Paw Paw Lake Future Management Recommendations for Improved Lake Health
Berrien County, Michigan
April, 2023

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1.0 PAW PAW LAKE MANAGEMENT & RESTORATION RECOMMENDATIONS SUMMARY

Paw Paw Lake is a large inland lake comprising 921.4 acres in surface area (Figure 1; RLS, 2023 digitized surface area). The lake lies in sections 10,11,14,15, and 16 of Watervliet and Coloma Townships in Berrien County, Michigan (T. 3S, R. 17W). The lake has two distinct deep basins with the north basin occupying over 217 acres with a maximum depth of 50 feet and the south basin occupying approximately 674 acres with a maximum depth of 90 feet. The mean overall depth of the entire lake is approximately 31.4 feet (PLM, 2020) which is very deep for an inland lake.

The lake water volume is estimated to be around 28,927 acre-feet (PLM, 2020) and the lake lies at an elevation of 621 above mean sea level. The length of the shoreline is approximately 12.2 miles (RLS, 2023 digitized distance). The hydraulic retention time of the lake is estimated to be 506 days (PLM, 2020). The fetch (longest distance across the lake) is approximately 2.1 miles (RLS, 2023 digitized distance). There is an outlet at the east end of the lake near North Watervliet road. The lake also has three key drains that contribute significant water and nutrients to the lake.

An urgent concern is that Paw Paw Lake is in the process of shifting from a clear-water aquatic plant-dominated state to an algal-dominant state that is occupied by excessive cyanobacteria blooms. Scheffer et *al*., (2001) discussed alternate stable states and the difficulty associated with reverting a lake back to the more favorable and less turbid condition. Unless significant improvements are made to Paw Paw Lake, the alternate stable state with increasing turbidity and algal blooms will persist.

Watershed Improvements and Citizen Engagement:

The Paw Paw Lake immediate watershed area is approximately 10,394 acres (RLS, 2023 digitized) which indicates a large watershed with many opportunities for nutrients and solids to enter Paw Paw Lake. The largest threat within the immediate watershed is the contribution of fine particulate organic matter (FPOM) that originates from specific soil types such as Palms and Houghton mucks. Since the destruction of filtration wetlands over the years and development of homes, farms, and drains, these fines are transported through the drains and into the lake. RLS recommends a much closer analysis of the locations of these fines in the entire immediate watershed in an effort to target specific Critical Source Areas (CSA's) where improvements can be made. These improvements will likely require approvals from property owners and funding which may be negotiated between the PPLA, PPLF, and the landowners and possibly supplemented with outside funding (often NPS grants or NRCS programs). Lastly, RLS recommends an annual Paw Paw Lake community workshop where aquatic management experts can address concerns from riparians, educate riparians on proper lake care, and present new data and data trends on various lake water quality and health parameters. The workshops can also invite other relevant stakeholders such as MDNR, EGLE, or others and have been an integral component of lake improvement programs throughout the state.

Water Quality Monitoring:

In the 2022 Paw Paw Lake evaluation report, RLS compared previously collected spring surface data to summer surface data and there were marked differences. RLS recommended sampling the same parameters in spring and summer for all of the proposed 6 deep basin sampling locations. The parameter of TIN is especially important since ammonia nitrogen is a major source of nutrient for blue-green algae. The following physical parameters should be collected once in the spring and once in mid to late summer using calibrated equipment only.

The parameters measured below should be measured in 0.5-meter increments:

1. Water temperature (measured in °C or °F)
2. Dissolved oxygen (DO measured in mg/L)
3. pH (measured in Standard Units SU)
4. Specific conductivity (measured in mS/cm)
5. Total Dissolved Solids (TDS measured in mg/L)
6. Secchi disk transparency (feet or meters)

The following chemical water quality parameters should be collected at the surface, mid-depth, and bottom of each of the N=6 water quality sampling stations with all samples taken to a NELAP (EPA-certified independent laboratory):

1. Total Phosphorus (TP in mg/L or µg/L)
2. Ortho-Phosphorus (SRP in mg/L or µg/L)
3. Total Inorganic Nitrogen (TIN in mg/L or µg/L)
4. Total Kjeldahl Nitrogen (TKN in mg/L or µg/L)
5. Total Suspended Solids (TSS in mg/L or µg/L)
6. Chlorophyll-a (Chl-a in µg/L); can be measured *in situ*

Algal Sampling and Toxin Testing:

In addition to the *in situ* fluorimeter sampling for chlorophyll-*a*, RLS recommends testing for all possible cyanobacteria toxins during a bloom. This includes additional toxins that may be present but have not been tested for in the past.

In addition, algal community composition should be determined with relative abundance of all taxa, including cell counts and biovolume from water samples collected during summer and during blue-green algal blooms from PhycoTech® laboratories. This representation of algal data is optimum for understanding changes in the blue-green and favorable algal communities over time which is key to understanding mitigation efficacy.

Aquatic Vegetation Survey Methods:

Although the AVAS survey method is used for the permit applications for whole-lake fluridone (SONAR AS®) treatments, RLS recommends that a GPS point-intercept survey be used for the majority of lake vegetation surveys. This method allows for the development of precise polygons used for treatment. Additionally, RLS recommends a whole-lake aquatic vegetation biovolume scan to help delineate polygons and measure the overall cover of all aquatic vegetation relative to the lake basin size. All of the surveys should be conducted by an unbiased lake manager with a strong aquatic aquatic botany background. This is important to reduce possible treatment bias by having the herbicide applicator conduct the surveys and make management decisions since they profit off of the sales of aquatic herbicides. Since the lake littoral zone is not very large, adequate retention of native submersed aquatic vegetation is critical for reducing blue-green algal blooms over time since they compete with aquatic plants for light and nutrients.

Aquatic Vegetation Treatments:

An emphasis on more selective treatments of nuisance natives is important for protecting the limited submersed aquatic vegetation in the littoral zone of Paw Paw Lake. Only systemic herbicides should be used on the EWM with less fluridone usage as this herbicide can exacerbate Starry Stonewort. The systemic herbicide ProcellaCOR® is highly recommended due to excellent sustained control and ability to use in target-specific areas. Starry Stonewort should not be treated with chelated copper algaecide long-term since copper does bioaccumulate in lake sediments, even in a chelated form. The use of diver-assisted suction harvesting (DASH) is recommended for more sustainable results. Although DASH is costly, it would remove many of the reproductive bulbils that lead to accelerated growth over time. Algaecides should only be applied to dense green, filamentous algae since they can exacerbate blue-green algae and may even contribute to toxin release.

Blue-green Algae Reduction:

Nutrient reduction is the optimum method for reducing blue-green algae over time. This can be achieved with watershed management and consideration of nutrient inactivation methods such as the use of PhosLock®, MetaFloc®, or EutroSORB®. These products must be individually quoted out as they require substantial lake data for accurate and effective-dose pricing. For immediate control of blooms, the use of PAK27® (a peroxide) is recommended over copper algaecides. In consideration of lake aeration, only aeration of the hypolimnion should be considered since previous implementation resulted in the transport of phosphorus from the deep basins to the shallows and enhanced algal growth. There are other aeration technologies that can increase dissolved oxygen in deeper areas and reduce the release of phosphorus to the shallow waters. These also must be individually quoted as they too will require substantial lake data.

Waterfowl Management:

Nuisance geese and waterfowl (seagulls) have become problematic for Paw Paw Lake. RLS offers many tools for riparian use later in the report and also recommends a goose nest destruction and/or egg replacement program as permitted by the MDNR. These programs are effective at reducing geese. In addition, the use of deicers or bubblers during the winter months encourage migratory geese to stop and leave waste in the lake. This waste is very high in nutrients that sink into the lake sediment porewater space and thus the use of the deicers is discouraged among riparians.

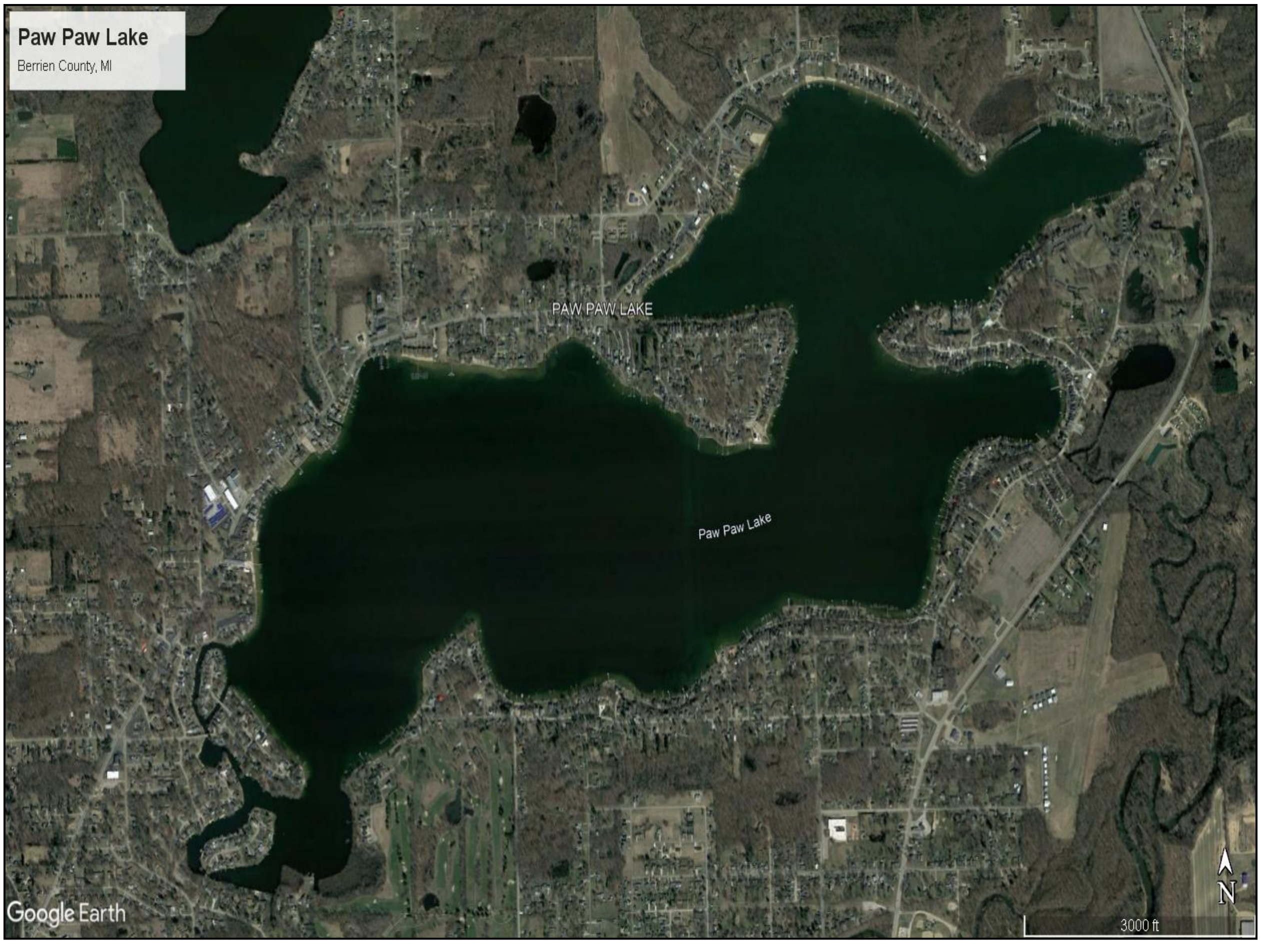

Figure 1. Aerial Photograph of Paw Paw Lake, Berrien County, Michigan.

