Green Lake
Aquatic Plant Community Assessment

Green Lake County, Wisconsin

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TABLE OF CONTENTS

FIGURES

TABLES

PHOTOS

MAPS

1.0 INTRODUCTION

Photo 1. Green Lake, Green Lake County, Wisconsin.

Green Lake, Green Lake County is approximate 7,456 acre drainage lake with a maximum depth of 236 feet and a mean depth of 104 feet (Photo 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 basins: three inlet basins called Silver Creek Estuary (215 acres), Beyers Cove (28 acres), and County Marsh (269 acres), and one outlet basin called City Millpond (48 acres). 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).

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 basins. Additionally, this project also included a comprehensive assessment of Green Lake's aquatic plant community in 2014. This report discusses the assessment of the aquatic plant communities in Green Lake and the previously mentioned adjoining basins; information pertaining to AIS monitoring and control within the Silver Creek Estuary, Beyers Cove, and City Millpond can be found within the respective years' annual AIS Monitoring and Control Strategy Assessment Report.

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 declining in Green Lake, they created the Green Lake Sanitary District (GLSD). Green Lake and its watershed have undergone a number of studies in an effort to improve the lake's water quality and ecosystem integrity. Most recently, a comprehensive lake management plan was completed for Green Lake in 2013 (Sesing 2013) that covered many aspects of the lake. 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.

Maintaining or improving the integrity of the native aquatic plant community includes reducing the populations of non-native species (EWM and CLP). Herbicide treatments aimed at reducing these exotic species were completed in Beyers Cove and City Millpond in 2014, and the results of these treatments are discussed in detail in the 2014 AIS Monitoring and Control Strategy

Assessment Report. In addition, to understand trends in Green Lake's aquatic plant community over time, the lake management plan calls for a comprehensive point-intercept survey to be completed at a minimum frequency of once every five years. The aquatic plant community assessment conducted by Onterra ecologists on Green Lake not only provides a snapshot of the condition of the community in 2014, but by comparing it to data collected in the past allows for an assessment of how the community has changed through time.

2.0 RESULTS & DISCUSSION

2.1 Primer on Data Analysis & Data 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 (Photo 2). 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 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.

Photo 2. Native aquatic plants are an important component in maintaining a healthy aquatic ecosystem.

The point-intercept method as described Wisconsin Department of Natural Resources Bureau of Science Services, PUB-SS-1068 2010 (Hauxwell et al. 2010) was conducted in Green Lake by Onterra in July 2014. Based upon guidance from the WDNR, a point spacing (resolution) of 100 meters was used resulting in 3,120 sampling points being evenly distributed across the lake (Map 1). 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 (Figure 1) 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 14 feet or less. A rake head tied to a rope (rope rake) was used at sites greater than 14 feet. Depth information was collected using graduated marks on the pole of the rake (ad depths < 14 ft) or using an onboard sonar unit (at depths greater than 14 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. 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.

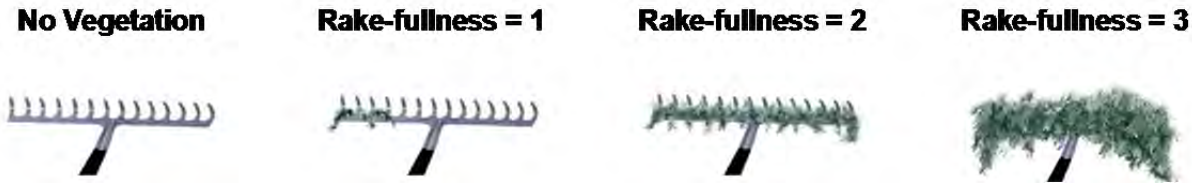

Figure 1. Aquatic plant rake-fullness ratings. Adapted from Hauxwell et al (2010).

Species List

The species list is simply a list of all of the species, both native and non-native, that were located during the 2014 surveys on Green Lake. The list also contains the growth-form of each plant found (e.g. submergent, emergent, etc.), its scientific name, common name, and its coefficient of conservatism. The latter is discussed in more detail below. Changes in this list over time, whether it is differences in total species present, gains and losses of individual species, or changes in growth forms that are present, can be an early indicator of changes in the ecosystem.

Frequency of Occurrence

The **Littoral Zone** is the area of the lake where sunlight is able to penetrate to the sediment providing aquatic plants with sufficient light to carry out photosynthesis.

Frequency of occurrence describes how often a certain species is found within a lake. Obviously, all of the plants cannot be counted in a lake, so samples are collected from pre-determined areas. In the case of the whole-lake point-intercept survey conducted on Green Lake in 2014, plant samples were collected from plots laid out on a grid that covered the lake (Map 1). Using the data collected from these plots, an estimate of occurrence of each plant species can be determined. In this section, the occurrences of aquatic plant species are displayed as their *littoral frequency of occurrence*. Littoral frequency of occurrence is used to describe how often each species occurred in the plots that are equal to or less than the maximum depth of plant growth (littoral zone), and is displayed as a percentage.

Floristic Quality Assessment

The floristic quality of a lake is calculated using its native aquatic plant species richness and those species' average conservatism values. Species richness is simply the number of aquatic plant species that occur in the lake, and for this analysis, only native species are utilized. Average species conservatism utilizes the coefficient of conservatism values (C-value) for each of those species in its calculation. A species coefficient of conservatism value indicates that species' likelihood of being found in an undisturbed system. The values range from 1 to 10. Species that can tolerate environmental disturbance and can be located in disturbed systems have lower coefficients, while species that are less tolerant to environmental disturbance and are restricted to high quality systems have higher values. For example, coontail (*Ceratophyllum demersum*), a submergent native aquatic plant species with a C-value of 3, has a higher tolerance to disturbed conditions and is often found thriving in lakes with higher nutrient levels and low water clarity. Other species, like algal-leaf pondweed (*Potamogeton confervoides*) with a C-value of 10, are intolerant of environmental disturbance and require minimally disturbed, high quality environments to survive.

On their own, the species richness and average conservatism values for a lake are useful in assessing a lake's plant community; however, the best assessment of the lake's plant community health is determined when the two values are used to calculate the lake's floristic quality. The floristic quality is calculated using the species richness and average conservatism value of the aquatic plant species that were solely encountered on the rake during the point-intercept survey. Green Lake falls within the Southeastern Wisconsin Till Plains *ecoregion* (Figure 2), 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.

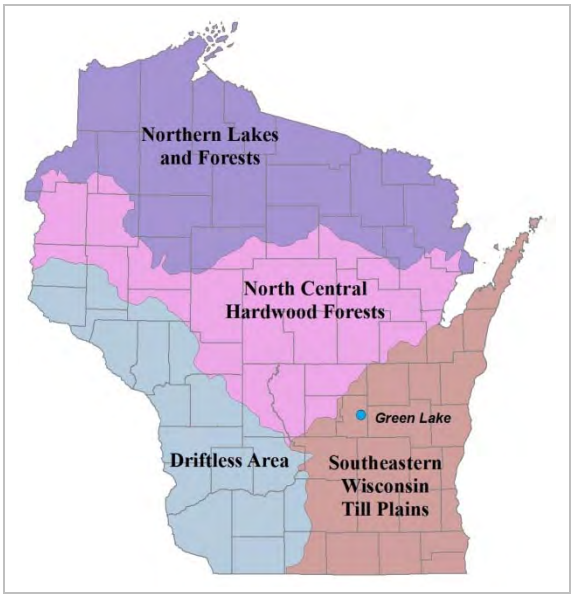

Figure 2. Location of Green Lake within the ecoregions of Wisconsin. After Nichols (1999).

Species Diversity

Species diversity is probably the most misused term in ecology because it is often confused with species richness. As defined previously, species richness is simply the number of species found within a system or community. Although these values are related, they are far from the same because species diversity also takes into account how evenly the species are distributed within the system. For example, Lake A with 25 species may be no more diverse than Lake B with 10 species if the community of Lake A is highly dominated by one or two species and the community of Lake B has a more even distribution of species abundance.

An aquatic system with high species diversity is much 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. For example, a lake with a diverse plant community is much better suited to compete against exotic infestation than a lake with a lower diversity. Simpson's diversity index is used to determine this diversity in a lake ecosystem.

Simpson's diversity (1-D) is calculated as:

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

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

If a lake has a diversity index value of 0.90, it means that if two plants were randomly sampled from the lake there is a 90% probability that the two individuals would be of a different species. Between 2005 and 2014, WDNR Science Services and Onterra conducted point-intercept surveys on 392 lakes within the state. The Simpson's Diversity Index values of the lakes within this dataset will be compared to Green Lake.

Community Mapping

A key component of the aquatic plant survey is the creation of an emergent and floating-leaf aquatic plant community map. The map represents a snapshot of these important plant communities in the lake as they existed during the survey and is valuable in the development of planning efforts and in comparisons with surveys completed in the future. Examples of emergents include cattails, bulrushes, and arrowheads, while floating-leaf species include water lilies and some species of bur-reeds. Emergents and floating-leaf communities lend themselves well to mapping because there are often distinct boundaries between communities.

2.2 2014 Green Lake Aquatic Plant Survey Results

On July 15 and 16, 2014, multiple crews from Onterra conducted the whole-lake point-intercept and community mapping surveys on Green Lake proper. During these surveys, a total of 34 aquatic plant species were located, of which four are considered to be non-native, invasive species: hybrid water milfoil, curly-leaf pondweed, purple loosestrife, and reed canary grass (Table 1). In 2010, specimens of EWM from Green Lake underwent DNA analysis and were confirmed as a hybrid between EWM and the indigenous northern water milfoil (*M. sibiricum*). In 2013, Onterra ecologists collected additional milfoil specimens and sent them to the Annis Water Resources Institute at Grand Valley State University in Michigan to undergo DNA analysis, and their results too confirmed the specimens were hybrid water milfoil (HWM). As is discussed later in the report, HWM presents some complications for management as ongoing research is indicating that some strains have a higher tolerance to aquatic herbicides. Hybrid water milfoil and the other non-native aquatic plants species are discussed in more detail within the Non-Native Aquatic Plant Section.

Aquatic plants located during 1921, 1971, and 2007 studies on Green Lake proper are also listed in Table 1. The majority of the species located in 2007 by the WDNR were relocated during the 2014 surveys; however, some species, like large-leaf pondweed, were not relocated during the 2014 surveys while others, like Fries' pondweed, were located in 2014 but not in 2007. Changes in species composition since the 1921 survey will be discussed later in this section, along with a statistical comparison of the abundance of the aquatic plant species from the 2007 and 2014.

During the 2014 whole-lake point-intercept survey, information regarding substrate type was collected at locations sampled with a pole-mounted rake (less than 14 feet). These data indicate that 71% of the point-intercept locations less than 14 feet deep contained sand, 21% contained soft sediments (muck), and 8% contained rock (Figure 3). Areas containing soft sediments were usually located in deeper water of the bays, while most of the sampling locations containing rock were located near shore (Figure 3). Like terrestrial plants, different aquatic plant species are adapted to grow in certain substrate types; some species are only found growing in soft substrates, others only in sandy areas, and some can be found growing in either. Lakes that have varying substrate types generally support a higher number of plant species because of the different habitat types that are available.

During the 2014 point-intercept survey, aquatic plants were found growing to a maximum depth of 23 feet, two feet deeper than the maximum depth recorded by the WDNR in 2007. Figure 4 and Map 2 illustrates the distribution of aquatic vegetation in Green Lake, and shows that the majority of littoral areas around the lake support aquatic plant growth. Of the 854 point-intercept sampling locations that fell at or below 23 feet in 2014, 79% contained aquatic vegetation, indicating the majority of Green Lake's littoral zone is vegetated. This finding was similar to what was found in 2007, with 80% of the 801 point-intercept sampling locations that fell at or below 21 feet containing aquatic plants. Figure 5 illustrates that the occurrence of aquatic vegetation increases with water depth from 1-14 feet, but the occurrence of vegetation quickly declines at depths greater than 14 feet, likely due to reductions in light availability.

Table 1. Aquatic plant species located in Green Lake during WDNR 2007 and Onterra 2014 surveys.

Growth Form	Scientific Name	Common Name	Coefficient of Conservatsim (C)	1921 (Rickett)	1971 (Bumby)	2007 (WDNR)	2014 (Onterra)
Emergent	*Carex comosa*	Bristly sedge	5				I
	Carex sp.	Sedge sp.	N/A	X			
	Eleocharis obtusa	Blunt spike-rush	3				
	Lythrum salicaria	Purple loosestrife	Introduced - Invasive				I
	Phalaris arundinacea	Reed canary grass	Introduced - Invasive				I
	Sagittaria rigida	Stiff arrowhead	8	X			
	Schoenoplectus acutus	Hardstem bulrush	5			X	X
	Schoenoplectus pungens	Three-square rush	5				
	Schoenoplectus sp.	Bulrush sp.	N/A	X			
	Schoenoplectus tabernaemontani	Softstem bulrush	4				I
	Sparganium eurycarpum	Common bur-reed	5				I
	Typha sp.	Cattail sp.	1	X			I
	Zizania sp.	Wild rice sp.	8	X			
FL	*Nymphaea odorata*	White water lily	6	X			X
Submergent	*Bidens beckii*	Water marigold	8	X			
	Ceratophyllum demersum	Coontail	3	X	X	X	X
	Chara spp.	Muskgrasses	7	X	X	X	X
	Drepanocladus sp.	Aquatic moss sp.	N/A	X	X		X
	Elodea canadensis	Common waterweed	3	X	X	X	X
	Heteranthera dubia	Water stargrass	6	X	X	X	X
	Myriophyllum sibiricum	Northern water milfoil	7			X	X
	Myriophyllum sibiricum X spicatum	Hybrid water milfoil	Introduced - Invasive		X	X	X
	Myriophyllum verticillatum	Whorled water milfoil	8	X			
	Najas flexilis	Slender naiad	6	X	X	X	X
	Najas marina	Spiny naiad	Introduced - Naturalized			X	
	Nitella spp.	Stoneworts	7			X	X
	Potamogeton amplifolius	Large-leaf pondweed	7	X	X	X	
	Potamogeton berchtoldii	Slender pondweed	7				X
	Potamogeton crispus	Curly-leaf pondweed	Introduced - Invasive		X	X	X
	Potamogeton foliosus	Leafy pondweed	6	X	X	X	X
	Potamogeton friesii	Fries' pondweed	8		X		X
	Potamogeton gramineus	Variable pondweed	7	X		X	
	Potamogeton illinoensis	Illinois pondweed	6			X	X
	Potamogeton natans	Floating-leaf pondweed	5	X	X		
	Potamogeton nodosus	Long-leaf pondweed	7			X	X
	Potamogeton praelongus	White-stem pondweed	8			X	X
	Potamogeton pusillus	Small pondweed	7				X
	Potamogeton richardsonii	Clasping-leaf pondweed	5		X	X	X
	Potamogeton sp.	Pondweed sp.	N/A			X	
	Potamogeton strictifolius	Stiff pondweed	8				X
	Potamogeton zosteriformis	Flat-stem pondweed	6	X		X	X
	Ranunculus aquatilis	White water-crowfoot	8	X	X	X	X
	Ruppia cirrhosa	Spiral ditch-grass	8			X	X
	Stuckenia pectinata	Sago pondweed	3	X	X	X	X
	Vallisneria americana	Wild celery	6	X	X	X	X
	Zanichellia palustris	Horned pondweed	8		X		X
S/E	*Armoracia lacustris*	Lake cress	9	X			
	Eleocharis acicularis	Needle spikerush	5				X
FF	*Lemna trisulca*	Forked duckweed	6		X		
	Spirodela polyrhiza	Greater duckweed	5				
	Wolffia columbiana	Common water-meal	5				

FL = Floating-leaf; S/E = Submergent & Emergent; FF = Free-floating
X = Located on rake during 2007/2014 point-intercept survey or recorded during 1921/1971 biomass surveys
I = Incidentally located

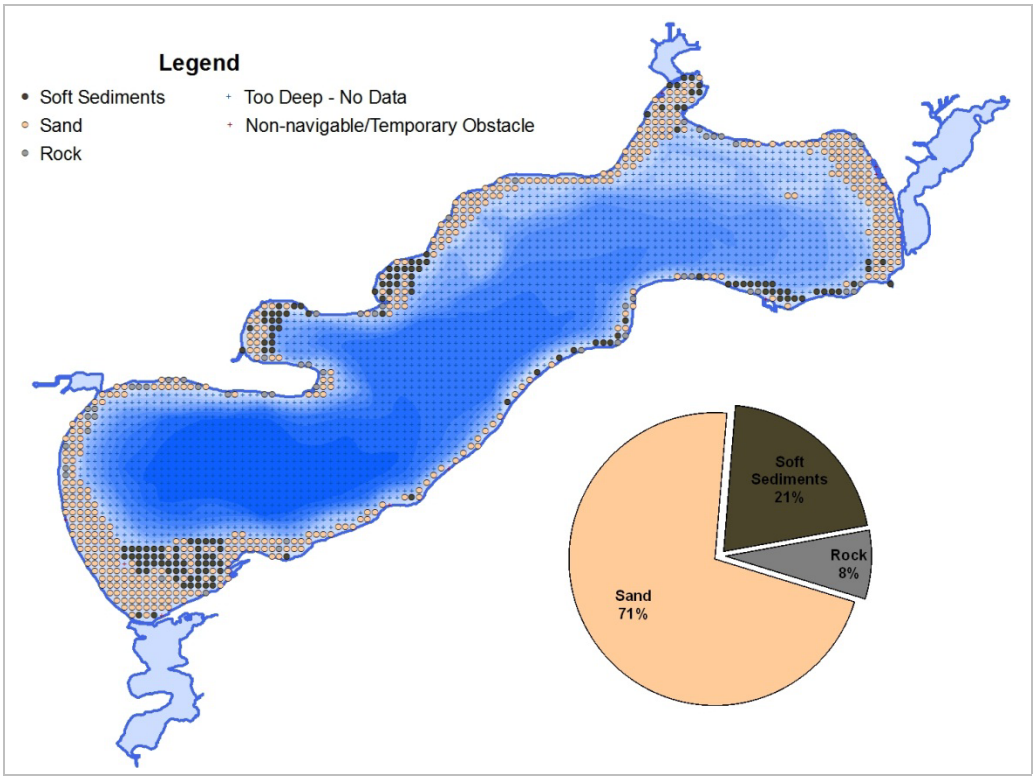

Figure 3. Green Lake 2014 sediment distribution. Please note that sediment type could only be recorded at sampling locations in ≤ 14 feet of water. Created using data from Onterra 2014 point-intercept survey.

