Minnie, the Lake Monster, Spotted in Lake Nokomis in 2010

Aquatic Invasive Species Action Plan for Greenleaf Lake, Le Sueur County, Minnesota

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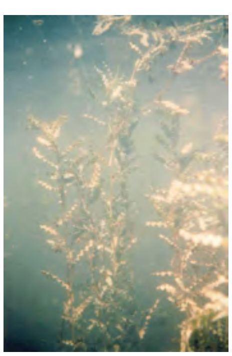
Summary

Overview of aquatic invasive species that could impact Greenleaf Lake are listed below. As of 2014, curlyleaf pondweed and common carp were the only non-native species known to be present in Greenleaf Lake.

Species	Lake Status	Potential for Growth in Greenleaf Lake	Management Action	
			Short Term	Long Term
Species of Interest				
1. Cylindro (blue-green algae)	Unknown	High	Monitoring	Reduce phosphorus loading
2. Curlyleaf pondweed	Established; control when necessary	Mostly moderate	Annual delineations or surveys to check curlyleaf growth	Selective treatment for heavy growth conditions
3. Eurasian watermilfoil	Not present in Greenleaf	Moderate to high	Annual surveys or delineations if detected	Selective treatment for heavy growth conditions
4. Zebra mussels	Not present in Greenleaf, but present in Prior lakes, Scott Co	Low	Mussel monitoring devices for early detection	Small-scale removal techniques if needed
5. Common carp	Sampled in Greenleaf (2011 MnDNR fish survey)	Moderate	Determine where carp are spawning if they are found	Carp management tasks if growth becomes abundant
Species to Watch				
Flowering rush	Present in watershed	Moderate	Annual observations or surveys	Selective treatment
Purple loosestrife	Present in watershed	Fair	Annual surveys or observations	Spot control and use of beetles for large area control
Hydrilla	Not present in Greenleaf	Low to moderate	MnDNR sponsored treatments	Ongoing control
Rusty crayfish	Not present in Greenleaf	Fair to moderate	Crayfish traps for early detection	Use fish to control rusty crayfish
Chinese and Banded Mystery snail	May be present in Greenleaf	Fair	Inform and educate	Small-scale removal techniques, if needed
Spiny waterflea	Not present in Greenleaf	Moderate to high	Inform and educate	Natural fish predation
Faucet snail	Not present in Greenleaf	Moderate to high	Inform and educate	
Asian carp	Not present in Greenleaf	Low	Inform and educate	Removal if practical
Snakehead	Not present in Greenleaf	Moderate	Inform and educate	



Curlyleaf Pondweed

Eurasian Watermilfoil

Zebra Mussel

Five Aquatic Invasive Species of Interest

1. Blue-green Algae (Cylindro)

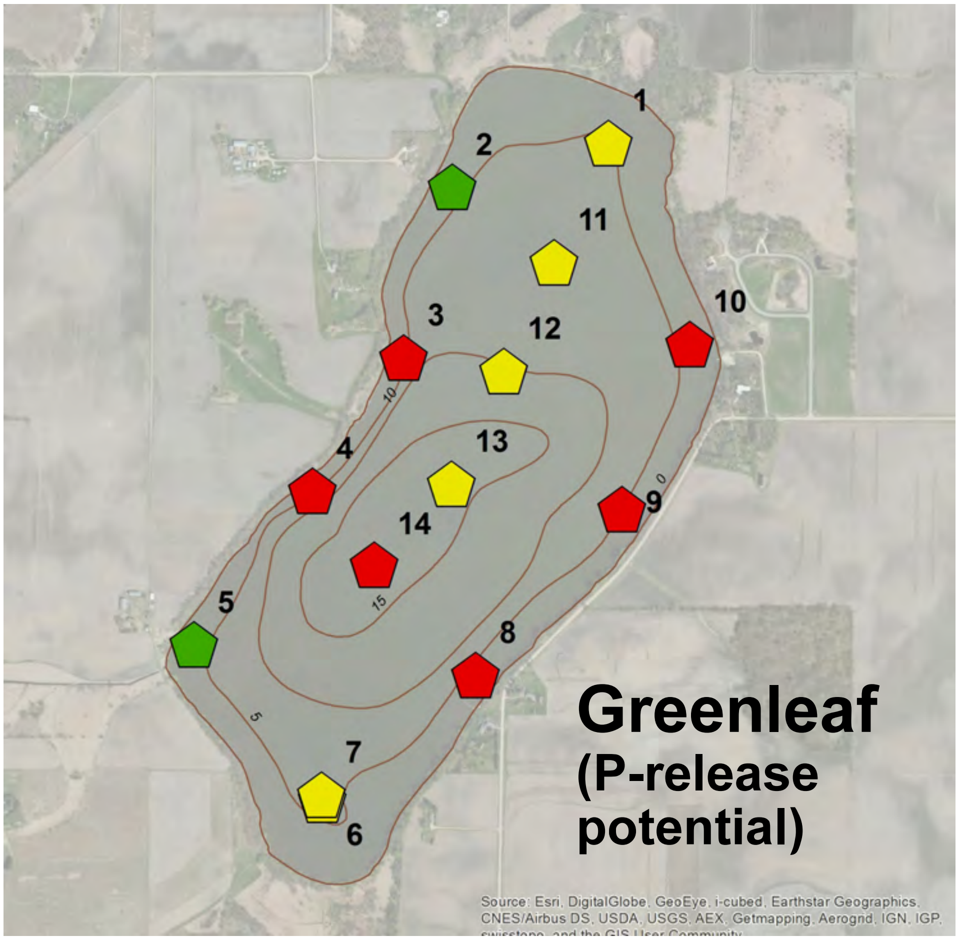


Figure S1. Sediment P-release potential with the possibility to produce excessive phosphorus loading in Greenleaf Lake that could produce blue-green algae and Cylindro blooms.
Key: Green = low potential, yellow = moderate potential, and red = high potential.

An invasive blue-green algae, *Cylindrospermopsis sp*, referred to as Cylindro, is spreading around the United States since it was observed in the early 2000s. Cylindro is typically found in lakes with low Secchi disc transparencies and high phosphorus concentrations. Greenleaf Lake currently has these characteristics but Cylindro has not been identified in Greenleaf Lake. Cylindro is known to produce toxins that at high concentrations could be harmful to other aquatic life.

Action Plan: If lake phosphorus concentrations are reduced, conditions will not be favorable to abundant Cylindro growth. Two sources of phosphorus to Greenleaf Lake come from watershed loading and internal phosphorus loading. A variety of factors contribute to internal phosphorus loading in lakes. Research by Jensen et al (1992) found when a total iron to total phosphorus ratio was greater than 15 to 1, phosphorus release from lake sediments was minor. That benchmark of 15:1 has been used to characterize the potential of Greenleaf Lake sediments to release phosphorus. Results of the sediment survey for Greenleaf Lake show 6 sediment sites (shown with red pentagons) have a low Fe:P ratio and that phosphorus release from lake sediments has the potential to be high (Figure S1). At other sites sediment phosphorus release appears to be light to moderate. If watershed phosphorus contributions are reduced, treating the lake sediment phosphorus hot spots with alum could lower lake phosphorus concentrations and reduce algal blooms.

2. Curlyleaf Pondweed

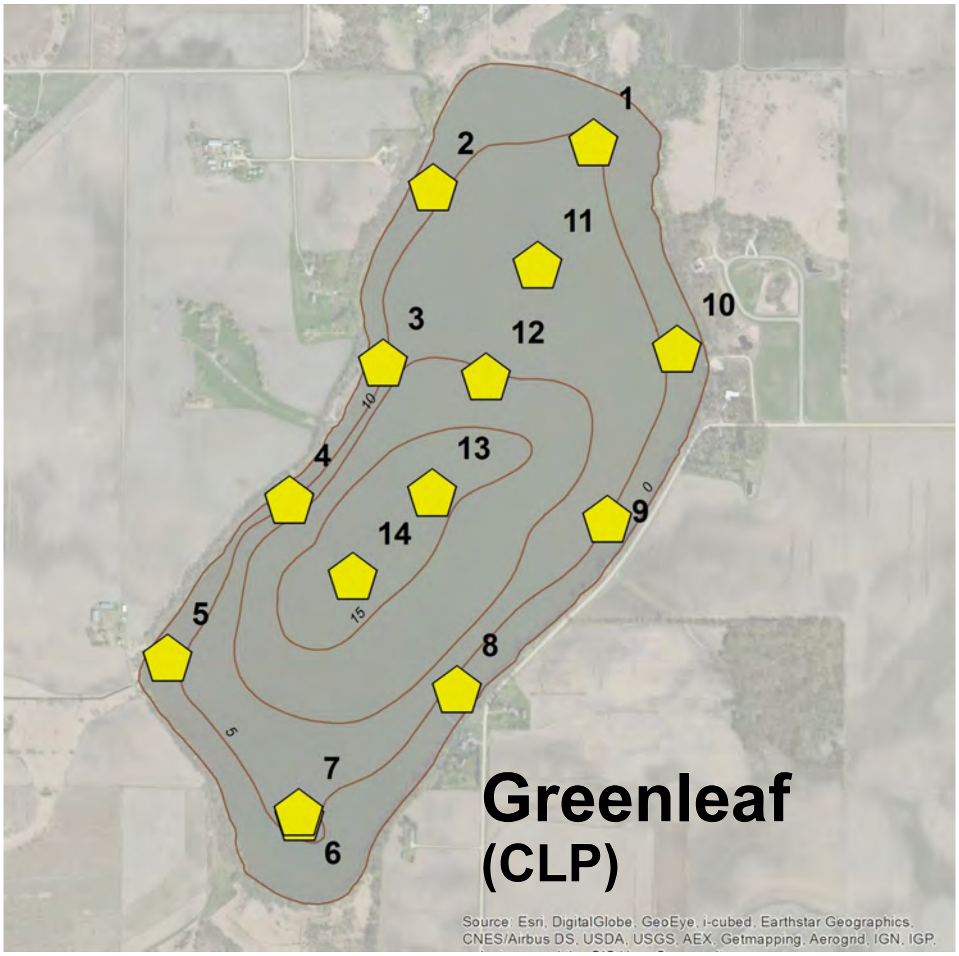


Figure S2. Curlyleaf potential growth based on lake sediment analyses for Greenleaf Lake.
Key for Potential Growth: Yellow = moderate growth.

Curlyleaf pondweed is present in Greenleaf Lake. Research has found curlyleaf is limited or enhanced based on lake sediment characteristics. Curlyleaf does best in sediments with a high pH and low iron content (McComas, unpublished).

Based on lake sediment survey results it is predicted curlyleaf will to grow in Greenleaf Lake at mostly moderate abundances.

Action Plan: Because curlyleaf pondweed is already established in Greenleaf Lake, it is past the point of eradication. Ongoing activities will concentrate on curlyleaf management. The use of herbicides produce annual control, but long-term control (where treatments could be discontinued in the future) has not been observed (McComas et al. In press). Therefore annual treatments for curlyleaf control may have to be considered.

Based on lake sediment surveys, it is predicted curlyleaf can grow in a number of areas around Greenleaf Lake although heavy growth will be limited in most years. These areas could be treated either with an endothall herbicide or by harvesting.

3. Eurasian Watermilfoil

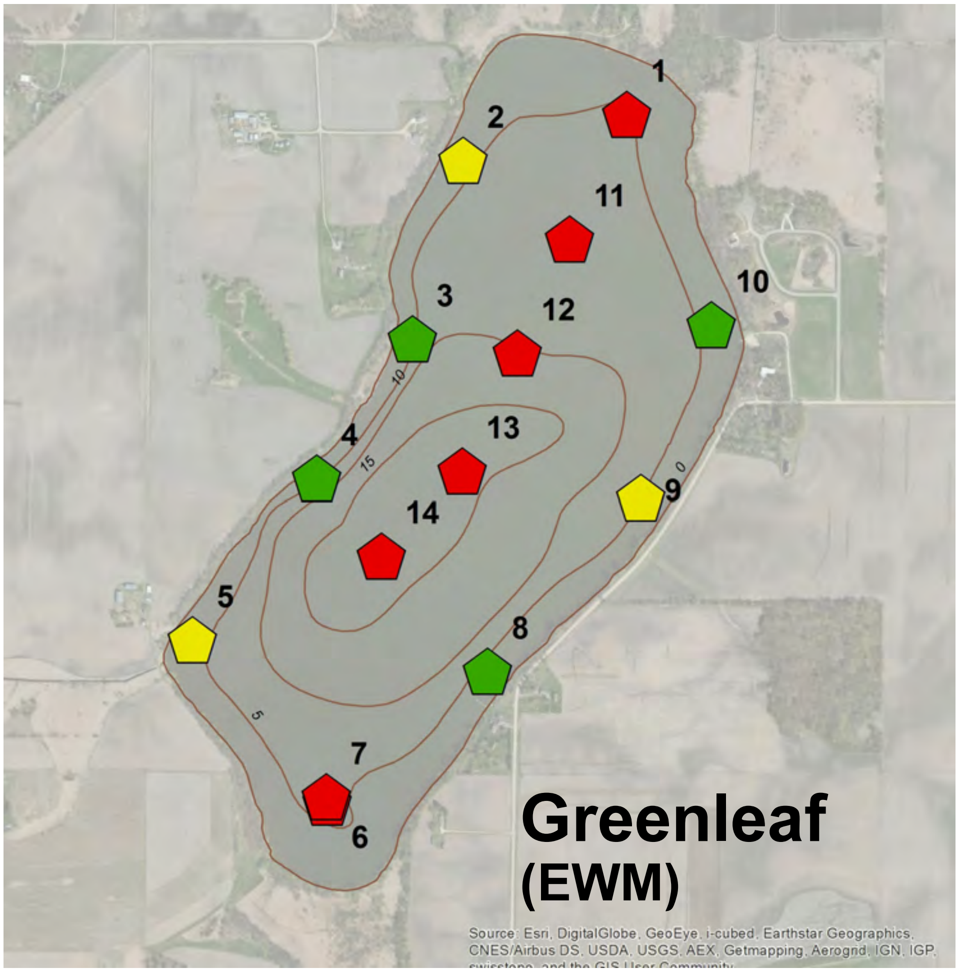


Figure S3. Eurasian watermilfoil potential growth based on lake sediment analyses for Greenleaf Lake. Key for Potential Growth: Green = light growth, yellow = moderate growth, red = heavy growth.