2.0 PAW PAW LAKE AQUATIC VEGETATION

Based on a review of aquatic vegetation data collected by PLM over the past several years, the lake currently has 19 native aquatic plant species including 14 submersed, 3 floating-leaved, and 2 emergent aquatic plant species (Table 1). In addition, the lake has 3 invasive aquatic plant species including hybrid Eurasian Watermilfoil, Curly-leaf Pondweed, and Starry Stonewort (Table 2).

Aquatic plants (macrophytes) are an essential component in the littoral zones of most lakes in that they serve as suitable habitat and food for macroinvertebrates, contribute oxygen to the surrounding waters through photosynthesis, stabilize bottom sediments (in the rooted growth form), and contribute to the cycling of nutrients such as phosphorus and nitrogen upon decay. In addition, decaying aquatic plants contribute organic matter to lake sediments which further supports healthy growth of successive aquatic plant communities that are necessary for a balanced aquatic ecosystem. An overabundance of aquatic vegetation may cause organic matter to accumulate on the lake bottom faster than it can break down. Aquatic plants generally consist of rooted submersed, free-floating submersed, floating-leaved, and emergent growth forms. The emergent growth form (i.e., cattails, native loosestrife) is critical for the diversity of insects onshore and for the health of nearby wetlands. Submersed aquatic plants can be rooted in the lake sediment (i.e., milfoils, pondweeds), or free-floating in the water column (i.e., Coontail). Nonetheless, there is evidence that the diversity of submersed aquatic macrophytes can greatly influence the diversity of macroinvertebrates associated with aquatic plants of different structural morphologies (Parsons and Matthews, 1995). Therefore, it is possible that declines in the biodiversity and abundance of submersed aquatic plant species and associated macroinvertebrates, could negatively impact the fisheries of inland lakes. Alternatively, the overabundance of aquatic vegetation can compromise recreational activities, aesthetics, and property values.

Paw Paw Lake has a favorable biodiversity of native aquatic plants; however, the invasive Eurasian Watermilfoil and Starry Stonewort are limiting space for successful germination and growth of other native submersed aquatic plants. Additionally, the low water clarity is also limiting the growth of lower-growing and favorable native submersed aquatic plants so many are scarce in relative abundance. Lastly, over-treatment of submersed aquatic vegetation is further selecting for blue-green algae and also limiting enhancement and relative abundance of biodiversity over time.

Table 1. Paw Paw Lake native aquatic plant frequency (2020 PLM data collected from EGLE Miwaters database).

Native Aquatic Plant Species Name	*Native Aquatic Plant Common Name*	*Paw Paw Lake Frequency*	*Native Aquatic Plant Growth Habit*
Chara vulgaris	Muskgrass	5.1	Submersed, Rooted
Stuckenia pectinata	Sago Pondweed	0.5	Submersed, Rooted
Potamogeton zosteriformis	Flat-stem Pondweed	0.04	Submersed, Rooted
Potamogeton robbinsii	Fern-leaf Pondweed	0.2	Submersed, Rooted
Potamogeton gramineus	Variable-leaf Pondweed	1.7	Submersed, Rooted
Potamogeton praelongus	White-stem Pondweed	0.08	Submersed, Rooted
Potamogeton illinoensis	Illinois Pondweed	1.3	Submersed, Rooted
Potamogeton amplifolius	Large-leaf Pondweed	3.3	Submersed, Rooted
Zosterella dubia	Water Stargrass	1.3	Submersed, Rooted
Elodea canadensis	Common Waterweed	0.02	Submersed, Rooted
Vallisneria americana	Wild Celery	33.0	Submersed, Rooted
Sagittaria sp.	Submersed Sagittaria	0.3	Submersed, Rooted
Ceratophyllum demersum	Coontail	9.1	Submersed, Non-Rooted
Najas sp.	Naiad	25.1	Submersed, Rooted
Nymphaea odorata	White Waterlily	2.6	Floating-leaved
Brasenia schreberi	Watershield	0.01	Floating-leaved
Nuphar sp.	Spatterdock	4.2	Floating-leaved
Arrow arum	Arrowhead	0.3	Emergent
Typha sp.	Cattails	0.09	Emergent

Table 2. Paw Paw Lake invasive aquatic plants, growth habit, and average cover (based on review of PLM 2020 survey data collected from EGLE MiWaters database).

Exotic Aquatic Plant Species Name	*Exotic Aquatic Plant Common Name*	*Exotic Aquatic Plant Growth Habit*	*Abundance in or around Paw Paw Lake*
Myriophyllum spicatum	Eurasian Watermilfoil	Submersed; Rooted	20.1
Nitellopsis obtusa	Starry Stonewort	Submersed; Rooted	0.6
Potamogeton crispus	Curly-leaf Pondweed	Submersed; Rooted	0

Hybrid Watermilfoil

Hybrid watermilfoil (*Myriophyllum spicatum var. sibiricum*; Figure 2) is an exotic aquatic macrophyte that is a serious problem in Michigan inland lakes and has been genetically identified in Paw Paw Lake. A similar watermilfoil species that is considered to be exotic by some scientists (*Myriophyllum heterophyllum*) in New Hampshire was found to have significant impacts on waterfront property values (Halstead et *al*., 2003). Moody and Les (2007) were among the first to determine a means of genotypic and phenotypic identification of the hybrid watermilfoil variant and further warned of the potential difficulties in the management of hybrids relative to the parental genotypes. It is commonly known that hybrid vigor is likely due to increased ecological tolerances relative to parental genotypes (Anderson 1948), which would give hybrid watermilfoil a distinct advantage to earlier growth, faster growth rates, and increased robustness in harsh environmental conditions. In regard to impacts on native vegetation, hybrid watermilfoil possesses a faster growth rate than Eurasian watermilfoil or other plants and thus may effectively displace other vegetation (Les and Philbrick 1993; Vilá et *al*. 2000). Most of the milfoil present in Paw Paw Lake has been determined to be hybridized.

Furthermore, the required doses of systemic herbicides needed for successful control of the hybrid watermilfoil are likely to be higher since there is much more water volume at greater depths it can occupy and also due to the fact that hybrid watermilfoil has shown increased tolerance to traditionally used doses of systemic aquatic herbicides, especially fluridone. There has been significant scientific debate in the aquatic plant management community regarding the required doses for effective control of hybrid watermilfoil as this usually varies among sites.

Starry stonewort (*Nitellopsis obtusa*; Figure 3) is an invasive macro-alga that has invaded many inland lakes of Michigan and was originally discovered in the St. Lawrence River. The “leaves” appear as long, smooth, angular branches of differing lengths. The alga has been observed in dense beds at depths beyond several meters and can grow to heights in excess of a few meters. It prefers clear alkaline waters and has been shown to cause significant declines in water quality and fishery spawning habitat. Starry Stonewort was the most recent invasive to reside in the lake in 2018 and was found in the bay at the northeast end of lake and along the north shore peninsula. In 2021, it was also found in the southwest corner of the lake. In 2022, there were approximately 13.4 acres treated. For some unknown reason, the use of SONAR AS® can select for increases in Starry Stonewort. Unfortunately, there are no systemic herbicides for the treatment of Starry Stonewort and thus treatments are limited to copper products which bioaccumulate in the lake sediments. RLS offers an alternative method that is costly but does not use algaecides and is likely to reduce cover over time.

Curly-leaf Pondweed (*Potamogeton crispus*; Figure 4) is an exotic, submersed, rooted aquatic plant that was introduced into the United States in 1807 but was abundant by the early 1900’s. It is easily distinguished from other native pondweeds by its wavy leaf margins. It grows early in the spring and as a result may prevent other favorable native aquatic species from germinating. The plant reproduces by the formation of fruiting structures called turions. It does not reproduce by fragmentation as invasive watermilfoil does; however, the turions may be deposited in the lake sediment and germinate in following seasons. Fortunately, the plant naturally declines around mid-July in many lakes and is also amenable to mechanical harvesting. Curly-leaf Pondweed is a pioneering aquatic plant species and specializes in colonizing disturbed habitats. It is highly invasive in aquatic ecosystems with low biodiversity and unique sediment characteristics. This plant is generally problematic in the spring months but has been promptly treated when dense with the use of a contact herbicide. Unfortunately, there are no systemic herbicides for Curly-Leaf Pondweed.

Figures 5-10 demonstrate the changes for all invasives and natives in Paw Paw Lake with time (adopted from the 2022 RLS report for emphasis). Based on these graphs, the EWM and CLP have been declining but the Starry Stonewort is steadily increasing. Additionally, native aquatic plants have been variable but are lower than they should be for the lake size. Thus, the following specific conclusions can be made regarding the trends in aquatic vegetation communities in Paw Paw Lake:

1. The native aquatic plant cumulative cover has increased in recent year (2018-2020) but declined in 2021. This was likely due to the strong presence of Eurasian Watermilfoil (EWM) that prevented native aquatic plant germination in many areas (pre-fluridone aka SONAR AS®).
2. The low native cumulative cover in 2012 and 2017 was likely due to excessive EWM that required fluridone treatment, as in 2021.
3. The submersed cover has increased in recent years (2018-2020) but declined in 2021 due to excessive EWM cover.
4. The emergent cover has fluctuated but remains stable during the past two years.

5. The EWM cover has declined with time but increased in 2020 which necessitated the use of a systemic herbicide such as fluridone.
6. The CLP cover has declined much since 2013 and is barely present now.
7. The Starry Stonewort (SS) has increased in the past two years with the highest growth noted in 2021.

