum sibiricum X spicatum	Hybrid watermilfoil	Non-Native - Invasive		X	X	X
	Myriophyllum verticillatum	Whorled water milfoil	Native	X			
	Najas flexilis	Slender naiad	Native	X	X	X	X
	Nitella spp.	Stoneworts	Native				X
	Potamogeton amplifolius	Large-leaf pondweed	Native	X	X		
	Potamogeton berchtoldii	Slender pondweed	Native				X
	Potamogeton berchtoldii & P. pusillus	Slender and Small pondweed	Native				X
	Potamogeton crispus	Curly-leaf pondweed	Non-Native - Invasive		X		X
	Potamogeton foliosus	Leafy pondweed	Native	X	X		X
	Potamogeton friesii	Fries' pondweed	Native		X		X
	Potamogeton gramineus	Variable-leaf pondweed	Native	X			X
	Potamogeton illinoensis	Illinois pondweed	Native				X
	Potamogeton natans	Floating-leaf pondweed	Native	X	X	X	
	Potamogeton nodosus	Long-leaf pondweed	Native				X
	Potamogeton praelongus	White-stem pondweed	Native				X
	Potamogeton pusillus	Small pondweed	Native				X
	Potamogeton richardsonii	Clasping-leaf pondweed	Native		X	X	X
	Potamogeton strictifolius	Stiff pondweed	Native				X
	Potamogeton zosteriformis	Flat-stem pondweed	Native	X		X	X
	Ranunculus aquatilis	White water crowfoot	Native	X	X		X
	Ruppia cirrhosa	Spiral ditch-grass	Native				
	Stuckenia pectinata	Sago pondweed	Native	X	X	X	X
	Vallisneria americana	Wild celery	Native	X	X	X	X
	Zannichellia palustris	Horned pondweed	Native		X	X	X
S/E	*Armoracia lacustris*	Lake cress	Native	X			
	Eleocharis acicularis	Needle spikerush	Native				X
FF	*Lemna minor*	Lesser duckweed	Native				X
	Lemna trisulca	Forked duckweed	Native		X		X
	Lemna turionifera	Turion duckweed	Native				X
	Spirodela polyrhiza	Greater duckweed	Native				X
	Wolffia spp.	Watermeal spp.	Native				X

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 and/or Emergent; FF = Free-floating

In Rickett's 1921 study, he measured the biomass of aquatic plants at various locations in the lake and found that muskgrasses, a type of macroalgae, dominated the lake, constituting 54% of the total aquatic plant biomass. Fifty years later, in 1971, Bumby replicated Rickett's study and observed a 92% decline in the biomass of muskgrasses. In the subsequent surveys of 2007 and 2014, muskgrasses were found to have a littoral frequency of occurrence of 6% and 7%, respectively, indicating that they were no longer dominant within the community.

Rickett's study also indicated that coontail and a native milfoil species called whorled watermilfoil (*Myriophyllum verticillatum*) were the subsequent most prevalent aquatic plants within the community in 1921. Although Bumby's 1971 study revealed that coontail remained one of the prominent plants in the lake, she observed a decline in its biomass compared to 1921. Coontail continued to be the most frequently encountered native aquatic plant species in the WDNR 2007, Onterra 2014, and 2023 studies. Nevertheless, Bumby's research in 1971 did not identify any instances of whorled watermilfoil; instead, it noted the emergence of Eurasian watermilfoil (EWM, *Myriophyllum spicatum*) as a replacement. In fact, as early as 1971, Bumby found EWM had become the predominant plant in Green Lake's aquatic plant community. Subsequent studies in 2007, 2014, and 2023 confirmed that the EWM population in Green Lake, likely predominantly or entirely hybrid watermilfoil (HWM, *Myriophyllum sibiricum X M. spicatum*), along with coontail, constituted the dominant species during those years.

Whorled watermilfoil has not been documented in Green Lake since Rickett's 1921 study, suggesting that this particular species likely no longer exists in the lake. Since Eurasian watermilfoil was not introduced to Wisconsin until the 1960s, Rickett could not have misidentified it as whorled watermilfoil. However, Bumby points out that Rickett did not collect any specimens of whorled watermilfoil for confirmation, raising the possibility that he might have mistaken these plants with another native milfoil species, northern watermilfoil, which still maintains a small population in Green Lake. Whether these plants were indeed whorled or northern watermilfoil, their population has experienced a significant decline since 1921.

Following the prevalence of coontail and the native watermilfoil, Rickett identified sago pondweed, common waterweed, wild celery, and an aquatic moss (*Drepanocladus* spp.) as the subsequent most abundant plants in Green Lake. In 1971, Bumby observed that the biomass of wild celery surpassed Rickett's recorded values, but she also noted a significant decline in the abundance of the aquatic moss. All of these plant species were observed in the 2007 and 2014 surveys, although the aquatic moss was only detected at a single sampling location (littoral frequency of occurrence = 0.1%) in 2014. Aquatic moss was not recorded on any sampling locations in 2023.

Four pondweed species—large-leaf pondweed, leafy pondweed, variable-leaf pondweed, and floating-leaf pondweed—identified in 1921 were not rediscovered in the 1971 survey. Although large-leaf pondweed, leafy pondweed, and variable-leaf pondweed were located in 2007, large-leaf pondweed was absent in the 2014 and 2023 survey. Furthermore, floating-leaf pondweed was not documented in Green Lake during either the 2007, 2014, and 2023 surveys. In addition to these changes, Rickett identified several plant species in Green Lake during his 1921 study that have not been observed since. These include water marigold, stiff arrowhead, wild rice, and lake cress. Notably, lake cress is currently classified as critically imperiled in Wisconsin due to its extreme rarity, with Rickett reporting findings of this plant in two locations in 1921.