Eurasian watermilfoil has not been found in Greenleaf Lake as of 2014. Heavy milfoil growth has been correlated with high sediment nitrogen conditions and Greenleaf Lake has several sites with high lake sediment nitrogen conditions. The potential for future milfoil growth, based on lake sediment sampling, predicts moderate to heavy growth with potential for heavy growth mostly down the center of Greenleaf Lake (Figure S3).

For Greenleaf Lake, it is estimated the plants have the potential to grow down to at least 5 feet of water depth based on low Secchi transparencies, restricting milfoil growth to nearshore areas. Results of the sediment survey indicate growth would be a mix of light to heavy growth.

Action Plan: Eurasian watermilfoil is not present in Greenleaf Lake currently. Ongoing annual scouting activities are recommended. Lake sediment analysis indicates the potential for moderate to heavy milfoil growth over much of the lake. At the present time the low Secchi transparency may restrict growth to water depths of less than 5 feet. However, if water clarity increases, Eurasian watermilfoil could colonize deeper water with potential heavy growth.

4. Zebra Mussel

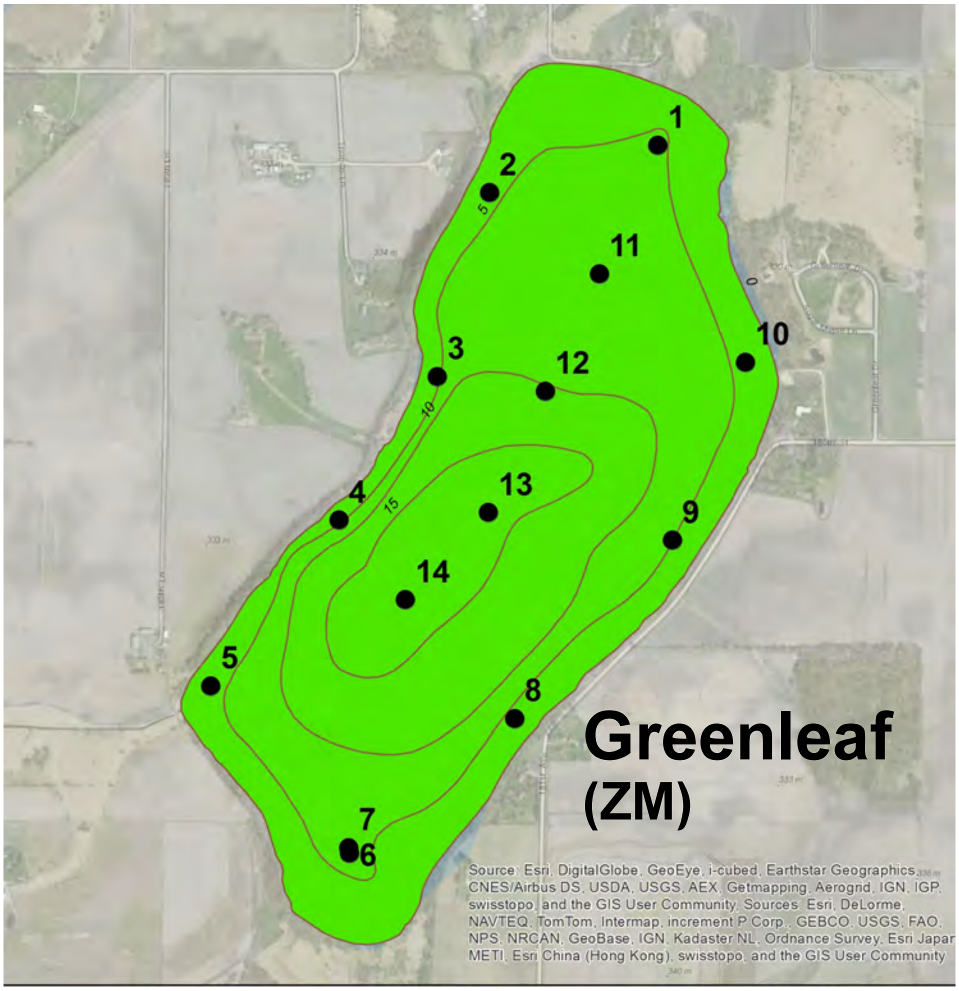


Figure S4. Zebra mussel potential growth based on water column and substrate characteristics. Key for Potential Growth: Green = light growth.

Zebra mussels have not been found in Greenleaf Lake as of 2014. A review of water column and substrate characteristics was used to evaluate the potential for zebra mussel growth. It appears that zebra mussel growth would be limited in Greenleaf Lake due to the high chlorophyll concentration which is indicative of summertime blue-green algae. Colonial blue-green algae are not easily filtered by zebra mussels and limit their growth. Although dissolved oxygen conditions are suitable for optimal to moderate growth down to water depths of about 16 feet and calcium concentrations are optimal for shell production, the blue-green algae would likely limit zebra mussel growth (Figure S4). A close cousin to the zebra mussel, the quagga mussel, has similar growth requirements and may be able to survive and propagate under more harsh conditions than zebra mussels. No quagga mussels have been reported in Le Sueur County as of 2014.

Action Plan: Zebra mussels have not been found in Greenleaf Lake as of 2014. Early detection activities are recommended through the growing season. If zebra mussels are detected, a rapid response plan includes a rapid response assessment. Because zebra mussel growth would likely be light, a rapid response treatment action is not a high priority. However, an action plan should be formulated and procedures should be outlined to prepare for future actions, if needed.

Under the right circumstances and depending on volunteer participation, costs would range from $5,000 to $50,000 if an eradication attempt was considered. Discussions with the MnDNR should be held prior to zebra mussel detection in Greenleaf Lake to outline control activities and the need for potential permits.

5. Common Carp

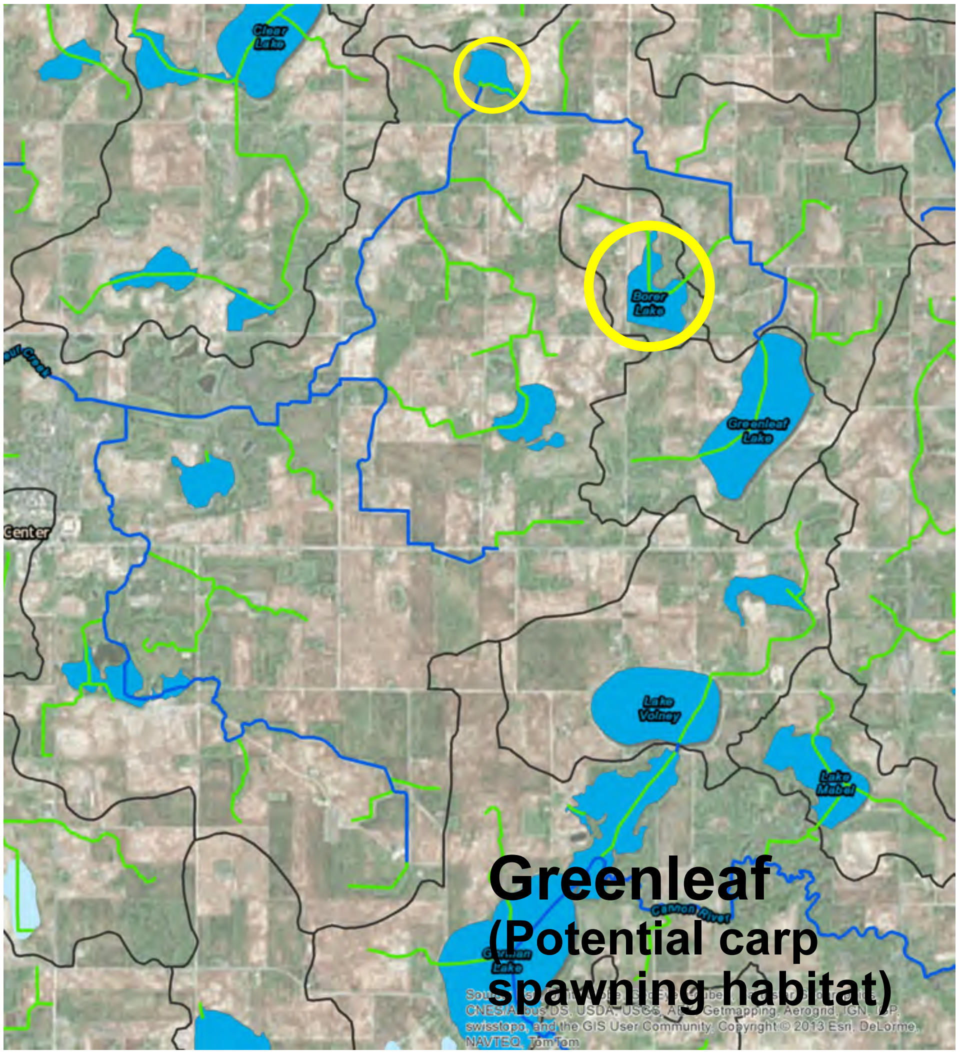


Figure S5. Common carp potential spawning habitat quality. Yellow circle indicates moderate potential for carp spawning sites for streams and lakes connected to Greenleaf Lake.

Common carp are present in Greenleaf Lake, the last MnDNR fish survey from 2011 did sample carp. Greenleaf Lake habitat suitability for future carp growth is moderate due to spawning conditions that are well suited for survival of young fish (Figure S5). Carp spawning success and population growth is limited when carp are confined to spawning within a lake. Usually predator fish will control the carp eggs and fry. Carp populations do best when there are shallow, off-lake spawning sites where fish predators would be low and thus allow the young carp to grow up to a size where predation is unlikely. It appears that Greenleaf Lake does have some potential for off-lake spawning habitat and it does appear to be favorable to successful carp spawning and rearing in Greenleaf Lake.

Action Plan: Carp are present in Greenleaf Lake, their size and abundance is slightly above average for the lake size according to the MnDNR. If carp abundance increases, aquatic plant coverage would likely decrease. As of 2014, no carp management is necessary, rather monitoring should be ongoing.

Summary of Environmental Risk Assessments for Five Aquatic Invasive Species for Greenleaf Lake, Le Sueur County, Minnesota

Two primary factors are used to define environmental risk assessment for aquatic invasive species: 1) the likelihood of establishment and 2) the consequences if it does become established. The likelihood of introduction and establishment is based on the distance to the nearest AIS population, the activity at the public access, and the suitability of Greenleaf Lake for supporting a new AIS population. The preceding pages outlined the growth potential for five AIS of interest. Typically if an AIS has the potential for heavy growth, the recreational and ecological consequences could be significant.

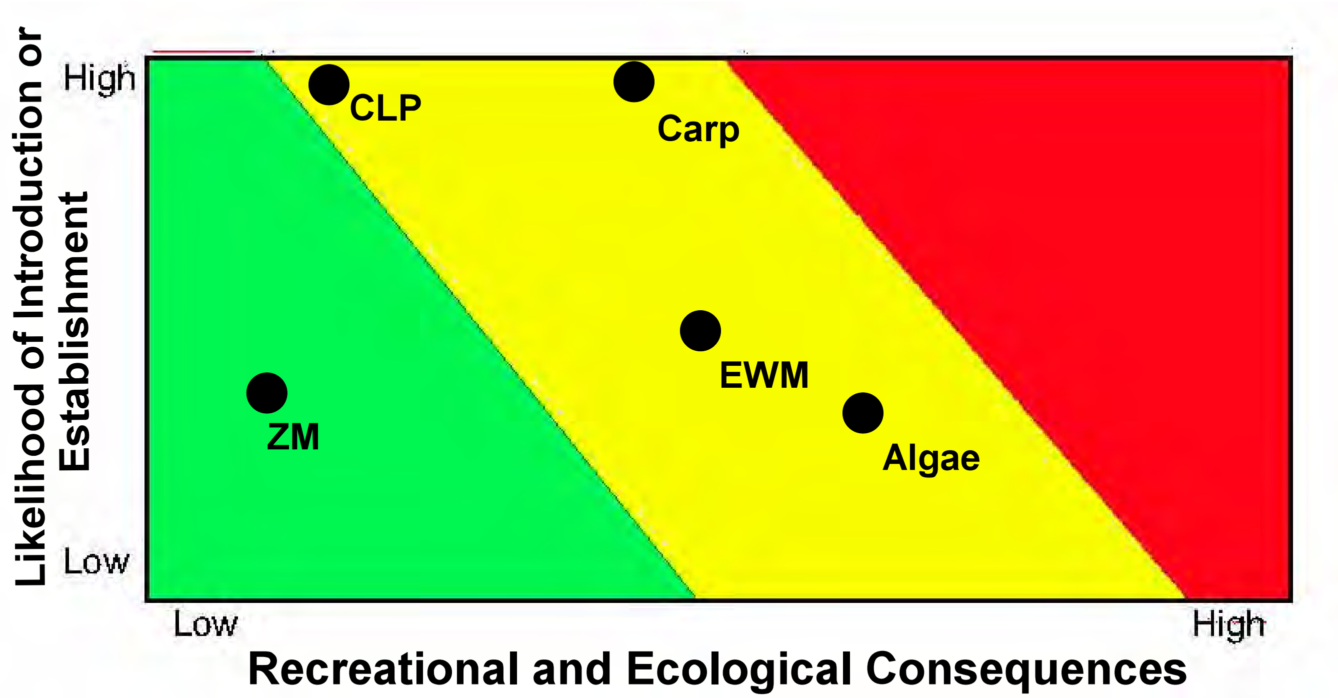


Figure S6. Based on available information, an environmental risk assessment (ERA) chart was prepared for five aquatic invasive species of interest for Greenleaf Lake.