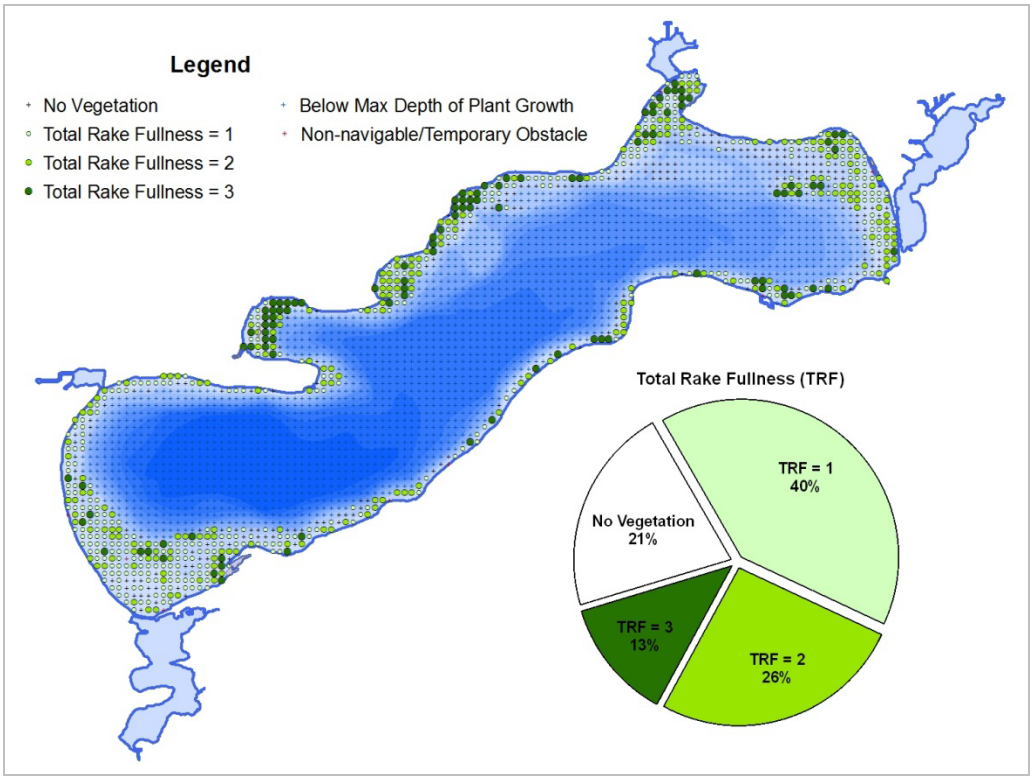

Figure 4. Green Lake 2014 aquatic vegetation distribution. Created using data from Onterra 2014 point-intercept survey.

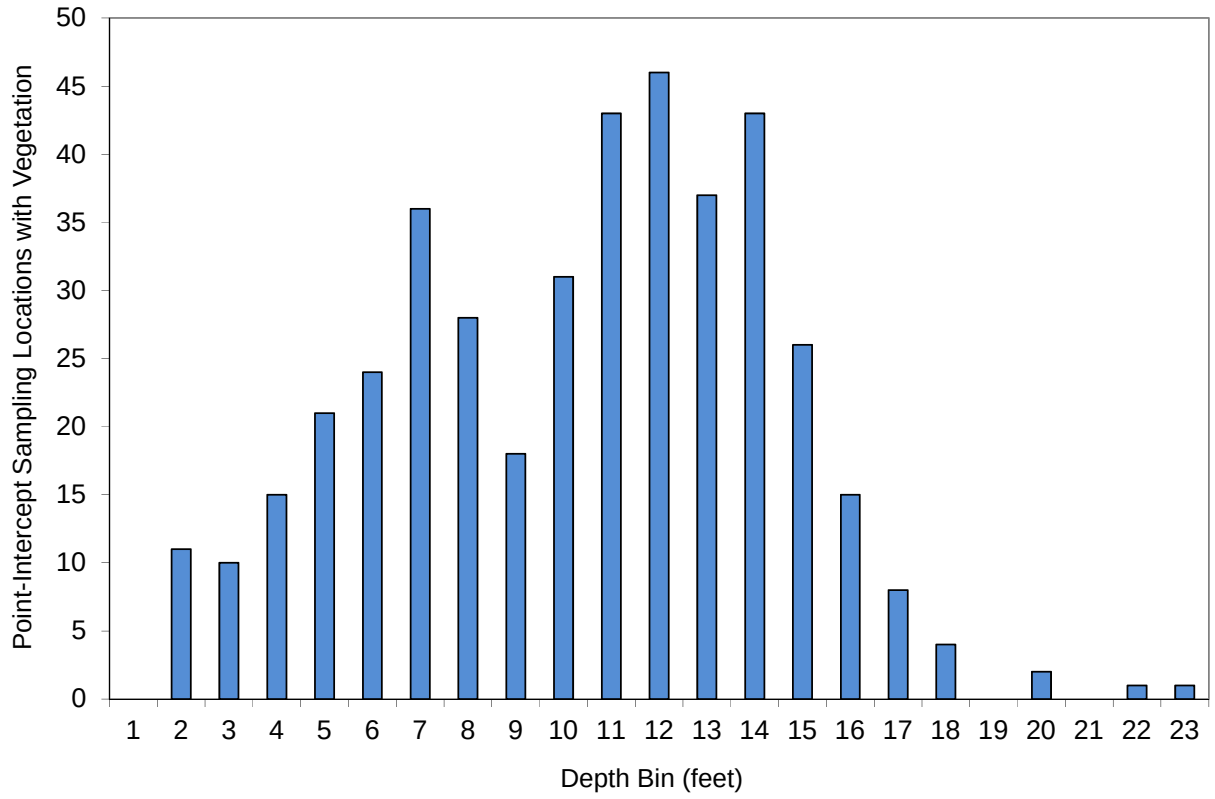

Figure 5. Number of point-intercept sampling locations containing aquatic vegetation across varying depths of Green Lake's littoral zone in 2014. Created using data from Onterra 2014 point-intercept survey.

Of the 34 aquatic plant species located during the 2014 surveys on Green Lake, 28 were physically encountered on the rake during the whole-lake point-intercept survey. The remaining 8 species were located incidentally. Of the 28 species encountered on the rake, coontail and hybrid water milfoil were the most frequently encountered species with littoral frequencies of occurrence of 53% and 45%, respectively (Figure 6). Coontail is arguably the most common aquatic plant species in Wisconsin, and it possesses bushy whorls of stiff leaves that resemble the shape of a raccoon's tail. Lacking roots, this species obtains the majority of its nutrients directly from the water and can grow prolifically in nutrient-rich water, often attaining nuisance levels and forming dense mats at the surface.

Also able to tolerate low-light conditions, coontail is usually one of the most dominant species found in eutrophic lakes. The dense foliage of coontail provides excellent habitat for aquatic invertebrates and fish, especially in deeper water where other native aquatic plants cannot grow. While coontail has the capacity to grow to nuisance levels, no surface-matted areas of coontail were observed on Green Lake proper during the 2014 surveys. The 2014 point-intercept data indicate that coontail was most abundant between 8 and 15 feet of water, but was located as deep as 23 feet (Map 3).

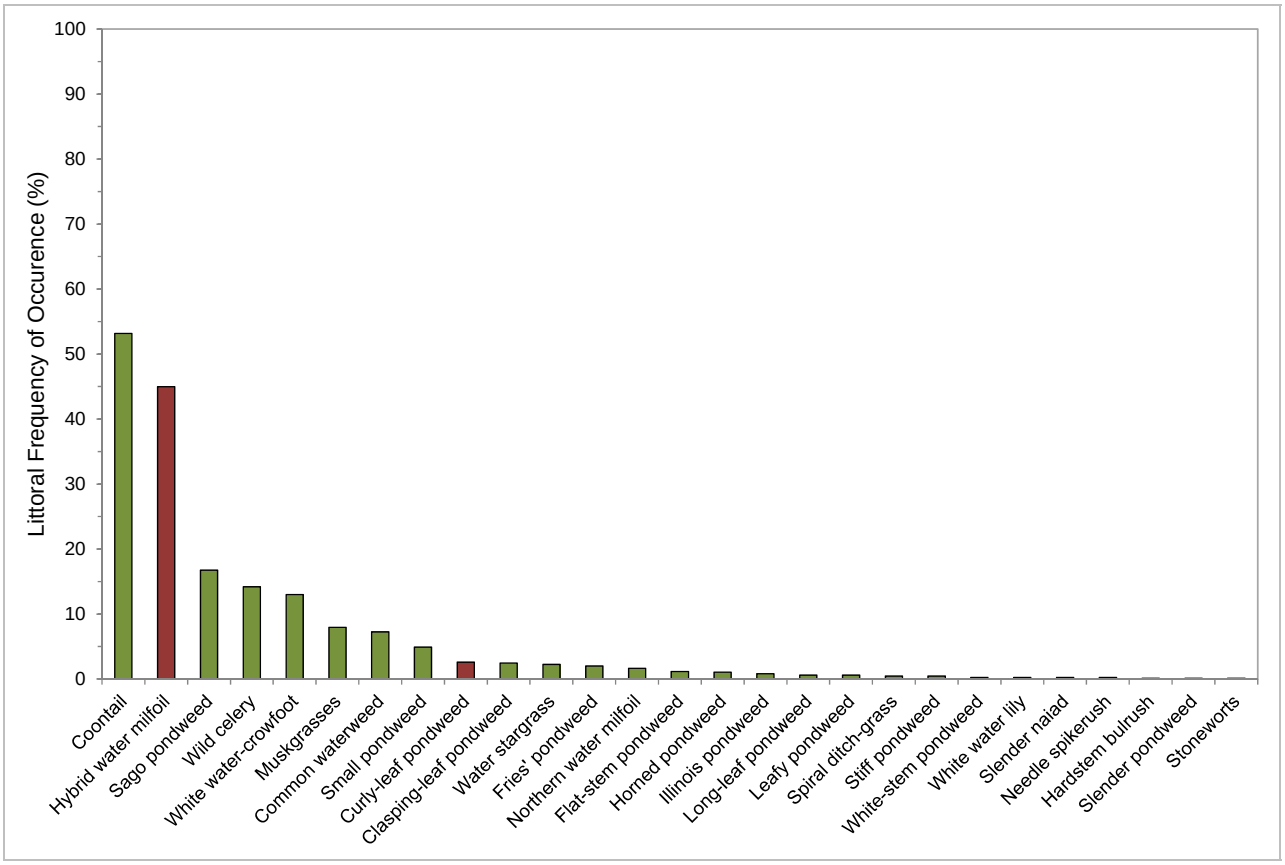

Figure 6. Green Lake 2014 littoral frequency of occurrence of aquatic plant species. Created using data from Onterra 2014 aquatic plant point-intercept survey. Exotic species indicated in red.

Hybrid water milfoil was the second-most frequently encountered aquatic plant species in Green Lake in 2014; and will be discussed in more detail in the Non-Native Aquatic Plant Section (2.4). Sago pondweed, wild celery, and white water-crowfoot were the next three most frequently encountered native aquatic plant species in 2014, with littoral frequencies of occurrence of 15%, 13%, and 12%, respectively (Figure 6 and Maps 4 and 5). Like coontail, sago pondweed is tolerant of low-light conditions, and is often found growing in higher-nutrient lakes. However, unlike coontail, sago pondweed is rooted in the lake bottom and spreads via rhizomes. These networks of rhizomes help to stabilize bottom sediments, and the numerous seeds and tubers produced by sago pondweed make it a very valuable food source for waterfowl and other wildlife (Borman et al. 1997). Sago pondweed was most abundant between 4 and 11 feet of water in 2014.

Wild celery, like Sago pondweed also is rooted submersed aquatic plant that spreads via rhizomes and tubers. The long, tape-like leaves that emerge from a basal rosette provide excellent habitat for aquatic organisms. Additionally, the leaves, fruits, and winter buds are food sources for numerous species of waterfowl and other wildlife (Borman et al. 1997). Wild celery was most abundant between a relatively narrow range of depths in Green Lake between 4 and 9 feet in 2014. White water-crowfoot, a member of the buttercup family, is a plant that is found growing in lakes with higher alkalinity and has finely dissected leaves that resemble milfoils or bladderworts. In shallower water, white water-crowfoot produces small, five-petalled flowers

above the water's surface, and it provides valuable sources of food and habitat to aquatic wildlife.

The non-native curly-leaf pondweed (CLP) was found to have a littoral frequency of occurrence of 2% in 2014 (Figure 6). However, this survey likely did not capture the true extent of the CLP population within Green Lake because the survey was conducted in mid-July when most of the CLP had likely already naturally senesced (died back for the year).

As mentioned, the WDNR conducted a whole-lake point-intercept survey on Green Lake in July of 2007. This survey utilized the same sampling locations as the survey conducted by Onterra in 2014 so the data collected from the surveys can be compared to determine if any changes in the plant community's composition has occurred over this seven-year period. Figure 7 displays the littoral frequency of occurrence of aquatic plant species from the 2007 and 2014 point-intercept surveys. Chi-square analysis ($\alpha = 0.05$) was used to determine if the occurrences of aquatic plant species between the two surveys are statistically different. However, only those species with an occurrence of at least 5% in one of the two surveys are applicable for analysis. Due to their morphological similarity and difficultly of identification, the occurrences of sago pondweed and spiral-ditch grass were combined for this analysis.

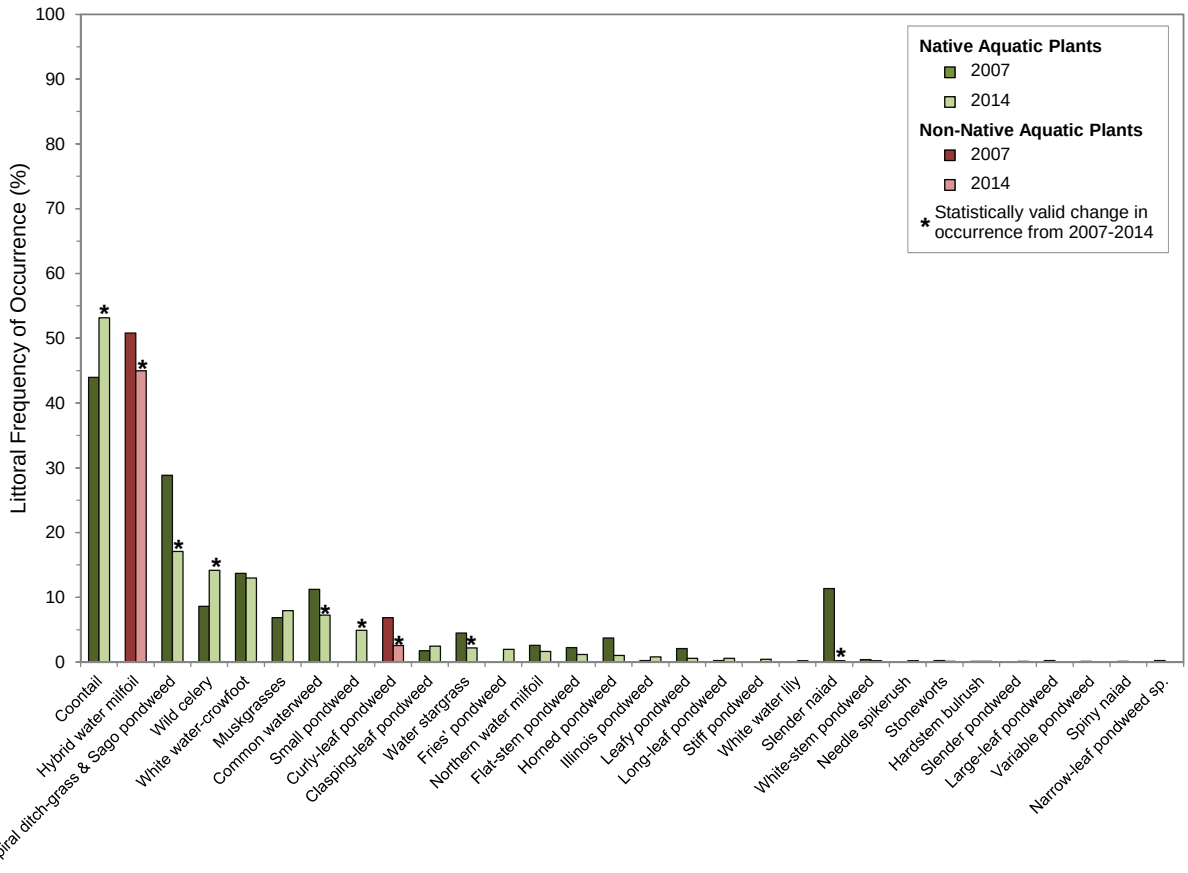

Figure 7. Littoral frequency of occurrence of aquatic plant species from WDNR 2007 and Onterra 2014 point-intercept surveys. Exotic species shown in red. Created using data from WDNR 2007 and Onterra 2014 point-intercept surveys.