In 1971, Bumby's research highlighted a significant transformation in Green Lake's aquatic plant community over the 50 years following Rickett's study, with numerous species experiencing a decline in their presence. She observed an overall reduction in the total biomass of aquatic plants, especially in the deeper regions of the lake. These alterations in Green Lake's aquatic plant community reflect the diverse anthropogenic (human-induced) pressures exerted on the ecosystem. Factors such as heightened nutrient inputs from the lake's watershed, shoreline development, and the introduction of invasive species have profoundly reshaped Green Lake's ecosystem. In the concluding paragraph of the 2023 study, the authors indicate that there may be some positive trends in the Green Lake aquatic vegetation condition. Recent surveys had more in common with 1921 vegetation assessments than in 1971.

4.0 SUMMARY AND CONCLUSIONS

As outlined within the Introduction Section (1.0), the goal of this project was to create an updated Aquatic Plant Management (APM) Plan for Green Lake. Having an up-to-date APM Plan will allow seamless continuation of ongoing aquatic plant management activities. But the overall objective of this project is to understand the overall aquatic plant condition of Green Lake and determine actionable goals to protect and enhance it.

Approximately 50 different species of plants were located within and along the margins of the Green Lake system, much higher than most Wisconsin systems. The Green Lake system contains a wide range of habitats, including sandy shoals, deep shelves, sediment-rich backwater bays, and riverine areas. Different aquatic plant species favor different habits and thus results in the high species richness found in Green Lake. A statistical measurement of aquatic plant diversity indicates that there is an 88% chance of the next plant species encountered in Green Lake being different from the previous one.

The submersed aquatic plant community of Green Lake is dominated by coontail and muskgrasses, which are important to sediment stabilization. The lake also has a robust population of wild celery, providing valuable aquatic habitat in sandy near-shore areas and providing an abundant food source for migratory waterfowl. The system is also known to contain approximately a dozen species of pondweeds, which provide important vertical fish habitat for the system.

Free-floating plants comprised largely of duckweed species are common to Silver Creek and other backwater areas of the Green Lake system. These small floating plants resemble floating algae, and can be found growing to nuisance levels at times. Concerns exist that these species are also a vector of nutrients being transferred from Silver Creek into Green Lake. This project identified numerous information gaps in the management of duckweeds, with intentions of gaining additional information that will lead to successful mitigation of the nuisance conditions and likely nutrient source.

The Green Lake system is known to harbor two non-native submersed aquatic plant species, Eurasian watermilfoil (EWM) and curly-leaf pondweed (CLP). Both of these plant species are native to Europe and Asia and can thrive in some Wisconsin waterways to levels that can impact navigation and recreation as well as alter the way the ecosystem functions. In some lakes like Green Lake, these species can integrate into the overall aquatic plant community and only provide minor negative attributes. This project outlines numerous aquatic invasive species protection and containment goals for the Green Lake system.

The overall submersed aquatic plant population of Green Lake is considered healthy. No new aquatic invasive species were discovered as part of the thought studies conducted in 2023. Aquatic plant populations are dynamic and population changes in some species have been documented compared to prior years whereas others have been stable. Metrics of aquatic plant health indicate an overall healthy ecosystem, with Beyers Cove improving since prior surveys, City Millpond showing some minor declines, Silver Creek and Green Lake (proper) being relatively stable, and County K Marsh continuing to be largely unvegetated.

Green Lake's robust aquatic plant populations can cause impediments to navigation and recreation, caused largely by a combination of submersed aquatic invasive species (EWM and CLP) and loosely rooted native vegetation (e.g. coontail, common waterweed, southern naiad, uprooted water celery). The GLSD targets nuisance levels of aquatic plants for removal with their mechanical harvester in order to benefit overall watercraft navigation patterns and riparian access. This project solidified continued operation plans for mechanical harvesting, as well as adopted modified management strategies to help meet stakeholder needs. While the ongoing mechanical harvesting program may not completely meet stakeholder goals in select areas of the system, this management plan aims to find future implementable solutions.

Green Lake also contains important emergent (e.g. bulrushes, cattails) and floating-leaf aquatic plant communities (i.e. water lilies). These communities are important for sediment stabilization and absorbing wave energy, thereby protecting shorelines form erosion. They also offer important spawning, nesting, and foraging habitat for numerous species of insects, fish, birds, and waterfowl. Many of the remaining communities in Green Lake have been designated by the WDNR as *critical habitat areas*. Emergent and floating-leaf communities have declined on my lakes due to unnatural water level conditions, shoreland development, competitiveness of invasive species, and high-speed boating. Surveys conducted on Green Lake in 2013 and 2023 have shown some of these populations have declined, whereas others have expanded. This project created a plan to protect these valuable habitats, and continue monitoring their populations periodically to understand short- and long-term trends.

This project also investigated the shoreland condition of Green Lake to understand this valuable habitat and nutrient buffering zone of the lake. Unfortunately, the 2023 studies indicate some facets of the shoreland condition have declined since a similar survey was conducted in 2017. The project identifies numerous management objectives to empower property owners to restore their shorelines to a more natural condition, while protecting those currently in a natural state.

5.0 IMPLEMENTATION PLAN

The objective of this project is to create updated aquatic plant-related goals and actions for Green Lake, based upon current best management practices (BMPs), the lessons learned during the years since the 2013 *Comprehensive Lake Management Plan* was developed, and the information gathered during the Onterra studies completed to date. The *Aquatic Plant Management* (APM) implementation plan presented here is designed to be primarily carried out by the Green Lake Sanitary District (GLSD). It is based upon the concerns, priorities, and capacity of these organizations. The GLSD, along with the greater Lake Management Planning Team will couple this APM Plan with a forthcoming Comprehensive Watershed & Lake Management Plan (WLMP), together providing a holistic approach to the management of the Green Lake system.