Key:

Algae: *Cylindrospermopsis*, a blue-green algae species, will do well in Greenleaf Lake under existing high nutrient conditions. Its introduction may be limited, since there are few tributary inflows. Consequences would be moderate.

CLP: Curlyleaf pondweed is already in Greenleaf Lake (establishment is 100%). Lake sediment analysis indicates curlyleaf has a moderate growth potential resulting in low to moderate consequences.

EWM: Public access has low traffic, but lakes with EWM are in the vicinity. Sediments indicate a potential to support heavy growth, but it may be limited by low clarity.

ZM: Zebra mussels are in Scott County, within 50 miles, but incoming boat access is low. If zebra mussels are introduced, they are predicted to produce mostly light growth due to food limitations.

Carp: Carp are in Le Sueur County and are in Greenleaf Lake. Conditions are good for establishing an abundant carp population. It appears spawning and recruitment conditions are favorable.

Aquatic Invasive Species Action Plan for Greenleaf Lake, Le Sueur County, Minnesota

Introduction

Greenleaf Lake is a 302 acre lake (263 littoral acres, maximum depth is 19 feet)(source: MnDNR) in Le Sueur County. The objective of this report was to evaluate the potential for ecological and recreational problems that might develop in Greenleaf Lake associated with non-native aquatic invasive species and then list possible management actions. The aquatic invasive species evaluated include the following:

Greenleaf Lake, Le Sueur County, Minnesota

Species of Interest:

1. Blue-green algae (*Cylindrospermopsis sp*)
2. Curlyleaf pondweed (present in Greenleaf Lake).
3. Eurasian watermilfoil (not present in Greenleaf Lake).
4. Zebra mussel (not present in Greenleaf Lake).
5. Common carp (present in Greenleaf Lake).

Species to Watch (not present in Greenleaf Lake unless noted):

Plants
- Purple Loosestrife
- Flowering Rush
- Hydrilla

Invertebrates
- Rusty Crayfish
- Chinese and Banded Mystery Snail (may be present in Greenleaf Lake)
- Faucet Snail
- Quagga Mussels

Fish
- Asian carp (Bighead and Silver Carps)
- Viral Hemorrhagic Septicemia (VHS)(fish virus)

Components that Were Evaluated for Each Species

- Status of species in lake: present or absent
- Potential for growth and colonization based on lake conditions and lake sediments
- Management options

Methods Used to Collect Information for AIS Evaluations

Water Quality: Greenleaf Lake is located in the Lower Minnesota River Watershed (Figure 1). To assist in evaluating the growth potential of various AIS, water quality data were obtained from existing reports or collected in this study. Water quality data was used to evaluate growth potential of algae and zebra mussels. Aerial maps from Google Earth and ESRI were used to determine potential carp spawning sites.

Lake Sediments: Lake sediments were collected in this study to evaluate growth potential of various AIS based on sediment characteristics. In Greenleaf Lake, 14 lake sediment samples were collected on September 17, 2014. Sediment samples were analyzed at the University of Minnesota Soil Testing and Research Analytical Laboratory. Additional information on soil testing methods is found in Appendix A. The full soil testing results are found in Appendix B. Specific parameters from the suite of parameters were used to evaluate the growth potential for algae, curlyleaf pondweed, and Eurasian watermilfoil.

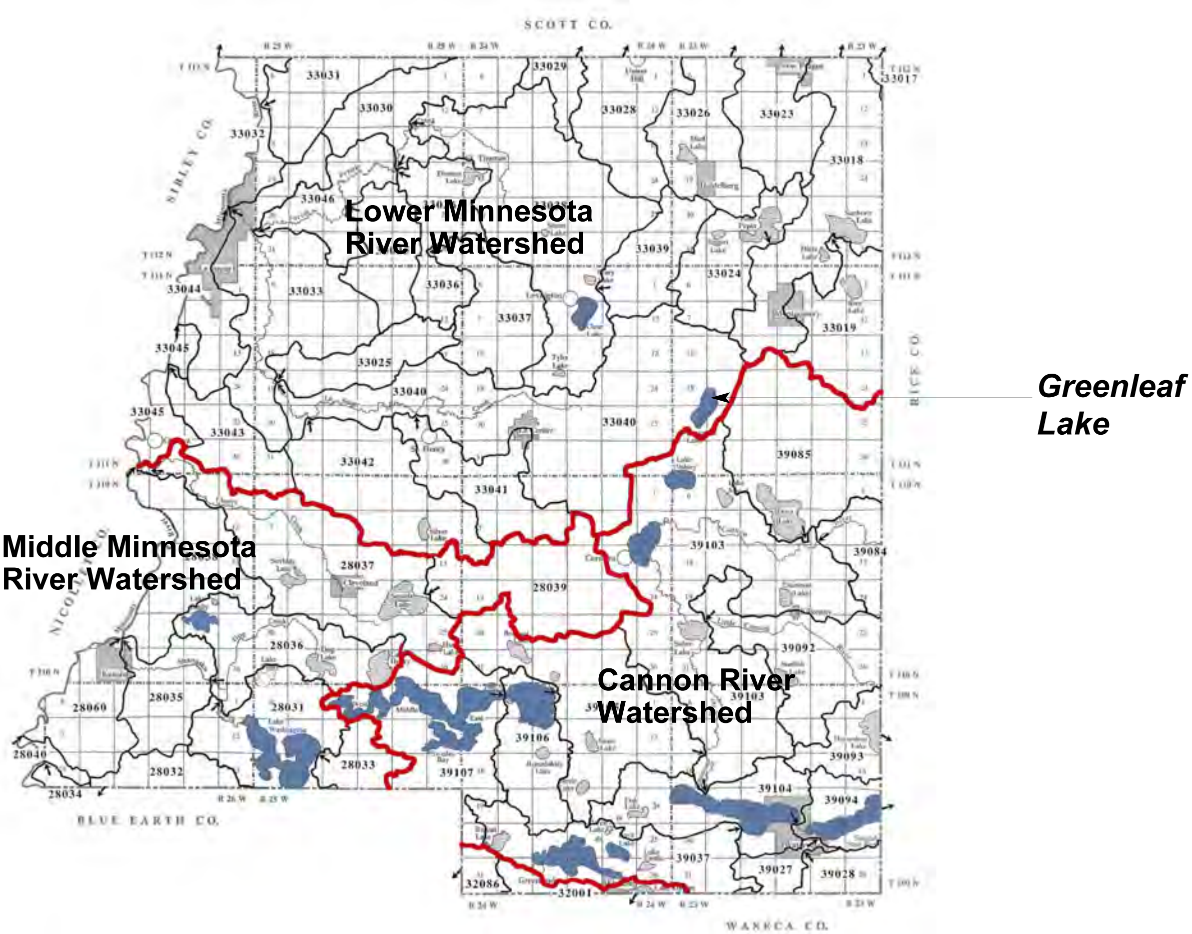


Figure 1. Three major watersheds are located in Le Sueur County. Greenleaf Lake is found in the Lower Minnesota River Watershed.

1. Blue-green Algae (*Cylindrospermopsis sp*)

Greenleaf Lake Status: Unknown for Greenleaf Lake.

Nearest Occurrence: Lake Nokomis, Minneapolis, MN

Potential for Bloom Conditions in Greenleaf Lake: The potential is high, as long as the nutrient concentrations remain elevated.

Cylindro (*Cylindrospermopsis raciborskii*)(Figure 2) is a relatively new invasive blue-green algae found in Minnesota. Just as other blue-green algal species sometimes produce a toxic strain, some strains of cylindro may produce a toxin called cylindrospermopsin.

When Cylindro is a problem it is generally associated with eutrophic conditions. Work in Indiana correlated high densities of cylindro with shallow lakes (maximum depth of 28 feet or less), a low Secchi transparency (average 2.3 feet), and high total phosphorus concentrations averaging 81 ppb (Jones and Sauter 2005). As of 2014, conditions are favorable in Greenleaf Lake for blue-green growth including cylindro (Table 1).

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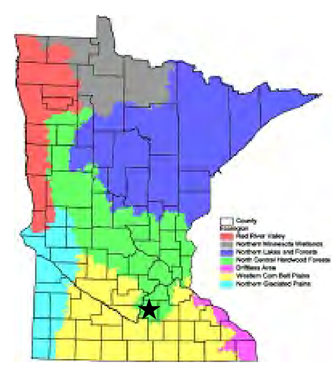
Figure 2. Cylindro is a filamentous blue-green algae.

Table 1. Lake water quality impaired criteria for the North Central Hardwood Forest Ecoregion and recent water quality conditions for Greenleaf Lake.

	Shallow Lake (MPCA impaired criteria for North Central Hardwood Forest Ecoregion)	Recent Values for Greenleaf Lake
Secchi Disc (ft & m) (water clarity)	<3.3 ft (1.0 m)	2.1 ft (9.17.14)
Total Phosphorus (fertilizer nutrient)	>60 ppb	84 (Jun-Sep 2010)
Chlorophyll a (measure of algae)	>20 ppb	50.7 (Jun-Sep 2010)



Greenleaf Lake is located in the North Central Hardwood Forest Ecoregion. Unimpaired shallow lakes in this ecoergion have water clarity greater than 3.3 feet.

Cylindro Growth Potential Based on Lake Sediment Nutrient Loading: Factors that will contribute to elevated lake phosphorus concentrations could lead to high cylindro concentrations. A variety of factors contribute to elevated phosphorus levels in lakes and internal loading, including phosphorus release from lake sediments, can be a significant factor. Research by Jensen et al (1992) found when a total iron to total phosphorus ratio was greater than 15 to 1, phosphorus release from lake sediments was minor. The ratio for the soil test results have been used in this report as well. That benchmark of 15:1 has been used to characterize the potential of Greenleaf Lake sediments to release phosphorus. If the Fe:P ratio is greater than 15:1, p-release was considered to be low. If the Fe:P ratio was 7.5 to 15, p-release was considered to be moderate and if the Fe:P ratio was less than 7.5, p-release was considered to be high.

A second factor was also considered. If available phosphorus, as determined by Bray-P or Olsen-P, was 3 ppm or less, p-release was considered to be minor, regardless of the Fe:P ratio (derived from Nurnberg 1988).

Results for Greenleaf Lake show 6 sediment sites (shown with red pentagons) have a low Fe:P ratio which is correlated to high potential phosphorus release from sediments. At other sites sediment phosphorus release appears to be light to moderate (Table 2).

Table 2. Greenleaf Lake sediment data for iron and phosphorus and the calculated Fe to P ratio. Samples were collected on September 17, 2014. The highest sediment phosphorus concentration of a site was used in the Fe/P ratio.

STANDARD SOIL TESTS					
Site	Depth (ft)	Iron (ppm)	Bray-P (ppm)	Olsen-P (ppm)	Fe/P
1	7	53	0.7	4.3	12.3
2	6	56	0.5	3.1	18.1
3	7	46	11.7	4.1	3.9
4	5	39	7.3	3.0	5.3
5	7	55	0.6	3.4	16.2
6	7	71	0.5	5.2	13.7
7	7	92	0.6	6.7	13.7
8	4	38	8.4	2.4	4.5
9	7	60	9.4	3.7	6.4
10	4	33	8.5	3.6	3.9
11	9	91	0.6	6.7	13.6
12	13	124	2.3	10.3	12.0
13	16	128	0.6	16.8	7.6
14	15	96	0.6	22.0	4.4

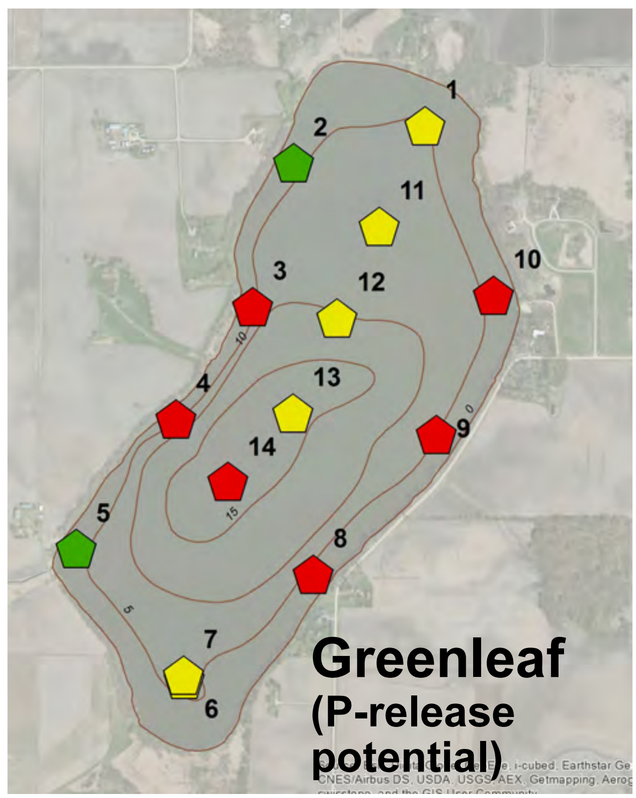


Figure 3. The color indicates the p-release potential of phosphorus in 2014. Key: green = low potential , yellow = moderate potential, and red = high potential.

Management Options for Blue-Green Algae

Scouting Activities: Very little information on algal species distribution in Le Sueur County is available. Occasional sampling in Greenleaf Lake on a monthly basis from June through September would be one way to evaluate the presence of cylindro as well as other algal species.

Rapid Response: A rapid response plan is not necessary, rather long-term plans to reduce phosphorus, which in turn reduce excessive algal growth, is a sound management approach.

Control Options: To reduce excessive algal growth in Greenleaf Lake, phosphorus reduction programs would help. Best management practices in the watershed and in-lake treatments to control phosphorus release from lake sediments would help reduce lake phosphorus concentrations (Figure 4).

Figure 4. Watershed management practices such as no-till farming (left)(source: USDA - Natural Resources Conservation Service) and lake alum treatments to inactivate lake sediment phosphorus (right) are two approaches that reduce lake phosphorus concentrations.

2. Curlyleaf Pondweed (non-native aquatic plant)

Greenleaf Lake Status: Present in Greenleaf Lake.

