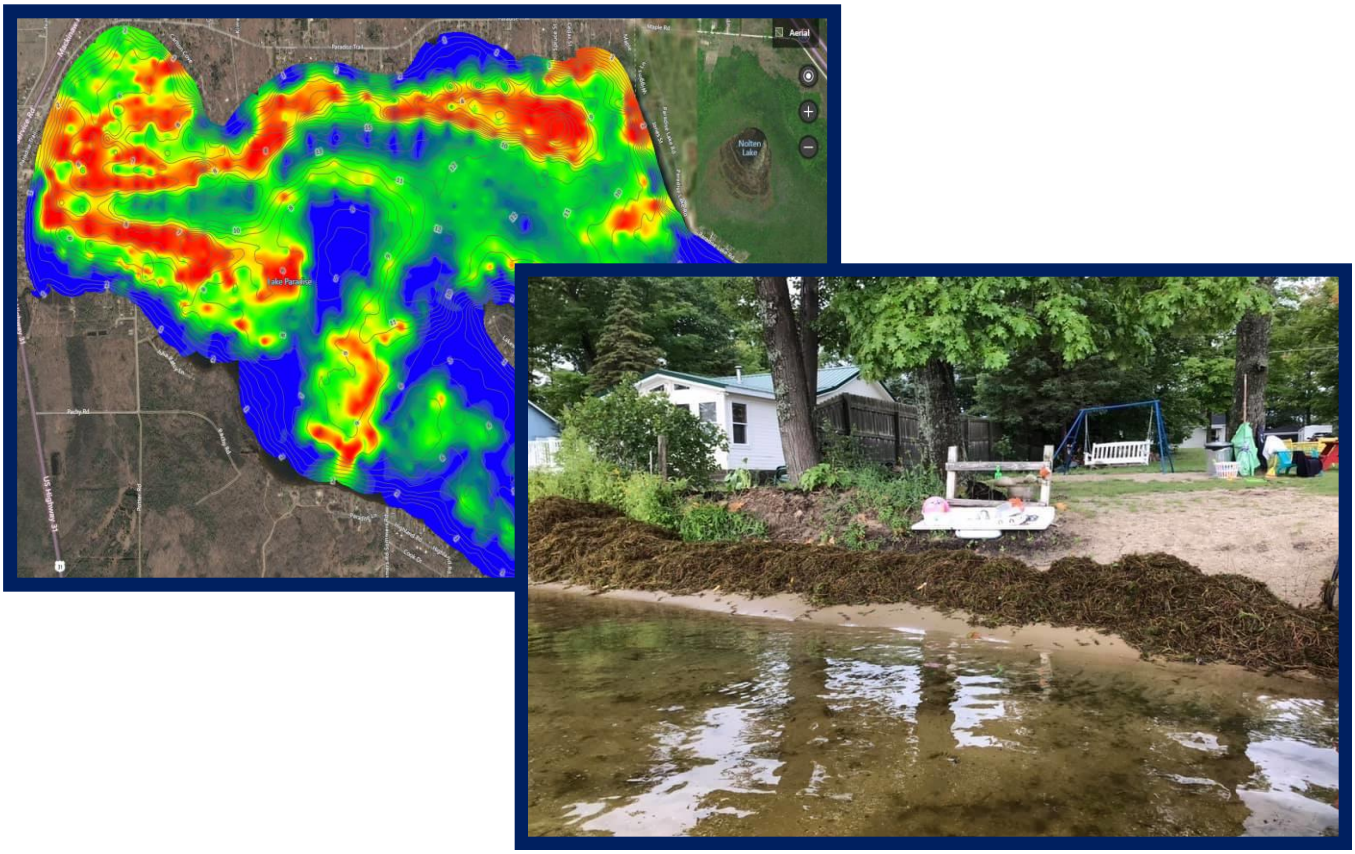
Restorative Lake Sciences™

A LAKE IMPROVEMENT FEASBILITY STUDY FOR MANAGEMENT OF INVASIVE WATERMILFOIL IN PARADISE LAKE EMMET AND CHEBOYGAN COUNTIES, MI



NOVEMBER, 2020

In memory of Rosemary and John Beeson.

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LAKE IMPROVEMENT FEASIBILITY STUDY REPORT FOR PARADISE LAKE EMMET AND CHEBOYGAN COUNTIES, MI

November, 2020

1.0 EXECUTIVE SUMMARY

A lake improvement feasibility study is required pursuant to part 309 Inland Lake Improvements, of the Natural Resources Environmental Protection Act (P.A. 451 of 1994), as amended. The purpose of a lake improvement feasibility is to determine the management methods that are most likely to improve the observed problem state of a natural resource. This feasibility report describes the following information relevant to Paradise Lake: 1.) Background information on Paradise Lake, 2.) The aquatic vegetation present within the lake, 3.) Management methods considered and previously used for the treatment of the exotic, invasive aquatic plant, Eurasian Watermilfoil (EWM), and 4) Conclusions and Recommendations for the future management of Paradise Lake EWM.

Paradise Lake (Figure 1) is an 1,878-acre, shallow, eutrophic lake with a maximum depth of 15.1 feet (Gannon and Paddock, 1974). Paradise Lake is located in sections 7, 18, 10-15, 23, and 24 of Emmet and Cheboygan Counties (T.38N, R. 3,4W). Previously, the lake had become colonized with zebra mussels (*Dreissena polymorpha*), which has resulted in increased light transparency of the lake water and has caused accelerated growth rates of all aquatic vegetation, including the exotic submersed aquatic plant, Eurasian Watermilfoil (*Myriophyllum spicatum*). Invasive milfoil has become a threat to the native aquatic vegetation communities within Paradise Lake, severely impedes navigation and recreational activities within the lake, creates a swimming hazard in areas of dense canopy growth, and has been shown to decrease lakefront property values (Halstead et *al*., 2003).

A whole-lake survey by aquatic scientists at RLS on September 10, 2020, consisted of 702 grid sampling locations located throughout Paradise Lake and determined that approximately 401 acres of *M. spicatum* exists in the lake. The lake also contains a moderate amount of submersed native vegetation that includes pondweeds and other native milfoil species such a Whorled Watermilfoil (*M. verticillatum*).

Prior recommended approaches for treatment of the EWM infestation in Paradise Lake included weevil stocking in protected areas where their reproductive life cycle success was most probable and where the *M. spicatum* canopy was least likely to be disturbed by boat propeller action (i.e. the most highly trafficked and developed areas). In addition, other methods such as laminar flow aeration (LFA) were used in the West Basin with a few years of acceptable results but eventually failed to reduce further growth. Mechanical harvesting was also used in the West Basin and at a dense area of growth in the North area of the lake with only temporary success in reducing the EWM canopy. A Diver Assisted Suction Harvesting (DASH) boat has also been used in some areas of Paradise Lake, but this method is used primarily for small areas of EWM growth, given the density and relative abundance of EWM in the lake.

It is clear that all natural alternatives used for control of EWM in Paradise Lake have had limited or short-term efficacy and a new approach is needed for sustained control. The use of aquatic herbicides is a common choice, especially in larger lakes with dense EWM beds. The use of aquatic herbicides is regulated by the USDA and also EGLE and requires a permit and application by a licensed aquatic herbicide applicator. RLS is present to oversee these treatments on all lakes to assure due diligence and that the proper herbicide doses are applied to the targeted areas. Additionally, the goal of any successful and sustainable EWM control program should be both to reduce the EWM and also the use of herbicides to the extent possible. Rigorous seasonal surveys and timely and responsive spot-treatments assure a rapid response and reduce the spread of EWM and consequential need for more herbicide use. It is critical to realize that there are no

eradication methods available for EWM. This means that although there may be periods of "no growth" between treatments, the seed bank will always be active and dormant seeds could germinate at any time. The goal for this program is to successful reduce the EWM over a period of a few years so that DASH could become a utilized method on remaining small areas of EWM to lessen the dependency on aquatic herbicide use.

In addition to the use of the recommended highly-selective aquatic herbicide triclopyr, it is also recommended that DASH be considered in small re-growth areas once the EWM is successfully reduced with the herbicide. Also, it is critical that all residents annually inspect their septic tanks and drain fields as septic nutrients are a likely contributor to the observed dense weed growth. Reduction of nutrients should also be pursued along with the program and septic system and drain field maintenance methods and resources are offered in this report.

Figure 1. Aerial photo of Paradise Lake, Emmet and Cheboygan Counties, Michigan (MIRIS, 2006 aerial photo database).

2.0 PARADISE LAKE BACKGROUND INFORMATION

Paradise Lake is approximately 1,878 acres and has a maximum and average depth of 15.1 feet and 3.9 feet, respectively (Figure 2). The shoreline length is approximately 14.3 miles and the volume of the lake is approximately 10,358,982 m^3. The watershed is approximately 16,685 acres, which is nearly 8.9 times the lake surface area. The shoreline development factor (SDF) is 1.5 (Gannon and Paddock, 1974). Primary land uses in the watershed include wetlands (nearly 50%), followed by forested lands (~21.4%). The watershed contains 3.3% urban land use and

8.3% agricultural land use (Tipp of the Mitt Watershed Council, 2008). Paradise contains one inlet (Mud Creek) and one outlet (Carp River). The Carp River outlet drains Paradise Lake into the Straits of Mackinaw. Lake sediments consist of a mixture of sands and organic deposits with the sands closer to shore and the organic deposits located in the deeper areas (Figure 3).

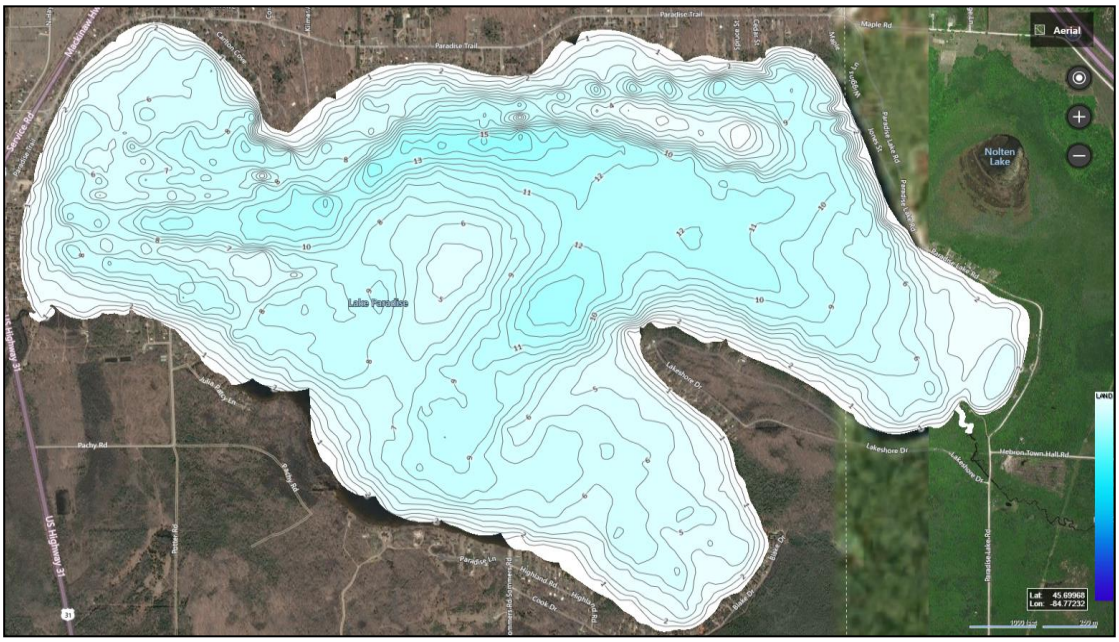

Figure 2. Depth contour map of Paradise Lake, Emmet and Cheboygan Counties, Michigan (RLS, September, 2020).