Management Goal 1: Ensure that Green Lake has a Functioning and Up-to-Date Aquatic Plant Management Plan

Management Action:	Formalizing an *Aquatic Plant Management (APM) Committee*
Timeframe:	Starting 2024
Facilitator:	GLSD
Description:	The Green Lake Sanitary District (GLSD) has historically taken the lead on the active management of aquatic plants in Green Lake including annual mechanical harvesting and nuisance herbicide management. The Green Lake Association (GLA) has taken an early lead on establishing an AIS prevention and education. The Green Lake County Land Conservation Department designed and helps manage a boat wash station and the USGS is investigating the role of duckweed on the water quality of Green Lake. As a part of this project, significant overlap with multiple organizations regarding aquatic plant management and education have been uncovered. While these organizations have a great working relationship and converse regularly, the formalization of an *Aquatic Plant Management (APM) Committee* will provide more structure to how aquatic plant management-related topics are addressed. The *APM Committee* would be chaired by the GLSD with representation by the GLA, partner organizations, and possibly community groups. The *APM Committee* would meet regularly to provide updates on applicable ongoing projects to ensure proper division of labor and reduce duplication of efforts. The *APM Committee* would work with community groups and community leaders as they pursue local aquatic plant management related challenges. As new aquatic plant-related projects present themselves, the *APM Committee* would meet to make sure project parameters are established and components are divided to the entity with the appropriate capacity and expertise.

Management Action:	Participate in Wisconsin Lakes and Rivers Convention
Timeframe:	Annually or as needed
Facilitator:	*APM Committee*
Description:	Wisconsin is unique in that there is a long-standing partnership between a governmental body, a citizen-based lake lobbying and protection association, and the state's primary educational outreach program. That unique group is the Wisconsin Lakes Partnership and its three members, the Wisconsin Department of Natural Resources, Wisconsin Lakes, and the UW-Extension Lakes Program, facilitate many lake-related events throughout the state. The primary event is the Wisconsin Lakes Partnership Convention held each spring in Stevens Point. This is the largest citizen-based lakes conference in the nation and is specifically suited to the needs of lake associations and associations. It is an exceptional opportunity for lake group members to learn about lake management and monitoring; network with other lake groups, agency staff, and lake management contractors; and learn how to effectively operate a lake association/association. Even though the *APM Committee* is comprised of paid professionals, periodic participation in this conference is important to stay relevant on lake-related issues, attend training sessions, and to network with other organizations and professionals dealing with similar lake management concerns. The *APM Committee* may also encourage active community group members and volunteers to attend the conference in relation to specific concerns raised.

Management Action:	Periodically update aquatic plant management plan
Timeframe:	Continuation of current effort; periodic
Facilitator:	GLSD
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. BMPs for aquatic plant management change rapidly, as new information about effectiveness, non-target impacts, and risk assessment emerges. To be eligible for multi-year mechanical harvesting permits (NR109) or APM-related WDNR surface water grants (NR193), "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."

The *APM Committee* will update the APM Plan at roughly 5-year intervals, unless the WDNR agrees that a slightly longer interval is appropriate. Figure 5.0-1 displays the timeline for the next APM Plan Update, including the timing of project design and grant application phases. Project budgets often need to lead project implementation by a year, so long range planning will be critical to ensuring this management action is completed within the interval frequency outlined. With this APM Plan being completed in 2025, the project design phase for the next updated APM Plan will start during the summer of 2028 with ambition for an updated APM Plan to be completed in 2030.

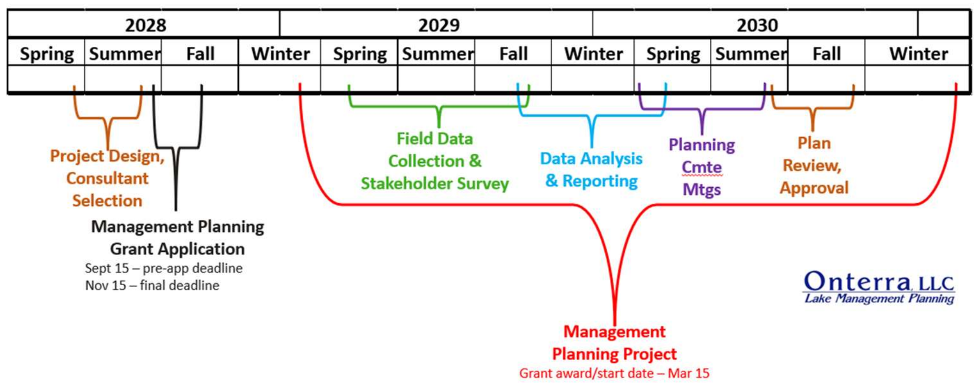


Figure 5.0-1. APM Plan Update Timeline. Created by Onterra.

Management Action:	Conduct periodic stakeholder surveys
Timeframe:	Periodic: 5-year intervals during APM Plan updates
Facilitator:	GLSD
Description:	An important component of any planning project is soliciting input from stakeholders. There are many ways to solicit stakeholder input, with a written user survey being one of the most straight forward. While meetings and listening sessions can be a good way to hear public thoughts, it often highlights those with the strongest opinions and may not represent the collective public sentiments. During an APM Plan update as outlined in the previous management action, the GLSD would conduct applicable public outreach opportunities, including a stakeholder survey about aquatic plans and management. 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's aquatic plants. All survey results would be fully shared with the *APM Committee*, and a summary would be shared to applicable Green Lake constituents. A defined population stakeholder user survey was conducted in 2023, being sent to all GLA and GLSD members around Green Lake. Essentially this is a survey of those that own property on the Green Lake system, which on most lakes is the population most concerned with the health of their lake. But on Green Lake, the greater community is more actively involved in the health of Green Lake than a standard inland lake. Therefore, the *APM Committee* would review the methodologies and target audience of a future survey to ensure it is reaching their needs. This may include a general user survey where any interested person can provide input. Conducting a general user survey offers more complexities than a defined population survey, particularly in gaining a sufficient response rate of transient users to provide useful data that would be commensurate with the cost and effort of implementation. The future survey would benefit from receiving approval from a WDNR Research Social Scientist, particularly if WDNR grant funds are used to offset the cost of the effort. This approval leads to credibility of the survey effort, ensuring it is completed in an objective and non-biased way.