Figure 2. Eurasian Watermilfoil

Figure 3. Starry Stonewort

Figure 4. Curly-leaf Pondweed

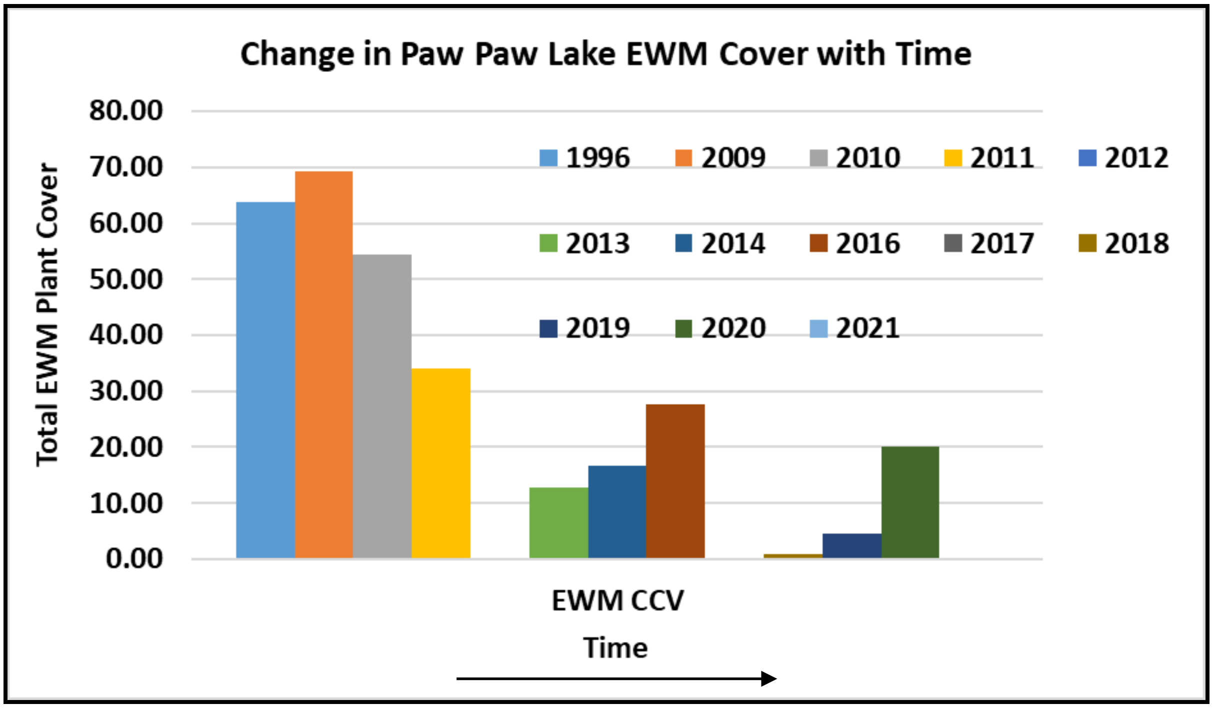

Figure 5. Change in Paw Paw Lake EWM cover with time.

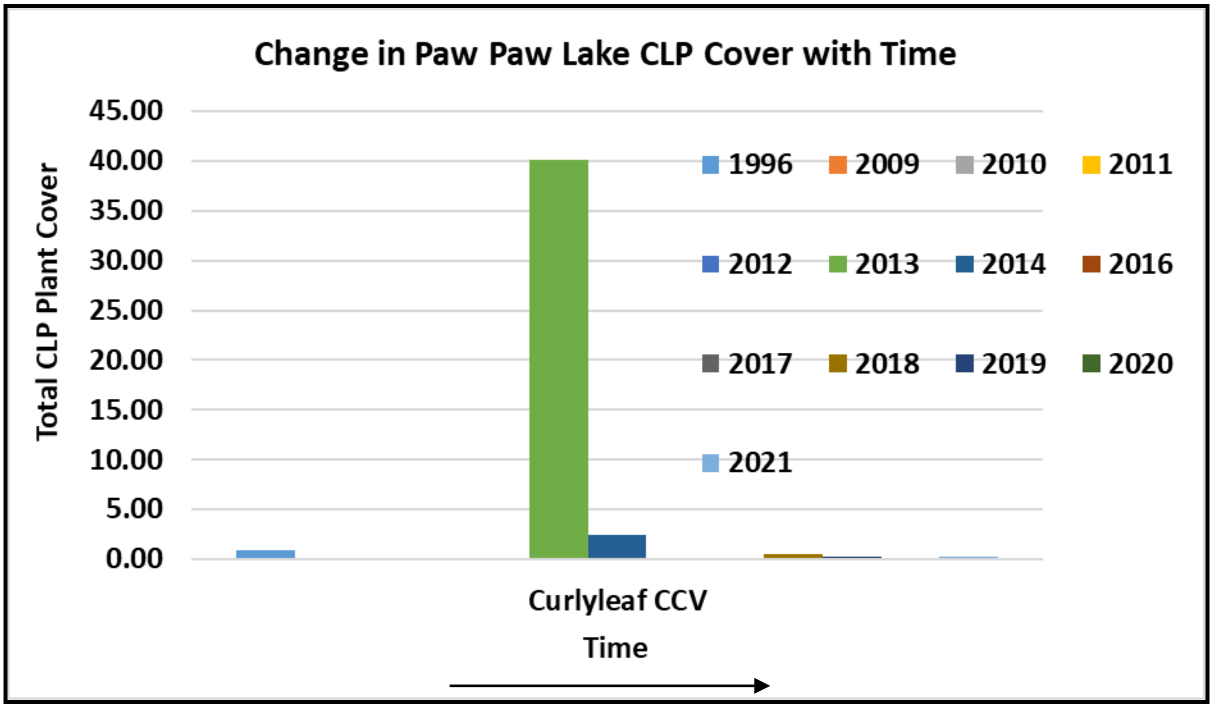

Figure 6. Change in Paw Paw Lake CLP cover with time.

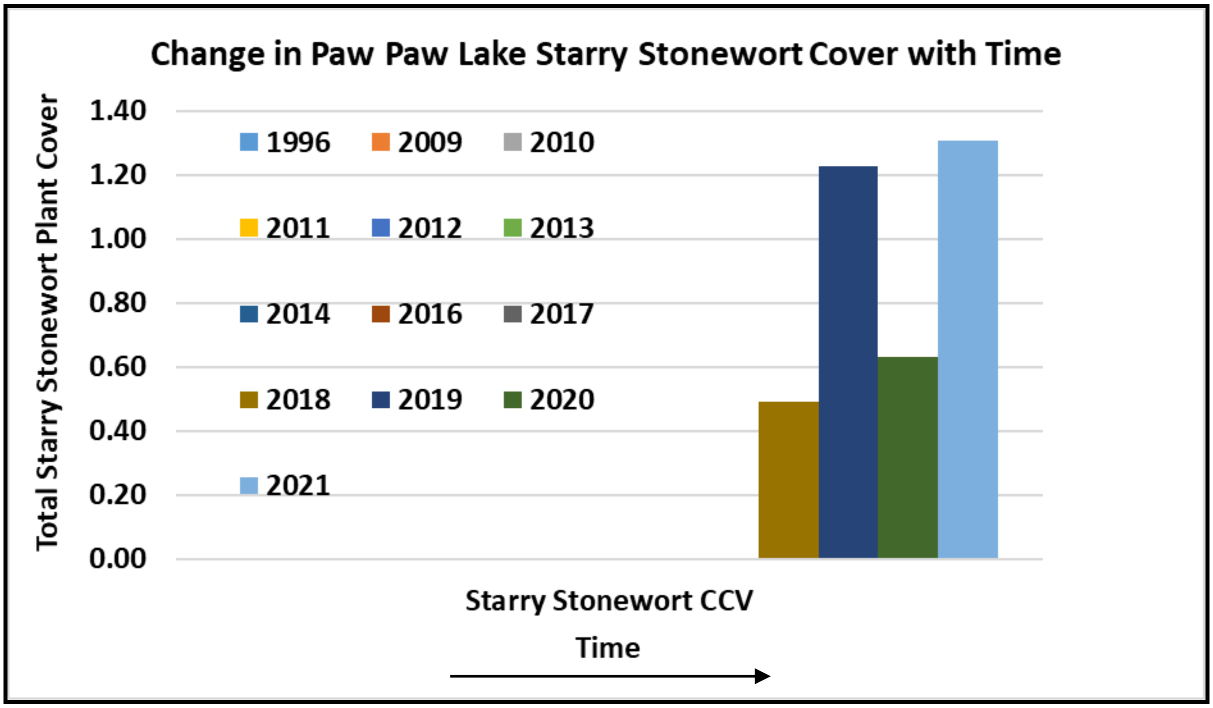

Figure 7. Change in Paw Paw Lake Starry Stonewort cover with time.

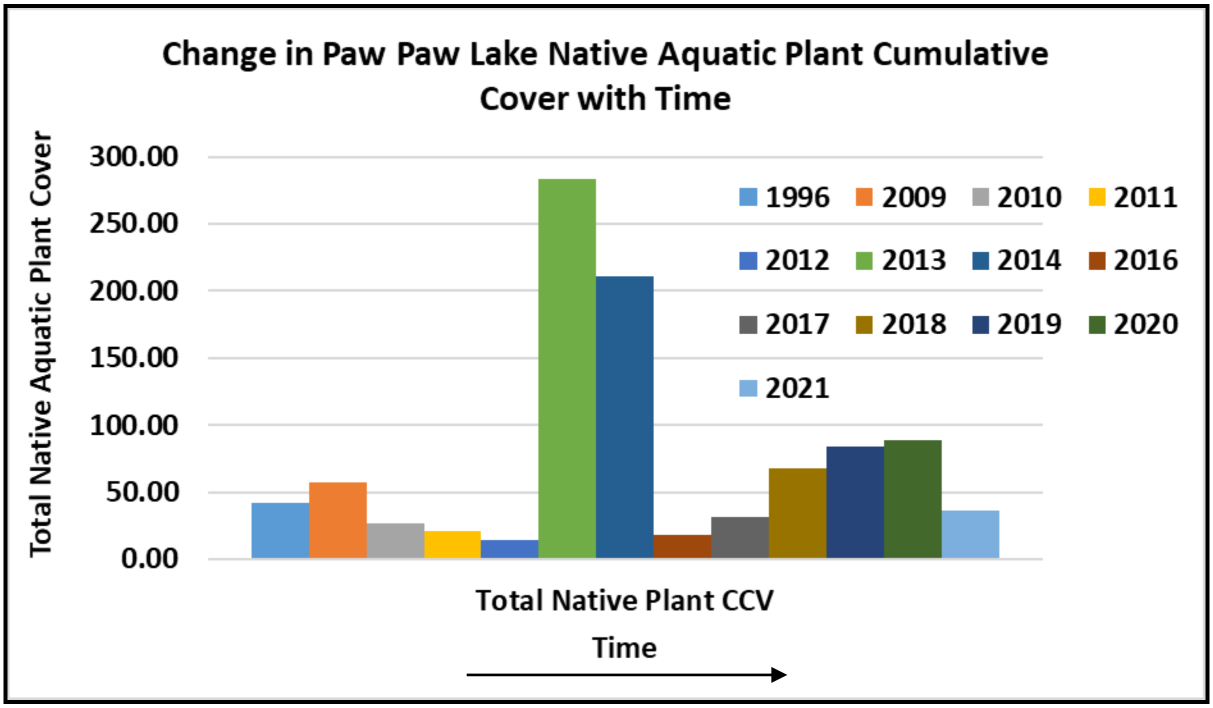

Figure 8. Change in Paw Paw Lake native aquatic plant cumulative cover with time.