The occurrences of seven native aquatic plant species were found to be statistically different in 2014 when compared to 2007 (Figure 7). Coontail, wild celery, and small pondweed saw increases in their occurrence in 2014, representing statistically valid increases in occurrence of 21%, 65%, and 100%, respectively. Common waterweed, the combined occurrence of sago pondweed and spiral-ditch grass, and water stargrass saw declines in their occurrence from 2007 to 2014, declining by 35%, 41%, and 51% respectively. Slender naiad, one of the more dominant aquatic plants in 2007 with a littoral frequency of occurrence of 10%, was found to only have a littoral frequency of occurrence of 0.2% in 2014, representing a statistically valid reduction of 98%. The occurrence of CLP was also found to have declined in 2014 by a statistically valid 63%; however, as discussed previously, these surveys likely did not capture an accurate picture of the CLP population as they were conducted in July. The occurrence of hybrid water milfoil was not found to be statistically different between 2007 and 2014.

Aquatic plant communities are dynamic and the abundance of certain species over short- or longer-term periods can fluctuate depending on climatic conditions, herbivory, competition, and disease among other factors. The differences in occurrence observed in the native plants coontail, wild celery, small pondweed, common waterweed, and sago pondweed/spiral ditch-grass between 2007 and 2014 were moderate and are not indicative of any significant environmental changes over this time period. However, the 98% reduction in occurrence of the once relatively abundant slender naiad is worth noting.

While slender naiad was rare in Green Lake in 2014, it is not known if this represents a permanent population collapse or interannual variation due to varying environmental factors. While studies have shown that eutrophication, specifically eutrophication in high pH lakes, can cause declines or extirpations of slender naiad (Wingfield et al. 2006), examination of Green Lake's water quality does not elude to any major changes from 2007-2014. Slender naiad is an annual, meaning it produces and relies on seeds to sustain its population from year to year. Conditions in 2013 may have been less favorable for seed production, and/or conditions in 2014 may have been less favorable for seed germination. Future surveys will reveal if the slender naiad population recovers from the low levels observed in 2014.

With the exception of slender naiad, there were no other major changes detected in Green Lake's aquatic plant community composition between the 2007 and 2014 surveys. However, historical aquatic plant data collected in 1921 indicates that Green Lake's aquatic plant community has undergone considerable changes over this past century. H.W. Rickett, a graduate student at the University of Wisconsin-Madison, conducted a study on Green Lake in 1921 where he measured the biomass of aquatic plants at various locations throughout the lake. His survey revealed that muskgrasses, a genus of macroalgae, were the dominant plants in the lake comprising 54% of the total aquatic plant biomass. Fifty years later in 1971, M.J. Bumby replicated Rickett's study and found that the biomass of muskgrasses had declined by 92%. In 2007 and 2014, muskgrasses were found to have a littoral frequency of occurrence of 6 and 7%, respectively, and were certainly not dominant within the community.

Rickett's study also showed that coontail and a species of native milfoil, whorled water milfoil (*Myriophyllum verticillatum*), were the next most dominant aquatic plants within the community in 1921. While Bumby found that coontail was also one of the dominant plants in the lake in 1971, she found that its biomass had also declined when compared to 1921. Coontail was also the most frequently encountered native aquatic plant species in the WDNR 2007 and Onterra

2014 studies. However, Bumby's study did not locate any occurrences of whorled water milfoil, and instead found it to have been replaced by EWM. In fact, already in 1971 Bumby had found that EWM was the most dominant plant in Green Lake's aquatic plant community. It has been confirmed that the EWM population in Green Lake is likely mostly (or all) HWM, and this population along with coontail was the dominant species in 2007 and 2014.

Whorled water milfoil has not been observed in Green Lake since Rickett's study in 1921, indicating that this species likely has been extirpated from Green Lake. Eurasian water milfoil was not introduced to Wisconsin until the 1960s, so Rickett could not have mistaken it for whorled water milfoil. However, Bumby notes that Rickett did not collect any whorled water milfoil specimens for verification and that he may have mistaken the plants for another native milfoil species, northern water milfoil, of which a small population is still present in Green Lake. Regardless if these plants were whorled or northern water milfoil, their population has seen a drastic decline since 1921.

Following coontail and the native water milfoil in abundance, Rickett found that sago pondweed, common waterweed, wild celery, and an aquatic moss (*Drepanocladus* sp.) were the next most abundant plants in Green Lake. In 1971, Bumby found that the biomass of wild celery was greater when compared to Rickett's values; however, she noted that the aquatic moss had greatly declined. All of these plants were located in the 2007 and 2014 surveys, though aquatic moss was only found at one sampling location (littoral frequency of occurrence = 0.1%) in 2014.

Four species of pondweeds, large-leaf pondweed, leafy pondweed, variable-leaf pondweed, and floating-leaf pondweed that were located in 1921 were not relocated in 1971. Large-leaf pondweed, leafy pondweed, and variable leaf pondweed were located in 2007; however, large-leaf pondweed was not located in 2014. Floating-leaf pondweed was not recorded in Green Lake in 2007 or 2014. Additionally, Rickett located plants in Green Lake that have not been observed since his 1921 study. These include: water marigold, stiff arrowhead, wild rice, and lake cress. Lake cress is currently listed as critically imperiled in Wisconsin due to its extreme rarity, and Rickett reported finding this plant in two locations in 1921.

Bumby's study in 1971 showed that Green Lake's aquatic plant community had changed dramatically in the 50 years since Rickett's study, with many species declining in their occurrence. Overall, she found that the total biomass of aquatic plants had declined, particularly in deeper areas of the lake. These changes in Green Lake's aquatic plant community are indicative of the multitude of anthropogenic (human-induced) stresses that have been put on the ecosystem. Increased nutrient inputs from the lake's watershed, shoreline development, and the introduction of invasive species have greatly altered Green Lake's ecosystem.

Sediment cores collected and analyzed from various locations in Green Lake in 1999 indicate that the amount of phosphorus entering the lake, the primary nutrient responsible for driving a lake's productivity, has doubled since 1930 (Garrison 2002). While the core study revealed that soil erosion to the lake has declined since 1960, phosphorus loading continues to increase, likely originating from the application of fertilizers within agricultural fields. Prior to European settlement within its watershed, Green Lake was in an *oligotrophic* state. Oligotrophic, or low-productivity lakes, are lakes that contain low levels of phosphorus (and other nutrients) and maintain sufficient levels of dissolved oxygen in deeper areas of the lake throughout the growing season. With increased levels of nutrients entering the lake, present water quality data from

Green Lake indicates the lake is now in a *mesotrophic* to *eutrophic* state (Sesing 2013). Eutrophic lakes are high in nutrients and thus see higher levels of plant and algae growth, and often deeper waters become deprived of oxygen due to increased biological activity. Mesotrophic lakes are moderately productive, falling between oligotrophic and eutrophic lakes.

Along with water quality degradation in Green Lake, the lake has also seen the introduction of a number of invasive species. Since their introduction, hybrid water milfoil and curly-leaf pondweed have spread throughout littoral areas of Green Lake. These plants may be responsible for the displacement and decline of a number of native aquatic plant species previously discussed. In addition, these plants alter habitat structure, predator-prey interactions, and nutrient dynamics.

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 et al. 2013). Green Lake resource managers, recognizing the impact carp were having on Green Lake's ecosystem particularly within the estuaries where turbidity was high and aquatic vegetation was sparse, installed a "bubble barrier" underneath County Highway A between Silver Creek Estuary and Green Lake (Photo 3). 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. Aquatic plant surveys of the Silver Creek Estuary following the installation of the barrier indicated aquatic plant growth had increased greatly. A point-intercept survey within the Silver Creek Estuary in 2014 revealed 87% of the 203 sampling locations contained aquatic vegetation. A carp barrier was also installed between the County Highway K Marsh and Green Lake, but has not yet reached management objectives. Of the 94 sampling locations within the County Highway K Marsh in 2014, only 2 (2.1%) contained aquatic vegetation.

Photo 3. Bubble barrier on Green Lake.

Zebra mussels (*Dreissena polymorpha*) were discovered in Green Lake in 2001. Since their discovery, no significant changes in the lakes water quality have been detected (Sesing 2013). However, numerous studies have shown that following the establishment of zebra mussels, many lakes experience increased water clarity as a result of decreased suspended material within the water from the filtering of zebra mussels (MacIsaac 1996; Karatayev et al. 1997; Reed-Andersen et al. 2000; Zhu et al. 2006). With increased water clarity, aquatic plants will likely be able to migrate and establish deeper waters where sufficient light is now available. At this time, it is not clear how the zebra mussel population may be affecting Green Lake's aquatic plant community.

As discussed in the primer section, the calculations used for the Floristic Quality Index (FQI) for a lake's aquatic plant community are based on the aquatic plant species that were encountered on the rake during the point-intercept surveys and does not include incidental species. For example, while a total 28 native aquatic plant species were located in Green Lake during the 2014 surveys, 25 (analysis does not include aquatic moss) were encountered on the rake during the point-intercept survey. These 25 native species and their conservatism values were used to calculate the FQI of Green Lake's aquatic plant community in 2014 (equation shown below).

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

Figure 8 compares the FQI components of Green Lake from the 2007 and 2014 point-intercept surveys to median values of lakes within the Southeastern Wisconsin Till Plains (SWTP) ecoregion as well as the entire State of Wisconsin. Sesing 2013 reported that 34 native aquatic plant species were recorded on the rake during the WDNR 2007 point-intercept survey; however, this number included filamentous algae and aquatic moss which are not included in the FQI analysis. Additionally, this number included plants that were identified differently by different survey crews that were found to be the same species after the survey, and two species located in City Millpond in 2007 were not included because City Millpond was surveyed separately in 2014 from the Green Lake whole-lake point-intercept survey. In total, 21 native aquatic plant species were located on the rake in 2007 in Green Lake proper compared to 25 in 2014 (Figure 8). Both of these values exceed the median value for lakes within the SWTP ecoregion and for lakes throughout Wisconsin.

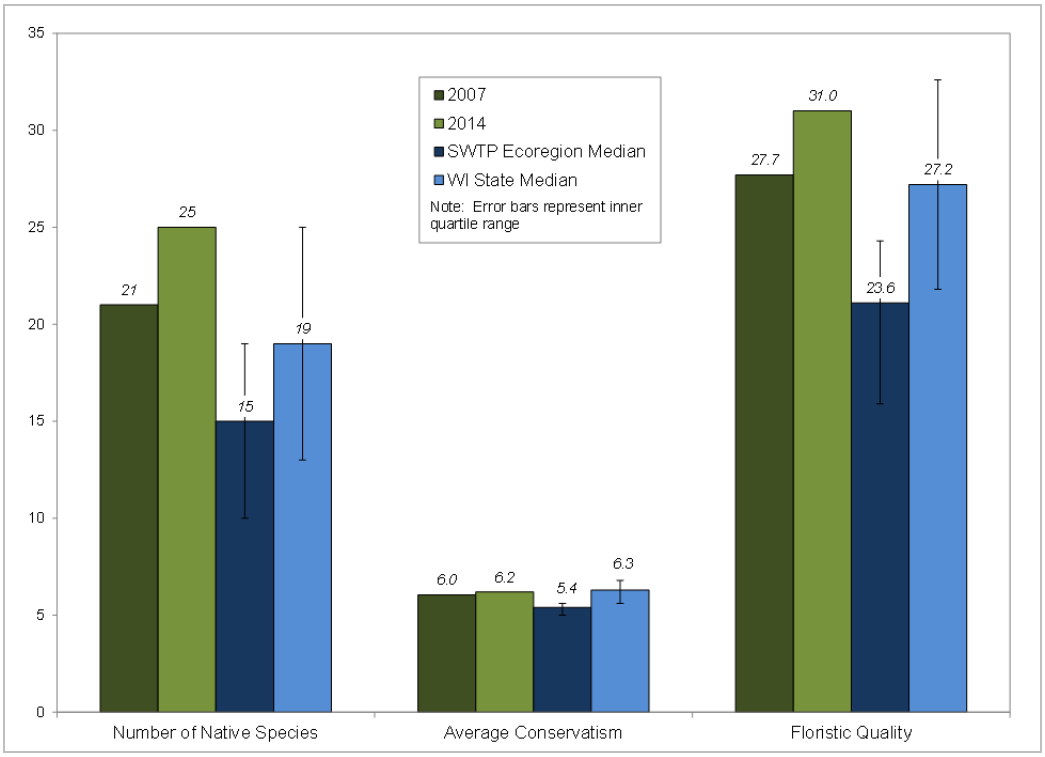

Figure 8. Green Lake Floristic Quality Analysis. Created using data from WDNR 2007 and Onterra 2014 point-intercept surveys. Regional and state medians created with Onterra and WDNR data. SWTP = Southeast Wisconsin Till Plains.

Littoral area, water clarity, depth and sediment variation, shoreline complexity, and water chemistry are all factors that influence aquatic plant species richness. Green Lake, having relatively high water clarity, has a large littoral zone, supporting aquatic vegetation throughout most of it. As discussed earlier, Green Lake contains areas comprised of sand and areas comprised of soft sediments, and in addition, it contains many bays sheltered from wind and waves. These differing habitats support aquatic plant communities of varying species composition and create a more species-rich environment.

The average conservatism value for Green Lake's aquatic plant community was 6.0 and 6.2 in in 2007 and 2014, respectively. These values are higher than the median value for lakes within the SWTP ecoregion but fall below the median value for lakes throughout the state (Figure 8). Combining the native species richness and average conservatism values yields a value of 27.7 for 2005 and a value of 31.0 for 2014. Both of these FQI values fall above the median values for lakes in the SWTP ecoregion and the state. This analysis indicates that despite the changes to Green Lake's aquatic plant community over the past century, it is still if higher quality than the majority of lakes throughout the ecoregion and the state.

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

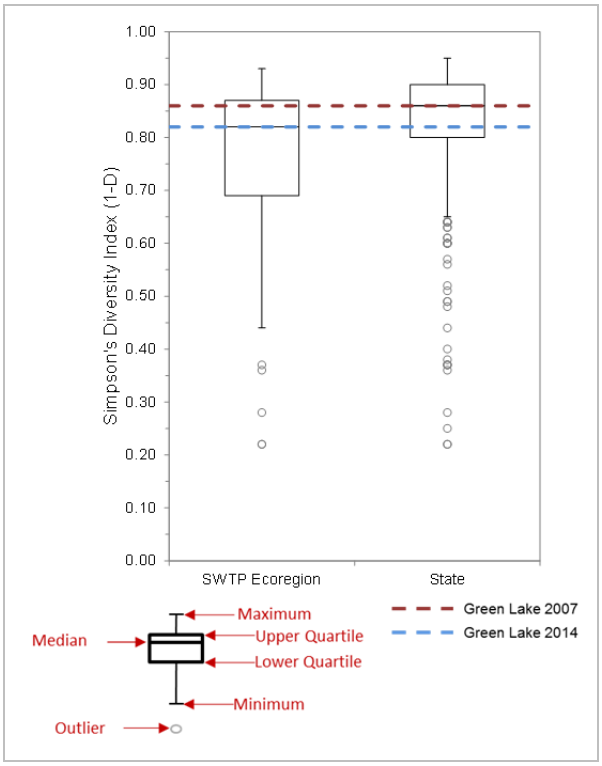

Figure 9. Green Lake Simpson's Diversity Index. Created using data from WDNR 2007 and Onterra 2014 point-intercept surveys. Ecoregion and state data created using Onterra and WDNR data.

While a method for characterizing diversity values of fair, poor, etc. does not exist, lakes within the same ecoregion may be compared to provide an idea of how Green Lake's diversity value ranks. Using data obtained from WDNR Science Services, quartiles were calculated for 77 lakes within the SWTP Ecoregion (Figure 9). Comparisons to Green Lake's species diversity are displayed using *boxplots* that showing median values and upper/lower quartiles of lakes in the same ecoregion and in the state. Box plots, or box-and-whisker diagrams, show data through five-number summaries: minimum, lower quartile, median, upper quartile, and maximum. Just as the median divides the data into upper and lower halves, quartiles further divide the data by calculating the median of each half of the dataset.

Using the data collected from the 2007 and 2014 point-intercept surveys, Green Lake's aquatic plant community was shown to have Simpson's Diversity Index values of 0.86 and 0.82 in 2007 and 2014, respectively (Figure 9). In other words, if two individual aquatic plants were randomly sampled from Green Lake in 2014, there would be an 82% probability that they would be different species, compared to 86% in 2007. In 2007, the value of 0.86 fell above the median value for lakes in the SWTP ecoregion and was even with the median value for lakes state-wide. However, diversity decreased to the median ecoregional value of 0.82 in 2014 and fell below the state-wide median value. This decrease in diversity in 2014 can largely be attributed to the decline observed in the slender naiad population.