Management Goal 2: Monitor Aquatic Vegetation on Green Lake

Management Action:	Coordinate periodic point-intercept aquatic plant surveys
Timeframe:	Periodic: at least once every 5 years, Timing: during July-August
Facilitator:	GLSD
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 on Green Lake and the adjoining basins periodically since 2007. 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 greater Green Lake system well as to other waterbodies throughout the state. These surveys are required to be conducted at 5-year increments and reported upon within APM Plan updates. 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 GLSD will ensure the point-intercept surveys is conducted at least once every five years on Green Lake and on each adjoining basin, or potentially more frequently if prompted by a specific rationale. For example, if management actions are being conducted to flip County Highway K Marsh to a plant-dominated system, bracketed surveys before and after a large management event would be justified to assess the aquatic plant community response.

Management Action:	Consider periodic community mapping (floating-leaf and emergent) surveys
Timeframe:	Periodic: every 10 years for Green Lake, 5 years for adjoining basins, or when prompted
Facilitator:	GLSD
Description:	A key component of any aquatic plant community assessment is the delineation of the emergent and floating-leaf aquatic plant communities within each lake as these plants are often underrepresented during the point-intercept survey. Many floating-leaf and emergent communities in Green Lake have been designated by the WDNR as *critical habitat areas*. The emergent and floating-leaf community mapping survey (often referred to as *community mapping survey*) creates a snapshot of these important communities within each lake as they existed during the survey and is valuable in the development of the management plan and in comparisons with future surveys. Since the community map represents a 'snapshot' of the important emergent and floating-leaf plant communities, a replication of this survey in the future will provide a valuable understanding of the dynamics of these communities within Green Lake. Previous community mapping surveys have been conducted in 2013/2014 and 2023 on Green Lake and adjoining basins. Relatively substantial changes in colonized floating-leaf and emergent communities have been observed during this time period, including within areas listed as WDNR Critical Habitat Areas. The *APM Committee* intends to conduct this survey on Green Lake at roughly 10-year intervals and on the adjoining basins at roughly 5-year intervals to understand if these populations are expanding or contracting over time. If emergent and floating-leaf communities are suspected of changing footprints rapidly, a shorter interval may be justified.

Management Goal 3: Prevent Establishment of New AIS & Contain Existing AIS Populations

Management Action:	Monitor Green Lake public entry points for aquatic invasive species
Timeframe:	Continuation of current effort
Facilitator:	GLA
Description:	Green Lake is an extremely popular destination by recreationists and anglers, making the lake vulnerable to new infestations of exotic species. Based upon modeling by the University of Wisconsin Center for Limnology, Green Lake is listed on the state's top 300 Aquatic Invasive Species (AIS Prevention Priority Waterbodies. This means that Green Lake has a high number of boats arriving from lakes that have AIS (receiving) and a high number of boats moving from Green Lake to uninvaded waters (sending). The *APM Committee* has identified public boat landings as a major pathway for AIS in and out of Green Lake. The GLA intends to continue staffing watercraft inspectors at the eight public access locations. Over the past three years, watercraft inspections have averaged just under 1,000 hours per year. Watercraft inspectors would follow the WDNR's Clean Boats Clean Waters (CBCW) program protocols, spreading awareness and education in addition to inspecting watercraft for hitchhiking aquatic plant and animals. The GLA would prioritize inspectors be present at appropriate 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 GLA will also ensure proper signage is available at the public access locations, describing AIS present, AIS of interest, and proper disinfection procedures.

Management Action:	Encourage watercraft disinfection procedures
Timeframe:	Continuation of current effort
Facilitator:	GLA will continue to establish this program in 2024-2025, but seeking broader partners to take the lead on this task for the future
Description:	While watercraft inspectors can look for large and obvious AIS hitchhikers on boats and trailers, some potential invaders are too small to be seen with the naked eye and/or can be easily overlooked. Therefore, properly cleaning watercraft between lakes can offer a much larger level of protection from being a vector of AIS transmission. The GLA currently offers two primary mechanisms for watercraft disinfection, a portable water-less cleaning stations (CD3 system) and an automated boat wash station (e.g., pressure washer).

	The CD3 machine, which stands for *clean, drain, dry, dispose*, is equipped with cleaning tools such as compressed air and wet/dry vacuum to help boaters clean their boat and equipment, which includes the removal of AIS. This machine was available for free use in 2024 at Horner's Landing. A self-service pressure washer station was placed at Dodge Memorial County Park. This allowed users free use of a pressure washer to knock-off any potential AIS from their boats and trailers before or after entering the lake. In 2024, the GLA incentivized use of the boat washing station by offering a drawing of $500 cash to each user each time they completed a quick survey following their use of the equipment. While the GLA was instrumental and getting this program established, they are seeking partner organizations, such as the entities that own and maintain the launch sites, to lead the operations and maintenance of these measures going forward. Ongoing discussions are occurring as a part of the WLMP regarding purpose and definition of the AIS prevention program.

<u>Management Action:</u>	Provide targeted AIS education materials to other entry pathways
Timeframe:	Continuation of current effort
Facilitator:	GLA
Description:	The previous management actions target the pathway of transient boaters, primarily those that use public access locations. The *APM Committee* has identified additional AIS introduction pathways to Green Lake, such as private launches at resorts, campgrounds, and marinas. The *APM Committee* has an established relationship with many of these entities and would extend additional AIS education, CBCW messaging, and encourage proper signage at these sites. The *APM Committee* has also identified specific user groups that would benefit from specific targeting of AIS messaging designed specifically for them. This would include area fishing clubs and local bait shops that may be more apt to spread concerning animals of interest.