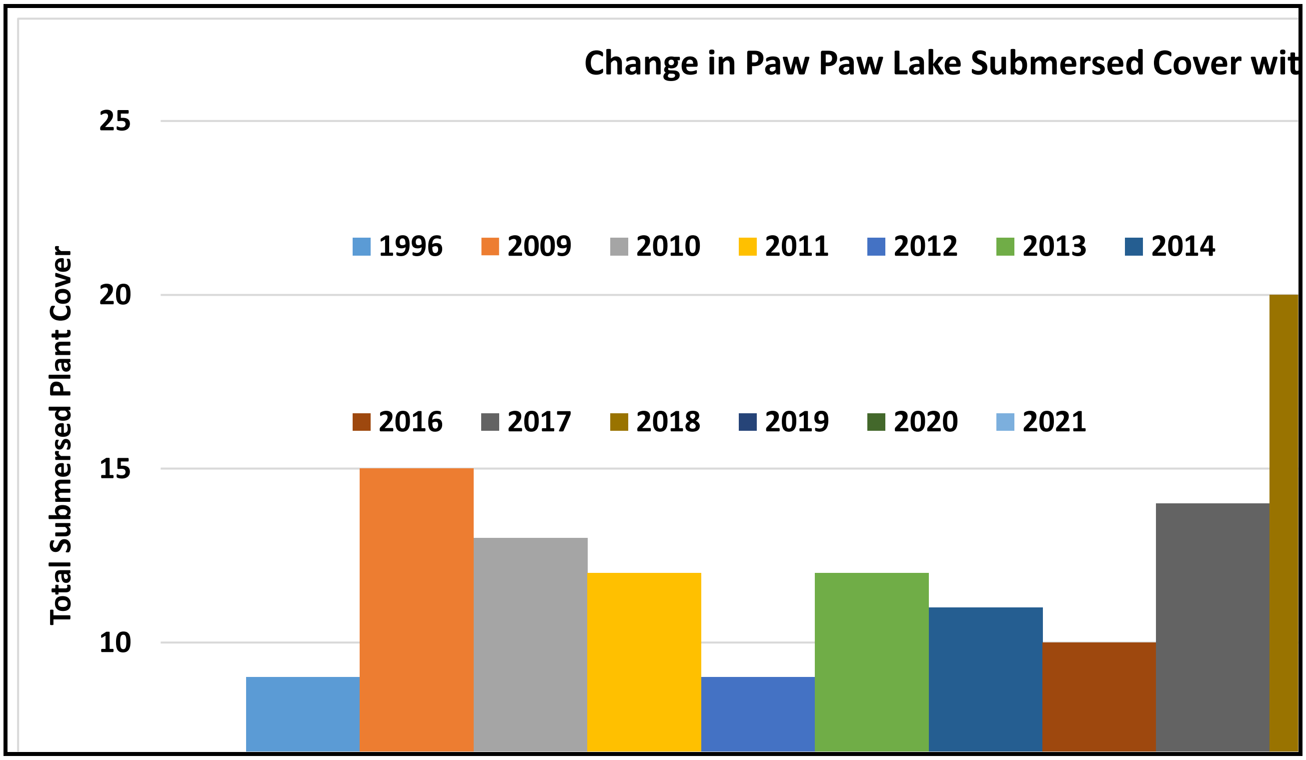

Figure 9. Change in Paw Paw Lake submersed cover with time.

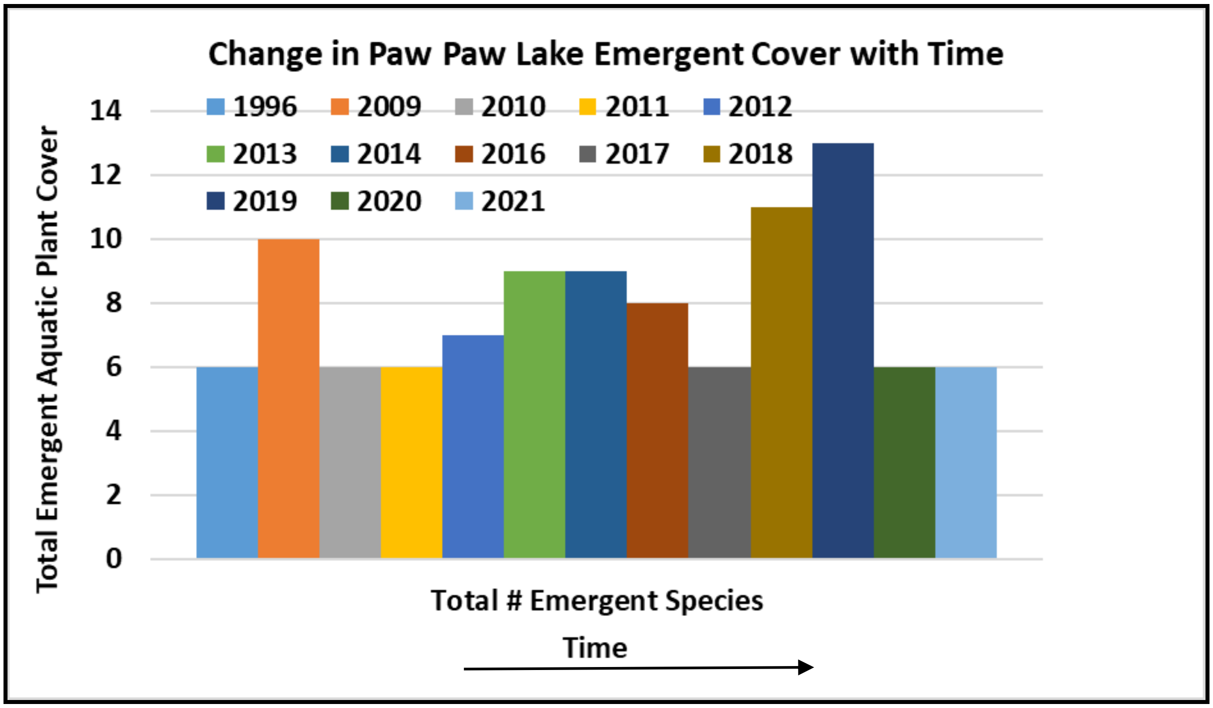

Figure 10. Change in Paw Paw Lake emergent cover with time.

2.1 Aquatic Vegetation Survey Methods

There are a few different aquatic vegetation survey methods used in inland lake management that provide various levels of data certainty relative to the presence of invasive and native aquatic plants. Aquatic vegetation surveys are a critical tool for the management of invasives and also the inventory of native aquatic plant biodiversity. The sections below summarize the operations of survey methods previously used on Paw Paw Lake and also methods that should be used. Without a sound knowledge of aquatic plants and their locations, proper management and protection of the lake vegetation is not possible. When possible, all of the proceeding techniques should be used for the evaluation of all aquatic vegetation communities. It is critical to use methods that will evaluate all forms of aquatic vegetation including submersed, floating-leaved, and emergent forms as all are critical for optimum lake health. Additionally, it is important that all methods be repeatable over time and thus specific protocols should always be followed. Furthermore, survey bias may be inherent if conducted by the same individual(s) that conduct the treatment(s).

2.1.1 Aquatic Vegetation Assessment Site (AVAS) Surveys

An Aquatic Vegetation Assessment Site (AVAS) Survey method is used to assess the relative abundance of submersed, floating-leaved, and emergent aquatic vegetation within and around the littoral zones of inland lakes. With this survey method, the littoral zone areas of the lakes are divided into lakeshore sections approximately 100 - 300 feet in length (Figure 11). Each AVAS segment is sampled using visual observation, dependent on water clarity, and weighted rake tows to verify species identification. The use of rake throws at each location is especially critical for turbid lakes such as Paw Paw Lake where visual observations are limited and thus not reliable especially in the determination of invasive locations.

The species of aquatic macrophytes present and density of each macrophyte are recorded onto an AVAS data sheet. Each separate plant species found in each AVAS segment is recorded along with an estimate of each aquatic plant density. Each macrophyte species corresponds to an assigned number. There are designated density codes for the aquatic vegetation surveys, where a = found (occupying < 2% of the surface area of the lake), b = sparse (occupying 2-20% of the surface area of the lake), c = common, (occupying 21-60% of the surface area of the lake), and d = dense (occupying > 60% of the surface area of the lake). In addition to the particular species observed (via assigned numbers), density information above has been used to estimate the percent cumulative coverage of each species within the AVAS site. If shallow areas are present in the open waters of the lake, then individual AVAS segments can be sampled at those locations to assess the macrophyte communities in offshore locations. This is particularly important since invasives often expand in shallow island areas located offshore in many lakes. The AVAS survey method may be required by EGLE during years when SONAR AS® is applied to the entire lake but it is a relatively quick survey and can be conducted alongside a more intensive survey which is discussed in the next section below.

There are limitations for the AVAS method that include the following:

1. This method misses areas between survey swaths that could include invasives.
2. This method is highly dependent on knowing all depths to the drop-off, which is especially difficult during low clarity conditions.
3. This method is not easily repeatable (and thus not amenable to statistical analysis).
4. This survey is more qualitative than quantitative (challenging since treatment calculations should be very quantitative).