As explained earlier, the littoral frequency of occurrence analysis allows for an understanding of how often each of the plants is located during the point-intercept survey. Because each sampling location may contain numerous plant species, relative frequency of occurrence is one tool to evaluate how often each plant species is found in relation to all other species found (composition of population). For instance, while coontail was found at approximately 48% of the littoral sampling locations in Green Lake in 2014, its relative frequency of occurrence is 30%. Explained another way, if 100 plants were randomly sampled from Green Lake, 30 of them would be coontail, 25 hybrid water milfoil, etc. Figure 10 displays the relative occurrence of aquatic plant species from Green Lake in 2014, and illustrates that 55% of the community is comprised of just two species: coontail and hybrid water milfoil. This dominance of the community by two species yields the lower species diversity.

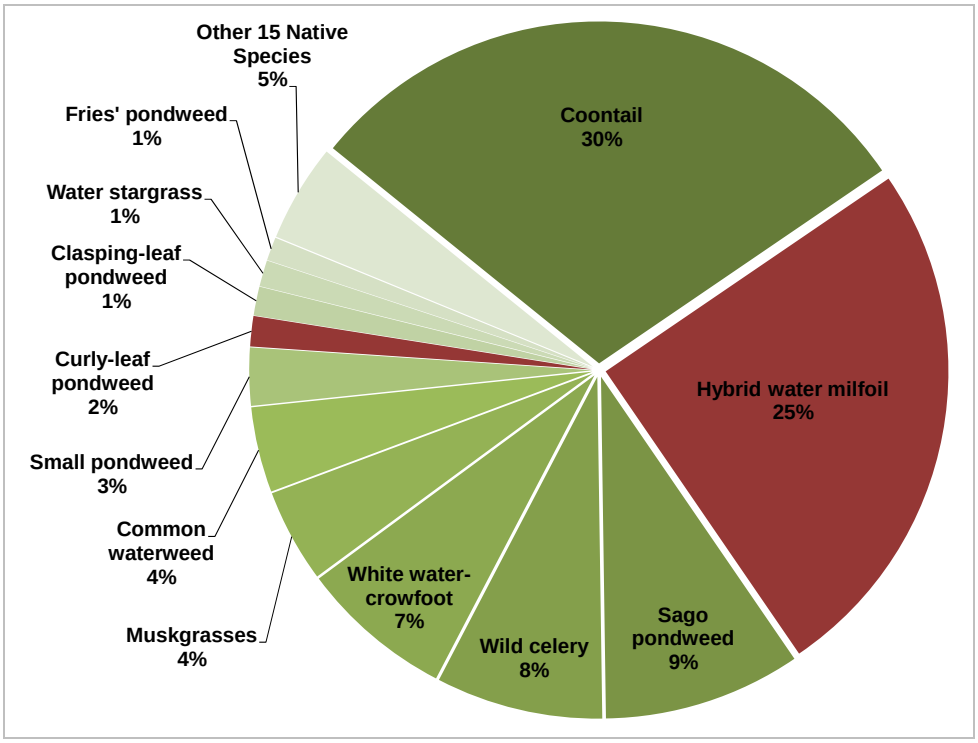

Figure 10. Green Lake 2014 relative frequency of occurrence of aquatic plant species. Created using data from Onterra 2014 point-intercept survey.

The 2014 aquatic plant community mapping survey on Green Lake revealed that only 0.1%, or 7.4 acres of the lake proper contain emergent and floating-leaf aquatic plant communities (Table 2; Maps 6 and 7). These communities are comprised of eight species, two of which are non-native, invasive species (purple loosestrife and reed canary grass) (Table 1). While these communities are relatively sparse in Green Lake, they are a valuable component of the aquatic ecosystem and provide valuable fish and wildlife habitat. In addition, these communities aid in stabilizing bottom sediments and reducing shoreline erosion. The community map represents a 'snapshot' of the important emergent and floating-leaf plant communities, and 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. The relatively sparse communities found on Green Lake may indicate that many of these communities may have already been lost due to shoreline development and water quality degradation.

Table 2. Acres of emergent and floating-leaf aquatic plant communities on Green Lake in 2014. Created using data from 2014 aquatic plant community mapping survey.

Aquatic Plant Community	Green Lake Acres
Emergent	3.6
Floating-Leaf	3.4
Mixed Emergent & Floating-Leaf	0.4
Total	**7.4**

2.3 2014 Green Lake Estuaries Aquatic Plant Survey Results

In 2013 and 2014, aquatic plant surveys were conducted on Beyers Cove, City Millpond, and Silver Creek Estuary. While one of the goals of these surveys served the AIS monitoring and control project, the data gathered during these surveys was also used to assess the overall health of the plant communities within these basins. Additionally, while County Marsh is not included within the AIS control and monitoring project, plant surveys were conducted within this basin in 2014 to assess its aquatic plant community. These basins are valuable components of the Green Lake ecosystem, providing shallow, quiet backwater areas that serve as essential habitats for a number of organisms. As previously discussed, these basins have been severely degraded by water quality degradation and invasive species, and the GLSD is attempting to restore the ecological integrity of these areas.

During the 2013 and 2014 plant surveys, a total of 15, 25, 14, and 23 aquatic plant species were located in Beyers Cove, City Millpond, County Marsh, and Silver Creek Estuary, respectively (Table 3 & 4). Between all four basins, a total of 41 aquatic plant species were located, five of which are considered to be non-native, invasive species: hybrid water milfoil, curly-leaf pondweed, purple loosestrife, pale-yellow iris, and reed canary grass (Table 3).

Table 3. Aquatic plant species located in Beyers Cove, City Millpond, County Marsh, and Silver Creek Estuary in 2013 and 2014.

Growth Form	Scientific Name	Common Name	Coefficient of Conservatism (C)	Beyers Cove	City Millpond	County Marsh	Silver Creek Estuary
Emergent	*Asclepias incarnata*	Swamp milkweed	5			I	
	Bolboschoenus fluviatilis	River bulrush	5			I	
	Calamagrostis canadensis	Canada bluejoint grass	5			I	
	Calystegia sepium	Hedge bindweed	2				
	Carex comosa	Bristly sedge	5			I	
	Eleocharis erythropoda	Bald spike-rush	3			I	I
	Iris pseudacorus	Pale-yellow iris	Exotic				I
	Iris versicolor	Northern blue flag	5		I	I	
	Lythrum salicaria	Purple loosestrife	Exotic		I	I	I
	Phalaris arundinacea	Reed canary grass	Exotic			I	I
	Phragmites australis subsp. *americanus*	Giant reed	5				I
	Sagittaria latifolia	Common arrowhead	3			I	
	Schoenoplectus acutus	Hardstem bulrush	5				I
	Schoenoplectus tabernaemontani	Softstem bulrush	4				I
	Sparganium eurycarpum	Common bur-reed	5	I	I		I
	Typha spp.	Cattail spp.	1	I	I	I	I
FL	*Nuphar variegata*	Spatterdock	6	X		I	
	Nymphaea odorata	White water lily	6	X	X	X	X
	Persicaria amphibia	Water smartweed	5	I			
Submergent	*Ceratophyllum demersum*	Coontail	3	X	X	X	X
	Chara spp.	Muskgrasses	7		X		
	Elodea canadensis	Common waterweed	3	X	X		X
	Heteranthera dubia	Water stargrass	6		X		
	Myriophyllum sibiricum	Northern water milfoil	7	X	X		
	Myriophyllum sibiricum X spicatum	Hybrid water milfoil	Exotic	X	X		X
	Najas guadalupensis	Southern naiad	7		X		
	Potamogeton crispus	Curly-leaf pondweed	Exotic	X	X	I	X
	Potamogeton friesii	Fries' pondweed	8		X		X
	Potamogeton nodosus	Long-leaf pondweed	7		X		
	Potamogeton praelongus	White-stem pondweed	8	X			
	Potamogeton richardsonii	Clasping-leaf pondweed	5	X	X		X
	Potamogeton strictifolius	Stiff pondweed	8		X		
	Potamogeton zosteriformis	Flat-stem pondweed	6		X		X
	Ranunculus aquatilis	White water-crowfoot	8	X	X		X
	Stuckenia pectinata	Sago pondweed	3	X	X		X
	Vallisneria americana	Wild celery	6		X		
	Zannichellia palustris	Horned pondweed	7		X		
S/E	*Eleocharis acicularis*	Needle spikerush	5				X
FF	*Lemna trisulca*	Forked duckweed	6		X		X
	Lemna turionifera	Turion duckweed	2	X	X		X
	Spirodela polyrhiza	Greater duckweed	5		X		X
	Wolffia spp.	Watermeal species	N/A		X		X

FL = Floating-leaf; S/E = Submergent and Emergent; FF = Free-floating
X = Located on rake during point-intercept survey; I = Incidentally located

Table 4. 2014 Green Lake Floristic Quality Analysis. Created using data from 2014 aquatic plant surveys.

Waterbody	Number of Exotic Species	Number of Native Species*	Average Conservatism**	Floristic Quality**
Big Green Lake	4	24 (28)	6.0	31.9
City Millpond	3	20 (22)	5.5	24.6
Silver Creek Estuary	5	12 (18)	5.0	17.3
Beyers Cove	2	10 (13)	5.1	16.1
County Marsh	3	2 (12)	4.5	6.4

* Reported as number of species encountered on rake during point-intercept survey. Total species encountered within basin, including incidentals indicated in parenthesis.

** Calculations based on species encountered on rake during point-intercept survey.

City Millpond contained the highest number of aquatic plant species, followed by Silver Creek Estuary, Beyers Cove, and County Marsh, respectively. Sediment data collected during the point-intercept surveys indicated that the majority of these basins contain soft sediments (muck), while only small portions of comprised of sand and/or rock (Figures 11 and Figures 13-16). Approximately 70-90% of the point-intercept sampling locations in Beyers Cove, City Millpond, and Silver Creek contained aquatic vegetation, while only 2% contained aquatic vegetation in County Marsh (Figure 12 and Figures 13-16).

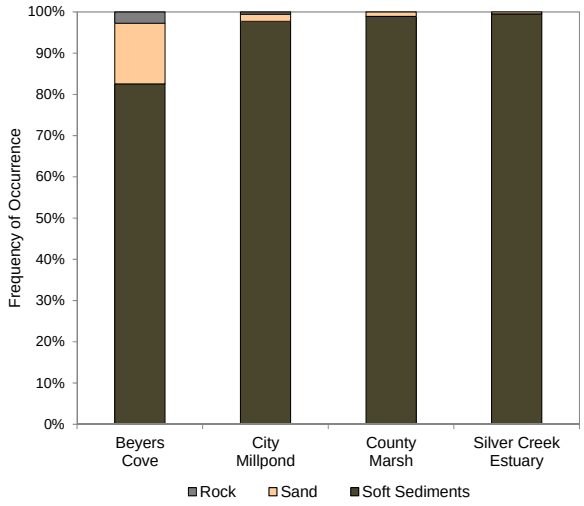

Figure 11. Proportion of substrate types within Beyers Cove, City Millpond, County Marsh, and Silver Creek Estuary. Created using data from 2014 point-intercept surveys.

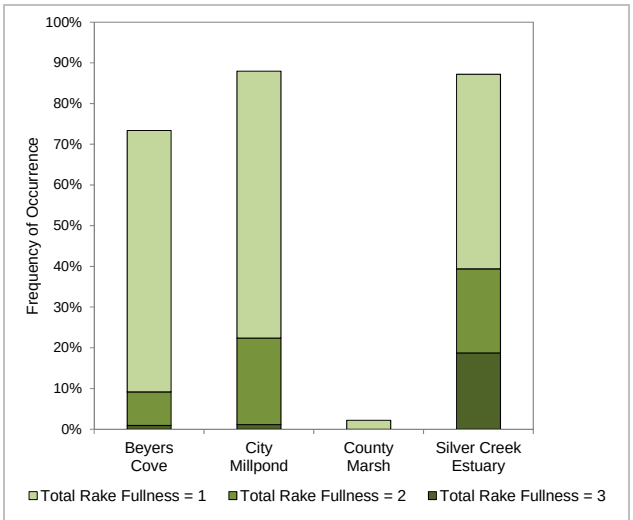

Figure 12. Frequency of aquatic vegetation and rake fullness ratings from Beyers Cove, City Millpond, County Marsh, and Silver Creek Estuary. Created using data from 2014 point-intercept surveys.

Coontail, the most frequently encountered aquatic plant in Green Lake was also the most frequently encountered in Beyers Cove, City Millpond, and Silver Creek Estuary. As discussed previously, because coontail derives the majority of its nutrients directly from the water, it often is one of the dominant plants in nutrient-rich waters that are found in these basins. While coontail 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 any other populations of submersed aquatic plants.

Hybrid water milfoil was also relatively common in Beyers Cove, City Millpond, and Silver Creek Estuary. However, following basin-wide herbicide treatments in Beyers Cove and City Millpond in the spring of 2014, the occurrence of HWM was reduced to approximately 20% in both basins compared to a 2013 pre-treatment occurrence of 82% and 53%, respectively. Hybrid water milfoil occurrence in Silver Creek Estuary was relatively low in 2014, with approximately 7% of the sampling locations containing HWM. For a more detailed discussion regarding the 2014 HWM treatments and future monitoring and control strategies within the basins, please see the *2014 Green Lake AIS Control and Monitoring Report* (Onterra 2014).

Common waterweed was one of the more dominant plants in Beyers Cove and Silver Creek Estuary in 2014, but it was relatively uncommon in City Millpond. Like coontail, common waterweed is tolerant of low-light conditions, and can persist in degraded environments. In City Millpond, white water lily and forked duckweed were the most frequently encountered plants following coontail. White water lily persists as large tubers under the sediment which sends up leaves and flowers to the water's surface. These plants aid in sediment and shoreline stabilization and are important structural habitat for wildlife. Forked duckweed, unlike the rest of the duckweeds present in Wisconsin which float on the surface, grows along the lake bottom or entangled amongst other aquatic plants. It has found to be an important food source for a number of water fowl.

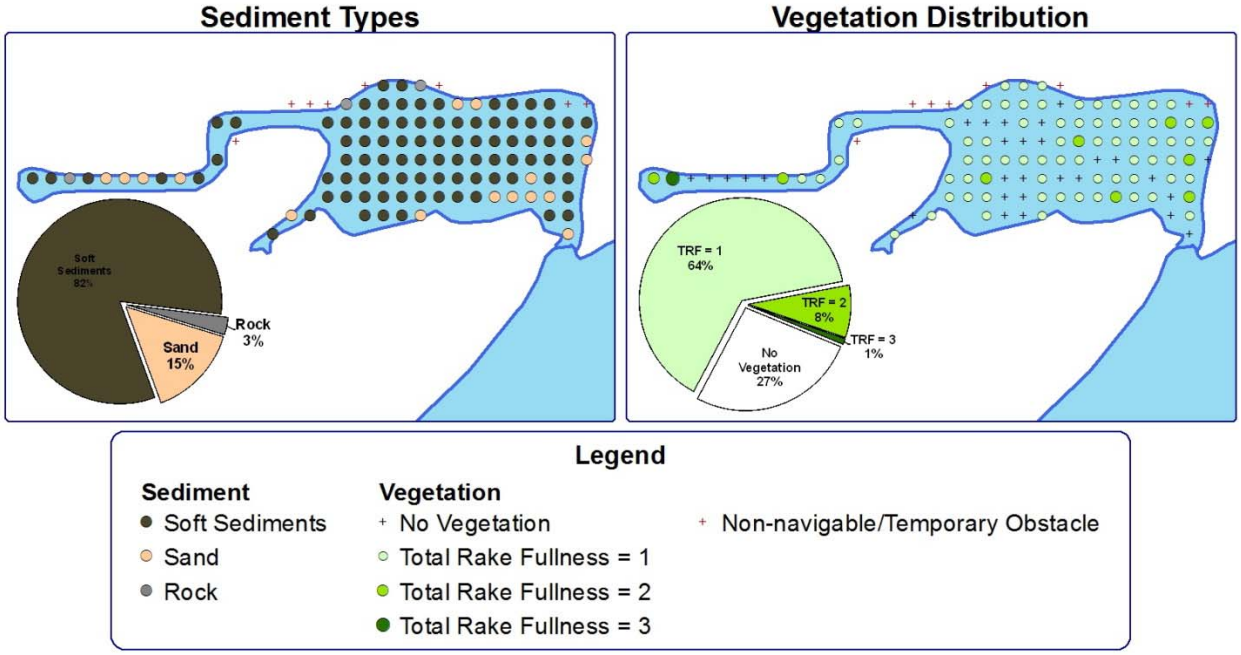

Figure 13. Beyers Cove 2014 sediment types and distribution of aquatic vegetation. Created using data from 2014 point-intercept survey.