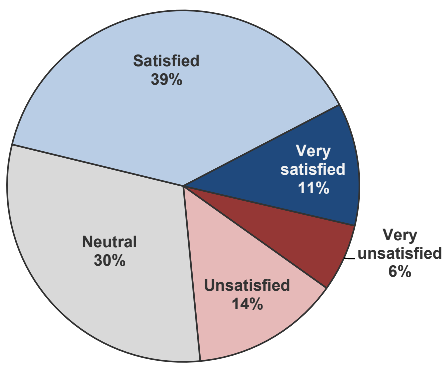
Management Action:	Initiate rapid response plan following detection of new AIS
Timeframe:	If/When Necessary
Facilitator:	*APM Committee*
Description:	The *APM Committee* will continue to support monitoring the lake and access points for new AIS. This may be passive efforts or formal efforts through the Citizen Lake Monitoring Network's AIS Early Detection Monitoring Program: https://www3.uwsp.edu/cnr-ap/UWEXLakes/Pages/programs/clmn/AIS.aspx If a new AIS is suspected from Green Lake, the location should be recorded or marked (e.g. GPS, maker buoy) and a specimen would be provided to a regional WDNR lakes biologist/specialist or other respected professional to confirm identification. If the suspected specimen is indeed a non-native species, the WDNR will properly prepare the specimen for vouchering and will fill out a formal WDNR incident form. The next step would be professionally the survey the system, either by agency personnel or a private consulting firm during that species' peak growth or most detectable phase. This will aid in determining the extent of the population to generate a realistic response and to determine if the project qualifies for funds through the WDNR Surface Water Grant Program's Early Detection and Response Grant. This continually offered grant opportunity is non-competitive and available to the sponsor of project waters that contain new infestations (found in an area less than 3 acres in size or within less than 3% of the littoral zone and officially documented less than 5 years from grant application date) of NR40 restricted or prohibited species. Currently this program will fund up to 75% percent of monitoring and control costs, up to $25,000. One grant is available for pioneering populations of NR40 restricted invasive species. Multiple grants sought in succession are available for NR40 prohibited species. More information can be found here: https://dnr.wisconsin.gov/aid/SurfaceWater.html Ultimately, the *APM Committee* would need to reach out to a consultant to develop a formal monitoring and/or control strategy. If the AIS is a NR40 prohibited species (i.e. quagga mussel, red swamp crayfish, starry stonewort, hydrilla, yellow floating heart, etc.), the WDNR may take a more active role in coordinating the response.

Management Goal 4: Maintain Navigability on Green Lake

Management Action:	Increase recreational use through planned and permitted mechanical harvesting activities
Timeframe:	Continuation of Current Effort
Facilitator:	GLSD
Description:	The *APM Committee* understands the importance of aquatic vegetation within Green Lake. However, nuisance aquatic plant conditions exist in certain parts of the lake, caused largely by a combination of submersed aquatic invasive species (e.g. Eurasian water milfoil and curly-leaf pondweed) and loosely rooted native vegetation (e.g. coontail, common waterweed, southern naiad, uprooted water celery). The mechanical harvesting operations are directed to avoid floating-leaf species when possible (i.e. water lilies). The *APM Committee* supports the reasonable and environmentally sound actions to facilitate navigability on the Green Lake system. These actions target nuisance levels of aquatic plants in order to benefit watercraft navigation patterns. Reasonable and environmentally sound actions are those that meet WDNR regulatory and permitting requirements and do not impact anymore shoreland or lake surface area than absolutely necessary. The WDNR oversees the management of aquatic plants on inland lakes. The manual cutting and raking of native aquatic plant species within a 30-foot-wide area containing a pier, boatlift, or swim raft is exempt from a state permit provided that the cut plants are removed from the lake. However, the use of mechanized or mechanical devices in all instances requires a WDNR permit. The GLSD currently performs mechanical harvesting operations starting at the pier-head (end of riparian docks) extending 30-ft around Green Lake proper, with 50-ft wide lanes in Silver Creek, City Millpond, and Beyers Cove (Map 12). This entire footprint spans approximately 135 acres, but the GLSD estimates only 10-15% of the area contains nuisance levels of aquatic plants requiring mechanical harvesting. The GLSD averages about 350 dump truck loads of harvested material each year, which are disposed of either at the Green Lake Wastewater Plant (Lake Steel Street) or at a private property on County Road TT. In 2023, riparian property owners and GLA members were asked a number of questions about perspective on current management techniques. Fifty percent (50%) of stakeholder respondents indicated they were satisfied (pooled *very satisfied* and *satisfied* responses) of the ongoing mechanical harvesting program, whereas 20% were unsupportive (pooled *very satisfied* and *satisfied* responses) (Figure 5.0-2, left frame). Thirty percent (30%) of respondents indicated a *neutral* level of satisfaction for the ongoing mechanical harvesting program. The GLSD is currently operating the mechanical harvesting program at their financial capacity. Stakeholders were asked if they would support or oppose

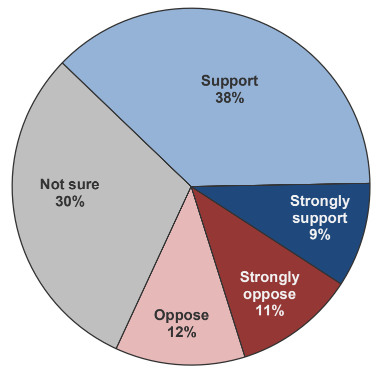
increasing funding levels to support an expanded mechanical harvesting effort (Figure 5.0-2, right frame). Forty-seven percent (47%) of stakeholder respondents indicated they were satisfied (pooled *very supportive* and *supportive* responses) of increasing the tax levy, whereas 23% were unsupportive (pooled *strongly oppose* and *oppose* responses) (Figure 5.0-1, left frame). Thirty percent (30%) of respondents indicated a *not sure* response, perhaps indicating more information would be needed to sway their opinion.

Q35: How satisfied are you with the past mechanical harvesting program?



Satisfied	50%
Unsatisfied	20%
Neutral	30%

Q36:Would you support or oppose increasing the tax levy in order to accomplish mechanical harvesting goals for Green Lake?