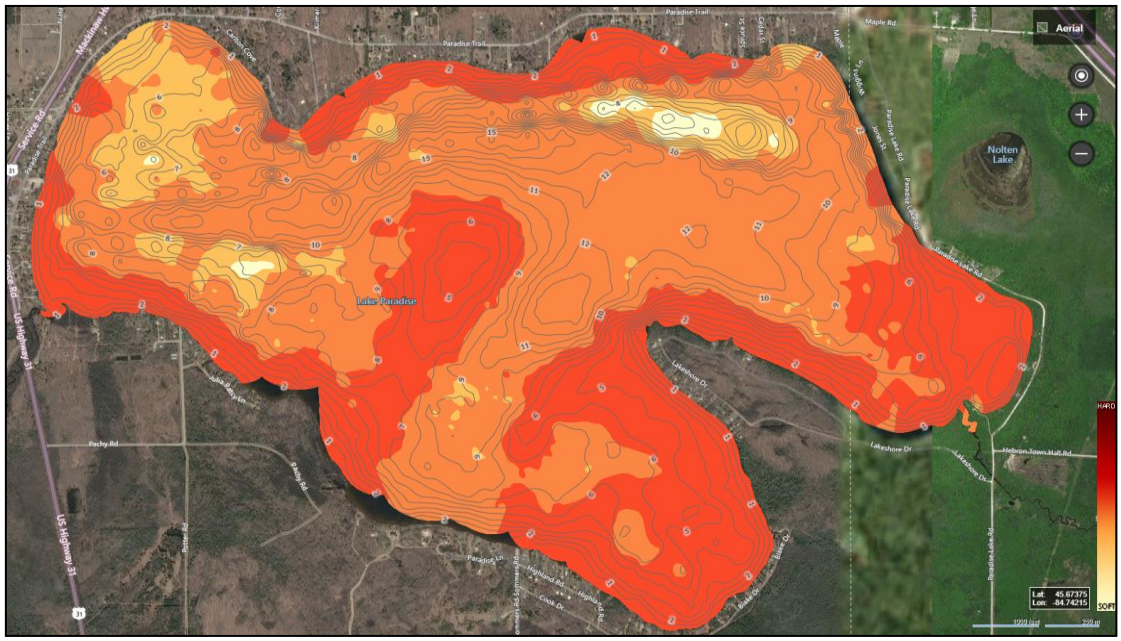

Figure 3. Sediment hardness map of Paradise Lake, Emmet and Cheboygan Counties, Michigan (RLS, September, 2020).

The land use and water quality study conducted by Gannon and Paddock (1974) from the University of Michigan Biological Station noted that Paradise Lake was green and turbid (secchi disk transparency ≤ 2 meters) and had high quantities of phytoplankton in 1974. The introductions of zebra mussels after that time, likely contributed to an increase in water transparency and lead to accelerated rooted aquatic vegetation growth.

Additionally, mean total alkalinity (based on 4 sampling sites) was between 100-120 mg L^{-1} of $CaCO_3$. The mean total phosphorus was between 7-37 µg L^{-1}, and mean nitrogen was between 60-100 µg L^{-1}, indicating that the lake had variable quantities of each but nutrient concentrations above the eutrophic threshold. These values are also similar to those measured by RLS in the past several years of water quality monitoring. Potential nitrogen and phosphorus loading rates were calculated for watershed inputs as 5,598 kg $year^{-1}$ and 308 kg $year^{-1}$, respectively. Potential

loads from shoreline septic systems for nitrogen and phosphorus were estimated to be 2,657 kg year^{-1} and 232 kg year^{-1}, respectively. Rainfall was estimated to contribute nearly 5,989 kg year^{-1} of nitrogen and 266 kg year^{-1} of phosphorus. Thus, the majority of the nitrogen in the lake was derived from rainfall, whereas the majority of the phosphorus originated from the watershed. Comparisons of this water quality data to that collected by Moore et *al*., 2009, indicates that all nutrient loads in Paradise Lake are actually declining and the lake is now considered phosphorus limited. However, proper maintenance of septic systems remains critical for further reducing nutrient loads to the lake that fuel aquatic vegetation growth.

3.0 AQUATIC VEGETATION IN PARADISE LAKE: AN OVERVIEW

The 2020 aquatic vegetation survey by RLS, Inc. utilized the GPS Point-Intercept Method for aquatic vegetation sampling, which is used widely among aquatic scientists to sample large aquatic ecosystems in an unbiased manner. The U.S. Army Corps of Engineers utilizes this methodology for pre-treatment and post-treatment surveys to assess the efficacy of lake improvement programs (Madsen et *al*., 1994; 1996). This type of survey is also amenable to statistical analysis, which is instrumental in measuring the success of any improvement protocol. At each of the 702 sampling locations (Figure 4), a WAAS-enabled 50-satellite capacity GPS unit with an accuracy of 2.0 feet was used to accurately record geo-referenced data.

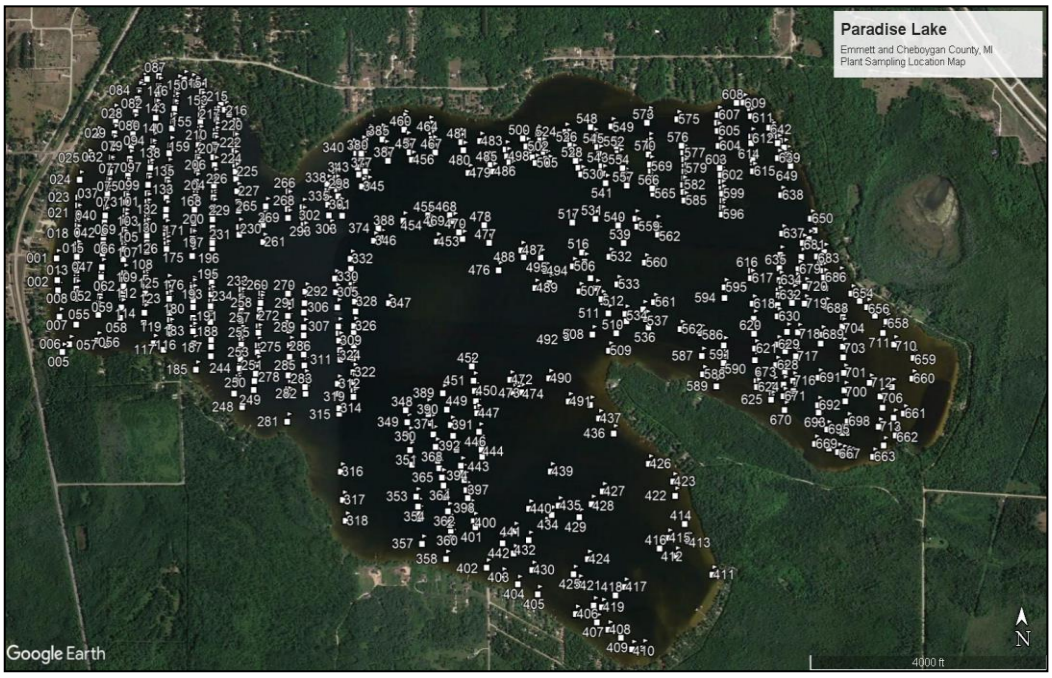

Figure 4. Aquatic vegetation sampling locations in Paradise Lake on September 10, 2020. Note: Only locations with vegetation present were sampled. The vacant areas were bare sand with no aquatic vegetation present.

At each grid point two rake tosses were conducted and all species and relative abundance of rake specimens collected were recorded unless bare lake sediments were in view. The survey determined that approximately 400 acres of EWM were present in Paradise Lake. During the 2020 aquatic vegetation survey, EWM was located in 58.0% of the GPS sampling locations, with 7.7% of those at the "a" (found) density level, 17.8% at the "b" (sparse) density level, 14.7% at the "c" (common) density level, and 17.8% at the "d" (dense) level while utilizing the EGLE density protocol. There were five distinct beds located throughout the lake that varied in size from < 1.0 acre to 98.7 acres. The smallest beds were located in the central and southern eastern portions of the lake.

Regular rigorous GPS Point-Intercept aquatic plant surveys utilizing this protocol are critical for the detection of exotic species such as EWM, which may limit more favorable, native aquatic plants and consequently alter the ecological balance and biotic integrity of aquatic ecosystems.

3.1 Paradise Lake Exotic Aquatic Plant Species

Eurasian Watermilfoil (*M. spicatum* or EWM; Figure 5) is an exotic, invasive, submersed, perennial aquatic plant which was introduced into the United States in the 1880's (Reed 1997), although other reports (Couch and Nelson 1985) suggest it was discovered in the 1940's. Exotic aquatic plants are not native to a particular site but are introduced by some biotic (living) or abiotic (non-living) vector. Such vectors include the transfer of aquatic plant seeds and fragments by boats and trailers (especially in lakes with a public access site), waterfowl, or by wind dispersal. In addition, exotic species may be introduced into aquatic systems through the release of aquarium or water garden plants into a water body. An aquatic exotic species may have profound impacts on the aquatic ecosystem. EWM is a major threat to the ecological balance of an aquatic ecosystem through causation of significant declines in favorable native vegetation within lakes (Madsen et *al*. 1991) and may limit light from reaching native aquatic plant species (Newroth 1985; Aiken et *al*. 1979). The aquatic plant frequently forms dense surface canopies on inland lakes such as Paradise Lake (Figure 6). Additionally, EWM can alter the macroinvertebrate populations associated with particular native plants of certain structural architecture (Newroth 1985). EWM beds have been associated with less macroinvertebrate biodiversity than native aquatic vegetation beds (Soszka 1975; Keast 1984; Cattaneo et *al*. 1998). The canopy created by EWM creates an unfavorable environment for aquatic biota through the creation of stagnant water conditions which lead to increased water temperatures and lower dissolved oxygen concentrations (Unmuth et *al.* 2000; Figure 4).

Cheruvelil et *al*. (2001) studied the macroinvertebrate communities on EWM in six southern Michigan lakes and discovered that the number of macroinvertebrates on the most dominant plant species declines as EWM biomass increases. Since the introduction of EWM, many nuisance aquatic plant management techniques such as chemical herbicides, biological control, and in extreme cases, mechanical harvesting, have been implemented. EWM must be managed as it reduces native aquatic plant biodiversity, impairs navigation and recreation, and accumulates on shorelines which can be difficult to remove (Figure 7).

Most of the areas where aquatic vegetation biovolume is dense are occupied by dense EWM beds (Figure 8). These areas appear red on the biovolume map and areas with green color denote low-growing native vegetation. It is the native plants that are under threat from the rapid growth and density of EWM beds. Figure 9 shows the overall EWM beds and Figure 10 shows the 10.5 acres of EWM present solely in Hebron Township.

Figure 5. Eurasian Watermilfoil with seed head and lateral branches. © RLS

Figure 6. Eurasian Watermilfoil canopy on Paradise Lake (2020).

Figure 7. Eurasian Watermilfoil accumulation on Paradise Lake shoreline (2019-2020).