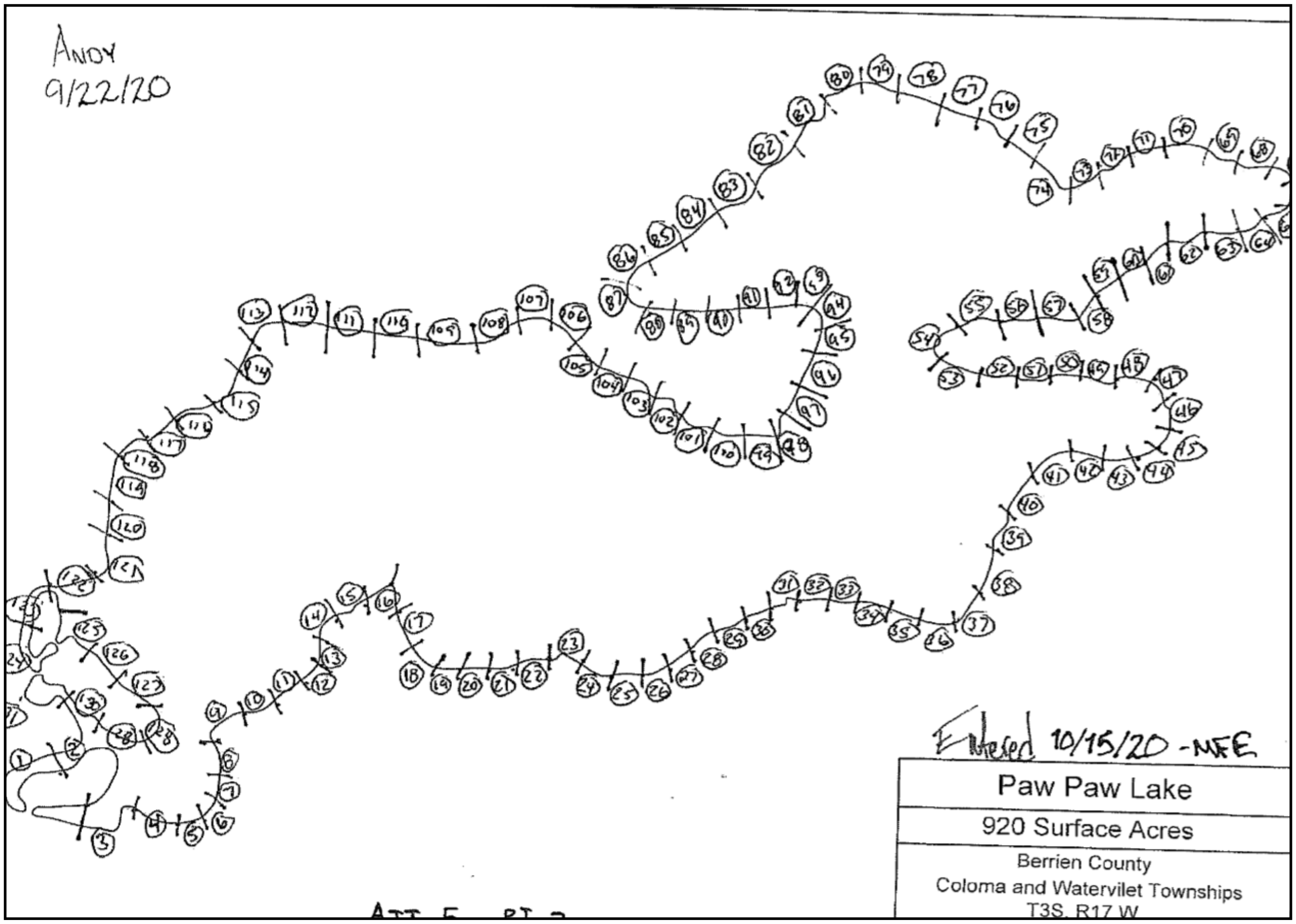

Figure 11. The AVAS Method survey map for aquatic vegetation assessment in Paw Paw Lake (PLM, 2020).

2.1.2 GPS Point-Intercept Surveys

The point-intercept method (Madsen, 1999) utilizes GPS points that are evenly spaced along transects that completely cover a large area. They are used for scientific data repeatability that is also amenable to statistical analysis for data quality assurance. There is a degree of subjectivity that occurs with other methods when GPS points are selected in the field. The points are assigned on a GIS system interface and uploaded into the GPS units for sampling in the field. If technological issues occur with the unit in the field, another similar approach includes measuring even distances between GPS locations. A UTM coordinate system is used in place of a degree-based system due to being set in linear distances that allow for easier movement to individual points. In Paw Paw Lake, it would be advantageous to place the GPS sampling points close together (<100 feet) within the littoral zone and evaluate them to the drop-off which will vary throughout the lake.

This would allow for optimum cover in the entire lake littoral zone growth area. At each GPS location, the aquatic plant species found are recorded, usually in association with their relative abundance. The coding scale used in the AVAS method can be used to estimate relative abundance at each sampling point. Figure 12 demonstrates a GPS Point-Intercept survey method map on a large area of aquatic vegetation within a much larger lake. These GPS locations can be re-visited within and among years to better determine the changes in aquatic vegetation communities through time.

There are limitations with this survey method that include the following:

1. This method requires significant time (a day of surveying for Paw Paw Lake)
2. The method is dependent upon technology such as GPS and geographic information systems (GIS).

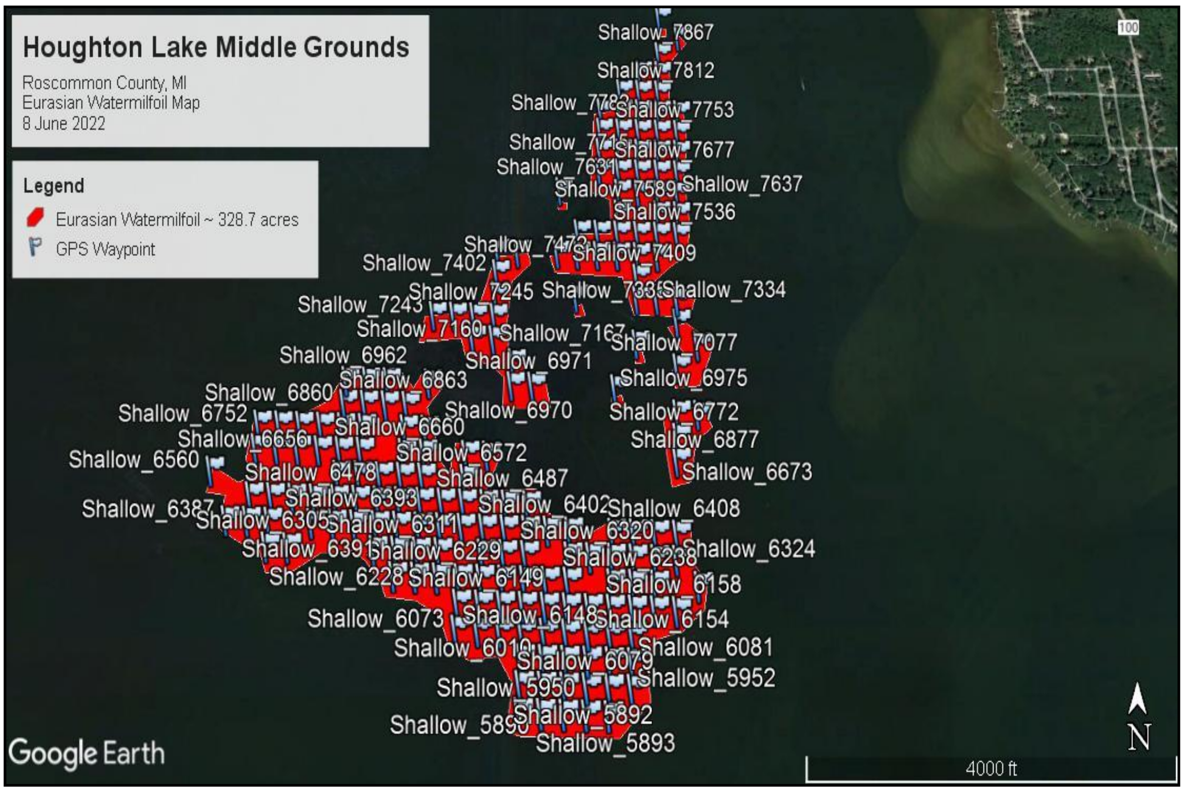

Figure 12. Example of a GPS Point-Intercept map (RLS, 2022).

2.1.3 Aquatic Vegetation Biovolume Scanning and Mapping

A Lowrance® HDS GPS unit utilizes different scanning frequencies to detect aquatic vegetation height (biovolume), bottom hardness, or bottom contours in a water body. A transducer is placed at the stern of a vessel about 1-foot below the lowest point of the vessel and synched with the on-board WAAS-enabled GPS unit. The unit is installed per the Lowrance® manufacturer's owner's operations manual which includes instructions on installation, operation, and trouble-shooting. Any operator of the GPS unit should be familiar with how to operate the unit, navigate through the menu options, navigate to various waypoints, save waypoints, and zoom in and out of the aerial view to view progress of individual surveys.

Once the GPS unit is turned on and the GPS internal card has been named for the existing field day, the screen will show an aerial view of the lake and will then be able to accept new GPS waypoints throughout the survey. During a CI BioBase® scan, the entire surface area of the lake is scanned. Thus, transects across the lake are made no less than 150 feet apart so that transects intersect and there is enough coverage to cover the entire lake bottom once all transects are made. This will take a considerable amount of time since the boat speed cannot exceed 5 mph. The boat must come as close to shore as possible on both sides of the lake to cover the lake completely.

Once the entire lake is scanned, all points are uploaded from the GPS unit to the GIS server on the computer to the CI BioBase® computer software where the algorithm is computed to convert the .gpx data files to colorful maps (Figure 13). Once the maps are complete, further analyses are possible. There is a report from the CI BioBase® company which reports the maximum and minimum depths, volume, and other statistics that can be useful for future lake calculations. Additionally, the area of individual aquatic vegetation polygons (if the specific plant assemblages are known) can be calculated with GIS software. This is highly useful for conducting treatment evaluation assessments. It can also be a useful tool for evaluation of bottom hardness changes over time.