Support	47%
Oppose	23%
Not Sure	30%

Figure 5.0-2. Mechanical harvesting-related stakeholder survey responses. Additional questions and response charts may be found in Appendix B.

As outlined on Map 12, the GLSD conducts mechanical harvesting in the Silver Creek Estuary. This part of the system offers extra challenges for these operations. The mechanical harvesting equipment cannot fit under the Highway A bridge, so the equipment needs to be trailered, decontaminated, and transported to a private launch that has an agreement with the GLSD. Areas of Silver Creek are becoming shallower with sedimentation and not suitable for the harvester to operate in those areas. Duckweed is a major nuisance to navigation, recreation, and aesthetics in the Silver Creek. While duckweed is targeted by the mechanical harvesting operations, the equipment is not efficient at picking up these species. The 50-ft wide lane in the main channel aims to remove coontail and other vegetation so duckweed species can flush out into the main lake and not become an incubator for these species. This action dovetails with water quality goals aiming to minimize duckweed and the nutrient impacts it brings to Green Lake proper.

The *APM Committee* reviewed its historic mechanical harvesting strategy as a part of this project and agrees that the areas outlined on Map 12 are meeting the needs of stakeholders. The GLSD also aims to use the mechanical harvester to allow the pickup of *floaters*. The GLSD would operate the mechanical harvester in its shallowest setting to pick up these floating plant fragments outside of areas permitted on Map 12 so long as they are in waters greater than 3 feet of water and lakeward from the pier-head. These largely non-rooted masses of aquatic plants change in species composition throughout the year. For example, floating mats of uprooted wild celery can be especially impactful in late-August and September. As summer ends and seasonal employment ceases, the GLSD's mechanical harvesting effort becomes reduced.

The GLSD seeks multi-year mechanical harvesting permits, which are available to applicants that have APM Plans that have been updated in the last 5 years. The bulleted list below outlines some of the conditions the GLSD intends to follow as likely outlined on the WDNR permit.

- No harvesting shall occur before June 1 to avoid impacting valuable fish spawning habitat. If mechanical harvesting is desired earlier than June 1, approval from the WDNR fisheries biologist would be required.
- Harvesting operations shall not disturb spawning or nesting fish. Harvesting shall be done in a manner to minimize accidental capture of fish. Any game fish accidentally captured shall be released immediately. Attempts should be made to release all other fish and aquatic species.
- Harvesting locations are limited to areas on the permit map
- Submerged plants are the target for this permit and removal of floating-leaf (e.g. water lilies) species needs to be minimized because of their ecological value and niche occupation.
- Aquatic plants that are cut must be removed from the water.
- "Floaters" consisting of dislodged or free-floating plants may be targeted outside of areas on harvest map so long they are outside of the pier head, and the harvester is set to its shallowest cutting setting.
- The current harvester would avoid shallow water harvesting to minimize sediment disturbance.
- Reports summarizing harvesting activities shall be given to the WDNR by November 30, each harvesting season.

<table>
<tr><td><u>Management Action:</u></td><td>Increase recreational use through herbicide treatment lanes</td></tr>
<tr><td>Timeframe:</td><td>Continuation of Current Effort</td></tr>
<tr><td>Facilitator:</td><td>GLSD</td></tr>
<tr><td>Description:</td><td>In addition to the mechanical harvesting activities outlined in the previous management action, the GLSD has implemented herbicide treatment since approximate 2020 by a contracted applicator to restore watercraft navigation patterns in Beyers Cove. These treatments are directed early in the season when curly-leaf pondweed (CLP) populations are at near peak growth. Herbicide treatment at this time of year allows reductions in CLP and EWM, allowing delaying of the need for mechanical harvesting until later in the growing season as part of an integrated pest management approach. The herbicide applications have used non-selective herbicides, namely June applications of diquat, flumioxazin, and copper. Figure 5.0-3 outlines the 2024 herbicide treatment strategy.

Figure 5.0-3. 2024 Beyers Cove Herbicide Treatment.

Decaying aquatic plants following an herbicide treatment can result in localized reductions in dissolved oxygen, especially in warmer waters. Large reductions in dissolved oxygen can cause sudden fish kills and cause harm to other important aquatic life. The early-season application timing is favored by the APM Committee, as cold water can hold larger amounts of oxygen that warm water which buffers the concerns of dissolved oxygen crashes following herbicide treatments. Onterra cautions that in highly enclosed situations such as confined channels, dissolved oxygen reductions following herbicide treatment are more likely regardless of water temperature. Therefore careful herbicide treatment</td></tr>
</table>

	planning is needed to ensure adequate oxygen levels exist if such management actions are taken. The *APM Committee* would also consider nuisance herbicide treatments using contact herbicides in select marinas or high-use areas when similar nuisance navigation concerns, especially those cause by CLP and EWM occur that mechanical harvesting operations are not able to restore use in a time- or cost-efficient manner. At this time, the *APM Committee* is not supportive of using herbicides to manage native aquatic plants, but would consider individual issues on a case-by-case basis. The GLSD is currently funding the herbicide management of Beyers Cove, as this nuisance relief action reduces the magnitude of mechanical operations required throughout the summer. The GLSD will continue to review this approach, with preference of diverting responsibility to the local community group. If additional areas are sought for herbicide management, such as the channels in City Millpond, the GLSD envisions the responsibility of permit applications, applicator selection, and funding be placed on the local community group with technical support and guidance coming from the *APM Committee* if the action is consistent with this APM Plan.