Potential for Curlyleaf Pondweed Growth in Greenleaf Lake: Mostly moderate growth potential.

Lake sediment sampling results from 2014 have been used to predict lake bottom areas that have the potential to support heavy curlyleaf pondweed plant growth. Various types of curlyleaf growth patterns are shown in Figures 5 and 6. Based on the key sediment parameters of pH, sediment bulk density, organic matter, and the Fe:Mn ratio (McComas, unpublished), the predicted growth characteristics of curlyleaf pondweed in Greenleaf Lake are shown in Table 3 and Figure 7.

Curlyleaf pondweed growth is predicted to produce moderate growth (Figure 7).

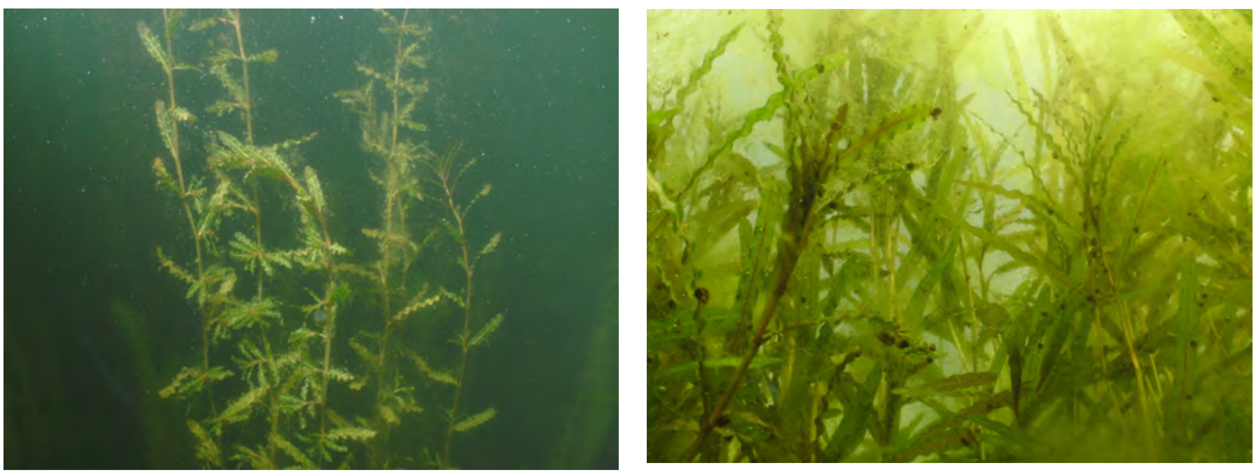


Figure 5. Underwater views of curlyleaf pondweed. Light growth (left) and moderate growth (right).

Examples of Curlyleaf Pondweed Growth Characteristics

Figure 6. Light growth (left) refers to non-nuisance growth that is mostly below the surface and is not a recreational or ecological problem. Moderate growth (middle) refers to growth that is just below the water surface. Heavy growth (right) refers to nuisance matting curlyleaf pondweed. This is the kind of nuisance growth predicted by high sediment pH and a sediment bulk density less than 0.51.

Curlyleaf Pondweed Growth Potential Based on Lake Sediments: Curlyleaf pondweed is present in Greenleaf Lake. Research has found curlyleaf is limited or enhanced based on lake sediment characteristics. Based on lake sediment characteristics, curlyleaf has the potential to produce moderate growth on an annual basis.

In Greenleaf Lake it is predicted that curlyleaf will grow at mostly moderate densities. Organic matter is relatively low in most samples, limiting heavy growth.

Table 3. Greenleaf Lake sediment data and ratings for potential growth of curlyleaf pondweed growth.

Site	Depth (ft)	pH (su)	Bulk Density (g/cm3 dry)	Organic Matter (%)	Fe:Mn Ratio	Potential for Curlyleaf Pondweed Growth
Light Growth		**<7.4**	**>1.04**	**0.1-5**	**>4.5**	**Light (green)**
Moderate Growth		**7.4 - 7.7**	**0.52 - 1.03**	**6-20**	**1.6 - 4.5**	**Moderate (yellow)**
Heavy Growth		**>7.7**	**<0.51**	**>20**	**<1.6**	**Heavy (red)**
GL1	7	7.9	0.85	3.7	3.6	Moderate
GL2	6	7.8	0.61	7.7	2.3	Moderate
GL3	7	7.7	1.37	0.6	2.9	Moderate
GL4	5	7.9	1.43	0.4	2.3	Moderate
GL5	7	7.7	0.67	7.3	3.2	Moderate
GL6	7	7.9	0.61	12.0	5.4	Moderate
GL7	7	7.9	0.65	12.6	5.9	Moderate
GL8	4	7.7	1.42	0.4	4.0	Moderate
GL9	7	7.7	1.10	1.7	4.8	Moderate
GL10	4	7.8	1.42	0.4	2.6	Moderate
GL11	9	7.8	0.72	11.3	4.9	Moderate
GL12	13	7.5	0.67	16.1	7.9	Moderate
GL13	16	7.5	0.76	12.5	6.2	Moderate
GL14	15	7.6	0.72	12.7	7.5	Moderate

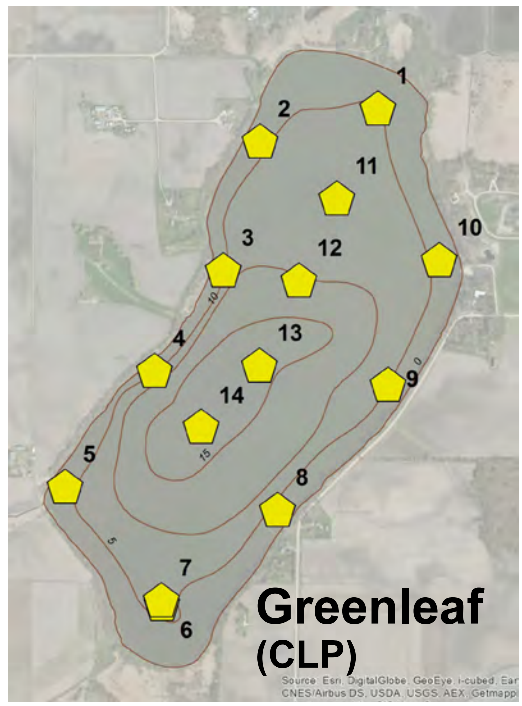


Figure 7. The color indicates the potential growth of curlyleaf pondweed.
Key: yellow = moderate growth.

Management Options for Curlyleaf Pondweed

Scouting Activities: Annual scouting activities can be used to delineate areas where curlyleaf pondweed (CLP) treatment is considered. Sediment characteristics, already collected, indicate there is a potential for mostly moderate growth of CLP in Greenleaf Lake. Scouting should be concentrated in areas that are conducive to heavy growth. If a delineation occurs it is recommended that all aquatic plants (including the natives) should be recorded within a delineated area containing curlyleaf pondweed. GPS mapping should be used to outline a treatment area. Areas of light curlyleaf pondweed growth do not need to be treated whereas areas of moderate to heavy growth are candidates for treatment.

Figure 8. Five stems of curlyleaf pondweed are shown on a rakehead sampler in a delineation survey in May. By the end of June this early season density could produce heavy growth.

Rapid Response: Unnecessary, curlyleaf is already present in Greenleaf Lake.

Control Options: The recommended treatment option at this time is the use of an endothall herbicide. Cost of herbicide applications range from about $300 to $500 per acre. Not all curlyleaf areas have to be treated. The areas to consider are areas with moderate to heavy growth. Curlyleaf will continue to grow in Greenleaf Lake even in years after treatment. Two common treatment methods are shown below. In the future, harvesting or cutting could be incorporated into a management program.

Herbicide applications

Mechanical harvesters

3. Eurasian Watermilfoil (non-native aquatic plant)

Greenleaf Lake Status: Not found in Greenleaf Lake.

Nearest Occurrence: Jefferson Chain, Le Sueur County

Potential for Eurasian Watermilfoil Growth in Greenleaf Lake: Light to heavy potential.

Lake sediment sampling results from 2014 have been used to predict lake areas that have the potential to support heavy Eurasian watermilfoil growth. Examples of milfoil growth characteristics are shown in Figures 9 and 10. Based on the key sediment parameters of NH_4 and organic matter (McComas, unpublished), a table and map were prepared that predict the type of growth that could be expected in the future if milfoil becomes established in Greenleaf Lake (Table 4 and Figure 11).

In Greenleaf Lake about half of sites had high nitrogen and suitable organic matter and these areas are predicted to have the potential to produce heavy growth of milfoil on an annual basis unless water clarity is limiting. It is estimated there is a potential for a few acres of heavy growth on an annual basis in Greenleaf Lake.

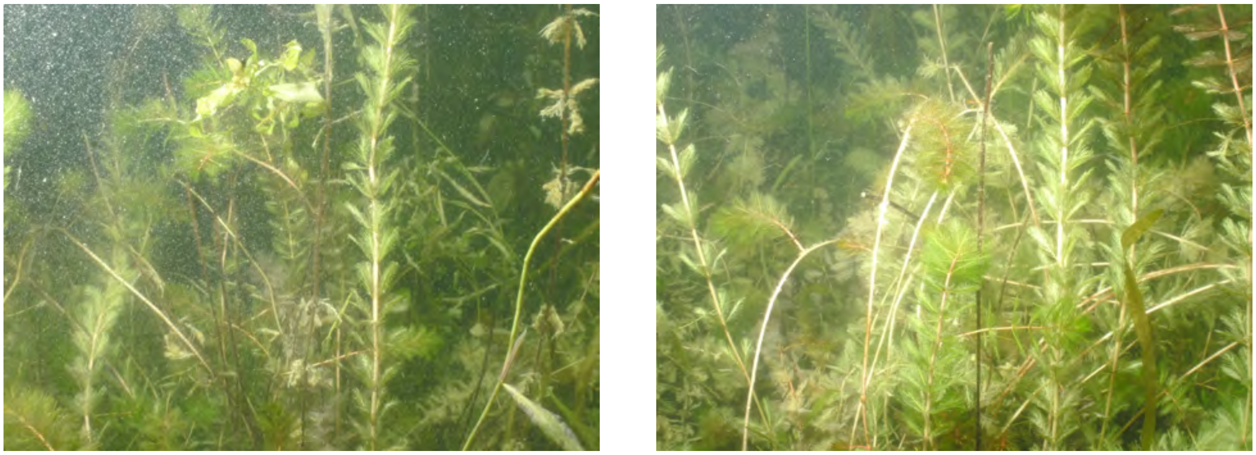


Figure 9. Underwater views of Eurasian watermilfoil.

Examples of Eurasian Watermilfoil Growth Characteristics

Figure 10. Light growth (left) refers to non-nuisance growth that is mostly below the surface and is not a recreational or ecological problem. Heavy growth (right) refers to nuisance matting Eurasian watermilfoil. This is the kind of nuisance growth predicted by high sediment nitrogen values and a sediment organic matter content less than 20%.

Eurasian Watermilfoil (EWM) Growth Potential Based on Lake Sediments: Lake sediment sampling results from 2014 have been used to predict lake bottom areas that have the potential to support heavy EWM growth. Eurasian watermilfoil has not been observed in Greenleaf Lake as of December 2014. The potential for milfoil growth, based on lake sediment sampling, would be light to heavy growth (Figure 11). Heavy milfoil growth has been correlated with high sediment nitrogen condition and Greenleaf Lake has mostly high nitrogen conditions, but organic matter could be limiting.

For Greenleaf Lake, it is estimated the plants have the potential to grow down to about 5 feet of water depth based on existing water clarity conditions and that could limit EWM distribution.

Table 4. Greenleaf Lake sediment data and ratings for potential growth of Eurasian watermilfoil.

Site	Depth (ft)	NH_4 Conc (ppm)	Organic Matter (%)	Potential for Eurasian Watermilfoil Growth
Light Growth		<4	<0.5 and >20	Light (green)
Moderate Growth		4 - 10	0.6 - 2 and 18 - 20	Moderate (yellow)
Heavy Growth		>10	3 - 17	Heavy (red)
GL1	7	6.3	3.7	Heavy
GL2	6	3.2	7.7	Moderate
GL3	7	1.9	0.6	Moderate
GL4	5	2.5	0.4	Light
GL5	7	6.7	7.3	Moderate
GL6	7	16.4	12.0	Heavy
GL7	7	25.1	12.6	Heavy
GL8	4	2.5	0.4	Light
GL9	7	4.9	1.7	Moderate
GL10	4	1.6	0.4	Light
GL11	9	28.6	11.3	Heavy
GL12	13	26.3	16.1	Heavy
GL13	16	40.4	12.5	Heavy
GL14	15	44.5	12.7	Heavy

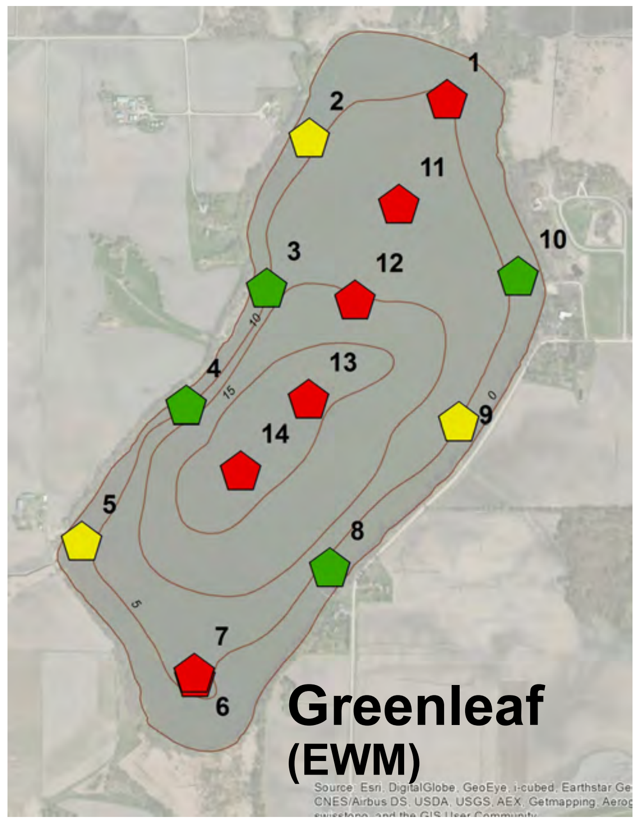


Figure 11. The color indicates the potential growth of Eurasian watermilfoil. Key: green = light growth , yellow = moderate growth, and red = heavy growth.