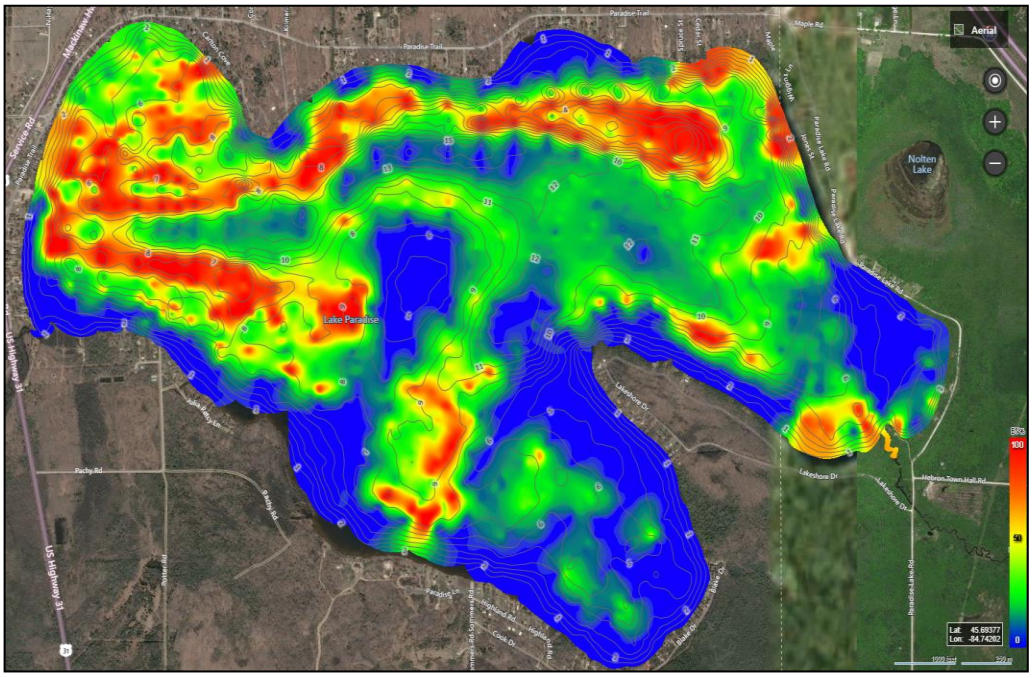

Figure 8. Aquatic Vegetation Biovolume in Paradise Lake (2020).

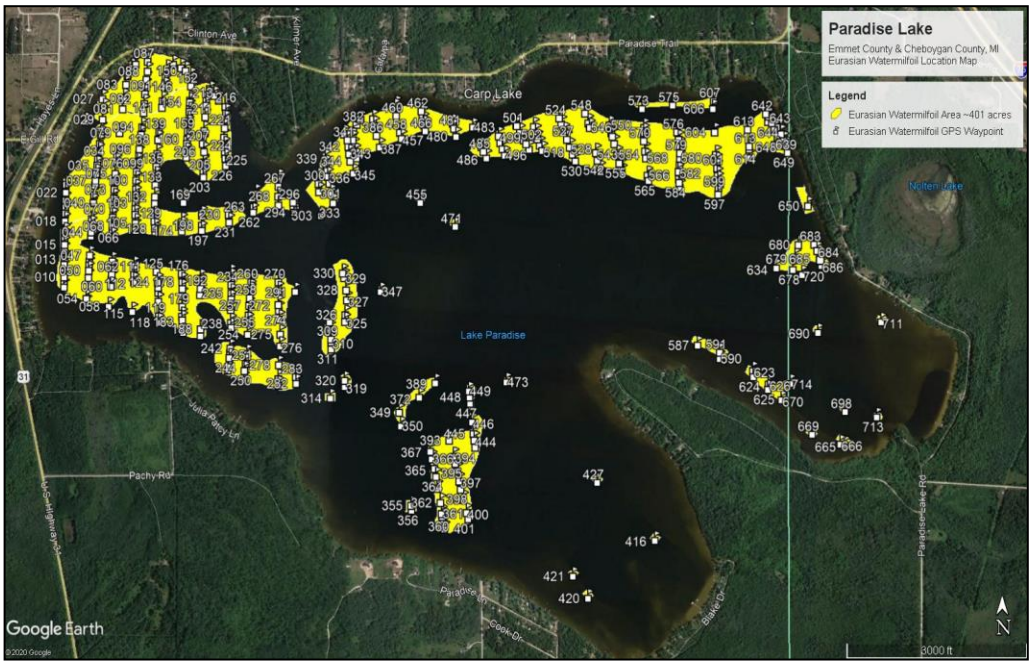

Figure 9. Eurasian Watermilfoil in Paradise Lake (2020).

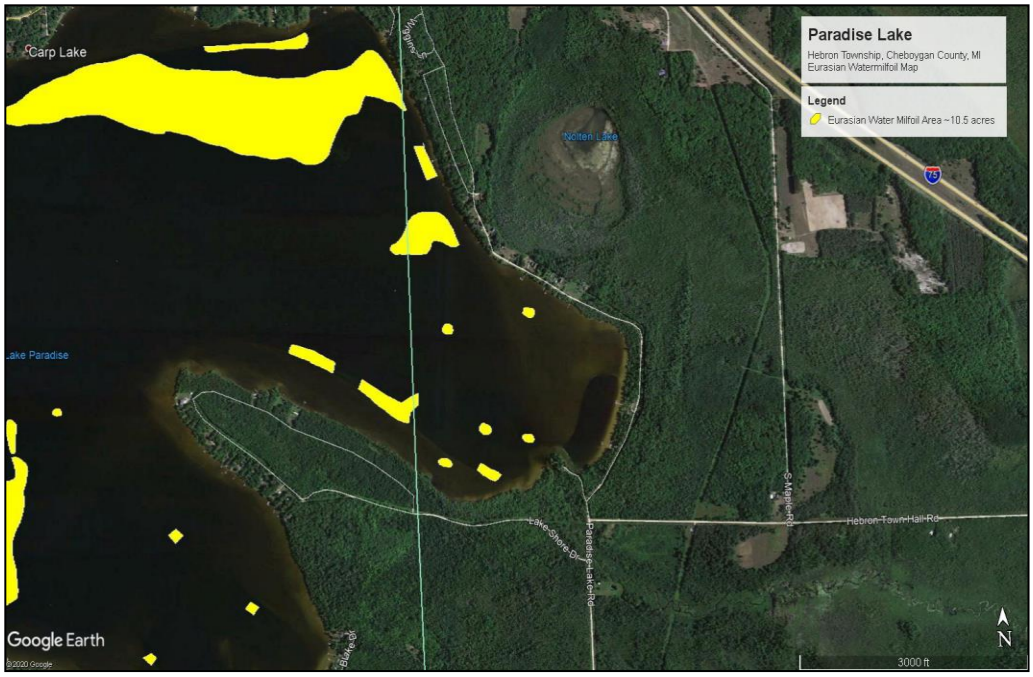

Figure 10. Eurasian Watermilfoil in Hebron Township portion of Paradise Lake (2020).

3.2 Paradise Lake Native Aquatic Plant Species

During the September, 2020 survey, a total of 17 submersed, 3 floating-leaved, and 3 emergent native aquatic plant species were found which is a total of 23 native species. Tables 1 and 2 display the relative frequencies and abundance of each species, respectively, The most dominant native aquatic plant species within Paradise Lake were in the Potamogetonaceae family, which included the Pondweeds such as White-stem Pondweed (*Potamogeton praelongus*), and Fern-leaf Pondweed (*P. robbinsii*). *P. praelongus* was present in 80.9% of the grid points sampled and thus was the most dominant rooted native submersed aquatic plant in the littoral zone. *P. robbinsii* was the second most abundant species which was present in 8.1% of the sampling locations. *P. robbinsii* often carpeted the lake bottom and formed a thick layer which makes it difficult for newly formed EWM fragments to root in the lake bottom sediment.

Thus, preservation of this and other low-growing species is critical for the long-term control of EWM and other nuisance species which spread through fragmentation. Another fairly abundant pondweed which occupied 6.4% of the sampling locations was *P. richardsonii,* which resembles a smaller version of *P. praelongus*.

The pondweeds serve as excellent cover for fish and macroinvertebrates and should be preserved to the extent possible to support a healthy fishery. The submersed aquatic plant, *Elodea canadensis* was present in 1.9% of the sampling locations. *E. canadensis* overwinters and has small, green, rounded leaves which grow in whorls of three and is often found in sediments with high organic matter content. The submersed aquatic macrophyte Variable-leaf Pondweed (*Potamogeton gramineus*), which occupied 1.4% of the sampling locations, is a key aquatic plant for many species of waterfowl and small mammals that graze in the shallows. The majority of the native aquatic plant species in Paradise Lake were sparse to common in abundance and do not currently impart a threat to the balance of the ecosystem or to the safety of recreationalists on the lake. They should be protected and are expected to thrive once EWM beds are removed and they receive more space and light for growth. Photos of all native aquatic plant species found are below in Figures 11-32.

Table 1. Paradise Lake native aquatic vascular plants (September 10, 2020) by relative abundance.

Native Aquatic Plant Species Name	***Native Aquatic Plant Common Name***	***Growth Form***	***% Frequency***
Chara vulgaris	Muskgrass	Submersed	1.3
Stuckenia pectinatus	Sago Pondweed	Submersed	0.3
Potamogeton zosteriformis	Flat-stem Pondweed	Submersed	0.3
Potamogeton robbinsii	Fern-leaf Pondweed	Submersed	8.1
Potamogeton gramineus	Variable-leaf Pondweed	Submersed	1.4
Potamogeton praelongus	White-stem Pondweed	Submersed	80.9
Potamogeton illinoensis	Illinois Pondweed	Submersed	0.7
Potamogeton richardsonii	Clasping-leaf Pondweed	Submersed	6.4
Potamogeton epihydrus	Ribbon-leaf Pondweed	Submersed	0.4
Potamogeton pulcher	Spotted Pondweed	Submersed	0.1
Potamogeton natans	Floating-leaf Pondweed	Submersed	0.3
Potamogeton amplifolius	Large-leaf Pondweed	Submersed	1.4
Myriophyllum sibiricum	Northern Watermilfoil	Submersed	0.6
Myriophyllum verticillatum	Whorled Watermilfoil	Submersed	2.1
Elodea canadensis	Common Waterweed	Submersed	1.9
Utricularia vulgaris	Bladderwort	Submersed	0.1
Najas guadalupensis	Southern Naiad	Submersed	0.1
Nymphaea odorata	White Waterlily	Floating-leaved	0.3
Nuphar advena	Yellow Waterlily	Floating-leaved	0.1
Brasenia schreberi	Watershield	Floating-leaved	0.3
Decodon verticillatus	Swamp Loosestrife	Emergent	0.1
Schoenoplectus acutus	Bulrushes	Emergent	7.5
Pontedaria cordata	Pickerelweed	Emergent	0.9

Table 2. Paradise Lake native aquatic vascular plants (September 10, 2020) by relative abundance.