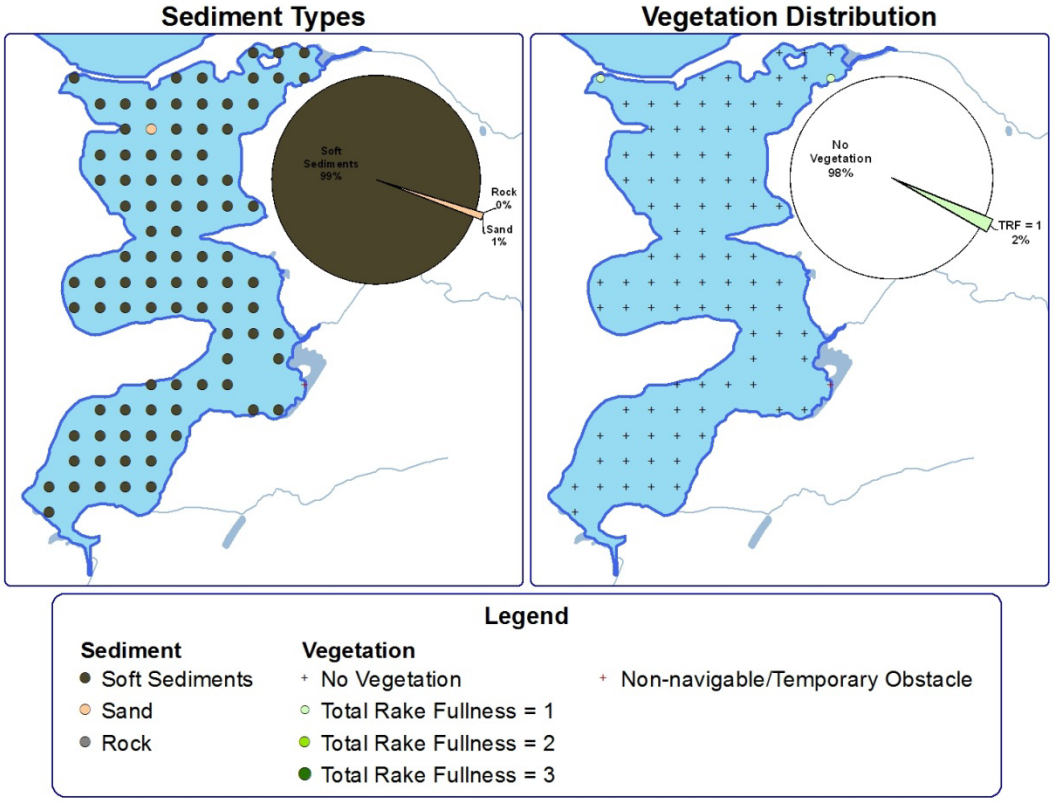

Figure 14. County Marsh 2014 sediment types and distribution of aquatic vegetation. Created using data from 2014 point-intercept survey.

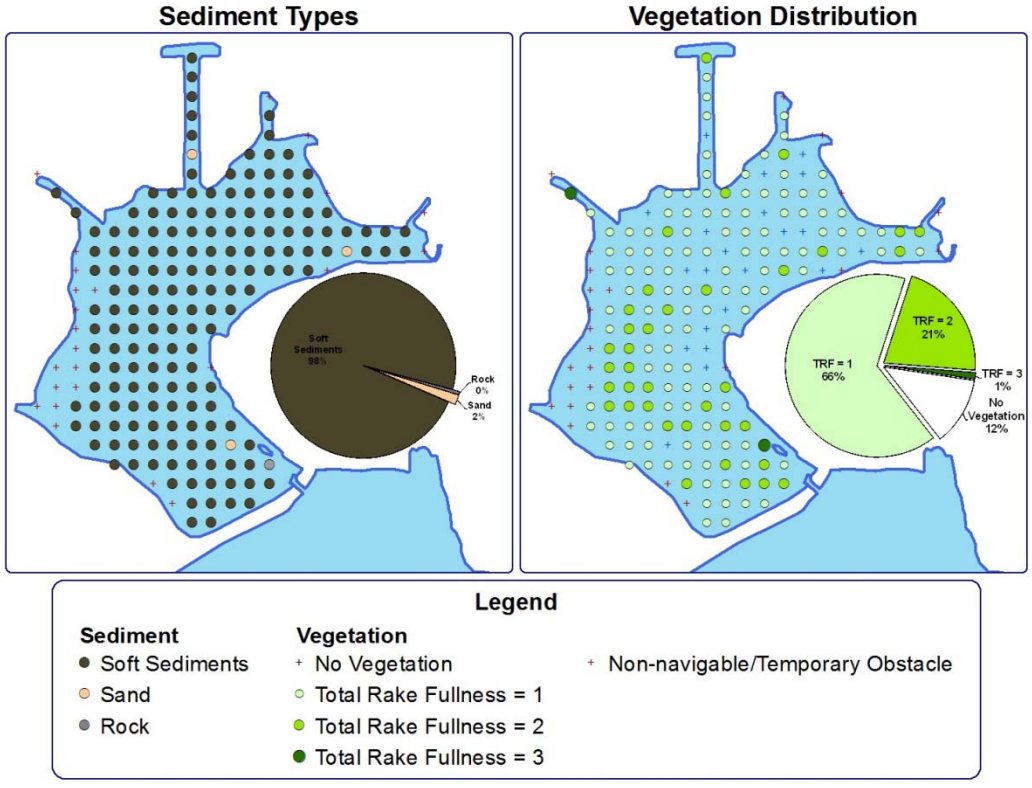

Figure 15. City Millpond 2014 sediment types and distribution of aquatic vegetation. Created using data from 2014 point-intercept survey.

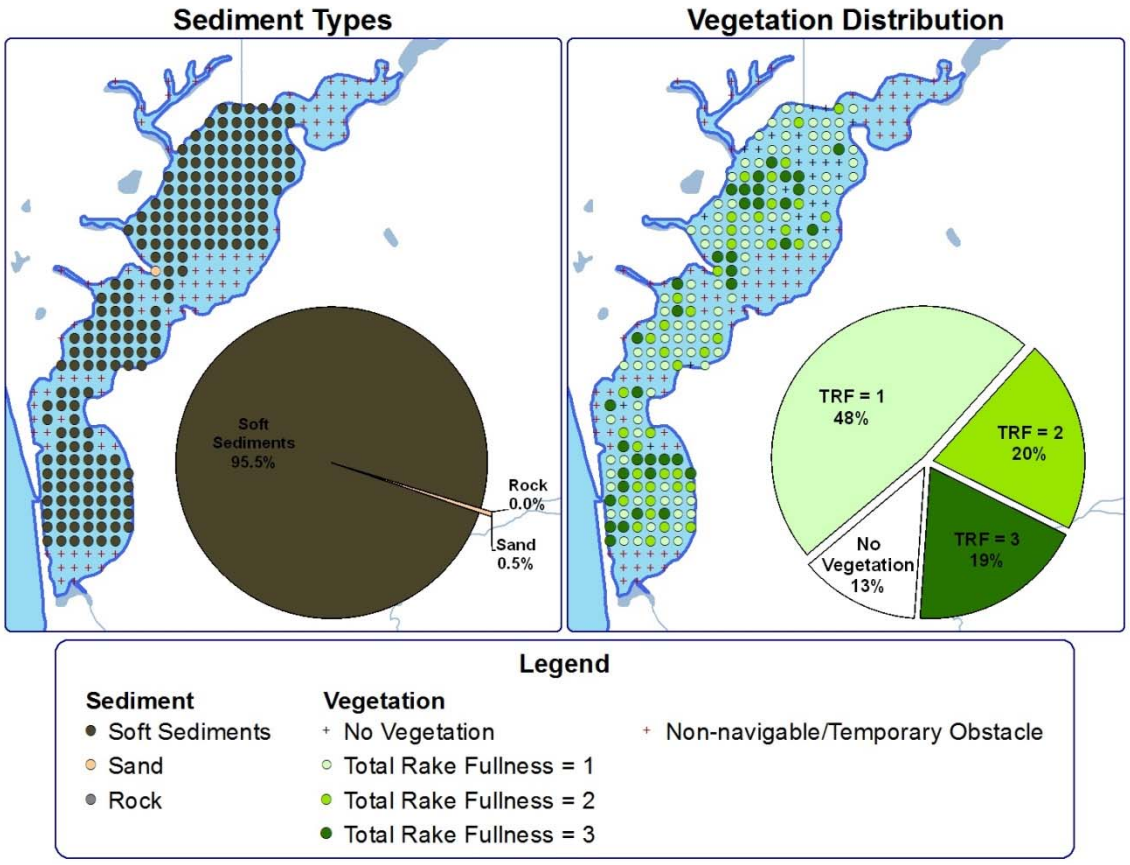

Figure 16. Silver Creek Estuary 2014 sediment types and distribution of aquatic vegetation. Created using data from 2014 point-intercept survey.

Community mapping of emergent and floating-leaf aquatic plant communities was also conducted on Beyers Cove, City Millpond, and Silver Creek Estuary in 2013 and in County Marsh in 2014. These surveys found that approximately 27% of Beyers Cove, 51% of City Millpond, 3.8% of County Marsh, and 47% of Silver Creek Estuary contain these types of communities (Table 5; Maps 8-11).

Table 5. Acres of emergent and floating-leaf aquatic plant communities on Beyers Cove, City Millpond, County Marsh, and Silver Creek Estuary. Created using data from 2013 and 2014 aquatic plant community mapping surveys.

		Plant Community Acres			
Aquatic Plant Community	**Big Green Lake**	**Beyers Cove**	**City Millpond**	**County Marsh**	**Silver Creek Estuary**
Emergent	3.6	0.1	3.4	5.8	6.6
Floating-Leaf	3.4	7.6	21.1	4.4	94.2
Mixed Emergent & Floating-Leaf	0.4	0.0	0.0	0.0	0.0
Total	**7.4**	**7.6**	**24.6**	**10.2**	**100.8**
% Waterbody Area	**0.1%**	**27.3%**	**51.3%**	**3.8%**	**46.9%**

2.4 Non-native Aquatic Plants

Hybrid water milfoil

Eurasian water milfoil (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 (Photo 4). This report only discusses the HWM population within Green Lake proper, and information regarding the HWM populations and control strategies implemented in 2014 within the estuaries can be found in the Green Lake 2014 Letter Report.

Photo 4. Hybrid water milfoil (*Myriophyllum sibiricum X spicatum*) in Beyers Cove, Green Lake. Photo taken on June 18, 2013.

While more extensive and detailed mapping surveys of HWM were completed on the three basins previously mentioned, the 2014 whole-lake point-intercept survey was used to collect information regarding the HWM in Green Lake. The point-intercept survey allows for a determination of HWM abundance within the lake and a relatively coarse picture of where it's located. As discussed in the previous section, HWM was the second-most frequently encountered aquatic plant in Green Lake with a littoral frequency of occurrence of 42%. Statistical analysis revealed that its occurrence in 2014 was not statistically different from its occurrence in 2007. Hybrid water milfoil has likely been a highly dominant plant within the lake for some time, as M.J. Bumby noted its high abundance in 1971. The 2014 point-intercept survey found that HWM grows throughout littoral areas in Green Lake, and the densest areas can be found along the northern portion of the lake (Figure 17 and Map 12). HWM was most abundant between 5 and 14 feet of water in 2014, and is similar to what was found in 2007.

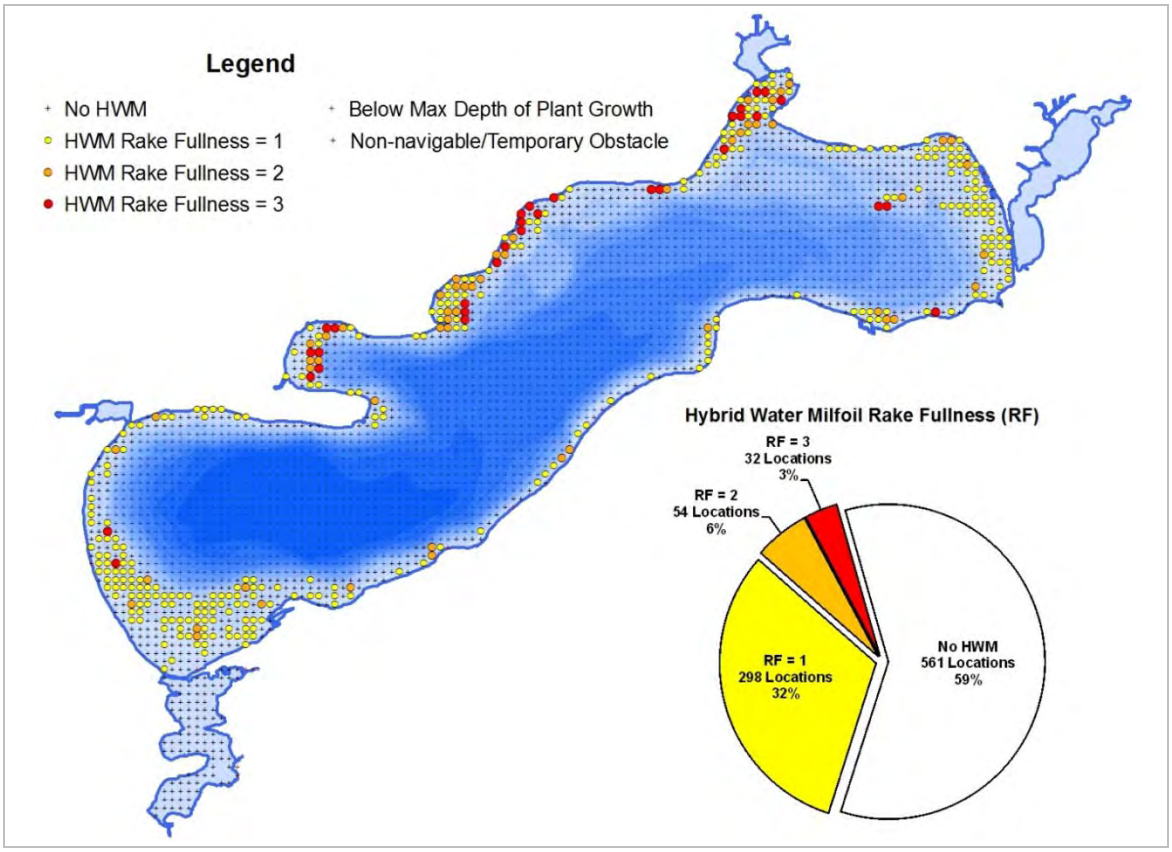

Figure 17. Point-intercept locations containing hybrid water milfoil in Green Lake in 2014. Created using data from Onterra 2014 point-intercept survey.

Curly-leaf pondweed

Curly-leaf pondweed (CLP) was first discovered in Green Lake in 1971 (Photo 5). To accurately assess a lake's CLP population, surveys need to be conducted in late spring or early summer when these plants are at or near their peak growth. However, the point-intercept survey on Green Lake proper in 2014 was conducted in July, likely after most of the plants had naturally senesced. For this reason, the full extent of the CLP population in Green Lake is not known.

Photo 5. Curly-leaf pondweed (*Potamogeton crispus*) in City Millpond, Green Lake. Photo taken on May 14, 2014.

Purple loosestrife

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

Isolated, scattered populations of purple loosestrife were located along the shorelines of City Millpond, Silver Creek Estuary, and County Marsh in 2013 and 2014 (Maps 4-7). There are a number of effective control strategies for combating this aggressive plant, including herbicide application, biological control by non-native beetles, and manual hand removal. At this time, hand removal by volunteers is likely the best option as it would decrease costs significantly. Additional purple loosestrife monitoring would be required to ensure the removal of the plant from the shorelines within these areas.

Photo 6. Purple loosestrife (*Lythrum salicaria*) on a northern Wisconsin Lake.

Reed canary grass

Reed canary grass (*Phalaris arundinacea*) is a large, coarse perennial grass that can reach three to six feet in height. Reed canary grass was found growing along the shorelines of Green Lake and Silver Creek Estuary (Map 6, 7, and 10). Often difficult to distinguish from native grasses, this species forms dense, highly productive stands that vigorously outcompete native species. Unlike native grasses, few wildlife species utilize the grass as a food source, and the stems grow too densely to provide cover for small mammals and waterfowl. It grows best in moist soils such as wetlands, marshes, stream banks and exposed lake shorelands.

Reed canary grass is difficult to eradicate; at the time of this writing there is no efficient control method. Small, discrete patches have been covered by black plastic to reduce growth for an entire season. However, the species must be monitored because rhizomes may spread out beyond the plastic.

Giant Reed

Giant reed (*Phragmites australis* subsp. *americanus*) is a tall, perennial grass found in wetlands and in shallow water throughout Wisconsin (Photo 7). While a non-native strain (*P. australis* subsp. *australis*) of this species exists in Wisconsin, the plants located along the shorelines of Silver Creek Estuary and County Marsh were identified by the UW-Stevens Point Herbarium as the native strain, subspecies *americanus* (Map 10 and 11).

Photo 7. Giant Reed (*Phragmites australis subsp. americanus*) on a northern Wisconsin Lake.

Spiny naiad

Spiny naiad is one of five naiad species found in Wisconsin. While spiny naiad is native to North America, it is currently listed as a non-native species in Wisconsin. However, some believe that the spiny naiad populations found within the western Great Lakes region are the result of recolonization of the area following the last period of glaciation (Stuckey 1985). It only inhabits lakes that are higher in alkalinity, like Green Lake. In 2007, spiny naiad was found at one sampling location, but it was not located during the surveys in 2014. At this time, the presence of spiny naiad in Green Lake is of minimal concern.

Photo 8. Pale-yellow iris (*Iris pseudacorus*).