This data is then uploaded into a cloud software program to reveal maps that displays depth contours, sediment hardness, and aquatic vegetation biovolume. On this scan map, the color blue refers to areas that lack vegetation. The color green refers to low-lying vegetation. The colors red/orange refer to tall-growing vegetation that can also include floating-leaved vegetation. There are many areas around the littoral (shallow) zone of the lake that contain low-growing plants like *Chara* or *Elodea*. For this reason, the scans are conducted in conjunction with a whole lake GPS Point Intercept survey to account for individual species identification of all aquatic plants in the lake. These types of scans are missing from the data archives but could be a critical tool for assisting with treatment area (polygon) delineation and conservation of non-target aquatic vegetation.

This method is not currently used in Paw Paw Lake but should be since it would serve as a useful tool for more precise treatment maps that would reduce the use of overall chemicals and associated costs over time.

There are limitations with this method that include the following:

1. This method requires a significant amount of time on the lake due to low required speeds (but can be used in parallel with the GPS Point Intercept method).
2. This method is dependent on GPS and GIS technology.
3. This method can take time to process on a cloud server (maps can however be created in a day if needed).

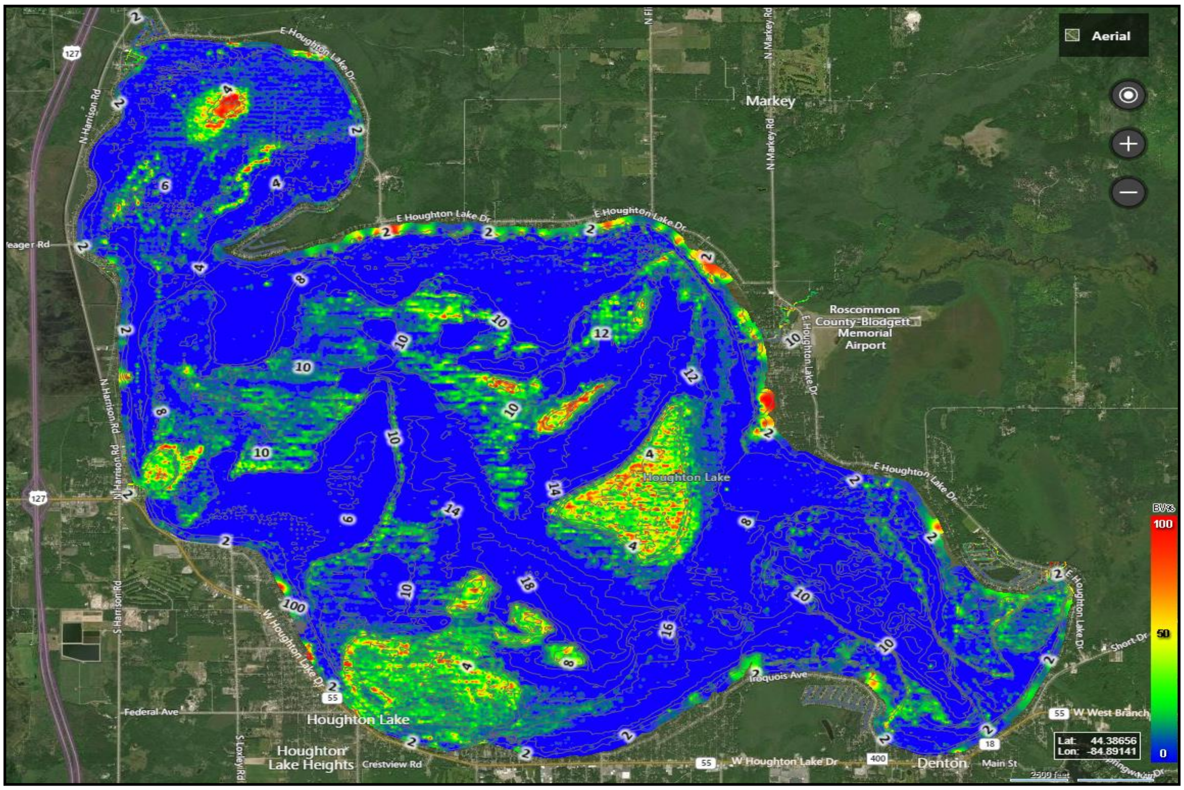

Figure 13. Example of an aquatic vegetation biovolume map (©RLS).

2.1.4 Aquatic Vegetation Treatment Polygon Mapping

As the lake is surveyed, individual GPS points are recorded on a GPS unit. These waypoints are then uploaded into a geographic information system (GIS) software where they are placed onto an aerial imagery map. At that time, these points are triangulated to develop "polygons" which are defined regions in-between and including the GPS points. The polygons are then delineated for acreage relative to proposed treatments. Since they are precise, they reduce the amount of herbicide needed in treatment areas and also protect desired native aquatic vegetation from blanket or broad treatments.

In addition, mapping of polygons allows the applicator to determine how much product is needed in each region. Lastly, since polygons are geo-referenced, they can be monitored for treatment efficacy over time and re-digitized to determine changes in treatment area. Figure 14 displays a polygon map for the entire area targeted for EWM control in Paw Paw Lake with the use of fluridone (SONAR AS®). Most of the other maps created by the applicator display hand-drawn polygons which are not recommended for accuracy and repeatability. Polygon maps can include very small areas (≤0.25 acres) or very large areas such as the entire littoral zone (as is the case for whole-lake SONAR AS® treatments). Furthermore, it is very important to use GPS points for consistency over time to determine if individual polygons (and treatment areas) have decreased.

There are limitations for this method that include the following:

1. The polygon boundaries are not exact but can be close to the actual size when more points are collected.
2. The delineation of polygons in the field can require much time and the delineation on GIS can also require ample time. Maps can usually be developed in one day.
3. When used for fluridone treatments, the areas are not discriminant

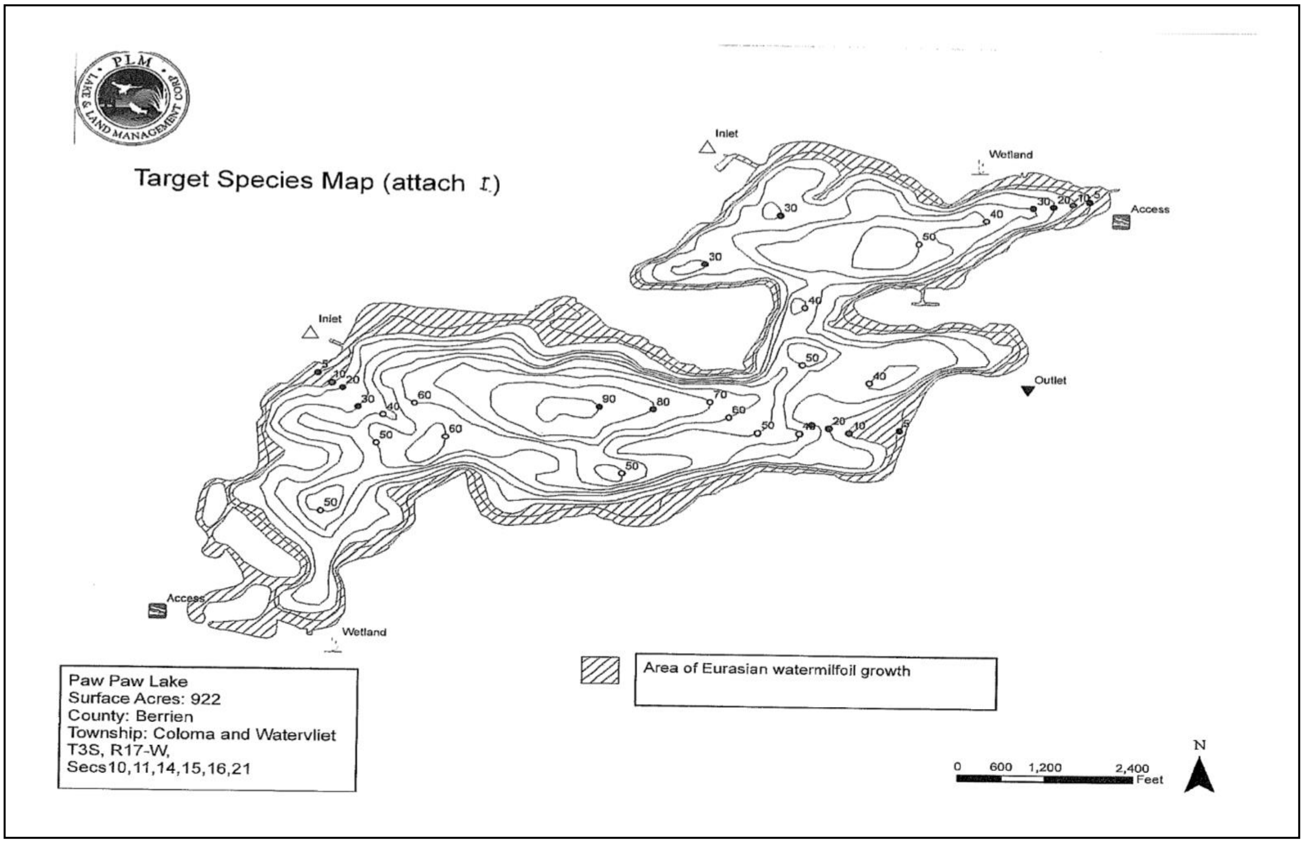

Figure 14. Whole-lake treatment polygon map developed by PLM (data collected from EGLE MiWaters database).

2.2 Summary of Paw Paw Lake Aquatic Vegetation Treatments:

The management of submersed nuisance invasive aquatic plants is necessary in Paw Paw Lake due to accelerated growth and distribution. Management options should be environmentally and ecologically-sound and financially feasible. Options for control of aquatic plants are limited yet are capable of achieving strong results when used properly. Implementation of more growth of favorable native aquatic plants (especially the low growing native plants) in Paw Paw Lake to provide for a healthier lake is recommended though this may require significant increases in water clarity along with reductions in invasive plant cover. All aquatic vegetation should be managed with solutions that will yield the longest-term results. A detailed Early Detection Rapid Response Protocol (EDRR) is recommended for Paw Paw Lake for each invasive species. The following section details the treatment history for invasive species and nuisance native submersed aquatic vegetation within Paw Paw Lake.

Herbicides have been necessary to use on Paw Paw Lake over the past decades due to the invasion of exotic species such as Eurasian watermilfoil, Curly-leaf Pondweed, and Starry Stonewort. These invasive species are able to out-compete native species and often times displace natives in large areas of a waterbody. Over the past several years, between 1.5-100% of Paw Paw Lake has been treated for invasive aquatic plant species. In years where the whole-lake herbicide (SONAR AS®) was applied, the lake surface area is entirely treated as the herbicide is applied to the whole lake volume.