Management Options for Eurasian Watermilfoil

Scouting Activities: When observers are on the lake they could be looking for any sign of milfoil growth. This scouting activity can occur at the time of curlyleaf scouting in May and June, but additional monitoring on the lake through the summer sampling season presents additional opportunities for a discovery.

Rapid Response Assessment: When EWM is first spotted, a rapid response assessment should be conducted. This involves monitoring the nearshore lake perimeter and looking for additional EWM occurrences. Any EWM observations should be marked on a map using GPS coordinates.

Rapid Response Action: A rapid response action will likely be limited. The probability of eradicating EWM through a rapid response is very low. The public access area could be treated, if EWM is present, to minimize possible transport to other lakes. Otherwise future control options should be considered.

Control Options: Even though Eurasian watermilfoil is not established in Greenleaf Lake, eradication of Eurasian watermilfoil is not likely to be feasible when it is first observed. Lake sediment analyses indicate the potential for moderate to heavy growth. However poor water clarity conditions may limit heavy growth of Eurasian watermilfoil or it's hybrid in Greenleaf Lake to water depths of 5 feet or less.

If treatment is to be conducted, two treatment options include herbicides and harvesting. Herbicide applications would be the preferred initial option for areas greater than 1 acre.

Herbicide Applications would use a 2,4-D herbicide

Mechanical harvesting

4. Zebra Mussels (invertebrate)

Greenleaf Lake Status: Not currently found in Greenleaf Lake as of December 2014.

Nearest Occurrence: Prior Lake, Scott County, Minnesota.

Potential for Colonization in Greenleaf Lake: Low.

The life cycle of zebra mussels is shown in Figure 12. Zebra mussels can change the water quality in a lake. A dense population filters large volumes of lake water and zebra mussels use the filtered algae for food. Eventually the build-up of excreted fecal material will fertilize the lake bottom and in some cases, generate nuisance growth of filamentous algae. However, zebra mussels do not take over every lake. Factors can limit their growth and three types of growth conditions are shown in Figure 13. A chart of water column parameters indicates a broad range of potential growth for zebra mussels in Greenleaf Lake (Table 5). Although zebra mussels prefer hard substrates for optimal growth, they will grow together forming clumps on sand and silt bottoms. Greenleaf Lake has extensive areas of sandy and mucky sediments that would support moderate zebra mussel colonization (Figure 13). However, blue-green algal dominance would likely restrict zebra mussels to light growth.

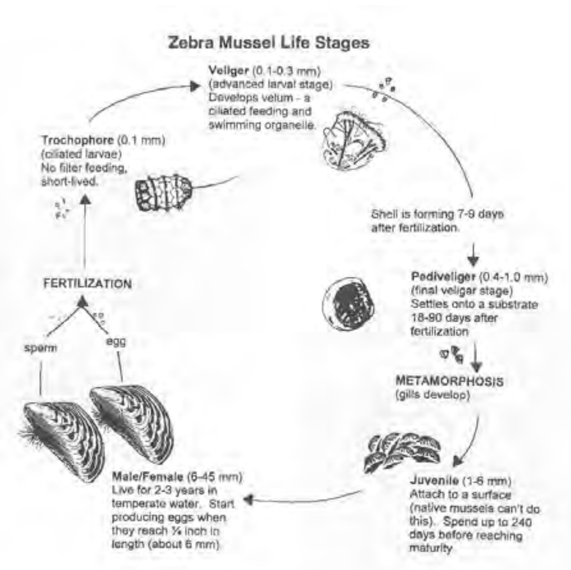


Figure 12. Zebra mussel life stages: Zebra mussels can be detected at the veliger stage using modified zooplankton nets, but this is usually performed by experts (Adopted from U.S. Army Corps of Engineers, WES)(from McComas, 2003. Lake and pond management guidebook).

Examples of Zebra Mussel Growth Conditions

Light Growth | **Moderate Growth (*suboptimal growth*)** | **Heavy Growth (*optimal growth*)**

Figure 13. Light growth (left). Small mussels can colonize on plants or hard substrates but sometimes conditions will limit growth to a single season followed by a zebra mussel die-off at the end of the year. Moderate growth (middle) can be found on soft sediments, in clumps, with zebra mussels attached to each other. Zebra mussels can colonize aquatic plants as well. Heavy growth (right) is found where there are hard surfaces such as rocks, woody structures, or docks and where water column conditions are suitable.

Zebra Mussels have not been found in Greenleaf Lake as of 2014. A review of water column characteristics for Greenleaf Lake was compared to characteristics suited for zebra mussels. It appears that zebra mussels would be food limited in Greenleaf Lake due to the excessive concentration of blue-green algae which are not easily ingested by zebra mussels (Table 5).

Table 5. Water column zebra mussel suitability criteria and Greenleaf Lake water column conditions.

		Little Potential for Adult Survival	Little Potential for Larval Development	Moderate (survivable, but will not flourish)	High (favorable for optimal growth)
Shell Formation Factors					
Calcium (mg/l)	**Greenleaf**			**28.6 (Sept. 17, 2014)**	
	Mackie and Claudi 2010	*<8*	*8 - 15*	*15 - 30*	*>30*
pH	**Greenleaf**				**8.5 (Sept 17, 2014)**
	Mackie and Claudi 2010	*<7.0 or >9.5*	*7.0 - 7.8 or 9.0 - 9.5*	*7.8 - 8.2 or 8.8 - 9.0*	*8.2 - 8.8*
Alkalinity* (as mg $CaCO_3$/l)	**Greenleaf**				**114 (Sept 17, 2014)**
	Mackie and Claudi 2010	*<30*	*30 - 55*	*55 - 100*	*100 - 280*
Conductivity* (umhos)	**Greenleaf**				**265 (Sept. 17, 2014)**
	Mackie and Claudi 2010	*<30*	*30 - 60*	*60 - 110*	*>110*
Food Factors					
Chlorophyll a (ug/l) (June-Sept)	**Greenleaf**	**50.7 26 - 87 (2010)**			
	Mackie and Claudi 2010	*<2.5 or >25*	*2.0 - 2.5 or 20 - 25*	*8 - 20*	*2.5 - 8*
Secchi depth (m) (June-Sept)	**Greenleaf**		**1.4 0.67 - 2.2 (2010)**		
	Mackie and Claudi 2010	*<1 or >8*	*1 - 2 or 6 - 8*	*4 - 6*	*2 - 4*
Total phosphorus (ug/l) (June-Sept)	**Greenleaf**	**84 66 - 138 (2010)**			
	Mackie and Claudi 2010	*<5 or >50*	*5 - 10 or 35 - 50*	*10 - 25*	*25 - 35*
Substrate Factors (Dissolved oxygen and sediment composition)					
Dissolved oxygen (mg/l)	**Greenleaf**		**0 - 16 feet**		
	Mackie and Claudi 2010	*<3 mg/l*	*3 - 7 mg/l*	*7 - 8 mg/l*	*>8 mg/l*
Bottom substrate	**Greenleaf**	9%		90%	1%
		soft muck with no hard objects		muck, silt, sand	rock or wood

Zebra Mussel Growth Potential Based on Water Column and Substrate Conditions: Two broad categories combine to produce growing conditions in lakes for zebra mussels. The two categories are water column conditions and lake bottom (also referred to as substrate) conditions. Water column conditions were summarized in Table 5 and indicate, based on chlorophyll data, blue-green algae could limit zebra mussel growth. Substrate conditions were also inspected at 14 sites where lake sediments were collected. The sediments were dominated by sand and silty-sand conditions. Zebra mussels will grow on these bottom sediments, but it is not the optimal substrate. A hard substrate of rocks and boulders is the optimal substrate and rocky areas in Greenleaf Lake are sparse. A map that combines the growth potential of water column and substrate characteristics is shown in Figure 14. It appears dissolved oxygen is adequate to allow growth over nearly all the lake bottom, but zebra mussel production will be mostly light. Zebra mussels will grow on each other in clumps (Figure 15) and begin to become commonly observed two to four years after first being discovered.

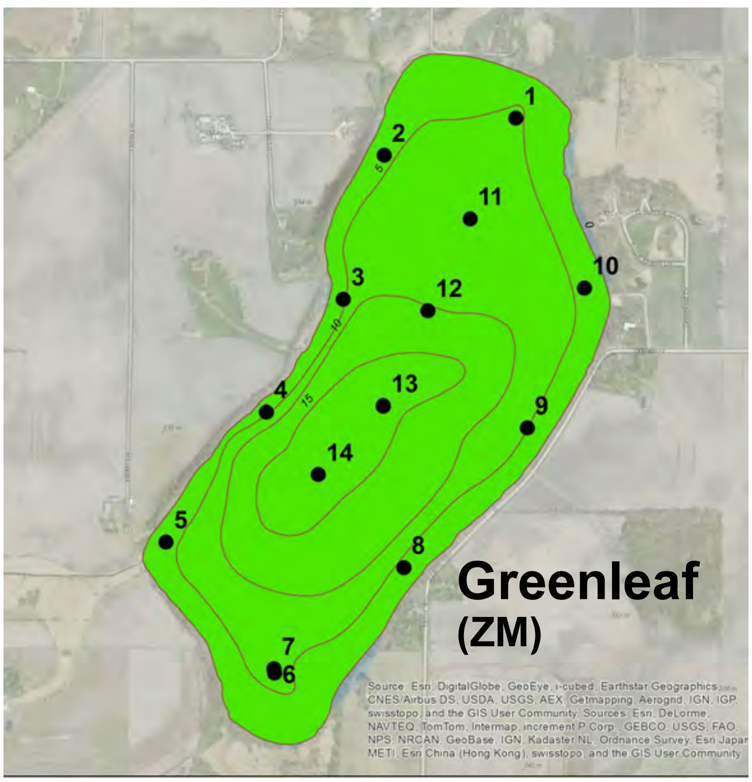


Figure 14. Key for potential growth: Green = light growth.

Figure 15. Distinctive zebra mussel growth pattern found in sandy and silty sediments. Zebra mussels will grow on each other and form clumps of zebra mussels.

Management Options for Zebra Mussels

Early Detection: The zebra mussel is an aquatic invasive species that could be scouted in Greenleaf Lake. An active scouting program consists of volunteers using a plate sampler, pvc pipe, or ceramic tiles hung from docks to monitor the appearance of juveniles. Samplers should be checked monthly over the summer months. Also docks and boats lifts should be inspected as they are removed at the end of each summer.

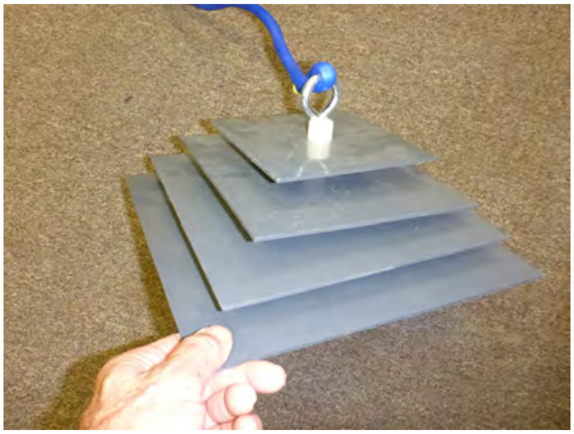


Figure 16. A zebra mussel plate sampler can be made from pvc materials. Ceramic tiles also make for good monitoring surfaces as well as pvc pipes.

Rapid Response Assessment: When zebra mussels are first discovered in Greenleaf Lake, a rapid response assessment should be conducted. Because search time will likely be limited, high quality target areas should be searched first. High quality areas include public access ramps and rocky shores. For Greenleaf Lake, a minimum of 20 search hours would be appropriate.

Rapid Response Action: One approach for eradicating an early zebra mussel introduction is to surround the area of all known zebra mussels with a floating silt curtain and treat within the site with a copper sulfate compound or potassium chloride. Special permits from the MnDNR would be needed for efforts like these. An intense assessment is necessary in order to locate all zebra mussel colonies in a lake if an eradication attempt is planned. It should be noted that there has been only one documented eradication of zebra mussels from a lake once they were discovered. The cost for an eradication attempt in Greenleaf Lake could cost up to $30,000.

Control Options: Because it takes male and female gametes combining to make trochophore (larvae) which turn into veligers and then into adults (Figure 12), it takes a critical number of mussels to establish a thriving colony. However efforts to control the mussels from reaching a threshold number have not been effective. Therefore zebra mussels will likely colonize around Greenleaf Lake, but at predicted low densities due to a limiting food source because blue-green algae dominate.

Use of small-scale controls that pick-up and remove zebra mussel clumps from the lake bottom could be considered. Modified clam rakes are an example of a small-scale zebra mussel removal tool that would be appropriate for a swimming beach or a boat landing area.

Figure 17. Small scale control devices maybe considered for removing zebra mussels in a clump form from swimming areas or sandy spawning sites.

5. Common Carp (fish)

Greenleaf Lake Status: Present in Greenleaf Lake (based on MnDNR fish surveys).

Potential for Excessive Abundance in Greenleaf Lake: Moderate.

Under the right conditions, common carp can become abundant in lakes and produce poor water quality. Three factors that influence carp population are shown in Figure 18. Common carp were sampled in the last survey in Greenleaf Lake, based on the MnDNR fish survey from 2011 (Table 6). Greenleaf Lake habitat suitability for future growth is moderate due to spawning conditions are well suited for survival of young fish (Figure 19). Since the 2011 survey, carp abundance has been moderate, probably due to limited immigration and poor recruitment of new carp. Elevated catch rates may indicate a shifting population.