Pale-yellow iris

One occurrence of pale-yellow iris (*Iris pseudacorus*) was located growing on the shoreline Silver Creek Estuary (Map 11). Pale-yellow iris a large, showy iris with bright yellow flowers. Native to Europe and Asia, this species was sold commercially in the United States for ornamental use and has since escaped into Wisconsin's wetland areas forming large monotypic colonies and displacing valuable native wetland species (Photo 8). At the time of this report, it appears that the only means of control are continual hand removal and monitoring.

3.0 SUMMARY & CONCLUSIONS

The results of the aquatic plant surveys conducted in 2014 indicate that the native aquatic plant population of Green Lake is of higher quality than the majority of lakes within the Southwest Wisconsin Till Plains ecoregion. The lake contains a relatively high number of species; however, greater than 50% of the community is dominated by coontail and the non-native hybrid water milfoil. Additionally, comparisons of the 2014 data to previous surveys dating back to almost a century indicate that Green Lake's aquatic plant community has been degraded over this time period. Human actions within Green Lake's watershed have changed the lake's water chemistry and productivity, and the introduction of invasive species have altered ecosystem processes.

The surveys revealed that HWM is widespread and abundant throughout littoral areas of Green Lake. While larger colonized areas of HWM could be targeted for control, due to the size of the lake and size of the population, lake-wide control the HWM in Green Lake is not feasible. The surveys also found that Beyers Cove, City Millpond, and Silver Creek Estuary support abundant populations of submersed aquatic plants, as well as emergent and/or floating-leaf aquatic plant communities. However, County Marsh is virtually devoid of submersed vegetation due to the turbid conditions present within this basin.

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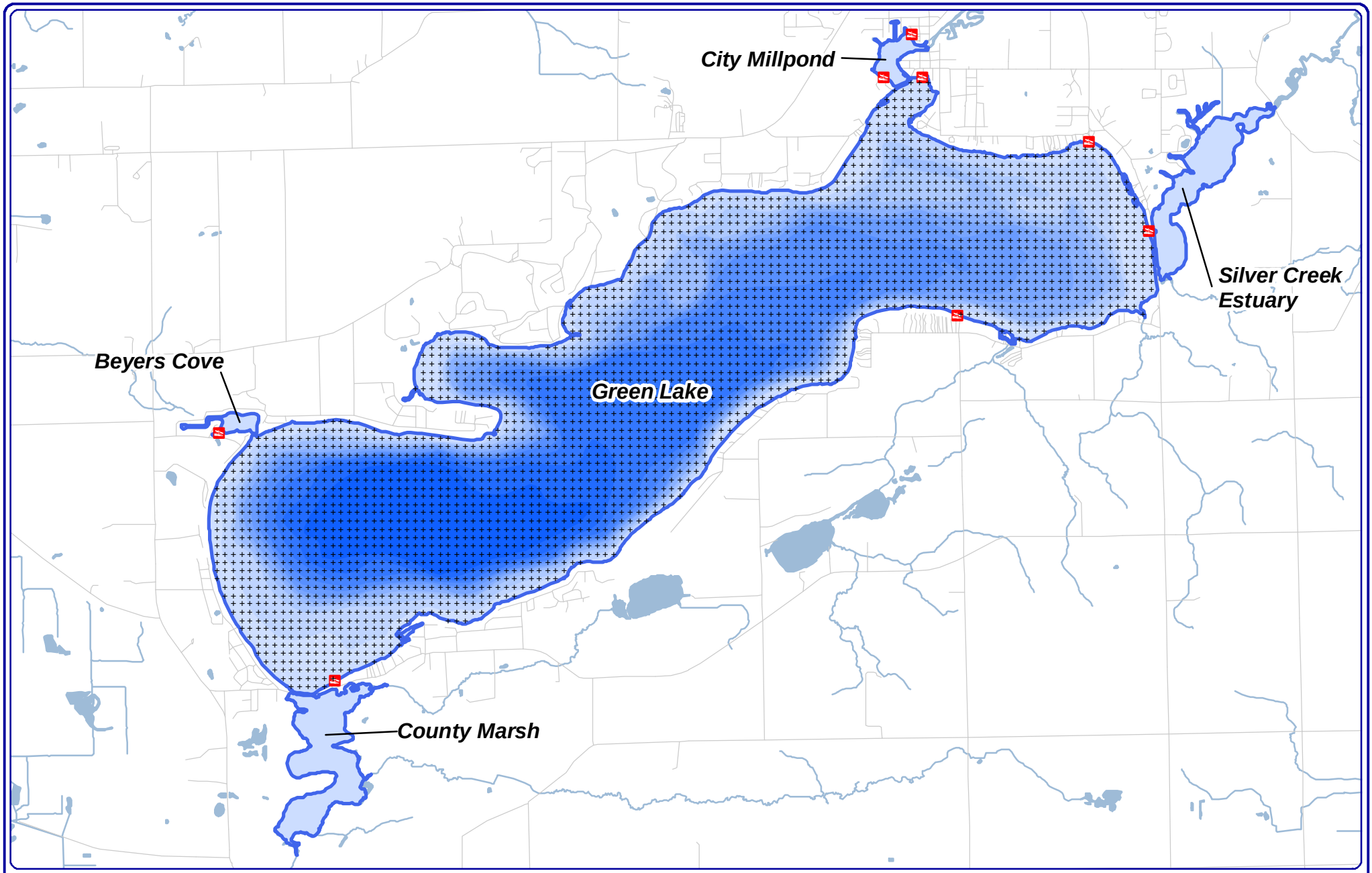

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5,100
Feet

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Sources:
Roads and Hydro: WDNR
Bathymetry: WDNR, digitized by Onterra
Map Date: December 2, 2014
Filename: Map1_GreenLake_Location.mxd


Project Location in Wisconsin

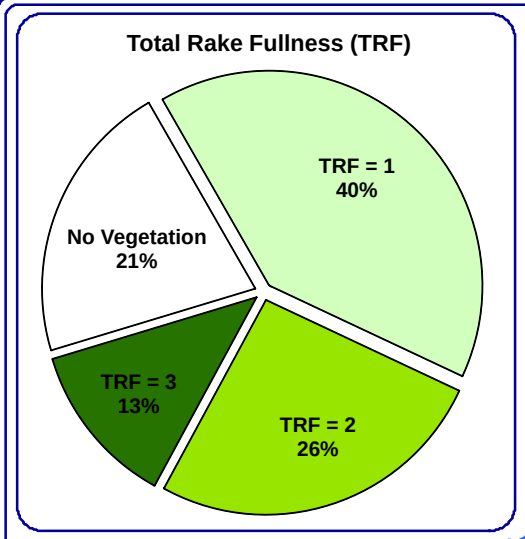
Legend

Green Lake ~7,346 acres
WDNR Definition

\+ Point-Intercept Survey Location
100-meter spacing, 3,120 total points

Public Boat Landing

Map 1
Green Lake
Green Lake County, Wisconsin
Project Location & Lake Boundaries



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Legend

- No Vegetation
- Total Rake Fullness = 1
- Total Rake Fullness = 2
- Total Rake Fullness = 3
- Greater Than Max Depth of Plant Growth
- Non-navigable/Temporary Obstacle
- Public Boat Landing

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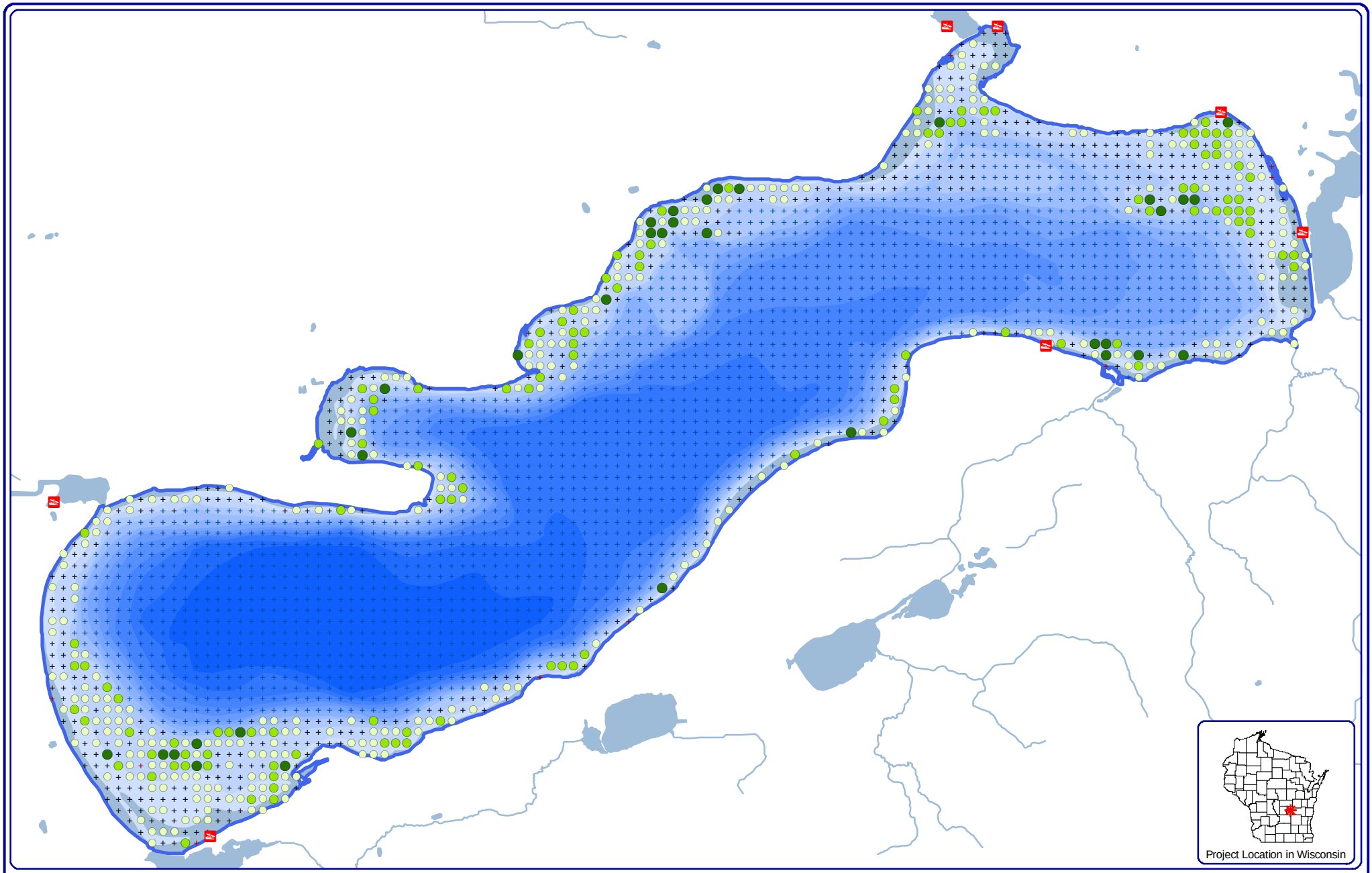
Sources:
Roads and Hydro: WDNR
Bathymetry: WDNR, digitized by Onterra
Map Date: December 2, 2014
Filename: Map2_GreenLake_TRFPI.mxd

Map 2
Green Lake
Green Lake County, Wisconsin
2014 PI Survey:
Aquatic Vegetation Distribution



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Legend

Coontail (July 2014)

- Not Present
- Total Rake Fullness = 1
- Total Rake Fullness = 2
- Total Rake Fullness = 3
- Greater Than Max Depth of Plant Growth
- Non-navigable/Temporary Obstacle
- Public Boat Landing

Map 3

Green Lake

Green Lake County, Wisconsin

2014 PI Survey: Coontail (*Ceratophyllum demersum*) Locations

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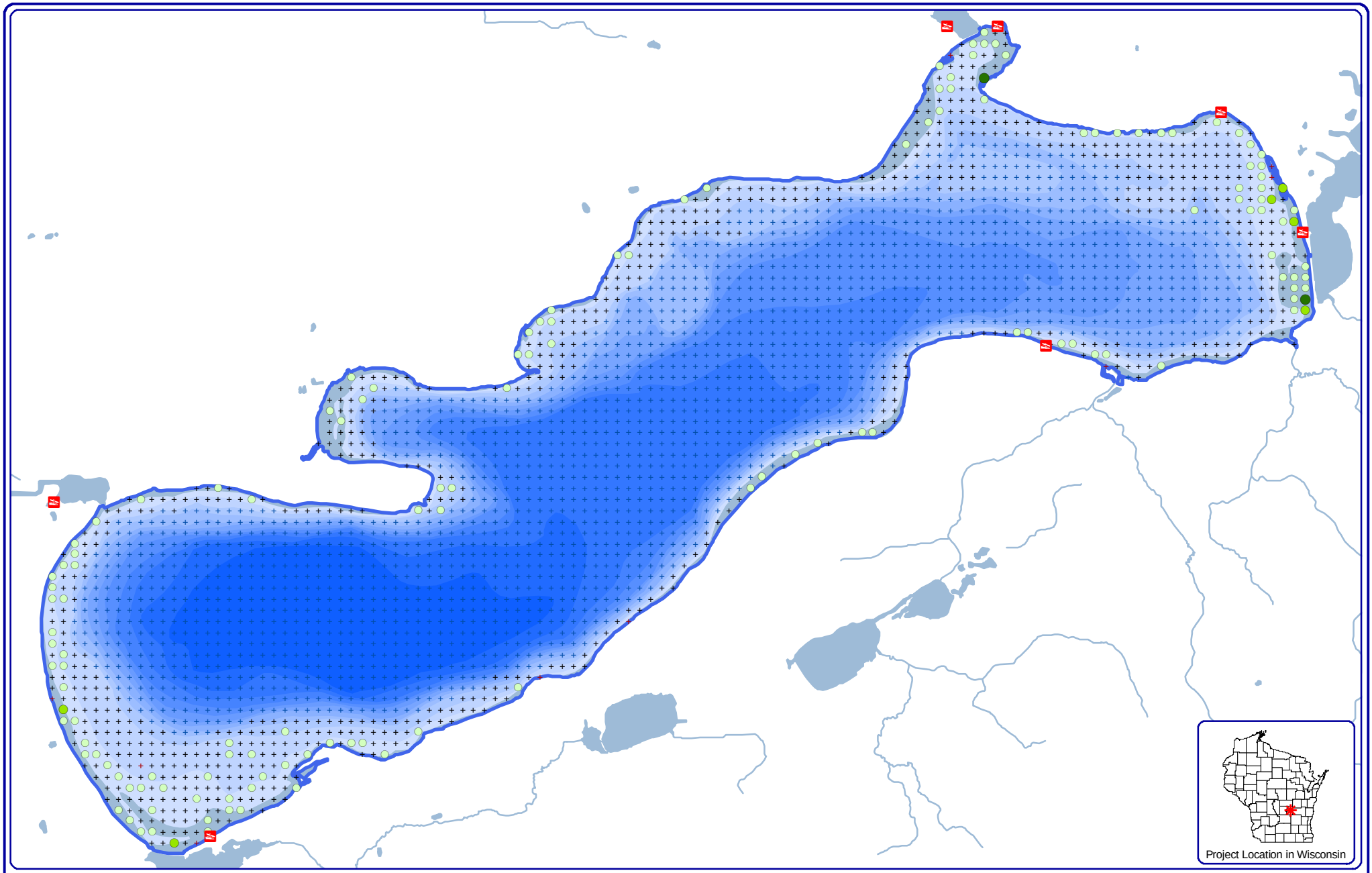
Sources:
Roads and Hydro: WDNR
Bathymetry: WDNR, digitized by Onterra
Aquatic Plants: Onterra, 2014
Map Date: December 2, 2014
Filename: Map3_GreenLake_Coontail.mxd



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Legend

Sago Pondweed (July 2014)

- Not Present
- Total Rake Fullness = 1
- Total Rake Fullness = 2
- Total Rake Fullness = 3
- Greater Than Max Depth of Plant Growth
- Non-navigable/Temporary Obstacle
- Public Boat Landing