Herbicides are a substance or combination of substances that have been developed to control vegetation. Most aquatic herbicides were developed for agricultural use initially and then vetted for potential use in aquatic environments. If an agricultural active ingredient is found to be scientifically useful in the aquatic ecosystem, then additional EPA registration for an aquatic label will be required. To be used in the State of Michigan, an aquatic labeled herbicide must be registered and labeled with the U. S. Environmental Protection Agency (USEPA), registered for use by the U.S. Department of Agriculture (USDA), and approved for use by the Michigan Department of Environment, Great lakes and Energy (EGLE). All herbicides used under the authority of the lake special assessment district (SAD) are applied by a licensed company and certified applicator and must follow the annual EGLE permit. Aquatic herbicide applicators are required to submit annual treatment reports on the lake treatment to EGLE for review. These can be found in the EGLE MiWaters database.

Aquatic herbicides are generally applied via an airboat or skiff equipped with mixing tanks and drop hoses. 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. Contact and systemic aquatic herbicides are the two primary categories used in aquatic systems.

Contact herbicides such as diquat, flumioxazin, and hydrothol cause damage to leaf and stem structures; whereas systemic herbicides (i.e., triclopyr, 2,4-D, fluridone (SONAR AS®), and the new ProcellaCOR®) are assimilated by the plant roots and are lethal to the entire plant. Wherever possible, it is preferred to use a systemic herbicide for longer-lasting aquatic plant control of invasives. In Paw Paw Lake, the use of contact herbicides (such as diquat and flumioxazin) would be highly discouraged since those offer short-term control of plants and are most commonly used on nuisance native aquatic plant species. Contact herbicides can be used for dense Curly-leaf Pondweed. Most of the native aquatic plants within Paw Paw Lake are sparse and should all be protected with limited treatments for dense natives (such as Wild Celery).

Algaecides such as copper sulfate should also be avoided on Paw Paw Lake. Copper accumulates in lake sediments and bio-persists over time. It is harmful to sediment biota and can be released into the water column with sediment perturbations. Additionally, they can exacerbate blue-green algae and contribute to toxin release. Chelated copper may be used on dense green filamentous algae if the mats are very thick.

Recommendations for improved treatment success and efficacy are offered in Section 5.0 of this report. Tables 3-12 display the aquatic herbicides used, the target aquatic plants, rates, and treatment areas over the past several years (data adopted from EGLE MiWaters database).

Herbicides on Paw Paw Lake should only be used after rigorous whole-lake surveys of numerous GPS sampling sites to establish those areas only where infestations are present. Herbicides should only be used after careful consideration by an independent consultant to avoid treatment bias and who do not have a conflict of interest relative to herbicide sales and profits. Like many substances, the amount of herbicide used needs to be tailored to the plant to be controlled, water depth, and water temperature. Herbicides have a range of toxicity, and many are less toxic than other common products such as aspirin, table salt or caffeine.

Table 3. Paw Paw Lake aquatic herbicide treatments for target plants over the past several years (data from EGLE MiWaters online lake database).

Year	EWM Treated	CLP Treated	Starry Treated	Natives Treated	Algae Treated	Total Acres Treated	% of Lake Area
2013	4.05	10				14.1	**1.5**
2014	125	78.5	8		61.25	272.8	**29.6**
2015	73	26	0	104	94	297	**32.2**
2016	138	27.5	0	55	137	357.5	**38.8**
2017	920					920	**100**
2018	67.5	63.75	16	57		204.3	**22.2**
2019	202.35	45	2.12	158		407.5	**44.2**
2020	246.5	120.5	1	120.25	45	533.3	**57.9**
2021	922		6			928	**100**
2022	3	60	13.4	20.5		96.9	**10.5**

Table 4. Paw Paw Lake 2013 aquatic herbicide treatment regimen (data from EGLE MiWaters online lake database).

Treatment Date	Product Used	Rate	Treatment Size	Used For
24-Jul-13	Cygnet Plus	0.168-.3 gal/acre ft		Adjuvant
	PLM Blue Tracer	0.01 gal/acre ft		Tracer
	Renovate OTF (Triclopyr)	67 lb/acre ft	1.3	EWM
	Tribune (Diquat Dibromide)	1-2 gal/acre	10	Nuisance Plants nearshore, CLP (Low Dose) offshore
28-Aug-13	Cygnet Plus	0.168-.3 gal/acre ft		Adjuvant
	Renovate OTF (Triclopyr)	67 lb/acre ft	2.25	EWM
	Tribune (Diquat Dibromide)	1-2 gal/acre	0.5	Nuisance Plants nearshore, CLP (Low Dose) offshore

Table 5. Paw Paw Lake 2014 aquatic herbicide treatment regimen (data from EGLE MiWaters online lake database).

Treatment Date	Product Used	Rate	Treatment Size	Used For
11-Jun-14	Old Bridge (Copper Sulfate)	2.6 lb/ acre ft	9.25	Algae
	Cygnet Plus	0.168-.3 gal/acre ft		Adjuvant
	PLM Blue Tracer	0.01 gal/ acre ft		Tracer
	Tribune (Diquat Dibromide)	1-2 gal/ acre	32.5	Nuisance Plants near shore CLP off shore (low dose)
19-Jun-14	Old Bridge (Copper Sulfate)	2.6 lb/ acre ft	10	Algae
	Cygnet Plus	0.168-.3 gal/acre ft		Adjuvant
	Tribune (Diquat Dibromide)	1-2 gal/ acre	10	Nuisance Plants near shore CLP off shore (low dose)
8-Jul-14	Alonglife (Copper Sulfate pentahydrate)	0.33-0.6 gal/acre ft		Free Floating Algae
	Old Bridge (Copper Sulfate)	4.4 lb/acre ft	8	Chara Starry Stonewort
	Cygnet Plus	0.168-0.3 gal/acre ft		Adjuvant
	Hydrothal 191 (Mono N,N- dimethylalkylamine salt of Endothall)	1 gal/acre	11.5	Nuisance Plants
	PLM Blue Tracer	0.01 gal/ acre ft		Tracer
	Tribune (Diquat Dibromide)	1-2 gal/ acre	11.5	Nuisance Plants near shore CLP off shore (low dose)
16-Jul-14	Alonglife (Copper Sulfate pentahydrate)	0.33-0.6 gal/acre ft	17.5	Algae
	Old Bridge (Copper Sulfate)	4.4 lb/acre ft	17.5	Algae
	Hydrothal 191 (Mono N,N- dimethylalkylamine salt of Endothall)	1 gal/acre	35	
	Tribune (Diquat Dibromide)	1-2 gal/ acre	35	
29-Jul-14	Cygnet Plus	0.168-.3 gal/acre ft	8	Adjuvant
	PLM Blue Tracer	0.01 gal/ acre ft	8	Tracer
	Tribune (Diquat Dibromide)	1-2 gal/ acre	8	Nuisance Plants near shore CLP off shore (low dose)
26-Aug-14	Captain (Copper Ethanolamine-Chelated Copper)	0.6 gal/acre ft	16.5	Algae
	Chem One (Copper Sulfate)	2.6 lb/ acre ft	16.5	Algae
	Cygnet Plus	0.168-.3 gal/acre ft	16.5	Adjuvant
	PLM Blue Tracer	0.01 gal/ acre ft	16.5	Tracer
	Tribune (Diquat Dibromide)	1-2 gal/ acre	16.5	Nuisance Plants near shore CLP off shore (low dose)

Table 6. Paw Paw Lake 2015 aquatic herbicide treatment regimen (data from EGLE MiWaters online lake database).

Treatment Date	Product Used	Rate	Treatment Size	Used For
25-May-15	Cygnet Plus	0.064 gal/acre ft	26	Adjuvant
	PLM Blue Tracer	0.003 gal/acre ft	26	Tracer
	Tribune (Diquat Dibromide)	1.25 gal/acre	26	CLP/EWM
24-Jun-15	Captain (Copper Ethanolamine-Chelated Copper)	0.068 gal/ acre ft	37	Algae
	Chem One (Copper Sulfate)	1.35 lb/acre ft	37	Algae
	Cygnet Plus	0.045 gal/acreft	37	Adjuvant
	Hydrothal 191 (Mono N,N- dimethylalkylamine salt of Endothall)	0.47 gal/acre	37	Thinleaf
	Tribune (Diquat Dibromide)	1.76 gal/acre	37	EWM & Thinleaf
23-Jul-15	Alonglife (Copper Sulfate pentahydrate)	0.056 gal/acre ft	15	Algae
	Old Bridge (Copper Sulfate)	1.11 lb/acre ft	15	Algae
	Cygnet Plus	0.11 gal/ acre ft	15	Adjuvant
	Hydrothal 191 (Mono N,N- dimethylalkylamine salt of Endothall)	0.33 gal/acre	15	Thinleaf
	Tribune (Diquat Dibromide)	1.67 gal/acre	15	Thinleaf
18-Aug-15	Alonglife (Copper Sulfate pentahydrate)	0.067 gal/acre ft	10	Algae
	Old Bridge (Copper Sulfate)	1.33 lb/acre ft	10	Algae
	Cygnet Plus	0.067 gal/acre ft	10	Adjuvant
	PLM Blue Tracer	0.003 gal/acre ft	10	Tracer
	Reward (Diquat Dibromide)	1 gal/ acre	10	EWM

Table 7. Paw Paw Lake 2016 aquatic herbicide treatment regimen (data from EGLE MiWaters online lake database).

Treatment Date	Product Used	Rate	Treatment Area	For
2-Jun-16	Old Bridge (Copper Sulfate)	1.82 lb/ acre ft	27.5	Filamentous Algae
	Cygnet Plus	0.08 gal/acre ft	27.5	Adjuvant
	Renovate OTF (Triclophyr)	49.75 lb/acre ft	3.35	EWM
	SeClear G (Copper Sulfate Pentahydrate)	0.15 gal/ acre ft	27.5	Filamentous Algae
	Tribune (Diquat Dibromide)	1 gal/acre	27.5	CLP/EWM
22-Jun-16	Old Bridge (Copper Sulfate)	1.28 lb/ acre ft	26	Filamentous Algae
	Cygnet Plus	0.06 gal/acre ft	26	Adjuvant
	SeClear G (Copper Sulfate Pentahydrate)	0.13 gal/acre ft	26	Filamentous Algae
	Tribune (Diquat Dibromide)	1 gal/acre	26	EWM
21-Jul-16	Cygnet Plus	0.1 gal/acre ft	42	Adjuvant
	Hydrothal 191 (Mono N,N- dimethylalkylamine salt of Endothall)	0.5 gal/acre	13	Thinleaf
	Polyan	0.008 gal/acre ft	42	Adjuvant
	Tribune (Diquat Dibromide)	1.49 gal. acre	42	Thinleaf/EWM
18-Aug-16	Captain (Copper Ethanolamine-Chelated Copper)	0.1 gal/acre ft	15	Filamentous Algae
	Old Bridge (Copper Sulfate)	1.78 lb/acre ft	15	Filamentous Algae
	Cygnet Plus	0.08 gal/acre ft	15	Adjuvant
	Tribune (Diquat Dibromide)	1 gal/acre	15	EWM

Table 8. Paw Paw Lake 2017 aquatic herbicide treatment regimen (data from EGLE MiWaters online lake database).