Management Action:	Facilitate riparian actions to minimize nuisance aquatic plants through manual removal methods
Timeframe:	Continuation of Current Effort
Facilitator:	GLSD
Description:	Each riparian owner can legally remove aquatic vegetation in a 30-foot wide area of one's frontage directly adjacent to one's pier without a permit. This access lane can extend perpendicular out into the lake as far as desired. A permit is only required if an area wider than the 30-foot corridor is being harvested or if a mechanical assistance mechanism, like a mechanical cutter or diver-assisted suction harvesting equipment is being used. Simply wading into the lake and removing aquatic plants with a non-mechanical device (e.g. rake or v-cutter) within this footprint is legal so long as all the dislodged or cut aquatic plants are removed from the lake. Riparians can hire contractors to remove plants in this manner without a permit so long as they stay in the designated 30-ft wide corridor and use non-mechanical removal methods. If aquatic plant impediments do not fit the criteria exempt from WDNR permitting, the impacted property owner or community group may seek a contractor to remove plants with a diver-assisted suction harvest equipment or other similar permittable equipment. These efforts will require a WDNR permit under NR109, which will require a specific map of where the operations will be occurring, the aquatic plant species to be harvested, and the disposal plan for removed vegetation. The WDNR would prefer that groups of riparians in a given area coordinate together and submit a consolidated permit for this effort. The

	APM Committee requests the requesting riparian, business/marina owner, and/or the contracted hand-harvesting firm provide information on the harvesting activity (i.e. location, quantity of plants removed) following implementation. The GLSD encourages manual removals trials be conducted to see if nuisance abatement goals are met before pursuing alternative vegetation removal options, such as those discussed in the next management action. The GLSD periodically conducts "weed pickup," where piles of aquatic vegetation raked by property owners are placed along their roadway frontage (<u>not</u> along lake frontage). The GLSD will not collect the aquatic plant material if it is mixed with any upland yard waste. Coordination with the GLSD is needed to ensure pickup during the next opportunity. The GLSD will continue to assess their ability to offer this program, especially on a no-cost basis.

<u>Management Action:</u>	Investigate and study alternative vegetation removal options for specific issues
Timeframe:	Initiate in 2024
Facilitator:	Benefiting community group with *APM Committee* involvement as applicable
Description:	As discussed in the two subsequent management actions, the *APM Committee* is investigating the role of sedimentation and duckweed in the system. However, these issues are causing immediate impacts to navigation, recreation, access, and aesthetics. The *APM Committee* acknowledges that there is an unknown fine line between their function of facilitating usability of the entirety of the Green Lake system and manicuring individual riparian footprints. The GLSD has been committed to facilitating watercraft navigability within the boundaries of the current mechanical harvesting plan and select permitted AIS-focused herbicide treatment, but these actions may be insufficient to solve localized impediments such as duckweed in Silver Creek Estuary and water lilies/nearshore plants in City Millpond. The *APM Committee* continues to investigate duckweed management and capture techniques, largely aimed at reducing nutrient inputs to Green Lake. A select review of local techniques used are included within Duckweed Population subsection of 3.2.2. It is likely that even if practical solutions are found to meet these goals, they may not completely address navigation issues in specific areas of Silver Creek. Emerging technologies such as specific mechanical harvesting equipment may be able to better target these issues. Newer equipment may allow for operation in shallower water without sediment disturbance and more precisely target the individual issue with specified tools. The *APM Committee* will continue to explore new techniques and technologies. If technologies are identified to manage these concerns, extensive conversations with the WDNR would occur to understand likelihood and operation boundaries of permitting. These

	technologies are likely to be expensive and require a workforce to operate. Therefore, the *APM Committee* will also need to explore funding sources and associated operation logistics. The *APM Committee* would work with local community groups to establish these technologies and determine which entity (i.e. the GLSD, contractor, or local community group) would be most suited to carrying out the operational aspects of implementation.

Management Action:	Understand causes, impacts, and ways to address overall duckweed issues
Timeframe:	Ongoing
Facilitator:	*APM Committee*
Description:	As discussed within the Silver Creek Section (3.2.6), duckweed populations negatively impact navigation, recreation, and aesthetics in this part of the system. In addition, it is unknown what the nutrient loading potential into Green Lake proper is from the duckweed produced in Silver Creek and upstream waters. The *APM Committee* and the greater Lake Management Planning Team have spent an enormous amount of effort studying the root cause of duckweed, the quantity of duckweed, and the nutrient impacts it has on Green Lake. Starting in 2024, the US Geological Survey (USGS) began a pilot project to document the quantity of duckweed entering Green Lake under the County Highway A bridge. This project will use video images and other measurements to quantify duckweed, and couple that with nutrient analysis from physical samples to extrapolate loading amounts. The *APM Committee* continues to be interested in understanding the root cause of the duckweed issue, which appears to have surfaced approximately 20 years ago. As outlined in the duckweed-specific subsection (3.2-9), duckweed limitation is often associated with nitrogen compared to most aquatic plants being limited by phosphorus. The *APM Committee* is in the process of studying nutrient levels entering from the watershed and groundwater. Within the *duckweed subsection* of Section 3.2.2, duckweed management options are discussed. It is important to note that at this time, there is no management technique that stands out as having great potential for the situation on Green Lake. The *APM Committee* would like to conduct a more expansive literature source of management techniques being undertaken by other entities around the world. Most of these activities are conducted on a local scale, and are not part of the established peer-reviewed literature database. So learning about these methods poses a great challenge.