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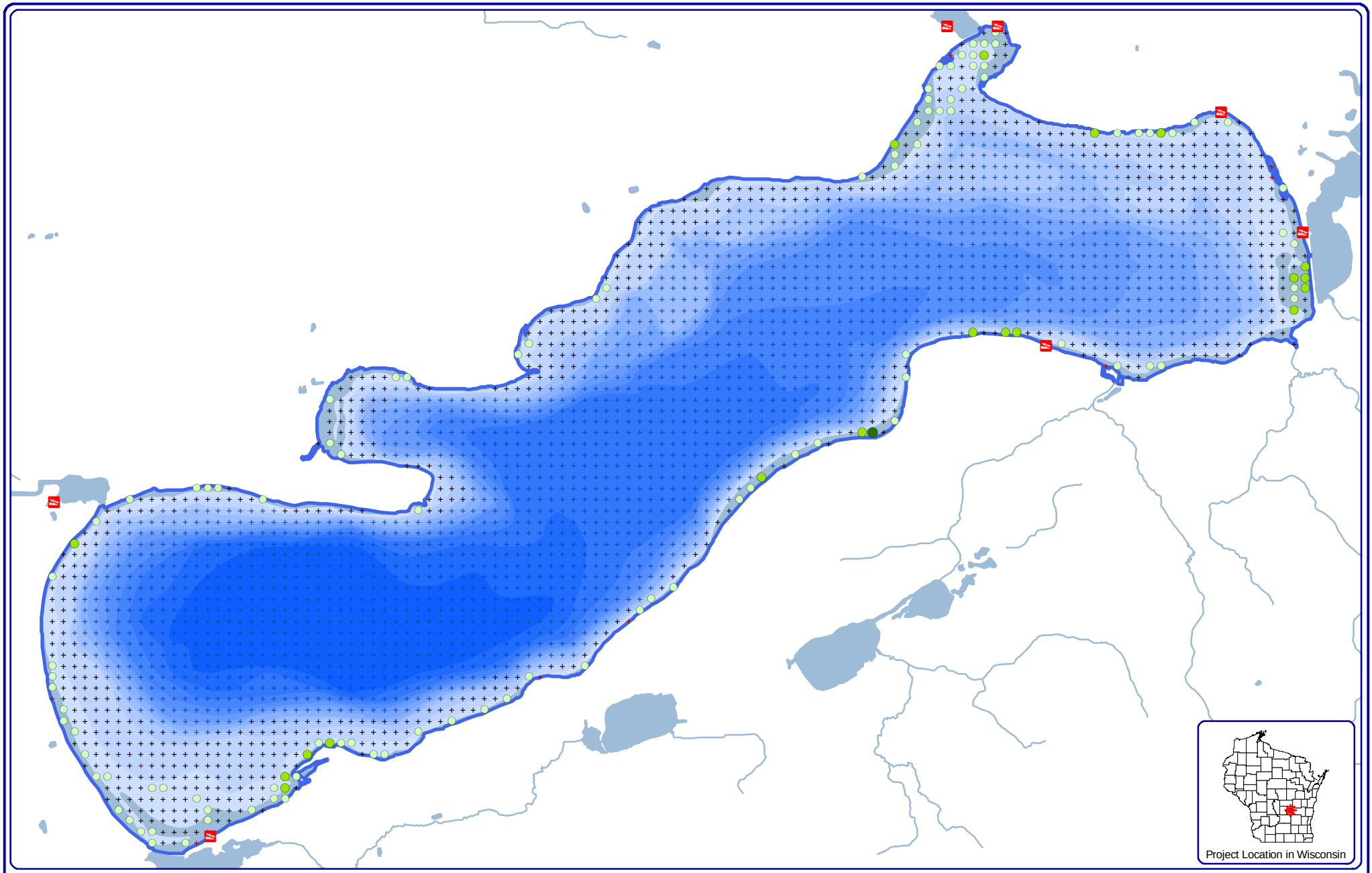
Sources:
Roads and Hydro: WDNR
Bathymetry: WDNR, digitized by Onterra
Aquatic Plants: Onterra, 2014
Map Date: December 2, 2014
Filename: Map4_GreenLake_SagoPondweed.mxd

Map 4
Green Lake
Green Lake County, Wisconsin

2014 PI Survey: Sago Pondweed (*Stuckenia pectinata*) Locations



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Legend

Wild Celery (July 2014)

- Not Present
- Total Rake Fullness = 1
- Total Rake Fullness = 2
- Total Rake Fullness = 3
- Greater Than Max Depth of Plant Growth
- Non-navigable/Temporary Obstacle
- Public Boat Landing

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Sources:
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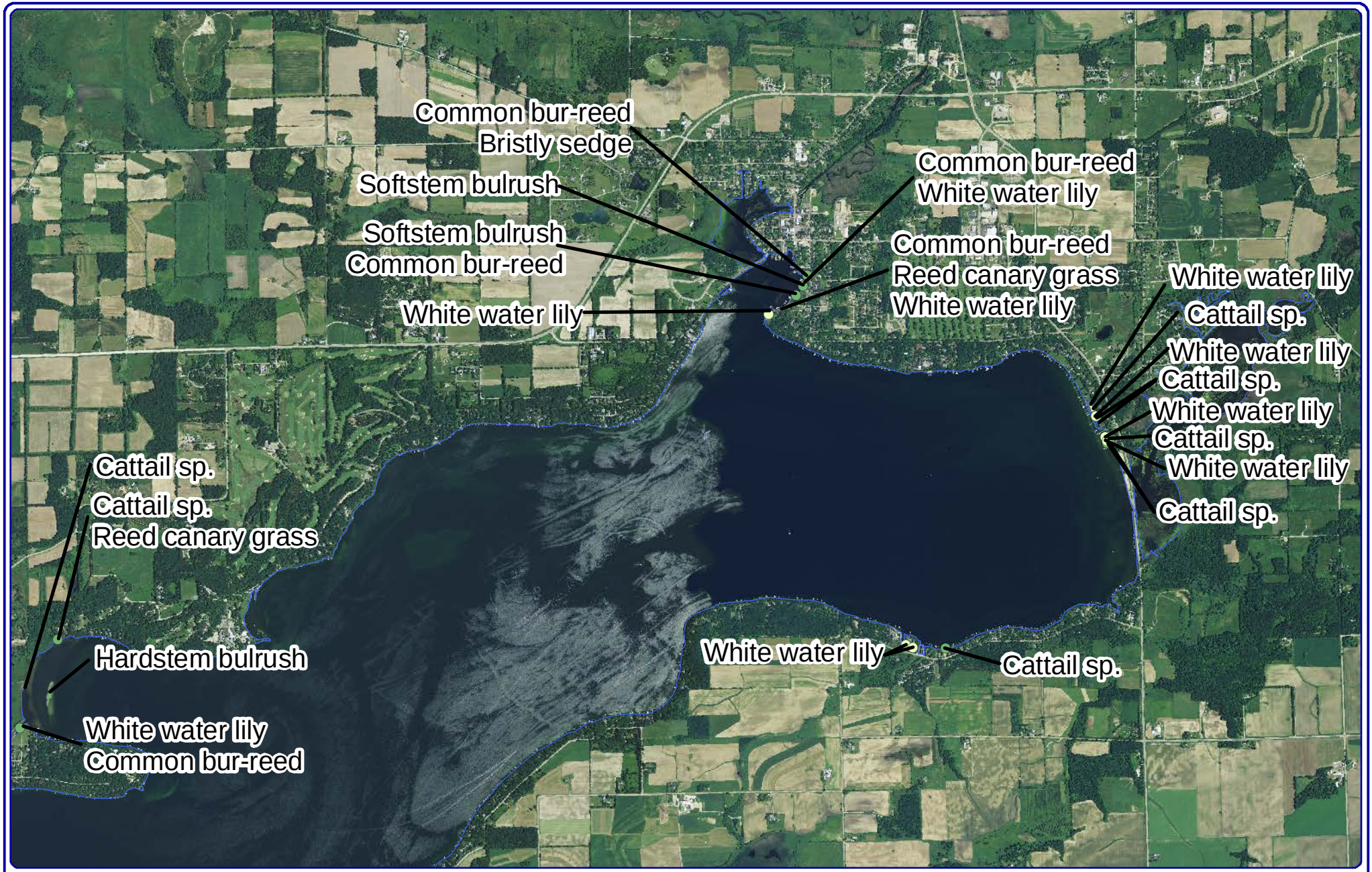
Bathymetry: WDNR, digitized by Onterra
Aquatic Plants: Onterra, 2014
Map Date: December 2, 2014
Filename: Map5_GreenLake_WildCelery.mxd

Map 5
Green Lake
Green Lake County, Wisconsin

2014 PI Survey: Wild Celery (*Vallisneria americana*) Locations



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Sources:
Aquatic Plants: Onterra, 2014
Orthophotography: NAIP, 2013
Map date: November 14, 2013
Filename: Map6_Green_Comm_2014_East.mxd

Project Location in Wisconsin

Legend

Small Plant Communities
- Emergent
- Floating-leaf
- Mixed Floating-leaf & Emergent
- Purple Loosestrife

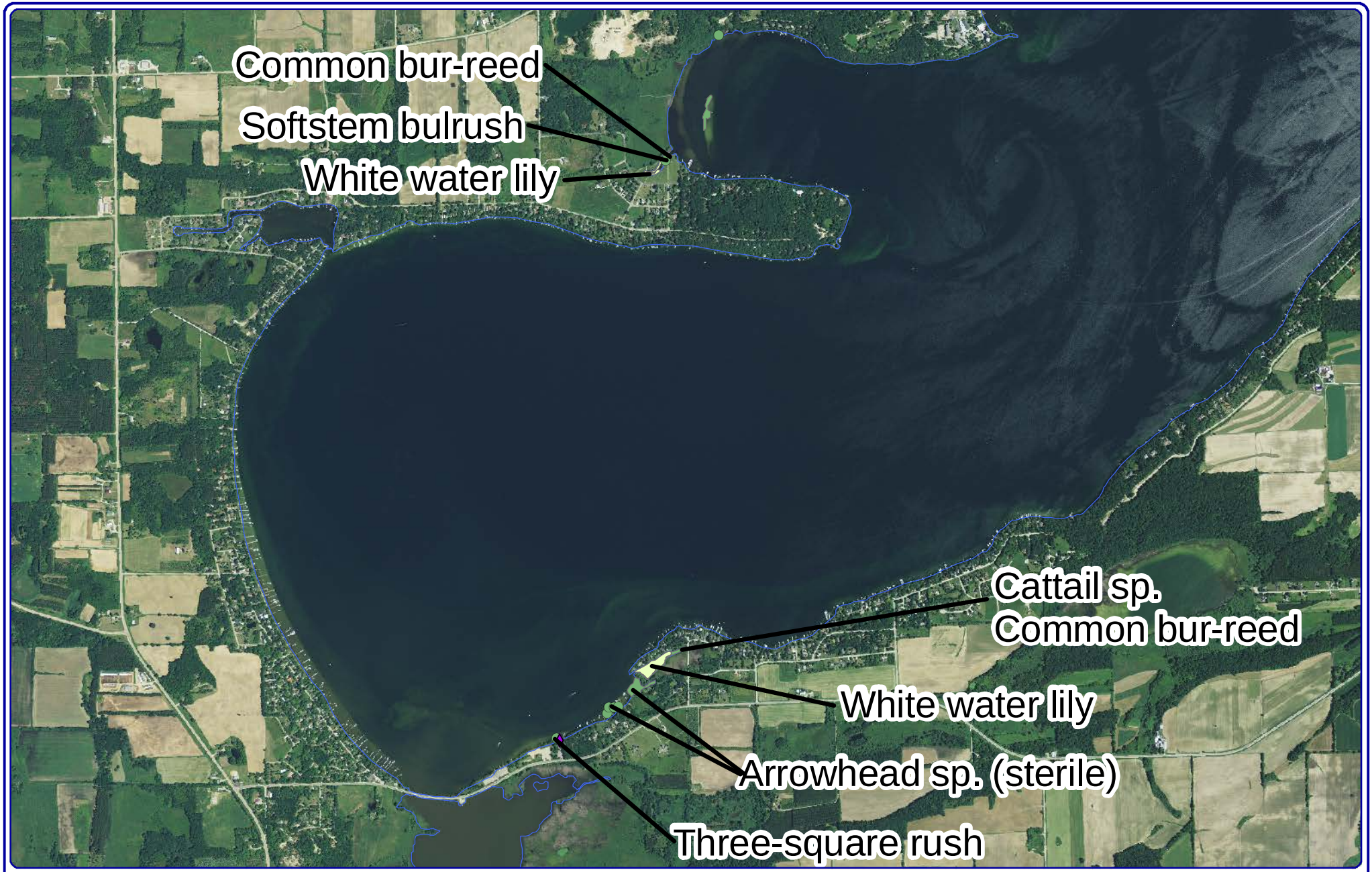
Large Plant Communities
- Emergent
- Floating-leaf
- Mixed Floating-leaf & Emergent

Map 6

Green Lake - East

Green Lake County, Wisconsin

Emergent & Floating-Leaf Aquatic Plant Communities



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Sources:
Aquatic Plants: Onterra, 2014
Orthophotography: NAIP, 2013
Map date: November 14, 2013
Filename: Map7_Green_Comm_2014_West.mxd

Project Location in Wisconsin

Legend

Small Plant Communities
- Emergent
- Floating-leaf
- Mixed Floating-leaf & Emergent
- Purple Loosestrife

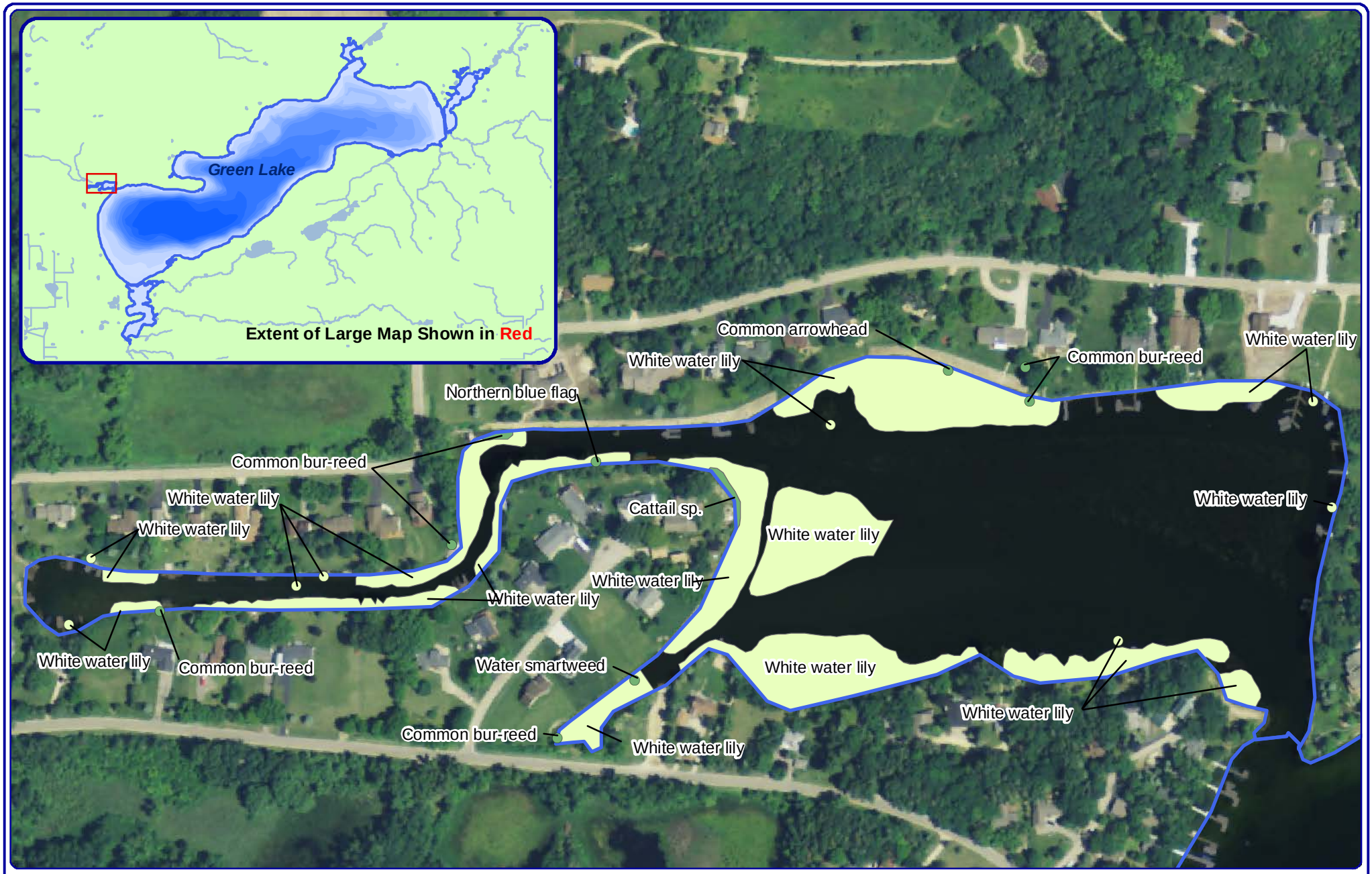
Large Plant Communities
- Emergent
- Floating-leaf
- Mixed Floating-leaf & Emergent

Map 7

Green Lake - West

Green Lake County, Wisconsin

Emergent & Floating-Leaf Aquatic Plant Communities



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Sources:
Hydro: WDNR
Orthophotography: NAIP, 2013
Aquatic Plants: Onterra, 2013
Map Date: December 2, 2014
Filename: Map8_BeyersCove_Comm_2013.mxd

Project Location in Wisconsin

Legend

Small Plant Community
- Emergent
- Floating-Leaf
- Mixed Emergent & Floating-Leaf