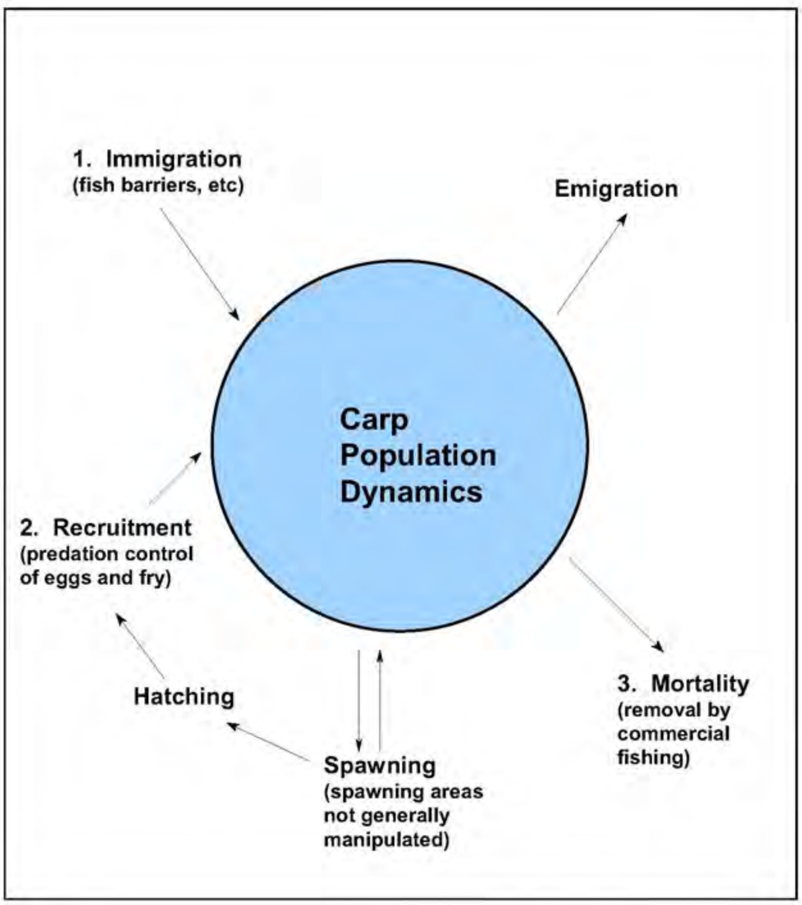


Figure 18. Three factors contribute to carp population dynamics. When carp populations are at a low density in lakes, immigration and recruitment generally limit populations.

Table 6. Fish sampled in the Greenleaf Lake 2011 MnDNR fish survey.

Species	Gear Used	Number of fish per net		Average Fish Weight (lbs)	Normal Range
		Caught	Normal Range		
Bigmouth Buffalo	Gill net	1.67	0.3 - 1.9	0.34	N/A
Black Bullhead	Trap net	15.88	1.5 - 58.0	0.43	0.2 - 0.5
	Gill net	46	7.7 - 104.7	0.32	0.2 - 0.5
Black Crappie	Trap net	32.12	2.1 - 24.1	0.19	0.2 - 0.4
	Gill net	127.67	1.7 - 17.5	0.18	0.1 - 0.3
Bluegill	Trap net	142	3.5 - 57.1	0.21	0.1 - 0.3
	Gill net	0.33	N/A	0.04	N/A
Common Carp	**Trap net**	**9.75**	**0.4 - 2.4**	**2.48**	**1.8 - 5.1**
	Gill net	**9**	**0.8 - 4.3**	**1.86**	**1.0 - 4.0**
Golden Shiner	Gill net	0.33	0.6 - 2.8	0.09	0.1 - 0.2
Hybrid Sunfish	Trap net	0.12	N/A	0.17	N/A
Walleye	Trap net	4.62	0.3 - 0.8	0.35	0.9 - 3.5
	Gill net	2	0.8 - 3.8	0.48	1.4 - 3.0
White Sucker	Trap net	0.25	0.2 - 1.2	2.22	1.3 - 2.5
Yellow Perch	Trap net	2	0.4 - 2.8	0.13	0.1 - 0.2
	Gill net	2.33	2.0 - 22.3	0.09	0.1 - 0.2

Normal Ranges represent typical catches for lakes with similar physical and chemical characteristics.

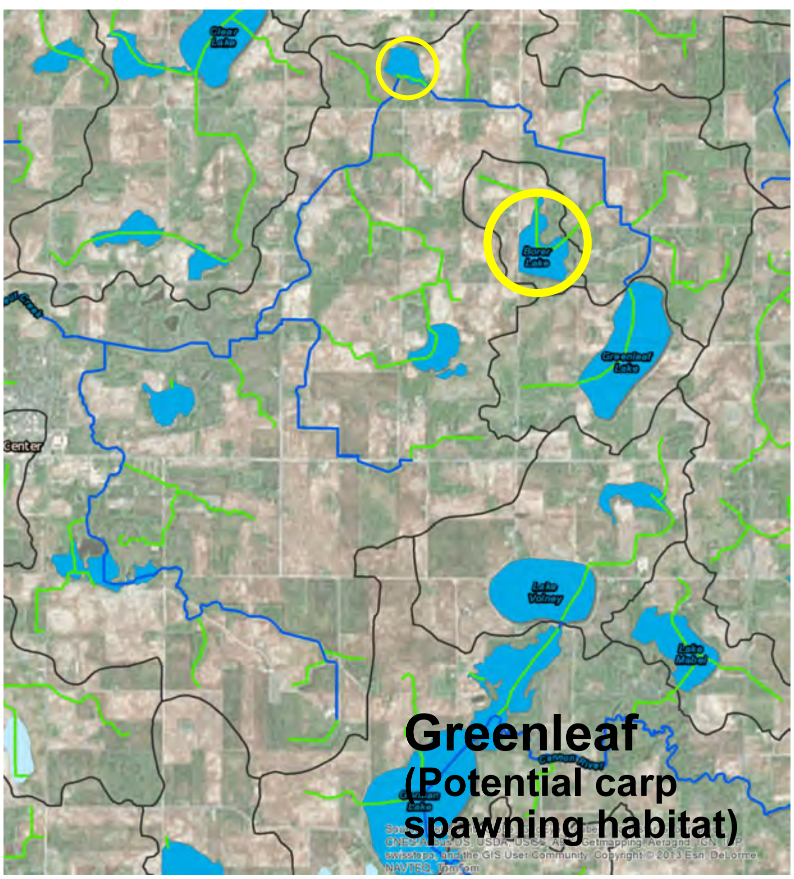


Figure 19. Common carp potential spawning habitat quality. Yellow circle indicates moderate potential for carp spawning sites for streams and lakes connected to Greenleaf Lake.

Management Options for Common Carp

Early Detection: Carp are present in Greenleaf Lake. Carp abundance in Greenleaf is higher than the average for similar sized lakes. Elevated carp numbers contribute to turbidity, reduced plant growth, and algae blooms.

Rapid Response: Unnecessary, rather, use MnDNR fish surveys to track carp numbers.

Control Options: When attempting to control carp abundance, there are three areas to address to implement a successful program. The three areas to address are 1) Immigration, 2) Recruitment, and 3) Mortality (Figure 20). Currently, there is no known carp immigration from other systems. Therefore the recruitment and mortality areas would be emphasized if control was needed. The recruitment category centers around the spawning habitat that is found in areas outside of the lake but connected by small streams. These areas are present in a couple of places, but are not found to be good carp spawning habitat. The third area, mortality, could be implemented by using commercial fishermen if necessary.

1. Immigration
(***Low in Greenleaf Lake***)

2. Recruitment
(***Low with some possible wetland spawning that could be a factor***)

3. Mortality
(***Only necessary if carp become too abundant***)

Figure 20. Three factors impacting carp population dynamics.

Other Non-native Species to Consider

Flowering Rush (aquatic plant)

Greenleaf Lake Status: Currently not in Greenleaf Lake

Potential for Colonization in Greenleaf Lake: High. Flowering rush will spread slowly unless it is disturbed.

Background Information:

- Flowering rush is actively expanding in some parts of the country. It has spread from a limited area around the Great Lakes and the St. Lawrence river to sporadic appearances in the northern U.S. and southern Canada.
- It competes with native shoreland vegetation.
- It is a Eurasian plant that is sold commercially for use in garden pools. It is now illegal to buy, sell or possess the plant.
- There is documentation from a site in Idaho, between 1956 and 1973, where flowering rush appeared to be out-competing willows and cattails.
- Flowering rush is on the DNR Prohibited invasive species list in Minnesota.

Figure 21. [left] Flowering rush plant and flowering rush flowerhead [right].

Management Options for Flowering Rush

Flowering rush is a perennial aquatic herbaceous plant. It grows 1-4' high on an erect stem along shores in shallow water. In deeper water it grows submerged without producing flowers. Flowering rush is very difficult to identify when not in flower. It closely resembles many native shoreland plants, such as the common bulrush.

Populations in the eastern U.S. produce seeds. Only one Minnesota population (Forest Lake, Washington County) produces viable seeds. Flowering rush reproduces by vegetative spread from buoyant rhizome fragments which may facilitate long distance disposal. Both seeds and bulb-lets are dispersed by water current.

Control Options

Mechanical: Cut below the water surface several times per summer and remove cut parts from water. This will help control spreading. Hand dig isolated plants with care, root fragments can spread and sprout

Chemical: Application of the herbicide diquat (trade name Reward). Preliminary testing indicates that a mid-summer application during calm wind conditions may be most effective.

Purple Loosestrife (aquatic and terrestrial plant)

Greenleaf Lake Status: Purple loosestrife has not been seen around the Greenleaf Lake shoreline in 2014.

Potential for Nuisance Colonization in Greenleaf Lake: Moderate.

Purple loosestrife can colonize a wide range of soil conditions. Because of it's high seed production it has a high potential to spread. It has moderate potential to produce nuisance growth conditions on individual lake lots because residents can control small infestations. It has a higher potential to produce moderate to heavy growth in undeveloped areas around Greenleaf Lake.

Purple Loosestrife in Greenleaf Lake: In 2014, Purple Loosestrife was not found in Greenleaf Lake. Purple loosestrife is able to establish and multiply rapidly (Figure 22). If it is found in or around Greenleaf Lake, its recommended that the lake association consider removal of the few individual plants before it can establish a foothold.

Source: MnDNR

Source: MnDNR

Figure 22. [left] Purple loosestrife flowerhead and a purple loosestrife plant [right].

Management Options for Purple Loosestrife

Scouting Activities: Using lake maps lake observers should make notes of where shoreland purple loosestrife plants are observed. The next step would be to notify lake residents that purple loosestrife is present on their property and that removal is encouraged.

Control Options: Information and education materials are abundant from the MnDNR and other sources that describe how to control purple loosestrife found in small or large patches. For small area control, like what would be found along a shoreline area, hand pulling or treatment with a herbicide such as Rodeo is recommended. Rodeo is a broad spectrum herbicide and will kill all plants it comes in contact with. Therefore applications should target individual plants. If chemical treatment occurs within the ordinary high water mark on Greenleaf Lake, a MnDNR aquatic nuisance control permit may be needed. There is no charge.

For large-scale control efforts encompassing an acre or more, biological control using flower-eating weevils and leaf-eating beetles could be considered. The MnDNR at the Brainerd office has information on the steps needed to implement a control program using weevils or beetles.

Hydrilla (aquatic plant)

Greenleaf Lake Status: Not present in Greenleaf Lake (or in Minnesota) as of 2014.

Nearest occurrence: Arkansas to the south and Maryland to the east. Hydrilla was reported in a pond in Wisconsin and a lake in Indiana. Both infestations were considered to be eradicated.

Potential for Nuisance Colonization in Greenleaf Lake: Low to moderate.

Hydrilla is an aquatic plant in the same family as Elodea, a native aquatic plant. Based on the ecology of hydrilla, studies have found it could survive in Minnesota. In the right settings hydrilla has the potential to produce more significant nuisance growth then curlyleaf pondweed or Eurasian watermilfoil. However, the correlation of hydrilla growth characteristics to sediment characteristics is not as well established compared to what is known for curlyleaf pondweed and Eurasian watermilfoil so it is difficult to predict what it would do in Greenleaf Lake.

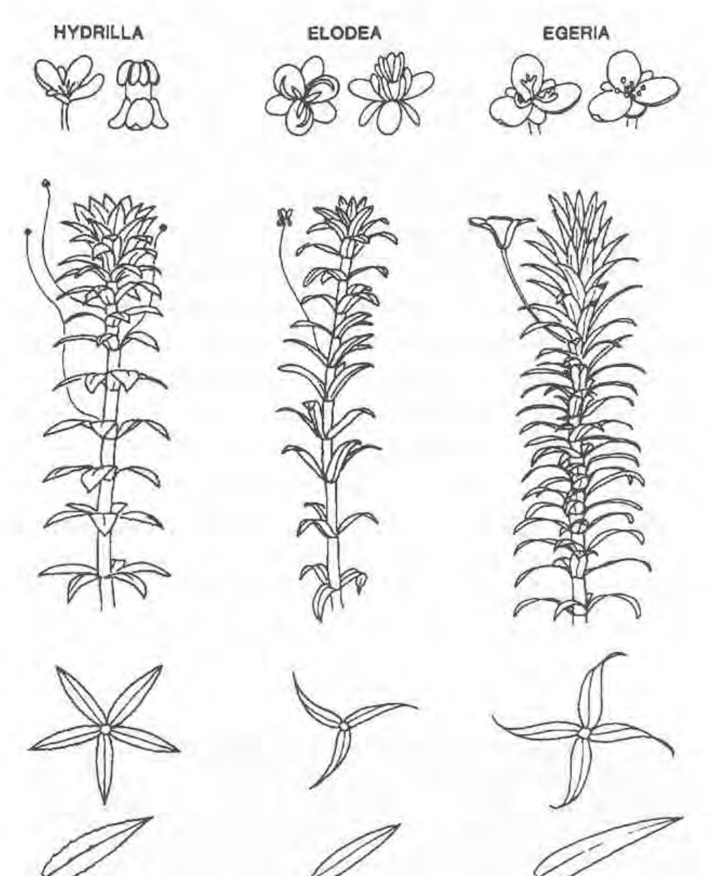


Figure 23.