Native Aquatic Plant Species Name	*Native Aquatic Plant Common Name*	*"a" Level*	*"b" Level*	*"c" Level*	*"d" Level*
Chara vulgaris	Muskgrass	8	1	0	0
Stuckenia pectinatus	Sago Pondweed	0	2	0	0
Potamogeton zosteriformis	Flat-stem Pondweed	0	2	0	0
Potamogeton robbinsii	Fern-leaf Pondweed	5	38	14	0
Potamogeton gramineus	Variable-leaf Pondweed	9	1	0	0
Potamogeton praelongus	White-stem Pondweed	235	302	29	2
Potamogeton illinoensis	Illinois Pondweed	3	2	0	0
Potamogeton richardsonii	Clasping-leaf Pondweed	24	21	0	0
Potamogeton epihydrus	Ribbon-leaf Pondweed	1	2	0	0
Potamogeton pulcher	Spotted Pondweed	1	0	0	0
Potamogeton natans	Floating-leaf Pondweed	2	0	0	0
Potamogeton amplifolius	Large-leaf Pondweed	9	0	1	0
Myriophyllum sibiricum	Northern Watermilfoil	4	0	0	0
Myriophyllum verticillatum	Whorled Watermilfoil	11	4	0	0
Elodea canadensis	Common Waterweed	9	4	0	0
Utricularia vulgaris	Bladderwort	1	0	0	0
Najas guadalupensis	Southern Naiad	1	0	0	0
Nymphaea odorata	White Waterlily	0	2	0	0
Nuphar advena	Yellow Waterlily	1	0	0	0
Brasenia schreberi	Watershield	2	0	0	0
Decodon verticillatus	Swamp Loosestrife	1	0	0	0
Schoenoplectus acutus	Bulrushes	11	39	3	0
Pontedaria cordata	Pickerelweed	1	3	1	1

Figure 11. Chara (Muskgrass)

Figure 12. Sago Pondweed

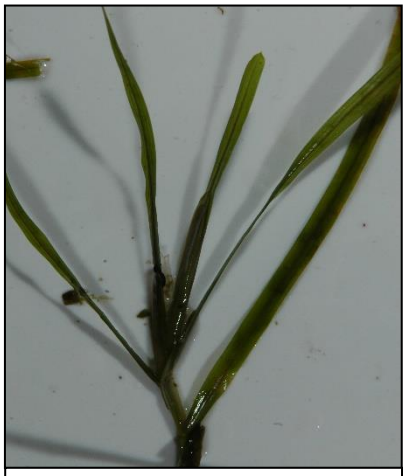

Figure 13. Flat-stem Pondweed

Figure 14. Fern-leaf Pondweed

Figure 15. Variable-leaf Pondweed

Figure 16. White-stem Pondweed

Figure 17. Illinois Pondweed

Figure 18. Clasping-leaf Pondweed

Figure 19. Ribbon-leaf Pondweed

Figure 20. Large-leaf Pondweed

Figure 21. Northern Watermilfoil

Figure 22. Bladderwort

Figure 23. Spotted Pondweed

Figure 24. Floating-leaved Pondweed

Figure 25. Whorled Watermilfoil

Figure 26. Southern Naiad

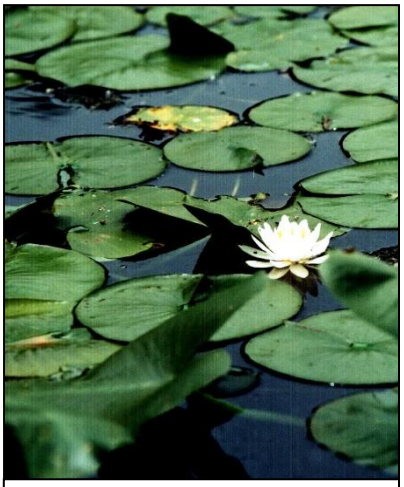

Figure 27. White Waterlily

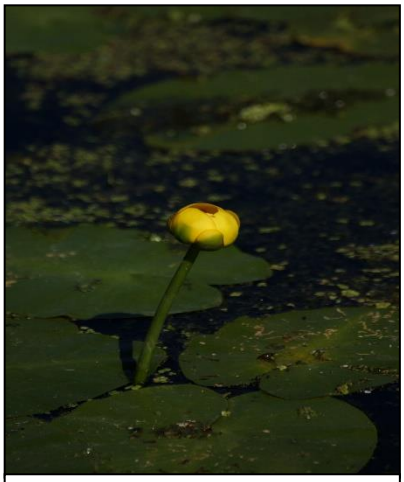

Figure 28. Yellow Waterlily

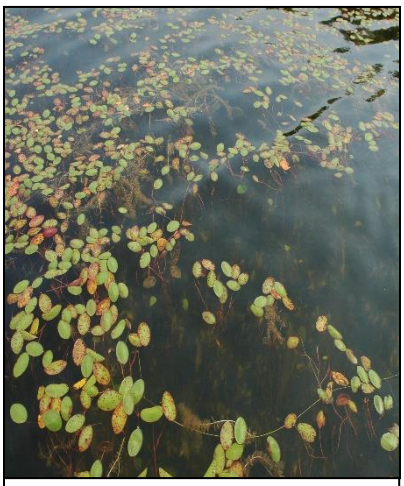

Figure 29. Watershield

Figure 30. Swamp Loosestrife

Figure 31. Bulrushes

Figure 32. Pickerelweed

4.0 AQUATIC VEGETATION MANAGEMENT METHODS PREVIOUSLY IMPLEMENTED

4.1 Biological Control with Weevils

The use of the aquatic weevil, *Euhrychiopsis lecontei* (Figure 33) to control *M. spicatum* used to be a viable option for many inland lakes. The use of the weevil for biocontrol is both inundative and classical (Harley and Forno, 1992). The inundative approach refers to the application of weevils at a higher density than the existing population to damage EWM. The classical approach refers to the use of a host-specific herbivore (weevil) to damage the target plant (EWM). The weevil naturally exists in many of our lakes; however, the lack of adequate populations in many lakes requires that they be implanted or stocked for successful control of EWM. The weevil feeds almost entirely on EWM and will leave native aquatic species unharmed if adequate amounts of EWM are present. The weevil burrows into the stems of EWM and damages the vascular tissue, thereby reducing the plant's ability to store carbohydrates (Newman et *al*. 1996). Eventually, the EWM stems lose buoyancy and the plant decomposes on the lake bottom.

Figure 33. The "milfoil" weevil. Imaged used with permission From Dr. Ray Newman, University of Minnesota

Previous research had shown that the weevils required a substantial amount of aquatic plant biomass for successful control of EWM. In addition, the weevils required adequate over-wintering habitat since they overwinter within shoreline vegetation. Lakes with sparse EWM distribution were not ideal candidates for the milfoil weevil. Peer-reviewed scientific research by Newman and Biesboer (2000) demonstrated that the requirements for weevil stocking density to obtain adequate control of EWM may be as high as 150-300 weevils per square meter. It is important to note that this number refers to a "stocking density", which implies the number of weevils that should be stocked in a stocking area for ultimate population growth. It does not mean that each acre within the lake must have this density stocked to obtain the desired result. There was much uncertainty however relative to the necessary stocking density for sustained EWM control. Due to the lack of successful long-term efficacy of the weevils, they were discontinued for commercial use a few years ago and thus are no longer a sustainable option for EWM reduction in inland waters.

4.2 Mechanical Harvesting

Mechanical harvesting involves the physical removal of nuisance aquatic vegetation with the use of a mechanical harvesting machine (Figure 34). The mechanical harvester collects numerous loads of aquatic plants as they are cut near the lake bottom. The plants are off-loaded onto a conveyor and then into a dump truck. Harvested plants are then taken to an offsite landfill or farm where they can be used as fertilizer. Mechanical harvesting is preferred over chemical herbicides when primarily native aquatic plants exist, or when excessive amounts of plant biomass need to be removed. This method was used on Paradise Lake in 2019-2020 with limited short-term reductions of EWM canopies in the West Basin and north region of the lake.

Mechanical harvesting is usually not recommended for the removal of Eurasian Watermilfoil since the plant may fragment when cut and re-grow on the lake bottom. Additionally, it is often not practical for very large lakes, given the long transfer times to offload harvested vegetation. Due to the high quantity of dense EWM in open water areas and the short-term efficacy of harvesting on EWM, mechanical harvesting is not recommended for the sustainable control of EWM in Paradise Lake.

Figure 34. A mechanical harvester used to cut aquatic plants.

4.3 Laminar Flow Aeration

A laminar flow aeration (LFA) system utilizes diffusers which are powered by onshore air compressors. The diffusers are connected via extensive self-sinking airlines which help to purge the lake sediment pore water of gases such as benthic carbon dioxide (CO_2) and hydrogen sulfide (H_2S), which is a primary nutrient necessary aquatic plant photosynthetic growth and productivity and is also a byproduct of microbial metabolism. In addition to the placement of the diffuser units, the concomitant use of bacteria and enzymatic treatments to facilitate the microbial breakdown of organic sedimentary constituents is also used as a component of the treatment. LFA systems are retrofitted to a particular site and account for variables such as water depth and volume, contours, water flow rates, and thickness and composition of lake sediment. The systems are designed to completely mix the surrounding waters and evenly distribute dissolved oxygen throughout the lake sediments for efficient microbial utilization. An LFA

system was retrofitted to the West Basin of Paradise Lake and consisted of in-water components such as 57 micro-porous ceramic diffusers, 77,000 feet of self-sinking airline, and bacteria and enzyme treatments for sediment nutrient reduction as well as on-land components consisting of 3 locally-sourced sheds and one 10.0HP rotary claw compressor and two 11.5HP claw compressors along with cooling fans and ventilation.

The LFA system installed into the West Basin of Paradise Lake operated for several years with some initial success at reducing the EWM canopy. A previous study by Turcotte et *al*. (1988) analyzed the impacts of bioaugmentation on the growth of *M. spicatum* and found that for two four-month studies, the growth and re-generation of this plant was reduced significantly with little change in external nutrient loading. This technology works best in highly organic sediments and as a whole-lake retrofitted system. Since the desired reductions in EWM were not achieved, this technology is not recommended for continued reduction in EWM as it would be cost-prohibitive.

4.4 Mechanical and Hydraulic Dredging

Dredging is a lake management option used to remove accumulated lake sediments to increase accessibility for navigation and recreational activities. Dredging is regulated pursuant to provisions of Part 301 (Inland Lakes and Streams) of the Natural Resources and Environmental Protection Act, P.A. 451 of 1994, as amended, and requires a joint permit through both the Michigan Department of Environmental Quality (MDEQ) and the U.S. Army Corps of Engineers (USACE). The two major types of dredging include hydraulic and mechanical. A mechanical dredge (Figure 35) utilizes a backhoe and requires that the disposal site be adjacent to the lake. In contrast, a hydraulic dredge removes sediments in aqueous slurry and the wetted sediments are transported through a hose to a confined disposal facility (CDF). Selection of a particular dredging method and CDF should consider the environmental, economic, and technical aspects involved. The CDF must be chosen to maximize retention of solids and accommodate large quantities of water from the dewatering of sediments.

It is imperative that hydraulic dredges have adequate pumping pressure which can be achieved by dredging in waters greater than 3 foot of depth. Dredge spoils cannot be emptied into wetland habitats; therefore, a large upland area is needed for lakes that are surrounded by wetland habitats. In addition, proposed sediment for removal must be tested for metal contaminants before being stored in a CDF. If the sediment is not contaminated, it could be used for habitat restoration, landfill cover, agriculture, strip mine reclamation, or in other industrial or construction uses (U.S. EPA/USACE 2004).

Dredging is a very expensive sediment removal method, as dredging operations cost of $22 per cubic yard. In addition, dredging would necessitate a separate dredging feasibility study and associated sampling and permitting costs, along with public hearing costs. Dredging would likely not reduce many EWM seeds in the seedbank and thus would also not be a likely mechanism for reducing EWM growth in Paradise Lake.