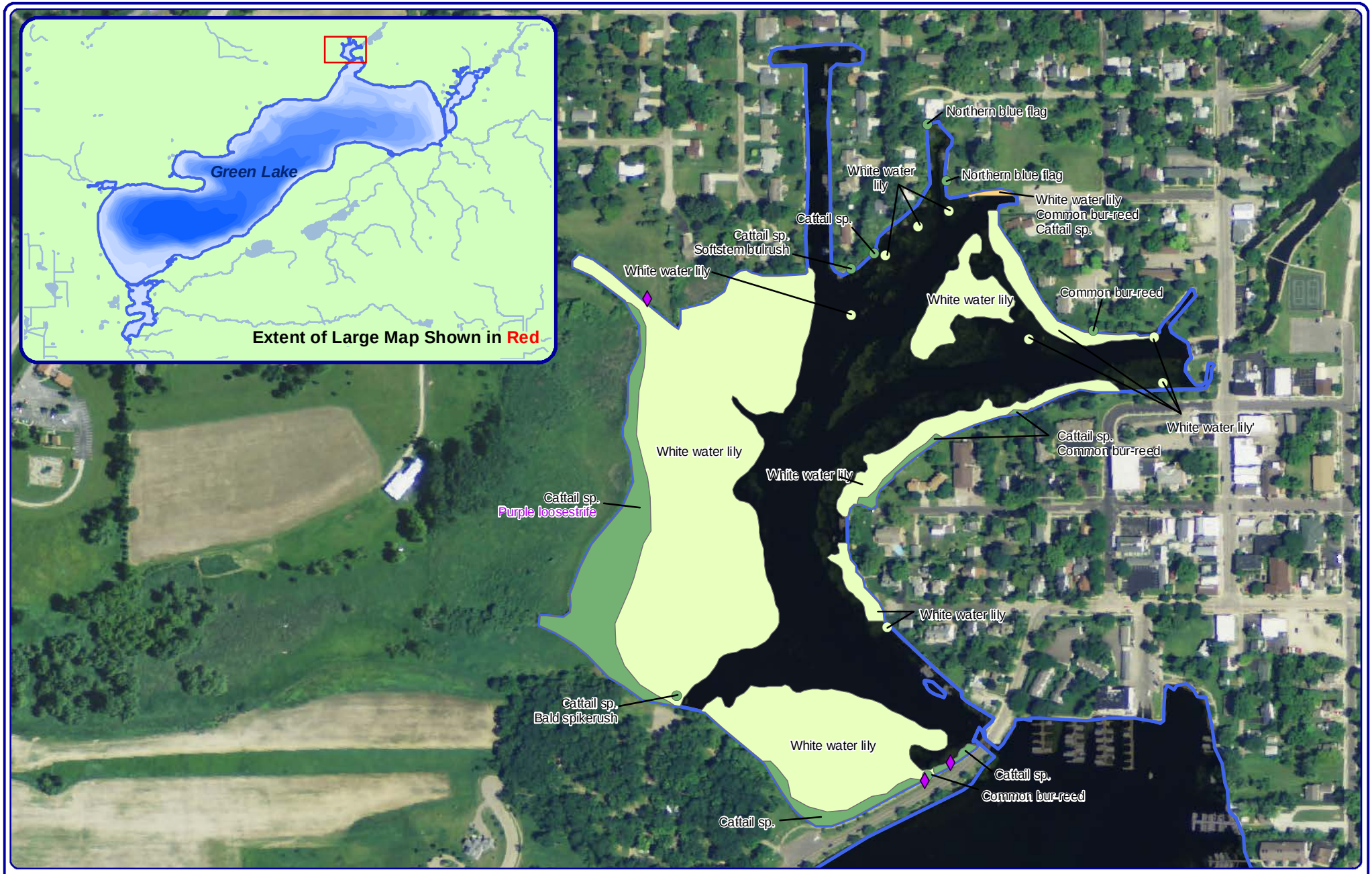
Large Plant Community
- Emergent
- Floating-Leaf
- Mixed Emergent & Floating-Leaf

Map 8

Green Lake - Beyers Cove

Green Lake County, Wisconsin

2013 Emergent & Floating-Leaf Aquatic Plant Communities



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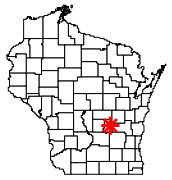
Sources:
Hydro: WDNR
Orthophotogaphy: NAIP, 2013
Aquatic Plants: Onterra, 2013
Map Date: December 2, 2014
Filename: Map9_CityMillpond_Comm_2013.mxd



Project Location in Wisconsin

Legend

Small Plant Community
- Emergent
- Floating-Leaf
- Mixed Emergent & Floating-Leaf
- Purple Loosestrife

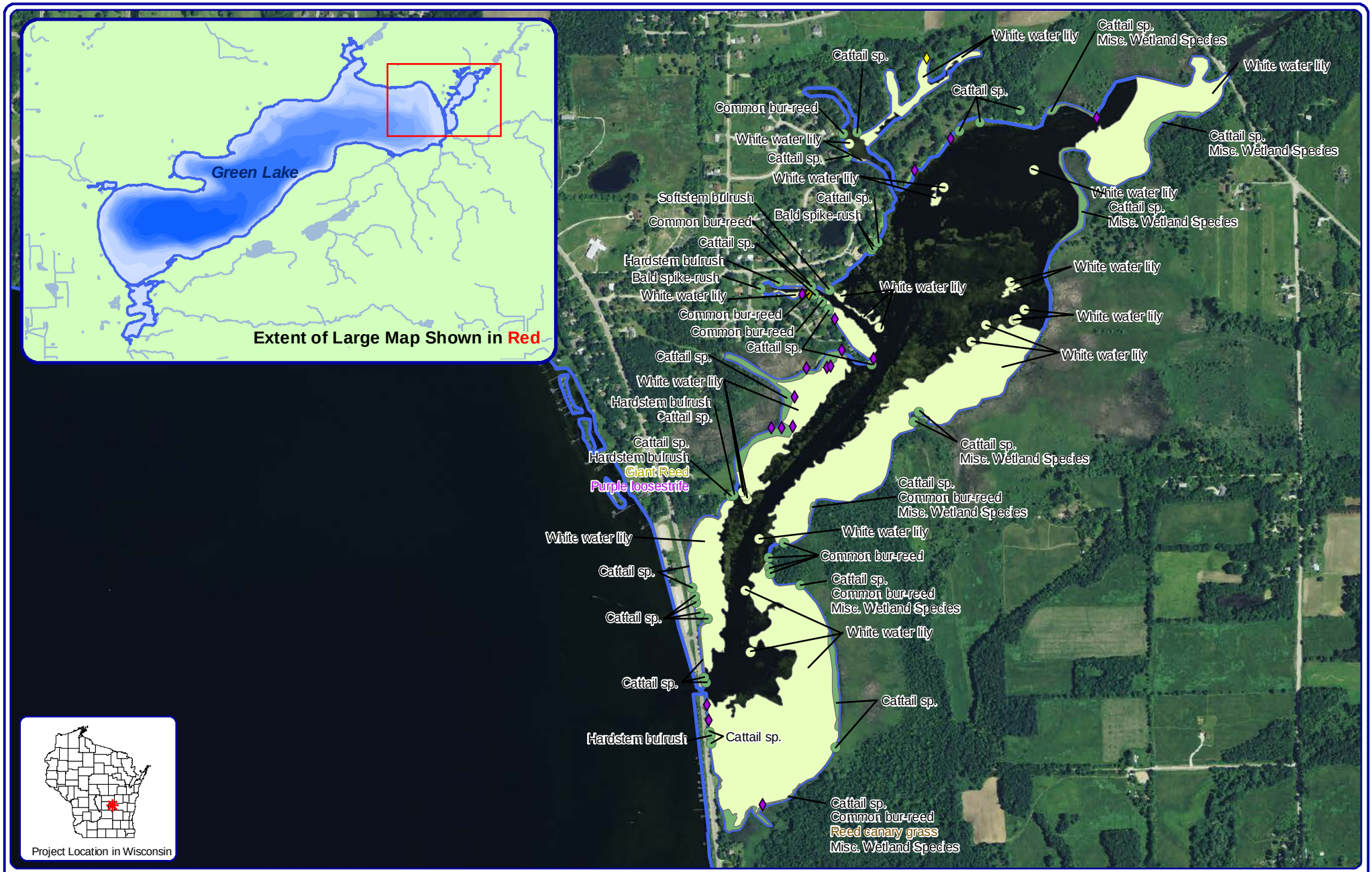
Large Plant Community
- Emergent
- Floating-Leaf
- Mixed Emergent & Floating-Leaf

Map 9

Green Lake - City Millpond

Green Lake County, Wisconsin

2013 Emergent & Floating-Leaf Aquatic Plant Communities



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Sources:
Hydro: WDNR
Orthophotogaphy: NAIP, 2013
Aquatic Plants: Onterra, 2013
Map Date: December 2, 2014
Filename: Map10_SilverCreek_Comm_2013.mxd

Legend

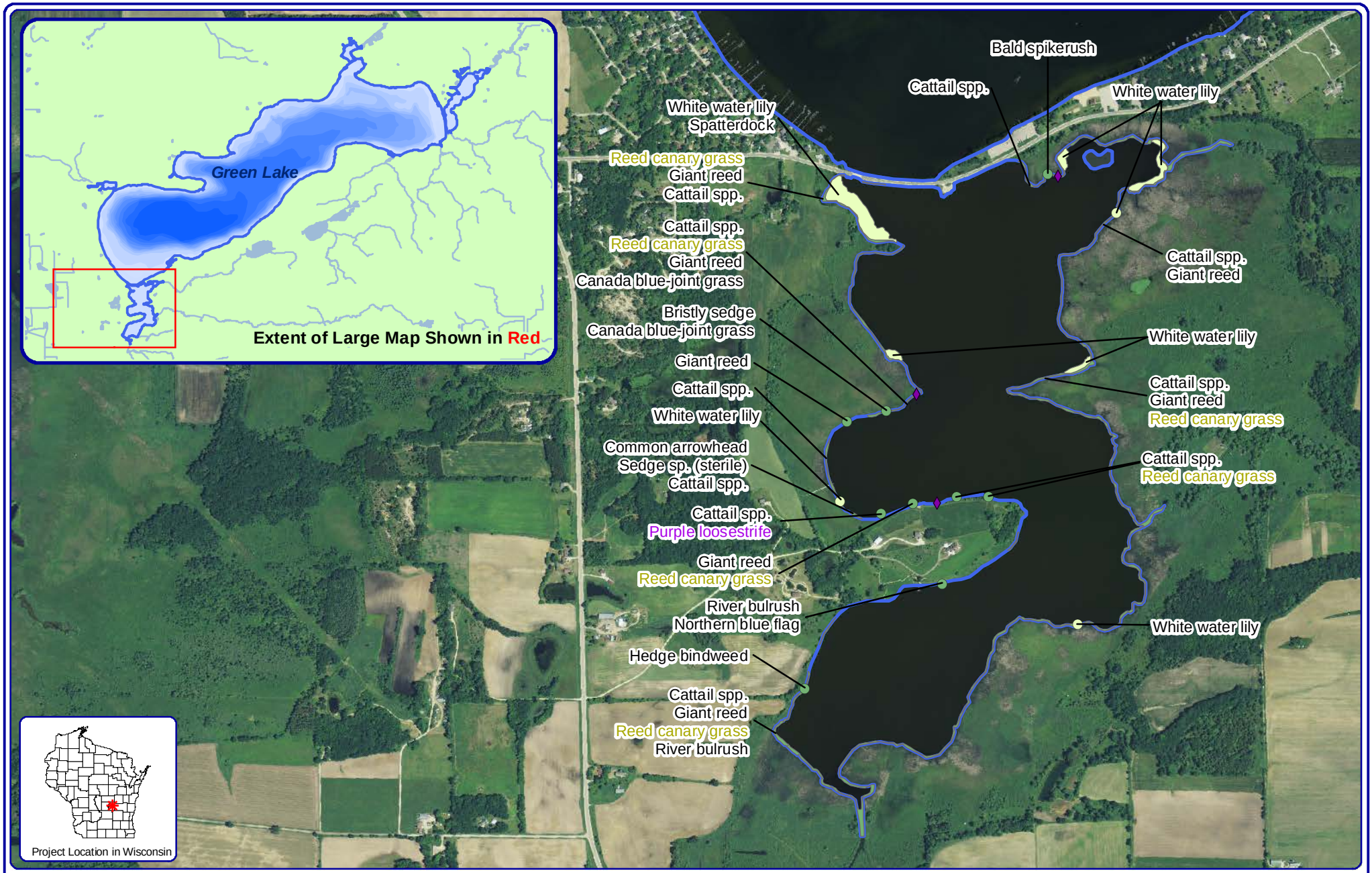
Small Plant Community	Large Plant Community	Exotic Plant Community
Emergent	Emergent	Purple Loosestrife
Floating-Leaf	Floating-Leaf	Pale-yellow Iris
Mixed Emergent & Floating-Leaf	Mixed Emergent & Floating-Leaf	Giant Reed

Map 10

Green Lake - Silver Creek Estuary

Green Lake County, Wisconsin

2013 Emergent & Floating-Leaf Aquatic Plant Communities



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Sources:
Hydro: WDNR
Orthophotogaphy: NAIP, 2013
Aquatic Plants: Onterra, 2013
Map Date: December 2, 2014
Filename: Map11_CountyMarsh_Comm_2014.mxd

Legend

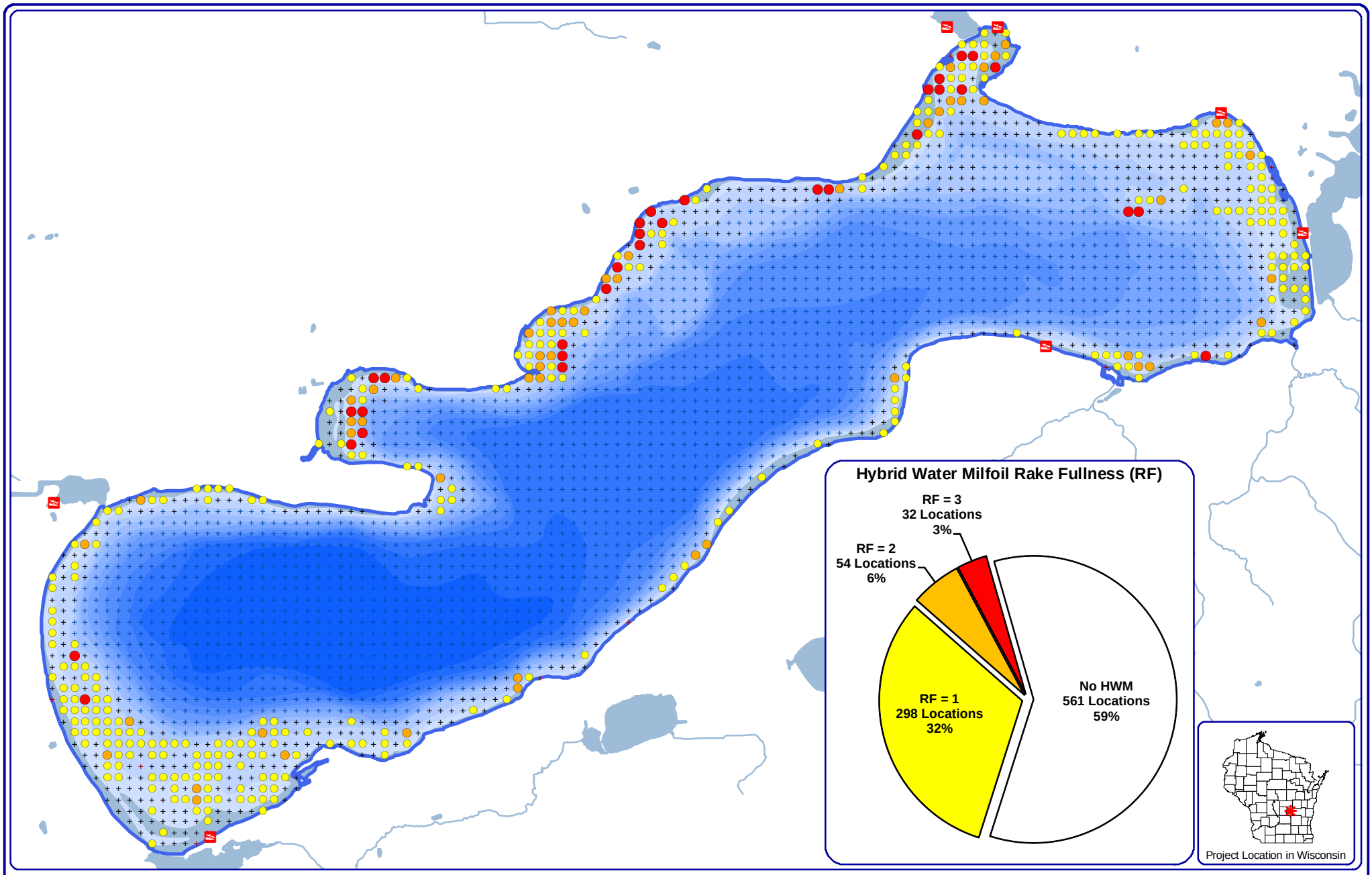
Small Plant Community	Large Plant Community	Exotic Plant Community
Emergent	Emergent	Purple Loosestrife
Floating-Leaf	Floating-Leaf	
Mixed Emergent & Floating-Leaf	Mixed Emergent & Floating-Leaf	

Map 11

Green Lake - County Marsh

Green Lake County, Wisconsin

2014 Emergent & Floating-Leaf Aquatic Plant Communities



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Sources:
Roads and Hydro: WDNR
Bathymetry: WDNR, digitized by Onterra
Aquatic Plants: Onterra, 2014
Map Date: December 2, 2014
Filename: Map12_GreenLake_HWM.mxd

Legend

Hybrid Water Milfoil (July 2014)

- Not Present
- Total Rake Fullness = 1
- Total Rake Fullness = 2
- Total Rake Fullness = 3
- Greater Than Max Depth of Plant Growth
- Non-navigable/Temporary Obstacle
- Public Boat Landing

Map 12

Green Lake

Green Lake County, Wisconsin

2014 PI Survey: Hybrid Water Milfoil (*Myriophyllum sibiricum X spicatum*) Locations