Hydrilla is closely related to Egeria (an exotic plant in the U.S.) and elodea (a native). All three can produce nuisance growth conditions, but hydrilla takes the prize. (Line drawings from University of Florida, IFAS, Center for Aquatic Plants, Gainesville. With permission.)

From McComas 2003. Lake and Pond Management Guidebook.

Management Options for Hydrilla

Scouting Activities: The picture of hydrilla should be copied and laminated and taken along with observers when they are scouting for curlyleaf pondweed and Eurasian watermilfoil. Any suspicious looking plant should be bagged and brought into the MnDNR for an identification confirmation. The probability is low that the first sighting of hydrilla in Minnesota would occur in Greenleaf Lake, but observers should be aware of the possibility.

Control Options: If hydrilla was confirmed in Greenleaf Lake, the MnDNR would more than likely handle the initial control or eradication tasks. Because hydrilla has the potential to be worse than curlyleaf pondweed or milfoil in the State of Minnesota, aggressive eradication efforts should be taken. Herbicides would be used immediately with follow-up inspections and treatments continuing for a year or more.

Rusty Crayfish (invertebrate)

Greenleaf Lake Status: Not presently found in Greenleaf Lake as of 2014.

Nearest Occurrence: They are found in Cass County in Leech Lake as well as several other lakes. Rusty crayfish may be in Le Sueur County, but not reported.

Potential for Nuisance Colonization in Greenleaf Lake: Low to moderate.

Rusty crayfish are regional non-native species. They are native to the Ohio River drainage, but once they get into a new area, rusty crayfish population controls are not in place and their population can increase dramatically. They feed heavily on vegetation and can devastate aquatic plant beds. If rusty crayfish invade Greenleaf Lake they could reduce the aquatic plants found in the bays. Rusty crayfish would have minimal effect in the main body of Greenleaf Lake since submerged aquatic plants are rare there.

Management Options for Rusty Crayfish

Scouting Activities: Over the course of the summer, modified minnow traps can be set to check for the presence of rusty crayfish. Several traps should be set around the Greenleaf Lake and checked weekly.

Figure 24. [top] Rusty crayfish in breeding colors (Plum Lake, Wisconsin). They can be identified by a reddish dot on their carapace (side of their body). Native crayfish do not have this marking.
[bottom] Rusty crayfish graze down aquatic plant beds and eventually eliminate them.

Rusty crayfish traps are basically standard minnows trap with a slightly enlarged opening to allow crayfish entry. It is often baited with fish parts. A goal for Greenleaf Lake is to deploy 5 to 10 rusty crayfish traps and monitor them over the summer for the presence of rusty crayfish, although any native crayfish appearances should be noted as well.

Control Options: Once in a lake, rusty crayfish are difficult to get under control and even more difficult to eradicate. Control efforts are two-pronged. Lake groups implement a trapping program to remove large crayfish and then rely on fish predation to control the smaller crayfish. Crayfish trapping would be concentrated in the bays that have aquatic plants. A total of 30 to 50 traps would be set in an initial control effort. If crayfish abundance was high, trapping would probably occur for 5 to 10 years. If crayfish abundance is low, trapping could be discontinued after a year or two and natural fish predation would be the main control.

Greenleaf Lake has several predator fish species that would prey on rusty crayfish. The fish species are dogfish (low numbers), largemouth bass (low numbers), walleye (low numbers), and yellow perch (low numbers). Because rusty crayfish are more aggressive defenders than native crayfish, it takes several years for the predator fish to "learn" how to capture rusty crayfish. Once this behavior is learned, it seems fish could be a long-term control.

Figure 25. Examples of three types of rusty crayfish traps. The trap on the right is a modified minnow trap.

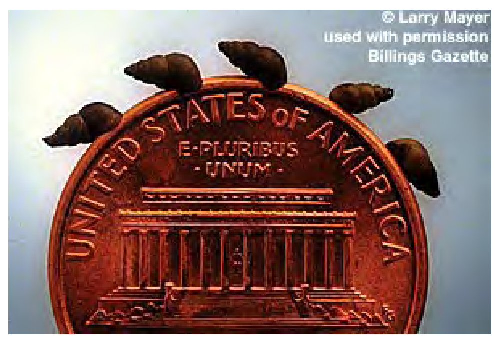
Figure 26. Big Bearskin Lake, Oneida County, Wisconsin has an active rusty crayfish control program. Volunteers run the rusty crayfish traps. Crayfish are collected and brought to a central site for sorting. Small crayfish are taken into the woods for bear and raccoon food and the large crayfish are taken to a restaurant in Green Bay.

Other Molluscs

Quagga Mussel: The Quagga mussel can inhabit both hard and soft substrates, including sand and mud, and can colonize to depths with lower dissolved oxygen than zebra mussels can handle but has a hard time colonizing in shallow water. The fan shaped mussel, has several life stages and is about the size of an adult's thumbnail. The quagga, like zebra mussels, is a filter feeder that can hurt fisheries by eating the zooplankton that native fish need to survive. It has also been noted to accumulate pollutants and pass them up the food chain.

Chinese and Banded Mystery Snail (CMS), (BMS): A larger olive colored snail species, CMS and BMS can form dense aggregations. CMS can transmit human intestional flukes, not documented in the US. Also a carrier of trematode parasites found in native mussels. CMS occur in over 80 waters and BMS are present in about 50 waters. The name "mystery" snail comes from their odd reproduction, where offspring appear, suddenly, fully developed. After a fourth year of reproduction, the snails die and the shells wash to shore. The snail was introduced as an aquarium organism that may have been dumped into a water body.

New Zealand Mudsnail: A small snail introduced with fish stocking and ballast waters in the 1980's. They reproduce asexually and their numbers can reach high densities, 100,000-700,000 per m^2. They are typically able to outcompete native snails that are important forage for fish. Found in Lake Superior in 2001, they have been slowly spreading inland since. The New Zealand mudsnail can attach to gear placed in the water or on hard surfaces.



Faucet Snail: Introduced in the great lakes in the 1870's the faucet snail has become fairly well established in Minnesota especially along the Mississippi River corridor. The snail acts as an intermediate host for 3 different hosts that can be fatal to ducks and coots, causing internal hemorrhaging and lesions. The parasites have a complex life cycle, requiring 2 intermediate hosts.

Asian Carp

Greenleaf Lake Status: Not present in Greenleaf Lake as of 2014.

Nearest occurrence: St. Croix and Mississippi Rivers eDNA found. Live fish caught March 2012 on the Mississippi River.

Potential for Nuisance Colonization in Greenleaf Lake: Low.

Asian carp are filter feeders that can consume large amounts of plankton. They are voracious feeders, reaching over a hundred pounds for bighead and 60 lbs for silver carp. The worry is they will outcompete native fishes and young of the year for the plankton, thereby reducing sport fish abundance. The river fish have been spreading up from Illinois where ideal conditions have allowed them to establish. In Minnesota, individual carps have been netted but no established populations have been found.

The spawning requirements for Asian carp require a river flow of 2 to 8 feet per second and 50 miles long. There are no rivers with that flow in the Greenleaf Lake watershed.

Management Options for Asian Carp

Control Options: Asian carp should not be able to spawn in Greenleaf Lake. Control options include commercial fishing or to let the carp die off naturally.

Figure 27. Bighead carp, *Hypophthalmichthys nobilis*, and distribution maps (USFWS photo).

Figure 28. Silver carp, *Hypophthalmichthys molitrix*, and distribution map (USFWS photo).

Snakehead

Greenleaf Lake Status: Not present in Greenleaf Lake as of 2014.

Nearest occurrence: East coast.

Potential for Nuisance Colonization in Greenleaf Lake: Moderate to high.

The northern snakehead is native to eastern Asia. In the United States, it has few predators, and could disrupt ecosystems and native fish assemblages. Snakeheads are very hardy, adaptive, and can even live and travel out of water. The snakehead is extremely aggressive and territorial, typically feeding on other fish species. Adult snakeheads have been shown to have a diet overlap with largemouth bass in the Potomac River where they are established.

The northern snakehead has a range that extends north of the great lakes region.

Management Options for Snakehead

Control Options: Preventative measures will be the most effective. Once established, rotenone can be used for eradication, however all fish species will be killed. A dissolved oxygen content of less than 3 parts per million should be achieved throughout the waterbody to ensure sufficient dosage.

Figure 29. Picture of a snakehead (left) and distribution map (right). From the USGS website (Nonindigenous Aquatic Species (NAS) page).

Viral Hemorrhagic Septicemia (VHS)(fish virus)

Greenleaf Lake Status: Not present in Greenleaf Lake as of 2014.

Nearest occurrence: Several inland lakes in Wisconsin and all the Great Lakes.

Potential for Nuisance Colonization in Greenleaf Lake: Moderate to high. Prevention is the key to minimize the impact of VHS. This fish virus will kill a variety of fish species, but does not eliminate the entire fish population in a lake. If it were to be introduced to Greenleaf Lake, it has a high probability of becoming established.

Management Options for VHS

Scouting Activities: The basic strategy is to make anglers aware that they should report any fish with signs of hemorraging to the MnDNR. If they have caught a fish with hemorraging they should bring the fish to the MnDNR. If a fish kill is observed involving hemorraging fish don't collect the fish, but call the MnDNR immediately.

Control Options: At the present time, there is no known way to reduce or inactivate the virus in the open water. The best approach is to remove infected fish as soon as feasible. The virus can be passed from one infected fish to another. If VHS is discovered in Greenleaf Lake, an intensive information program should be implemented by the Le Sueur County Environmental staff. Staffing public access landings could be considered to prevent the spread of VHS by way of livewell and bilge water transport to other lakes. Costs for these actions could be partly covered by grants.

Figure 30. Examples of hemorraging in fish with the VHS virus.

References

Christy, M.T., A.A.Y. Adams, G.H. Rodda, J.A. Savidge, and C.L. Tyrrell. 2010. Modelling detection probabilities to evaluate management and control tools for an invasive species. Journal of Applied Ecology 47:106-113.

Gamble, A. 2014. Flowering rush infestation survey of the Cannon River watershed by the invasive species program. Prepared by the Minnesota Department of Natural Resources.

Harvey, C.T., S.A. Qureshi, and H.J. MacIsaac. 2009. Detection of a colonizing, aquatic, non-indigenous species. Diversity and Distributions 15:429–437

Hoffman, J.C., J.R. Kelly, A.S. Trebitz, G.S. Peterson, and C.W.West. 2011. Effort and potential efficiencies for aquatic non-native species early detection. Can. J. Fish. Aqua. Sci 68:2064-2079.

Jensen, H.S., P. Kristensen, E. Jeppesen, and A. Skytthe. 1992. Iron:phosphorus ratio in surface sediment as an indicator of phosphate release from aerobic sediments in shallow lakes. Hydrobiologia 235/236: pp731-743.

Jones, W.W. and S. Sauter. 2005. Distribution and abundance of *Cylindrospermopsis raciborskii* in Indiana lakes and reservoirs. Prepared for Office of Water Quality. Indiana Depart. of Environ. Man. Indianapolis, IN.

Kery, M. 2002. Inferring the absence of a species - a case study of snakes. J. Wildl. Manage. 66:330-338.

Mackie, G.L. and R. Claudi. 2010. Monitoring and control of macrofouling mollusks in fresh water systems. Second Edition. CRC Press, Boca Raton, FL.

McComas, S.R. 2003. Lake and pond management guidebook. CRC Press, Boca Raton, FL.

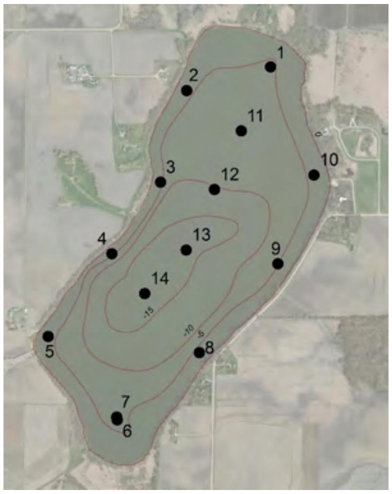
McComas, S.R., Y.E. Christianson, and U. Singh. In press. Effects of curlyleaf pondweed control on water quality and coontail abundance in Gleason Lake, Minnesota. Lake and Reservoir Management.

Nurnberg, G. 1988. Prediction of phosphorus release rates from total and reductant-soluble phosphorus in anoxic lake sediments. Can. J. Fish. Aquatic. Sci. 45:453-462.

Roley, S.S. and R.M. Newman. 2008. Predicting Eurasian watermilfoil invasions in Minnesota. Lake and Reservoir Management 24:361-369.

APPENDIX A

Methods



Lake Soil Survey: A total of 14 samples were collected from depths ranging from 4 to 16 feet. Location of sample sites is shown in Figure A1. Samples in shallow water were collected using a modified soil auger, 5.2 inches in diameter. Samples in deeper water (13 - 16 feet) were sampled using a ponar dredge. Soils were sampled to a sediment depth of 6 inches. The lake soil from the sampler was transferred to 1-gallon zip-lock bags and sent to the University of Minnesota Soil Testing and Research Analytical Laboratory.

Figure A1. Location map of the lake sediment collection sites.

Lake Soil Analysis Using Standard Soil Tests: At the lab, sediment samples were air dried at room temperature, crushed and sieved through a 2 mm mesh sieve. Sediment samples were analyzed using standard agricultural soil testing methods. Fifteen parameters were tested for each soil sample. A summary of extractants and procedures is shown in Table A1. Routine soil test results are given on a weight per volume basis.

Table A1. Soil testing extractants used by University of Minnesota Soil Testing and Research Analytical Laboratory. These are standard extractants used for routine soil tests by most Midwestern soil testing laboratories (reference: Western States Laboratory Proficiency Testing Program: Soil and Plant Analytical Methods, 1996-Version 3).