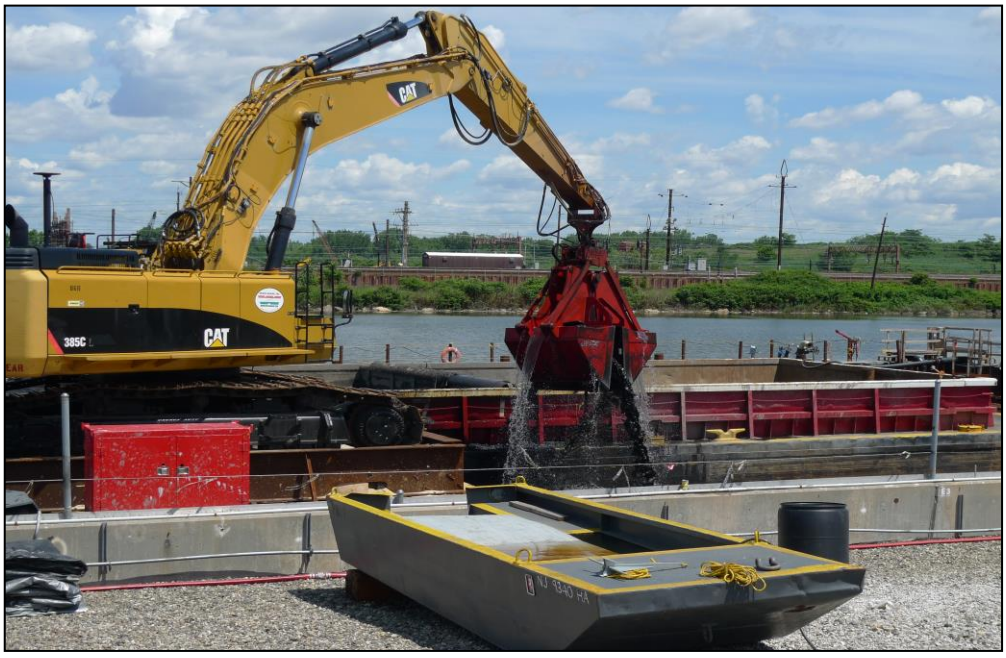

Figure 35. A mechanical dredge for sediment removal.

4.5 Diver Assisted Suction Harvesting

Suction harvesting via a Diver Assisted Suction Harvesting (DASH) boat (Figure 36) involves hand removal of individual plants by a SCUBA diver in selected areas of lake bottom with the use of a hand-operated suction hose. Samples are dewatered on land or removed via fabric bags to an offsite location. This method is costly on a large scale and so it used on a spot-removal basis or in small areas. It has been used to remove nuisance invasive aquatic vegetation in inland lakes and requires a joint permit with EGLE and the U.S. Army Corps of Engineers (USACE). The DASH process may cause re-suspension of sediments (Nayar et *al*., 2007) which may lead to increased turbidity and reduced clarity of the water. . The process could lead to disruption of the benthos unless carefully executed by trained professionals. Permitting requirements include the use of a turbidity curtain that reduce the transport of solids to locations outside of treatment areas and also help define areas where intensive aquatic vegetation removal efforts are being implemented. This technology has been used in small areas of Paradise Lake in recent years and may be a useful method if only a few small areas of EWM remain after a large-scale herbicide treatment.

Figure 36. A DASH boat used in a lake for aquatic plant removal.

5.0 RECOMMENDED MANAGEMENT METHODS: AQUATIC HERBICIDES AND DASH

5.1 Different Types of Aquatic Herbicides

The use of aquatic chemical herbicides is regulated by the MDEQ under Part 33 (Aquatic Nuisance) of the Natural Resources and Environmental Protection Act, P.A. 451 of 1994, and requires a permit from the Michigan Department of Environmental Quality (MDEQ). Aquatic herbicides are applied to lakes with a treatment vessel such as a skiff (Figure 37) or airboat. The permit contains a list of approved herbicides for a particular body of water, as well as dosage rates, treatment areas, and water use restrictions. Furthermore, residents that reside within 100 feet of the proposed treatment area must be notified at least seven days, but not more than forty-five days prior to the initial treatment date. A certified herbicide applicator notices the residents in advance of the proposed treatment date, and during the day of treatment. Treatment posting signs must be placed along the shoreline using EGLE standards for posting requirements and can be installed in advance of the day of treatment. These signs list important treatment information such as the treatment date, products used, treatment map, and relevant water use restrictions relative to swimming, fishing, or watering plants or turf. Contact and systemic aquatic herbicides are the two primary herbicide types used in aquatic systems and are discussed in detail below.

Figure 37. An aquatic herbicide application vessel.

Contact Aquatic Herbicides and Algaecides

Contact aquatic herbicides cause damage to leaf and stem structures but are not translocated by plant roots like systemic herbicides. Contact herbicides are often faster-acting but their effects are shorter in control duration than systemic herbicides. Common contact herbicides include hydrothol, diquat, or flumioxazin. These herbicides are recommended only for nuisance, dense native aquatic plant growth or dense EWM growth that may have a limited treatment budget. In general, contact herbicides are usually lower in cost because they are not translocated by the plant roots.

Algaecides are a form of contact herbicide for nuisance algae. Algaecides are used to control nuisance algae that may be in the planktonic or filamentous form. Typically, these products contain some form of elemental copper or a chelated form of copper. RLS does not recommend them unless very severe filamentous algal blooms are present.

Ultimately, the cause of the nuisance algal blooms should be determined, and a long-term solution derived to reduce nutrients that are responsible for dense algal blooms. Algaecides should never be applied to blue-green algal blooms as they may cause the algae to die and re-grow at faster rates and release possible toxins into the water column. Neither of these types of herbicides are recommended for use in Paradise Lake as the lake contains a healthy abundance of native plants and little algae.

Systemic Aquatic Herbicides-2,4-D and Triclopyr

Systemic herbicides are translocated through the plant roots and interfere with cell growth and division. Wherever possible, it is preferred to use a systemic herbicide for longer-lasting aquatic plant control. There are often restrictions with usage of some systemic herbicides around shoreline areas that contain shallow drinking wells. There are often restrictions with usage of some systemic herbicides around shoreline areas that contain shallow drinking wells. Systemic herbicides such as 2,4-D and triclopyr could be used to successfully treat localized or widely dispersed beds of Eurasian Watermilfoil. The systemic herbicide granular 2,4-D is present in three highly effective formulas: Navigate®, Renovate Max G®, and Sculpin®. EGLE regulates all herbicide applications and 2,4-D must not be used within 75 feet of any drinking water well or within 250 feet of any shallow well less than 30 feet in depth. The application of 2,4-D in public trust waters follows a required 24-hour swimming restriction posting plus any other restrictions that are recommended by the manufacturer (usually a turf grass irrigation restriction). Due to the presence of many shallow wells around Paradise Lake and the location of EWM beds close to shore in many areas, this product is not recommended. Triclopyr is recommended and is discussed in detail in Section 5.2.1 below.

Whole-lake Fluridone Aquatic Herbicide Treatments

Fluridone (trade name, SONAR®) is a systemic whole-lake herbicide treatment that is applied to the entire lake volume typically in the spring. The objective of a fluridone treatment is to selectively control the growth of EWM in order to allow other native aquatic plants to germinate and create a more diverse aquatic plant community. Due to the fact that only 21% of the lake contained EWM, a fluridone treatment would not be recommended, as it would likely lead to a reduction of too many aquatic plants which could have significant detrimental impacts on the lake fishery and entire aquatic ecosystem. With this herbicide, it would be critical that there be adequate support from the community and Carp Lake Township as well as Hebron Township for this approach to be possible since the whole-lake treatment will affect waters of Paradise Lake that lie in both township jurisdictions.

5.2 Aquatic Herbicides Recommended for Paradise Lake

The discussions above focused on the different types of contact and systemic herbicides and algaecides commonly used in our inland lakes for exotic and nuisance aquatic plant control. The recommended aquatic herbicide for Paradise Lake is the systemic herbicide triclopyr which should only be used on EWM. This herbicide when used properly and according to label, is effective on EWM and poses little risk to the Paradise Lake ecosystem and its inhabitants. The sections below discuss the risk, safety, and characteristics of this particular herbicide.

5.2.1 Triclopyr

The active ingredient in triclopyr is 3,5,6-trichloro-2-pyridinyloxyacetic acid. It is sold in both liquid (Renovate 3.0®) and granular (Renovate OTF®) formulas. There is also a combination of triclopyr and 2,4-D (Renovate Max G®). Triclopyr should be used with an adjuvant to increase its ability to adhere to the aquatic plants.

The use of liquid Triclopyr with adjuvant may be the best solution since the entire littoral zone volume would be treated with the herbicide and allow the most effective systemic control. The wind conditions, regardless of which herbicide is applied, must be very calm (wind speeds under 10 mph) during the treatment. After triclopyr is applied to the EWM, the plant will begin to twist, turn brown, or have bright green apical stems that later die. It may take several weeks for the plants to die and decompose and thus evaluation should take place at least a month or two after application to determine true efficacy of the herbicide on EWM. There are no swimming or fishing restrictions or shallow well restrictions with triclopyr. There is a 120-day irrigation restriction for watering of ornamentals with lake water. This restriction is often lifted within two weeks and an assay can be conducted to confirm that the residual herbicide concentrations are low enough to resume watering. The half-life of triclopyr is about one day and in lakes this may range from 0.5-7.5 days with no bioaccumulation in the lake sediments. RLS has confirmed that triclopyr does not bioaccumulate in lake sediments (Lake Angelus RLS data, 2017-2020). Due to its low toxicity to aquatic biota and fast breakdown rate, triclopyr is considered very safe for lakes.

5.3 Safety of Aquatic Herbicides

Aquatic herbicides used in the State of Michigan need to be approved for the intended use by the United States Environmental Protection Agency (USEPA). Registration requires very significant testing and review of the data by the agency. This is a process that oftentimes can take ten years including trials in controlled waterbodies. Once approved by the Federal Government, the herbicide is then reviewed and may be approved by the State of Michigan. This process is time consuming and costly which is why there are so few aquatic use herbicides available for consideration. Registration and re-registration of a compound are estimated to cost the producer between 2.4 and 4.0 million dollars. Most herbicides are agricultural products that have undergone further testing in the aquatic arena. The State of Michigan in addition to the federal restrictions have historically added a 24-hour swimming restriction for herbicide use even when it is not a label restriction.

All aquatic herbicides come with a product label that controls the use of the product. A partial list of this information is precautionary statements, hazards to humans and domestic animals, personal protective equipment, user safety recommendations, environmental hazards, directions for use, general information for aquatic and wetland sites, avoiding drift, types of plants controlled, and application methods. All aquatic herbicide applicators need certification by the State of Michigan Department of Agriculture (MDARD). Both Private and Commercial tests are administered. Commercial testing is required to be renewed every three (3) years and is administered in-person. This is a very comprehensive test that requires substantial study.

Use of herbicides on lakes in Michigan is under the authority of the Aquatic Nuisance Control (ANC) Unit within the Department of Environment, Great Lakes, and Energy (EGLE). A permit is required and is obtained by the applicator and the fee is based on the amount of area being treated. This permit requires that a sign be posted at each public access point and in front of every property owner on the lake. Additionally, a notification is required to be mailed to each riparian within 45 days of the treatment. The sign that is posted cites the permit number, the estimated time of application, the products used, any restrictions on the use such as swimming, watering, and use of water for drinking or livestock, and the name of the company doing the application.

Dosing is a critical component of proper herbicide usage and application. Prescription drugs, for example, are therapeutic if taken in low doses, but can be dangerous if abused or taken in larger than prescribed doses. Toxicology is the measure of a substance to cause harm. The risk associated with harmful substances is a combination of the toxicity and the amount of exposure. Aquatic herbicides are mixed with water and then applied to the surface or beneath the surface of the lake. Dilution soon occurs that effects the concentration of the herbicide in the water column.