Management Action:	Investigate and study sediment management techniques
Timeframe:	Initiate in 2024
Facilitator:	Benefiting community group with *APM Committee* involvement as applicable
Description:	The *APM Committee* acknowledges that increased sediment buildup is causing navigation and access impediments in select parts of the system. Challenges with low water levels in recent years are thought to have exacerbated these concerns. Respondents to the riparian stakeholder survey indicated sedimentation rates have been greatly accelerated in recent years. Sediment accumulation and muck buildup occur as a natural part of lake-aging on every system, primarily from the decay of algae, plants, and animals. Sedimentation rates increase with human presence and use. Sedimentation rates are increased when watersheds are developed such that runoff delivers sediment and nutrients to the lake. Increased nutrients from nearshore properties can also fuel aquatic plants and algae, which decompose and contribute to sedimentation. Much of the Green Lake benefits from having a sanitary system to stifle a portion of these nutrients, but specific areas still lack a sanitary system. Sedimentation is also accelerated on waterbodies where water levels are stabilized or held at unnatural levels by water control structures. The best way to understand sediment composition and sedimentation rates is conducting a *full sediment core* analysis. A full-core analysis refers to an approximate 5-foot deep sediment core that is divided into 1-2 cm sections for geochemical analysis, carbon dating, and paleoecological analysis. Nutrient concentrations, sedimentation rates, and inferred aquatic plant abundance, could be explored on roughly a decade-by-decade scale from the core. This would help quantify the amount of sediment that was deposited over a period of time, supporting or refuting claims regarding the magnitude of sedimentation. The collection, sectioning, and analysis of a full core may cost $15,000, so exploratory actions may be justified to help determine if a full-core analysis is warranted. Onterra believes two legitimate methods exist for reducing sediments in lakes: dredging and drawdown. At this time Onterra is not aware of any scientific studies that show muck pellets or aeration equipment that would result in increased lake depth for specific areas of Green Lake. *Drawdowns* would need to completely expose sediments for a significant amount of time so chemical oxidation processes can occur. The Green Lake system is unable to be lowered to a sufficient level for this to be a viable option. *Dredging* is the physical removal of the sediment from the lake through mechanical means, most likely for Green Lake by suction dredging. The sediments must then be properly disposed of on land. One example prepared by Onterra during this planning project that would yield an increase of 2-feet over 50 acres would cost $3.8 to $4.6 million dollars, depending on the fate of the removed material (geotubes or sediment basin). While the *APM Committee* is not

	considering dredging at this time, it acknowledges that further investigations into this action will be sought by local community groups. Dredging may be applicable for smaller footprints in the Green Lake system, such as man-made basins or channels where sediment accumulation is hindering navigation and access. Although an exhaustive study of dredging a portion of the Silver Creek Estuary has not occurred, Onterra questions the longevity of benefit from targeting this site due to the natural hydraulic processes in this delta area. The *APM Committee* plans to explore the role of sedimentation in select areas of the Green Lake system. The *APM Committee* or partnering community group would likely need to work with a natural resources engineering firm to design an applicable research project and potentially follow-up dredging feasibility project.

Management Goal 6: Promote Lake Stewardship and Conservation Ethics

Management Action:	Periodically monitor the shoreland conditions and use that data to drive shoreland restoration priorities and initiatives
Timeframe:	Ongoing with periodic updates
Facilitator:	*APM Committee*.
Description:	The entire shoreline of the Green Lake system was surveyed by Golden Sands Resource Conservation & Development Council, Inc.in the summer of 2017 following the WDNR Lake Shoreland & Shallows Habitat Monitoring Field Protocol. A change in Wisconsin shoreline zoning regulation in 2015 resulted in a boom in boat houses building along the shoreline increasing impervious surface in a zone critical to the lake's health. The *APM Committee* was interested in documenting the effect of the change in the zoning statute on Green Lake, initiating a replicate survey by Onterra in 2023, which are used as the foundation of the Shoreland Condition component of this APM Plan. The *APM Committee* also sponsored a supplemental survey of the Green Lake system's shoreline in 2023 to determine the extent and type of seawalls on the lake and nearshore structures commonly referend to as *boathouses.* These data are critical in identifying the overall condition of Green Lake, as well as priority areas for restoration and preservation. In an effort to increase the flow of information between lake stakeholders and project planners, this project piloted an interactive web map application for the system, allowing users to see the *Shoreland and Shallows Survey* and the supplemental *Human-modified Shoreland Practices Assessment* and *Buffer Zone Boathouses & Structures Assessment* as it relates to their property or favorite recreation areas. Access to this interactive map is provided below: https://onterra.maps.arcgis.com/apps/webappviewer/index.html?id=5ce030a7a3de436d917c66f38c600563

	The *APM Committee* would like to periodically revisit these surveys to understand changes in the nearshore condition over time. The *APM Committee* would consider a replication of the *Shoreland & Shallows Survey* in roughly 10 years (i.e. 2033). Changes in the supplemental *Human-modified Shoreland Practices Assessment* and *Buffer Zone Boathouses & Structures Assessment* may be accommodated on a roughly 5-year basis.

Management Action:	Educate stakeholders on the importance of shoreland condition and shoreland restoration and protection
Timeframe:	Ongoing
Facilitator:	*APM Committee*
Description:	The intrinsic value of natural shorelands is found in numerous forms. Vegetated shorelands prevent polluted runoff from entering lakes by filtering this water or allowing it to slow to the point where particulates settle. Nutrient management can be an important component of aquatic plant management, as issues caused by plants can be exacerbated in high nutrient situations. The roots of shoreland plants stabilize the soil, thereby preventing shoreland erosion. Shorelands also provide habitat for both aquatic and terrestrial animal species. Many species rely on natural shorelands for all or part of their life cycle as a source of food, cover from predators, and as a place to raise their young. Shorelands and the nearby shallow waters serve as spawning grounds for fish and nesting sites for birds. Thus, both the removal of vegetation and the inclusion of development reduces many forms of habitat for wildlife. The GLA and GLSD have been active in watershed management initiatives, including the nearshore shoreland watershed. The *APM Committee* will continue to provide education and technical advisement on the importance of shoreland condition and the resources that are available (planning and funding). *Example Topics/Activities:* • Importance of natural landscapes • Convey best management practices on lawn fertilizer use, providing perspective on collective magnitude of impact • Encourage existing regulations and zoning ordinances for shoreland development including impervious surfaces, construction activity, human-modified shoreland practices (i.e. rip-rap and retaining walls) pier sizes, and swim platform placement • Identification of shoreland restoration contractors, potentially with a certification credential process • Encouraging participation in WDNR Healthy Lakes & Rivers Grant program, and/or implementing shoreland restoration and protection measures consistent with this program.

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