Parameter	Extractant
P-Bray	0.025M HCL in 0.03M NH_4F
P-Olsen	0.5M $NaHCO_3$
NH_4-N	2N KCL
K, Ca, Mg	1N NH_4OA_c (ammonium acetate)
Fe, Mn, Zn, Cu	DTPA (diethylenetriamine pentaacetic acid)
B	Hot water
SO_4-S	$Ca(H_2PO_4)_2$
pH	water
Organic matter	Loss on ignition at 360^oC

Figure A2a. Soil auger used to collect lake sediments in water depths to 10 feet.

Figure A2b. Ponar dredge used to collect lake sediments in deeper water.

The Adjustment Factor for Reporting Results as Volume/Weight: There has been discussion for a long time on how to express analytical results from soil sampling. Lake sediment research results are often expressed as grams of a substance per kilogram of lake sediment, commonly referred to as a weight basis (mg/kg). However, in the terrestrial sector, to relate plant production and potential fertilizer applications to better crop yields, soil results typically are expressed as grams of a substance per cubic foot of soil, commonly referred to as a weight per volume basis. Because plants grow in a volume of soil and not a weight of soil, farmers and producers typically work with results on a weight per volume basis.

That is the approach used here for lake sediment results: they are reported on a weight per volume basis or $\mu g/cm^3$.

A bulk density adjustment was applied to lake sediment results as well. For agricultural purposes, in order to standardize soil test results throughout the Midwest, a standard scoop volume of soil has been used. The standard scoop is approximately a 10-gram soil sample. Assuming an average bulk density for an agricultural soil, a standard volume of a scoop has been a quick way to prepare soils for analysis, which is convenient when a farmer is waiting for results to prepare for a fertilizer program. It is assumed a typical silt loam and clay texture soil has a bulk density of 1.18 grams per cm^3. Therefore a scoop size of 8.51 cm^3 has been used to generate a 10-gram sample. It is assumed a sandy soil has a bulk density of 1.25 grams per cm^3 and therefore a 8.00 cm^3 scoop has been used to generate a 10-gram sample. Using this type of standard weight-volume measurement, the lab can use standard volumes of extractants and results are reported in ppm which is close to $\mu g/cm^3$. For all sediment results reported here, a scoop volume of 8.51 cm^3 was used.

Although lake sediment bulk density has wide variations, a scoop volume of 8.51 cm^3 was used for all lake sediment samples in this report. This would not necessarily produce a consistent 10-gram sample. Therefore, for our reporting, we have used adjusted weight-volume measurements and results have been adjusted based on the actual dry lake sediment bulk density. We used a standard scoop volume of 8.51 cm^3, but sediment samples were weighed. Because test results are based on the premise of a 10 gram sample, if our sediment sample was less than 10 grams, then the reported concentrations were adjusted down to account for the less dense bulk density. If a scoop volume weighed greater than 10.0 grams than the reported concentrations were adjusted up. For example, if a 10-gram scoop of lake sediment weighed 4.0 grams, then the correction factor is 4.00 g/ 10.00 g = 0.40. If the analytical result was 10 ppm based on 10 grams, then it should be 0.40 x 10 ppm = 4 ppm based on 4 grams. The results could be written as 4 ppm or 4 $\mu g/cm^3$. Likewise, if a 10-gram scoop of lake sediment weighed 12 grams, then the correction factor is 12.00 g / 10.00 g = 1.20. If the analytical result was 10 ppm based on a 10 gram scoop, then it should be 1.20 x 10 ppm = 12 ppm based on 12 grams. The result could be written as 12 ppm or 12 $\mu g/cm^3$. These are all dry weight determinations.

This adjustment factor is important for evaluating the ammonium-nitrogen raw data. There appears to be a threshold nitrogen concentration at 10 ppm. If nitrogen is greater than 10 ppm, heavy milfoil growth can occur. If the adjustment factor is not applied, light, fluffy sediments may produce a high nitrogen reading based on a weight basis, but would not support heavy milfoil growth. When the adjustment factor is applied, and if the nitrogen concentration falls below 10 ppm, light or moderate growth of milfoil is predicted rather than heavy growth.

APPENDIX B

2014 sediment data for Greenleaf Lake. Sediments were collected on September 17, 2014.

ADJUSTED DATA SET

Sample Name	Depth (ft)	Bulk Density (wt/8.51)	Bray P (ppm) *adjusted*	Olsen P (ppm) *adjusted*	NH4OAc-K (ppm) *adjusted*	LOI OM (%)	Water pH	Boron (ppm) *adjusted*	DTPA-Fe (ppm) *adjusted*	DTPA-Mn (ppm) *adjusted*	DTPA-Zn (ppm) *adjusted*	DTPA-Cu (ppm) *adjusted*	NH_4OAc-Ca (ppm) *adjusted*	NH_4OAc-Mg (ppm) *adjusted*	SO_4-S (ppm) *adjusted*	NH4-N (ppm) *adjusted*	Avg Scoop Wt	Correct Factor
Greenleaf 1	7	0.85	0.7	4.3	78	3.7	7.9	0.3	53	15	0.6	1.52	2523	308	38	6.3	7.24	0.72
Greenleaf 2	6	0.61	0.5	3.1	29	7.7	7.8	0.5	56	25	0.4	0.78	1930	152	16	3.2	5.15	0.52
Greenleaf 3	7	1.37	11.7	4.1	67	0.6	7.7	0.2	46	16	0.5	0.61	1546	256	90	1.9	11.67	1.17
Greenleaf 4	5	1.43	7.3	3.0	56	0.4	7.9	0.3	39	17	0.4	0.53	981	209	54	2.5	12.19	1.22
Greenleaf 5	7	0.67	0.6	3.4	33	7.3	7.7	0.5	55	17	0.5	0.72	2188	169	25	6.7	5.74	0.57
Greenleaf 6	7	0.61	0.5	5.2	54	12.0	7.9	0.4	71	13	0.5	1.84	2145	197	9	16.4	5.17	0.52
Greenleaf 7	7	0.65	0.6	6.7	67	12.6	7.9	0.6	92	16	0.7	2.40	2558	251	6	25.1	5.56	0.56
Greenleaf 8	4	1.42	8.4	2.4	78	0.4	7.7	0.2	38	10	0.4	0.41	1279	221	36	2.5	12.05	1.21
Greenleaf 9	7	1.10	9.4	3.7	82	1.7	7.7	0.3	60	12	0.6	1.26	2220	315	58	4.9	9.37	0.94
Greenleaf 10	4	1.42	8.5	3.6	53	0.4	7.8	0.2	33	13	0.3	0.34	1194	194	70	1.6	12.09	1.21
Greenleaf 11	9	0.72	0.6	6.7	106	11.3	7.8	0.5	91	18	0.7	3.17	2867	287	8	28.6	6.12	0.61
Greenleaf 12	13	0.67	2.3	10.3	99	16.1	7.5	0.7	124	16	1.2	2.02	2346	377	72	26.3	5.74	0.57
Greenleaf 13	16	0.76	0.6	16.8	150	12.5	7.5	0.8	128	21	1.3	2.60	2935	462	67	40.4	6.47	0.65
Greenleaf 14	15	0.72	0.6	22.0	139	12.7	7.6	0.7	96	13	1.1	1.81	2666	401	73	44.5	6.11	0.61

REPORTED FROM THE LAB DATA SET

Sample Name	Bray P (ppm)	Olsen P (ppm)	NH4OAc-K (ppm)	LOI OM (%)	Water pH	Boron (ppm)	DTPA-Fe (ppm)	DTPA-Mn (ppm)	DTPA-Zn (ppm)	DTPA-Cu (ppm)	NH_4OAc-Ca (ppm)	NH_4OAc-Mg (ppm)	SO_4-S (ppm)	NH4-N (ppm)	10 gm Scoop Wt	10 gm Scoop Wt	10 gm Scoop Wt
GL1	1	6	108	3.7	7.9	0.4	74	20	0.8	2.1	3485	426	52	8.8	7.41	7.18	7.13
GL2	1	6	57	7.7	7.8	0.9	109	48	0.8	1.5	3748	295	31	6.2	5.13	5.23	5.09
GL3	10	4	57	0.6	7.7	0.2	39	13	0.5	0.5	1325	220	77	1.7	11.71	11.59	11.70
GL4	6	3	46	0.4	7.9	0.2	32	14	0.3	0.4	805	171	44	2.0	12.15	12.26	12.16
GL5	1	6	58	7.3	7.7	0.9	96	30	0.8	1.3	3812	294	43	11.6	5.71	5.76	5.75
GL6	1	10	105	12.0	7.9	0.8	138	26	0.9	3.6	4151	382	17	31.8	5.04	5.24	5.22
GL7	1	12	121	12.6	7.9	1.0	166	28	1.3	4.3	4600	451	11	45.1	5.58	5.54	5.56
GL8	7	2	65	0.4	7.7	0.2	32	8	0.4	0.3	1061	183	30	2.0	11.99	12.06	12.11
GL9	10	4	88	1.7	7.7	0.3	64	13	0.6	1.4	2369	336	62	5.2	9.41	9.25	9.45
GL10	7	3	44	0.4	7.8	0.2	27	11	0.3	0.3	987	161	58	1.3	12.03	12.21	12.03
GL11	1	11	173	11.3	7.8	0.9	148	30	1.1	5.2	4684	469	13	46.7	6.16	6.01	6.19
GL12	4	18	172	16.1	7.5	1.2	217	27	2.0	3.5	4090	658	125	45.8	5.86	5.58	5.77
GL13	1	26	232	12.5	7.5	1.2	198	32	2.0	4.0	4536	714	104	62.4	6.52	6.46	6.43
GL14	1	36	228	12.7	7.6	1.2	158	21	1.8	3.0	4363	656	119	72.8	6.06	5.97	6.30

APPENDIX C

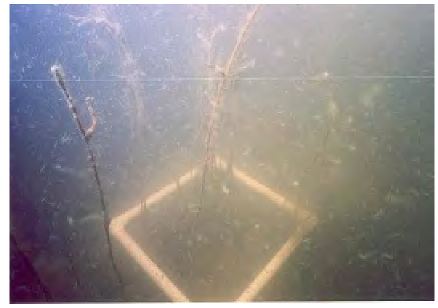
Curlyleaf Pondweed Growth Characteristics
(source: Steve McComas, Blue Water Science, unpublished)

Light Growth Conditions

Plants rarely reach the surface.

Navigation and recreational activities are not generally hindered.

Stem density: 0 - 160 stems/m^2
Biomass: 0 - 50 g-dry wt/m^2
Estimated TP loading: <1.7 lbs/ac



MnDNR rake sample density equivalent for light growth conditions: 1, 2, or 3.

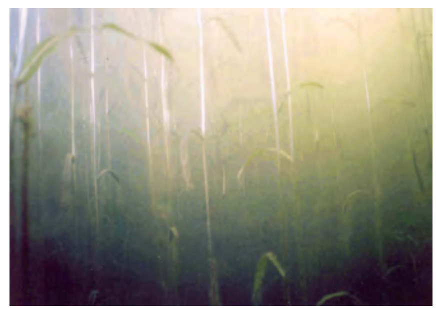
Moderate Growth Conditions

Broken surface canopy conditions.

Navigation and recreational activities may be hindered.

Lake users may opt for control.

Stem density: 100 - 280 stems/m^2
Biomass: 50 - 85 g-dry wt/m^2
Estimated TP loading: 2.2 - 3.8 lbs/ac



MnDNR rake sample density equivalent for moderate growth conditions: 2, 3 or sometimes, 4.

Heavy Growth Conditions

Solid or near solid surface canopy conditions.

Navigation and recreational activities are severely limited.

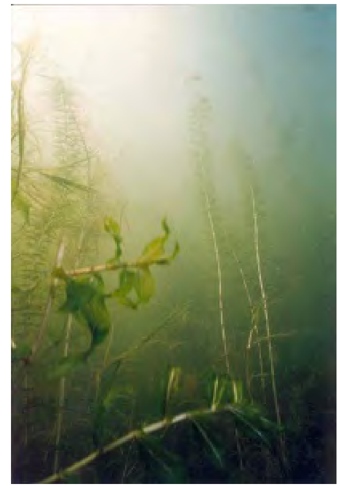
Control is necessary for navigation and/or recreation.

Stem density: 400+ stems/m^2
Biomass: >300 g-dry wt/m^2
Estimated TP loading: >6.7 lbs/ac

MnDNR rake sample density has a scale from 1 to 4. For certain growth conditions where plants top out at the surface, the scale has been extended: 4.5 is equivalent to a near solid surface canopy and a 5 is equivalent to a solid surface canopy. Heavy growth conditions have rake densities of a 4 (early to mid-season with the potential to reach the surface), 4.5, or 5.

Eurasian Watermilfoil Growth Characteristics
(source: Steve McComas, Blue Water Science, unpublished)

Light Growth Conditions



Plants rarely reach the surface.

Navigation and recreational activities generally are not hindered.

Stem density: 0 - 40 stems/m^2
Biomass: 0 - 51 g-dry wt/m^2

MnDNR rake sample density equivalent for light growth conditions: 1, 2, or 3.

Moderate Growth Conditions

Broken surface canopy conditions. However, stems are usually unbranched.

Navigation and recreational activities may be hindered.

Lake users may opt for control.

Stem density: 35 - 100 stems/m^2
Biomass: 30 - 90 g-dry wt/m^2

MnDNR rake sample density equivalent for moderate growth conditions: 3 or 4.

Heavy Growth Conditions

Solid or near solid surface canopy conditions. Stems typically are branched near the surface.

Navigation and recreational activities are severely limited.

Control is necessary for navigation and/or recreation.

Stem density: 250+ stems/m^2
Biomass: >285 g-dry wt/m^2

MnDNR rake sample density has a scale from 1 to 4. For heavy growth conditions where plants top out at the surface, the scale has been extended: 4.5 is equivalent to a near solid surface canopy and a 5 is equivalent to a solid surface canopy.