For example, the herbicide Reward when applied at 2-gallons per acre would require a 150 pound person to consume 3,750 to 7,500 gallons of treated water immediately after application to ingest enough active ingredient to achieve a lethal dose concentration 50 per cent of the time. The table below lists the relative toxicity of numerous substances for acute toxicity comparisons. LDC/50 (lethal dose/50%) is the amount of active ingredient required to cause the death of one-half the test population

RELATIVE TOXICITY OF DIFFERENT SUBSTANCES

	Acute oral-rates
Less toxic	**LDC/50 mg/kg**
Glyphosate	5,600
Table salt	3,000
Triclopyr	2,574
Aspirin	1,000
Copper Sulfate	300
Caffeine	192
Nicotine	53
Sodium Cyanide	6.4

Most Toxic

Many questions are asked about what happens after a pesticide is used in a lake. Generally, pesticides are diluted upon application and break down rapidly in the environment. Depending on the products use, a combination of sunlight, water chemistry and microbial action break the herbicide down into natural components. Some herbicides bind with sediments and are no longer available as an herbicide.

5.4 Evaluation of Aquatic Herbicide Efficacy

Restorative Lake Sciences is the only consulting firm that routinely over-sees each major herbicide application. Each application is documented for the product used, the weather conditions, wind speed, and other environmental conditions. RLS then accompanies the herbicide applicator to insure proper application of the herbicide. This process is lengthy and time-consuming as both parties assure that all GPS points with EWM are thoroughly treated to provide the best outcomes. RLS recommends that herbicide applicators honor a target level of 80 to 90% success reduction in EWM in their contracts. Systemic herbicides usually take 6 to 8 weeks for successful results. After this time period, RLS again surveys the treatment area to verify the actual success rate. If the treatment is not successful in matching the guarantee, then the applicator must retreat at no cost to bring the treatment rate up to a successful condition. Since RLS uses strong geo-referenced data, comparisons can be made within and among years on the efficacy of EWM treatment by location. This allows for precise determination of weed bed reduction.

5.5 Case Studies of Aquatic Herbicides on EWM

The following case studies represent the successful long-term management of EWM on other Michigan lakes that had been infested with dense EWM. To date, all of these lakes exhibit low EWM growth due to extensive annual GPS-guided aquatic vegetation surveys and oversight of any necessary seasonal treatments.

Round Lake, Mason County, Michigan

Round Lake is a 571-acre closed-basin lake located in Sections 28, 29, 32, and 33 of Sheridan Township in Mason County, Michigan (T. 19N, R. 15W). The lake has one primary inlet located at the north side of the lake, and an outlet. In 2004, it was discovered that approximately 50 acres of Eurasian Watermilfoil (EWM) covered the surface of the lake. **However, a formal Lake Improvement Board and Special Assessment District (SAD) were not established until 2006 when the lake was colonized by over 375 acres of EWM.** During the summer of 2007, the Round Lake Improvement Board evaluated techniques such as biological control of the EWM and the Little River Band of Ottawa Indians Inland Fisheries Division assessed the potential impacts of the associated panfish fishery on weevils that were used to control the EWM. It was determined that biological control could not keep up with the aggressive spread of the plant, and spot-treatment of the plant was not economically feasible at the scale that was necessary to treat all of the required acres. Thus, the preferred option was a whole-lake fluridone treatment which was pursued in the spring of 2008. The year following the fluridone treatment, approximately 120 acres of Eurasian Watermilfoil returned and was treated with granular, systemic 2,4-D. Figures 38 and 39 below demonstrate the conditions of Round Lake before the infestation and after it was treated with a whole-lake aquatic herbicide. At present, the lake supports a good balance of native aquatic plants and a healthy inland lake fishery. **Round Lake achieved an eradication in 2010 and has typically has a low treatment acreage each year with 0 acres found again in 2020.**

Figure 38. Round Lake pre-treatment, August, 2006

Figure 39. Round Lake, post-treatment May, 2012.

Bear Lake, Manistee County, Michigan

Bear Lake (N 44º 26.232, W 86º 09.311) is located in sections 4 - 6 of Bear Lake Township, (T.23N, and R.15W) and sections 28 - 29, and 31 - 33 of Pleasanton Township (T.24N, R.15W) in Manistee County, Michigan. The lake surface area is approximately 1,843 acres and may be classified as a glacial-origin, drained lake with a small to moderate littoral zone area and steep slopes leading to a large central deep basin. Bear Lake has a maximum depth of 24 feet and a mean depth of 14.4 feet. **In 2007, a lake improvement feasibility study determined that approximately 320 acres of Eurasian Watermilfoil (EWM) covered the surface of the lake.** A formal Lake Improvement Board and Special Assessment District (SAD) were established in 2008 to fund the control of the Eurasian Watermilfoil. Prior to implementation of selective spot-treatments of aquatic herbicides to treat the Eurasian Watermilfoil, the use of the aquatic weevil, *Euhrychiopsis lecontei* as a biological control vector for the control of Eurasian Watermilfoil was evaluated. Jennifer Jermalowicz-Jones and the Little River Band of Ottawa Indians Inland Fisheries Division assessed the potential impacts of the associated pan fish fishery on weevils that were used to control the Eurasian Watermilfoil. It was determined that the weevils were not a significant source of food for the pan fish; however, they were slow-acting on the milfoil stems. Thus, it was decided upon by the Bear Lake Improvement Board to utilize spot-treatments with systemic aquatic herbicides such as 2,4-D for offshore areas and Triclopyr (Renovate OTF) in near shore areas. A GPS grid survey of over 500 points was used to locate all areas in the lake that contained Eurasian Watermilfoil. Figures 40 and 41 below demonstrate the conditions of Bear Lake before the infestation and after it was treated with the systemic aquatic herbicides such as 2,4-D and triclopyr. **At present, the lake supports a good balance of native aquatic plants and a healthy inland lake fishery, and consistently demonstrated great control of the Eurasian Watermilfoil problem.**

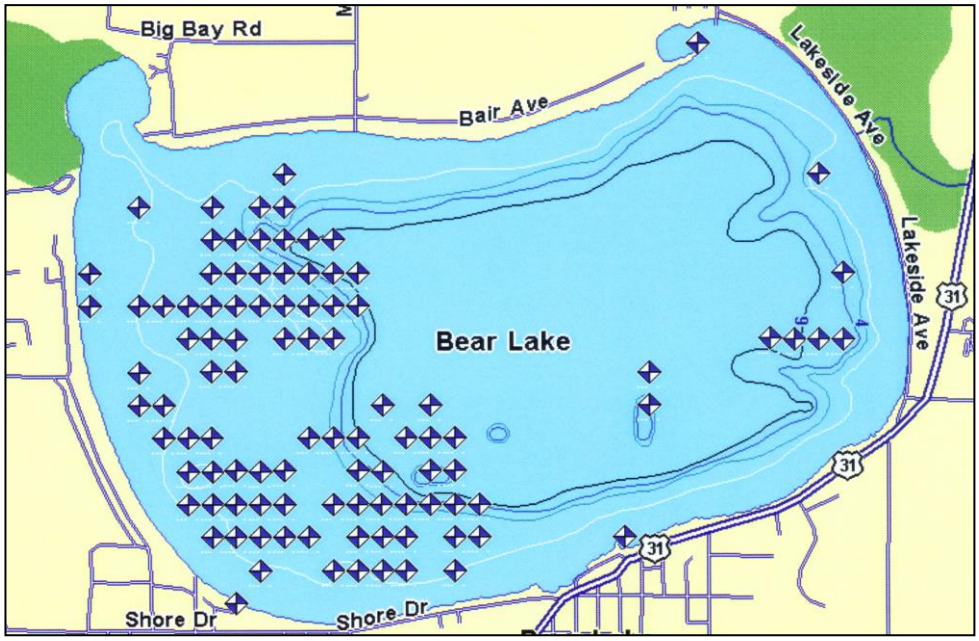

Figure 40. Bear Lake EWM, pre-treatment, 2007.

Figure 41. Bear Lake EWM in June, 2020.

Long Lake, Iosco County, Michigan

Long Lake is a 493-acre natural lake with 8.1 miles of shoreline that currently supports dense quantities of native vegetation and exotic aquatic plant growth. The overall mean depth of the lake is approximately 16.8 feet which is deep; however, the majority of the littoral zone of the lake is vegetated. In addition to the abundant native plant species, there is an overabundance of the invasive species Eurasian Watermilfoil (*Myriophyllum spicatum* L.). **The results of a detailed 2012 GPS-guided aquatic plant (AVAS) survey consisting of 268 sampling points in Long Lake (August 18, 2012; Appendix A), demonstrated that approximately 290 acres of pure Eurasian Watermilfoil infested the lake.** Some individual plants of Eurasian Watermilfoil were found at depths up to 17 feet; however, the majority of the growth was located at depths between 5-12 feet. Some growth of Eurasian Watermilfoil in Long Lake may also be suppressed near shore due to coarse lake sediments that impede growth or due to high wave energy. The Eurasian Watermilfoil growth in Long Lake was very robust, with wide, thick stems, capable of producing dense surface canopies (Figure 42). Much of this excessive submersed aquatic plant growth is due to the likelihood of enriched sediment nutrients whereas abundant rootless plant growth is due to the presence of nutrients such as phosphorus and nitrogen in the water column. The treatment of this EWM consisted of the application of aquatic herbicides during the spring and summer of 2013 and included liquid triclopyr nearshore and granular 2,4-D in deep, offshore areas. **Currently, Long Lake has little EWM that requires treatment (Figure 43) due to annual intensive aquatic vegetation surveys and oversight of spot-treatments of any new growth.**

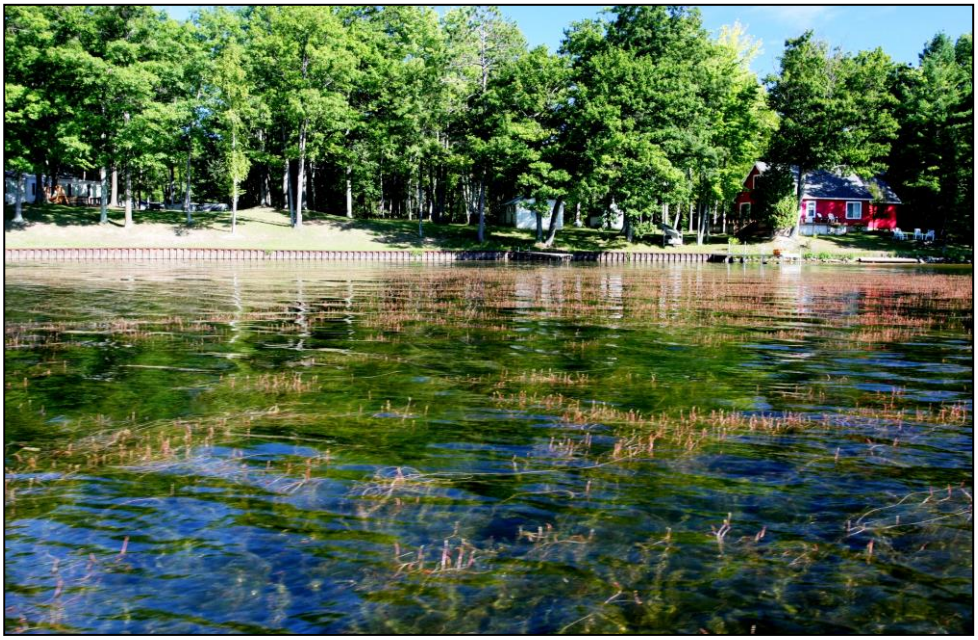

Figure 42. Long Lake, pre-treatment, 2013.

Figure 43. Long Lake, post-treatment, 2013.

Diamond Lake, Osceola County, MI

Diamond Lake is a 60-acre eutrophic lake located in section 26 of Osceola County (T.20N, R. 10W). The lake is primarily a closed-basin system with steep slopes around the littoral zone (shallow area) which are covered with thick submersed aquatic vegetation such as Water Stargrass (*Heteranthera dubia*), Pondweeds (various Potamogeton) and an abundance of emergent vegetation around the lake perimeter. **In 2010, approximately 26 acres of dense EWM (Figure 44) were found around the littoral zone of the lake. The management approach included the use of the systemic herbicide (liquid triclopyr in the form of Renovate 3®) which was applied in September of 2010 to control the EWM. The treatment was very successful, with minimal re-growth of the Eurasian Watermilfoil by late summer of 2010 and into recent years (Figure 45).**

Figure 44. Diamond Lake, pre-treatment, 2010

Figure 45. Diamond Lake, post-treatment, 2010.

5.6 Integration of Aquatic Herbicides with DASH

Integrated management involves the combined use of chemical, biological, mechanical, aeration, or other control methods for aquatic plant control. Integrated management is becoming increasingly common since aquatic ecosystems are multi-dimensional and have different vegetation communities in certain lake areas and thus may show variable responses to specific treatments. The eastern-most region of the lake lies within Hebron Township which is currently not a part of the Paradise Lake Improvement Program Special Assessment District (SAD). Although there are only 10.5 acres of EWM within this region of the lake, it is capable to re-infesting other areas of the lake once the herbicide treatments remove the EWM in those areas. Due to this possibility, it is recommended that either individual property owner permissions be obtained for treatment in specific areas, or a DASH permit be applied for to remove this EWM over a period of 2-5 years.

6.0 ADDITIONAL RECOMMENDED MANAGEMENT METHODS: AIS PREVENTION & SEPTIC SYSTEM MAINTENANCE

In addition to the recommended use of triclopyr and rigorous aquatic vegetation surveys, RLS recommends the following additional improvements to reduce further spread and infestation of EWM on Paradise Lake.

6.1 Aquatic Invasive Species Education and Prevention

An exotic species is a non-native species that does not originate from a particular location. When international commerce and travel became prevalent, many of these species were transported to areas of the world where they did not originate. Due to their small size, insects, plants, animals, and aquatic organisms may escape detection and be unknowingly transferred to unintended habitats.

The first ingredient to successful prevention of unwanted transfers of exotic species to Paradise Lake is awareness and education (Figures 46 and 47). The exotic species of concern have been listed in this report. Other exotic species on the move could be introduced to the riparians around Paradise Lake through the use of a professionally developed educational newsletter or through public workshops on the health of the Paradise Lake ecosystem. Public boat launches are a primary area of vector transport for all invasive species and thus boat washing stations have become more common. With over 13 million registered boaters in the U.S. alone, the need for reducing transfer of aquatic invasive species (AIS) has never been greater. The Minnesota Sea Grant program identifies five major boat wash scenarios which include: 1) Permanent washing stations at launch sites, 2) Portable drive-thru or transient systems, 3) Commercial car washes, 4) Home washing, and 5) Mandatory vs. volunteer washing. Paradise Lake has already pioneered a general boat washing station in recent years.

Boat washing stations promote the Clean Waters Clean Boats volunteer education program by educating boaters to wash boating equipment (including trailers and bait buckets) before entry into every lake. Critical elements of this education include: 1) How to approach boaters, 2) Demonstration of effective boat and trailer inspections and cleaning techniques, 3) The recording of important information, 4) Identification of high-priority invasive species, and 5) Sharing findings with others. Boat washing stations offer opportunities for collaborative efforts between lake groups, the MDNR, and EGLE. Figures 48-49 demonstrate the use of a boat washing station to prevent the spread of invasives into lakes with public access such as Paradise Lake.

Additional educational information regarding these stations and education can be found on the following websites:

1) USDA: https://www.invasivespeciesinfo.gov/us/Michigan
2) Michigan Wildlife Federation Invasive animals, plants list, and native plants/animals list: https://www.Michiganwildlife.org/wildlife
3) Stop Aquatic Hitchhikers!: www.protectyourwaters.net

Recently, MSU partnered with EGLE to study the various forms of boat washing stations (including the innovative CD3 units) on lakes to analyze effectiveness of invasive removal, behavior patterns and preference for use, and short and long-term cost effectiveness of each system. This will assist in the placement of specific types of wash stations around other portals of entry around the lake. Boat washing stations and invasive species prevention signs are recommended at all public entry sites where practical.

Figure 46. An aquatic invasive prevention sign for public access sites.

Figure 47. An aquatic hitchhiker (milfoil) on a boat trailer.

Figure 48. A public boat washing station on Higgins Lake, Michigan.

Figure 49. A responsible boat owner using a boat washing station.

Zebra Mussels and Quagga Mussels

Zebra Mussels (*Dreissena polymorpha*; Figure 50) were first discovered in Lake St. Clair in 1988 and likely arrived in ballast water or on shipping vessels from Europe (McMahon 1996). They are easily transferred to other lakes because they inherit a larval (nearly microscopic) stage where they can easily avoid detection. The mussels then grow into the adult (shelled) form and attach to substrates (i.e. boats, rafts, docks, pipes, aquatic plants, and lake bottom sediments) with the use of byssal threads. The fecundity (reproductive rate) of female Zebra Mussels is high, with as many as 40,000 eggs laid per reproductive cycle and up to 1,000,000 in a single spawning season (Mackie and Schlosser 1996). Although the mussels only live 2-3 years, they are capable of great harm to aquatic environments. In particular, they have shown selective grazing capabilities by feeding on the preferred zooplankton food source (green algae) and expulsion of the non-preferred blue green algae (cyanobacteria). Additionally, they may decrease the abundance of beneficial diatoms in aquatic ecosystems (Holland 1993). Such declines in favorable algae, can decrease zooplankton populations and ultimately the biomass of planktivorous fish populations. Zebra Mussels are viewed by some as beneficial to lakes due to their filtration capabilities and subsequent contributions to increased water clarity. However, such water clarity may allow other photosynthetic aquatic plants to grow to nuisance levels (Skubinna et *al*. 1995).

Quagga Mussels (*Dreissena bugensis;* Figure 50) are native the Ukraine and have created an economical burden to the Great Lakes fishery due to their great ability to alter the planktonic food chain in the lakes. They currently outrank the Zebra Mussels in abundance in the Great Lakes and are capable of filtering larger quantities of water and therefore assimilating more plankton. These mussels were shown to be highly selective in choosing naked flagellates such as Rhodomonas as well as larger diatoms (NOAA research; noaa.gov). **Only Zebra Mussels were found in Paradise Lake which has likely led to increased water clarity through reduction of planktonic algae in the water column.**

The recommended prevention protocols for further introduction of mussels includes steam-washing all boats, boat trailers, jet-skis, and floaters prior to placing them into Paradise Lake. Fishing poles, lures, and other equipment used in other lakes (and especially the Great Lakes) should also be thoroughly steam-washed before use in Paradise Lake. Additionally, all solid construction materials (if recycled from other lakes) must also be steam-washed. Boat transom wells must always be steam-washed and emptied prior to entry into the lake. Excessive waterfowl should also be discouraged from the lake since they are a natural transportation vector of the microscopic Zebra Mussel larvae or mature adults.

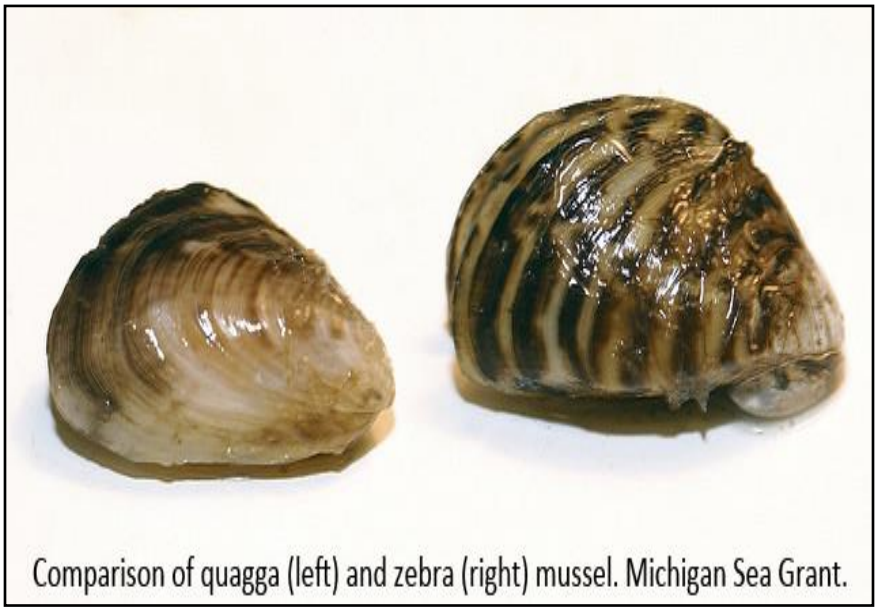

Figure 50. Zebra Mussels and Quagga Mussels (Photo courtesy of Michigan Sea Grant).

Invasive Aquatic Plants

In addition to Eurasian Watermilfoil (*M. spicatum*), many other invasive aquatic plant species have been introduced into waters of the North Temperate Zone. The majority of exotic aquatic plants do not depend on high water column nutrients for growth, as they are well-adapted to using sunlight and minimal nutrients for successful growth, but excess nutrients often result in exacerbated growth.

These species have similar detrimental impacts to lakes in that they decrease the quantity and abundance of native aquatic plants and associated macroinvertebrates and consequently alter the lake fishery. Such species include *Hydrilla verticillata* (Figure 51) and *Trapa natans* (Water Chestnut; Figure 52). *Hydrilla* was introduced to waters of the United States from Asia in 1960 (Blackburn et *al*. 1969) and is a highly problematic submersed, rooted, aquatic plant in tropical waters. Many years ago, *Hydrilla* was found in Lake Manitou (Indiana, USA) and the lake public access sites were immediately quarantined in an effort to eradicate it. *Hydrilla* retains many physiologically distinct reproductive strategies which allow it to colonize vast areas of water and to considerable depths, including fragmentation, tuber and turion formation, and seed production. Currently, the methods of control for *Hydrilla* include the use of chemical herbicides, rigorous mechanical harvesting, and Grass Carp (*Ctenopharyngodon idella* Val.), with some biological controls currently being researched. Water Chestnut (*Trapa natans*) is a non-native, annual, submersed, rooted aquatic plant that was introduced into the United States in the 1870's yet may be found primarily in the northeastern states. The stems of this aquatic plant can reach lengths of 12-15 feet, while the floating leaves form a rosette on the lake surface. Seeds are produced in July and are extremely thick and hardy and may last for up to 12 years in the lake sediment.

If stepped on, the seed pods may even cause deep puncture wounds to those who recreate on the lakes. Methods of control involve the use of mechanical removal and chemical herbicides. Biological controls are not yet available for the control of this aquatic invasive plant.

Figure 51. Hydrilla from a Florida lake.

Figure 52. Water Chestnut from a northeastern lake.

6.2 Septic System and Drain field Maintenance

Nutrient pollution of inland lakes from septic systems and other land use activities is not a modern realization and has been known for multiple decades. The problem is also not unique to Michigan Lakes and was first described in Montreal Canada by Lesauteur (1968) who noticed that summer cottages were having negative impacts on many water bodies. He further noted that a broader policy was needed to garner control of these systems because they were becoming more common over time. Many of our inland lakes are in rural areas and thus sewer systems or other centralized wastewater collection methods are not practical. Thus, septic systems have been common in those areas since development on inland lakes began. Septic systems have four main components consisting of a pipe from the residence, a septic tank or reservoir, a drainage field, and the surrounding soils Figure 53).

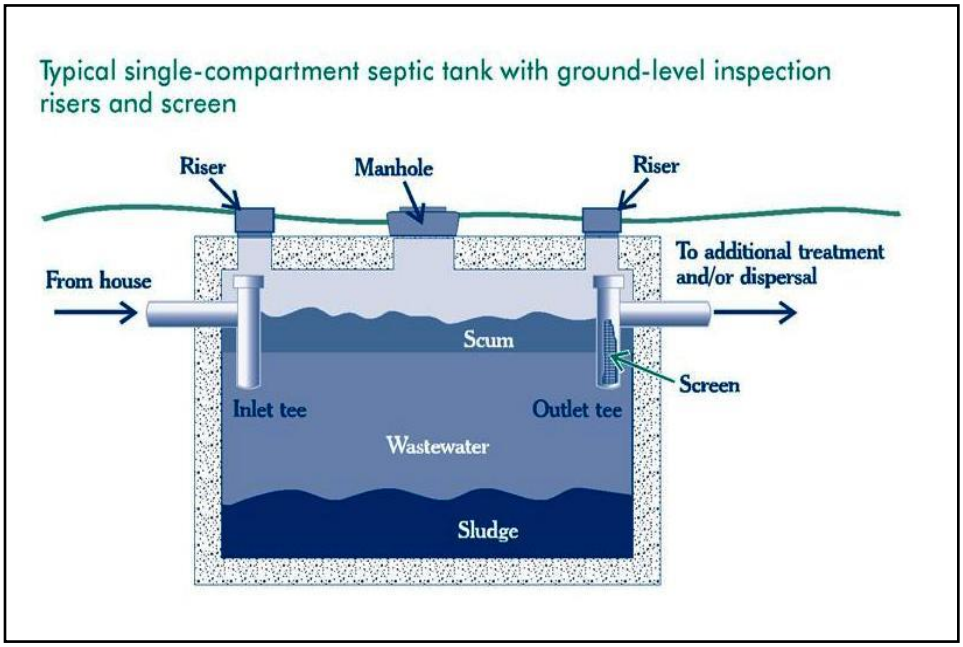

Figure 53. Diagram of essential septic tank components (US EPA).

On ideal soil types, microbes in the soil are able to decompose nutrients and reduce the probability of groundwater contamination. However, many lakes in Michigan contain soils that are not suitable for septic systems. **Such soils that are not very permeable, prone to saturation or ponding, and have mucks exist around many lakes and currently have properties with septic systems. There are many areas around Paradise Lake that have mucky soils.** In fact, soils that are saturated may be associated with a marked reduction in phosphorus assimilation and adsorption (Gilliom and Patmont, 1983; Shawney and Starr, 1977) which leads to the discharge of phosphorus into the groundwater, especially in areas with a high water table. In the study by Gilliom and Patmont (1983) on Pine Lake in the Puget Sound of the western U.S., they found that it may take 20-30 years for the phosphorus to make its way to the lake and cause negative impacts on water quality.

Typical septic tank effluents are rich in nutrients such as phosphorus and nitrogen, boron, chlorides, fecal coliform, sulfates, and carbon (Cantor and Knox, 1985). Phosphorus and nitrogen have long been identified as the key causes of nuisance aquatic plant and algae growth in inland lakes. Although phosphorus is often the limiting growth factor for aquatic plant growth, nitrogen is often more mobile in the groundwater and thus is found in abundance in groundwater contributions to lakes. A groundwater seepage study on submersed aquatic plant growth in White Lake, Muskegon County, Michigan, was conducted in 2005 by Jermalowicz-Jones (MS thesis, Grand Valley State University) and found that both phosphorus and nitrogen concentrations were higher in developed areas than in undeveloped areas. This helped to explain why the relatively undeveloped northern shore of White Lake contained significantly less submersed aquatic plant growth than the developed southern shoreline. The research also showed that more nutrients were entering the lake from groundwater than some of the major tributaries.

Spence-Cheruvelil and Soranno (2008) studied 54 inland lakes in Michigan and found that total aquatic plant cover (including submersed plants) was most related to secchi depth and mean depth.

However, they also determined that man-made land use activities are also predictors of aquatic plant cover since such variables can also influence these patterns of growth. Prior to changes in offshore aquatic plant communities, an additional indicator of land use impacts on lake water quality in oligotrophic lakes (lakes that are low in nutrients) includes changes in periphytic algae associated with development nearshore. Such algae can determine impacts of septic leachate before other more noticeable changes offshore are found (Rosenberger et *al*., 2008).

Development in the watershed also may influence the relative species abundance of individual aquatic plant species. Sass et *al*. (2010) found that lakes associated with rigorous development in surrounding watersheds had more invasive species and less native aquatic plant diversity than less developed lakes. Thus, land use activities such as failing septic systems may not only affect aquatic plant biomass and algal biomass, but also the composition and species richness of aquatic plant communities.

A groundwater investigation of nutrient contributions to Narrow Lake in Central Alberta, Canada by Shaw et *al*., 1990, utilized mini-piezometers and seepage meters to measure contributions of groundwater flow to the lake. They estimated that groundwater was a significant source of water to the lake by contributing approximately 30% of the annual load to the lake. Additionally, phosphorus concentrations in the sediment pore water were up to eight times higher than groundwater from nearby lake wells.

It is estimated that Michigan has over 1.2 million septic systems currently installed with many of them occurring in rural areas around inland lakes. The number of septic systems that are a risk to the aquatic environment is unknown which makes riparian awareness of these systems critical for protection of lake water.

Construction of new septic tanks requires notification and application by the homeowner to the county Department of Public Health and also that soils must be tested to determine suitability of the system for human health and the environment. **It is recommended that each septic tank be inspected every 1-2 years and pumped every 1-2 years depending upon usage. The drain field should be inspected as well and only grasses should be planted in the vicinity of the system since tree roots can cause the drain field to malfunction. Additionally, toxins should not be added to the tank since this would kill beneficial microbes needed to digest septic waste.** Areas that contain large amounts of peat or muck soils may not be conducive to septic tank placement due to the ability of these soils to retain septic material and cause ponding in the drain field. Other soils that contain excessive sands or gravels may also not be favorable due to excessive transfer of septage into underlying groundwater. Many sandy soils do not have a strong adsorption capacity for phosphorus and thus the nutrients are easily transported to groundwater. Nitrates are especially more mobile and travel quickly with the groundwater and thus are also a threat to water quality.

The utilization of septic systems by riparians is still quite common around inland lake shorelines. A basic septic system typically consists of a pipe leading from the home to the septic tank, the septic tank itself, the drain field, and the soil. The tank is usually an impermeable substance such as concrete or polyethylene and delivers the waste from the home to the drain field. The sludge settles out at the tank bottom and the oils and buoyant materials float to the surface. Ultimately the drain field receives the contents of the septic tank and disperses the materials into the surrounding soils. The problem arises when this material enters the zone of water near the water table and gradually seeps into the lake bottom. This phenomenon has been noted by many scholars on inland waterways as it contributes sizeable loads of nutrients and pathogens to lake water. Lakebed seepage is highly dependent upon water table characteristics such as slope (Winter 1981).

The higher the rainfall, the more likely seepage will occur and allow groundwater nutrients to enter waterways. Seepage velocities will different greatly among sites and thus failing septic systems will have varying impacts on the water quality of specific lakes**. Lee (1977) studied seepage in lake systems and found that seepage occurs as far as 80 meters from the shore. This finding may help explain the observed increases in submersed aquatic plant and algae growth near areas with abundant septic tank systems that may not be adequately maintained.** Loeb and Goldman (1978) found that groundwater contributes approximately 44% of the total soluble reactive phosphorus (SRP) and 49% of total nitrates to Lake Tahoe from the Ward Valley watershed. Additionally, Canter (1981) determined that man-made (anthropogenic) activities such as the use of septic systems can greatly contribute nutrients to groundwater.

7.0 CONCLUSIONS, RECOMMENDATIONS, AND ESTIMATED COSTS

The urgent control of the EWM infestation throughout Paradise Lake is essential for the long-term preservation of the native aquatic plant communities and for continued safe navigation and recreation on the lake. Furthermore, the selected methods for the control of EWM should also protect native aquatic plant species through targeted control of EWM only. Precise, GPS-guided aquatic herbicide applications with the systemic herbicide triclopyr are recommended. Paradise Lake possesses a strong fishery, with many species of native aquatic plants that help to support the associated fishery through housing macro invertebrates (fish food) and providing habitat and shelter in the lake. The management options discussed in the sections above complement the socio-economic climate that influences both riparians and individual components of the Paradise Lake ecosystem. The overall goal of this program is to use liquid triclopyr to reduce EWM growth over time so that non-chemical methods such as DASH may reasonably and sustainably be used to reduce EWM as it may re-occur in some areas.

The proposed improvement program would be funded through both lake SAD funds from Carp Lake Township and possible initial contributions from Hebron Township. An SAD is currently in place, but the scope of work has changed. Public hearings must by statute be held pursuant to P.A. 451 of 1994, as amended, within 60 days of receipt and acceptance of this feasibility report. Public notices must also be mailed first-class to each person in the proposed SAD with the date, time, location, and purpose of the hearing of practicability not less than 10 days prior to the hearing. Rules for such noticing are available in P.A. 451 of 1994, as amended. RLS strongly encourages a review of Part 309, Inland Lakes by the PLIB prior to sending notices and holding the hearing of practicability. If the public and the PLIB approve of the proposed improvements during the public hearing of practicability, a resolution is passed to proceed with the improvements as presented. Notices then must be sent out within 20 days of a second hearing of assessment roll, where the completed assessment roll is then on file at the Township offices for review and those in the SAD can then approach the PLIB with any errors or concerns with their proposed assessment. The tables

below demonstrate the proposed costs for the proposed EWM reduction program for Paradise Lake.

Table 3. Cost Estimates for the Paradise Lake EWM reduction program. Note: This budget does not include possible contributions from Hebron Township.

Proposed Paradise Lake Improvement Item	**Estimated 2021 Cost**	**Estimated 2022 Cost**	**Estimated 2023-2025 Cost**
Triclopyr (Renovate 3.0) herbicide in liquid form with adjuvant for control of 401 acres of invasive EWM @ $290 per acre (includes notifications from applicator and EGLE permit fees)	$116,290	$87,217	$43,609
DASH operations (includes up to 10.5 acres of removal with annual removal of 3.0 acres and permit fees)	$10,000	$10,000	$10,000
Professional Services (limnologist surveys, oversight, sampling, monitoring, education, meetings)[1]	$15,500	$15,500	$16,500
Contingency[2]	$14,179	$11,272	$7,011
Total Annual Estimated Cost	$155,969	$123,989	$77,120
Estimated Cost per Front-lot[5]	$367	$292	$181
Estimated Cost per Back-lot	$183	$146	$91
Estimated Cost per Commercial lot	$734	$583	$363

[1]Professional services include professional limnologist services as outlined in the annual contract between the Paradise Lake Improvement Board and RLS.
[2]Contingency is 10-15% of total budget and may be used towards any item as needed.
3 Based on 318 front lots, 126 backlots, 22 commercial lots, for a total of 466 lots. Front lots are assessed 1.0 unit of benefit; backlots are assessed 0.5 units of benefit' commercial lots are assessed 2.0 units of benefit. Units: 318 front; 63 back; 44 commercial—for a total 425 units.

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