Treatment Date	Product Used	Rate	Treatment Area	Used For
1-May-17	Sonar AS (Fluridone)	6ppb	920 acres	EWM
19-May-17	Sonar AS (Fluridone)	3.7 ppb	920 acres	EWM

Table 9. Paw Paw Lake 2018 aquatic herbicide treatment regimen (data from EGLE MiWaters online lake database).

Treatment Date	Product Used	Rate	Treatment Area	Used For
7-Jun-18	Cygnet Plus	0.168-.3 gal/ acre ft	8.75	Adjuvant
	Tribune (Diquat Dibromide)	1.04 gal/ acre	6.5	EWM/CLP
	Tribune (Diquat Dibromide)	1 gal/ acre	1.25	CLP offshore
	Tribune (Diquat Dibromide)	2 gal/ acre	1	Thinleaf
10-Jul-18	Cygnet Plus	0.095 gal/ acre ft	28	Adjuvant
	Schooner (Flumioxazin)	0.24 lb/ acre ft	28	CLP, EWM, Thinleaf
	Tribune (Diquat Dibromide)	2 gal/ acre	28	CLP, EWM, Thinleaf
20-Sep-18	Old Bridge (Copper Sulfate)	4.17 lbs/ acre ft	8	Starry Stonewort
	Hydrothal 191 (Mono N,N- dimethylalkylamine salt of Endothall)	0.5 gal/acre	8	Starry Stonewort
	Renovate OTF (Triclophyr)	40 lb/ acre ft	5	EWM

Table 10. Paw Paw Lake 2019 aquatic herbicide treatment regimen (data from EGLE MiWaters online lake database).

Treatment Date	Product Used	Rate	Treatment Area	Used For
5-Jun-19	Cygnet Plus	0.056 gal/ acre ft	45	Adjuvant
	Tribune (Diquat Dibromide)	1 gal/ acre	34	CLP/ EWM
	Tribune (Diquat Dibromide)	1 gal/ acre	11	Offshore EWM/CLP
9-Jul-19	Old Bridge (Copper Sulfate)	3.93 lb/ acre ft	2.12	Starry Stonewort
	Cygnet Plus	0.102 gal/acre ft	65	Adjuvant
	Hydrothal 191 (Mono N,N- dimethylalkylamine salt of Endothall)	0.577 gal/ acre	65	EWM/Thinleaf/Coontail
	Tribune (Diquat Dibromide)	2 gal/ acre	65	EWM/Thinleaf/Coontail
18-Jul-19	Clipper (Flumioxazine)	1 lb/acre ft	4	Coontail
	Cygnet Plus	0.056 gal/ acre ft	24	Adjuvant
	Tribune (Diquat Dibromide)	1.93 gal/acre ft	24	EWM/Thinleaf/Coontail
8-Aug-19	Cygnet Plus	0.085 gal/ acre ft	3.35	Adjuvant
	Tribune (Diquat Dibromide)	1.493 gal/acre	3.35	EWM

Table 11. Paw Paw Lake 2020 aquatic herbicide treatment regimen (data from EGLE MiWaters online lake database).

Treatment Date	Product Used	Rate	Treatment Area	Used For
28-May-20	Cygnet Plus	0.08 gal/acre ft	20.5 acres	Adjuvant
	Tribune (Diquat Dibromide)	1.14 gal/acre	14 acres	EWM/CLP
	Tribune (Diquat Dibromide)	1 gal/acre	6.5 acres	Offshore EWM/CLP
24-Jun-20	Captain (Copper Ethanolamine-Chelated Copper)	0.15 gal/acre ft	45 acres	Filamentous Algae
	Cygnet Plus	0.08 gal/acre ft	100 acres	Adjuvant
	Hydrothal 191 (Mono N,N- dimethylalkylamine salt of Endothall)	0.5 gal/ acre	100 acres	Thinleaf, EWM, CLP, Coontail
	Tribune (Diquat Dibromide)	1.94 gal/ acre	100 acres	Thinleaf, EWM, CLP, Coontail
16-Jul-20	Cygnet Plus	0.09 gal/ acre ft	9 acres	Adjuvant
	Tribune (Diquat Dibromide)	1.94 gal/ acre	9 acres	Coontail, Thinleaf, EWM
5-Aug-20	Old Bridge (Copper Sulfate)	3.67 lb/ acre ft	1 acre	Starry Stonewort
	Cygnet Plus	0.12 gal/acre ft	17 acres	Adjuvant
	Tribune (Diquat Dibromide)	1.54 gal/ acre	17 acres	EWM
3-Sep-20	Aquathol K (Dipotassium salt of Endothall)	0.24 gal/ acre ft	3.75 acres	Naiad, Coontail
	Cygnet Plus	0.09 gal/ acre ft	3.75 acres	Adjuvant
	Hydrothal 191 (Mono N,N- dimethylalkylamine salt of Endothall)	0.53 gal/ acre	3.75 acres	Naiad, Coontail
	Tribune (Diquat Dibromide)	1.6 gal/ acre	3.75 acres	Naiad, Coontail

Table 12. Paw Paw Lake 2021 aquatic herbicide treatment regimen (data from EGLE MiWaters online lake database).

Treatment Date	Product Used	Rate	Treatment Area	Used For
18-May-21	Sonar As (Fluridone)	6ppb	922	EWM
24-Jun-21	Sonar As (Fluridone)	2.6ppb	922	EWM
15-Sep-21	SeClear G (Copper Sulfate Pentahydrate)	16.67 lb/ acre ft	6	Starry Stonewort

Table 13. Paw Paw Lake 2022 aquatic herbicide treatment regimen (data from EGLE MiWaters online lake database, EGLE).

Treatment Date	Product Used	Rate	Treatment Area	Used For
8-Jun-22	Cygnet Plus	0.06 gal/acre ft	60	Adjuvant
	Tribune (Diquat Dibromide) (2.5gal Wilbur)	1 gal/acre	51	CLP
	Tribune (Diquat Dibromide) (2.5gal Wilbur)	1 gal/acre	9	CLP
29-Jun-22	Cygnet Plus	0.12 gal/acre ft	10	Adjuvant
	Hydrothal 191 (Mono N,N- dimethylalkylamine salt of Endothall)	0.5 gal/acre	10	Thinleaf Pondweed
	Tribune (Diquat Dibromide) (2.5gal Wilbur)	2 gal/acre	10	Thinleaf Pondweed
27-Jul-22	Hydrothal 191 (Mono N,N- dimethylalkylamine salt of Endothall)	0.895 gal/acre	6.7	Starry Stonewort
	Propeller (Flumioxazin)	0.995lb/ acre ft	6.7	Starry Stonewort
24-Aug-22	Cygnet Plus	0.022 gal/acre ft	1.5	Adjuvant
	Hydrothal 191 (Mono N,N- dimethylalkylamine salt of Endothall)	1 gal/acre	0.25	Coontail, Thinleaf
	ProcellaCOR EC 2x22	6.33 oz/ acre ft	1.5	EWM
	Propeller (Flumioxazin)	1 lb/ acre ft	0.25	Coontail, Thinleaf
	Tribune (Diquat Dibromide) (2.5gal Wilbur)	1 gal/acre	1.5	EWM

2.3 AIS Prevention and Early Detection Rapid Response Protocol (EDRR)

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 Paw Paw Lake is awareness and education (Figure 15). The majority of the exotic species of concern have been listed in this report. Other exotic species on the move could be introduced to the riparians around Paw Paw Lake through a local community educational workshop or other educational events and should be included in an EDRR document. RLS can assist the PPLA with the development of an EDRR specific to Paw Paw Lake.

Public boat launches are a primary area of vector transport for all invasive species and thus boat washing stations (Figures 16-18) 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. 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. If boat washing stations are installed at the Paw Paw Lake primary public access, the PPLA, PPLF, and SAD should work together to educate the public and lake users on proper cleaning techniques and other invasive species information. A “Landing Blitz” can be held once the station is in place and the public can be invited to a field demonstration of how to properly use the washing station. A typical boat washing station typically costs around $15,000-$35,000 but lower cost ones are available (e.g., hand-held sprayer units).

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

1) USDA: https://www.invasivespeciesinfo.gov/us
2) Stop Aquatic Hitchhikers!: www.protectyourwaters.net

Figure 15. An aquatic invasive prevention sign for public access sites.

Figure 16. An aquatic hitchhiker (milfoil fragment). NOTE: This can also include zebra mussels or other invasive species.

Figure 17. A public boat washing station for boat access sites.

Figure 18. A responsible boat owner using a boat washing station prior to entering an inland lake.

3.0 PAW PAW LAKE ALGAE

Algae are a critical component to the health of a lake ecosystem. They are called primary producers since they manufacture their own food from photosynthesis and serve as a food source for lake zooplankton that become food for the lake fishery. Algae thus serve as a major food chain base for aquatic systems. There are numerous types of algae in freshwater and marine ecosystems but in freshwater there are three groups that are most prevalent which include: 1.) Green algae (Chlorophyta), 2.) Diatoms (Bascillariophyta), and the Blue-green algae (Cyanophyta). The green algae and blue-green algae can exist as single cells, colonies, or as filaments. Diatoms are unique from the other two groups as they contain silica in their cell walls. In moderation, all of these taxa are favorable, especially the diatoms. When blue-green algae are over-abundant they result in blooms that are capable of producing toxins harmful to humans and wildlife and contribute to water quality degradation.

3.1 Summary of Paw Paw Lake Basin Algal Data

Chlorophyll-*a* is a measure of the amount of green plant pigment present in the water, often in the form of planktonic algae. High chlorophyll-*a* concentrations are indicative of nutrient-enriched lakes. Chlorophyll-*a* concentrations greater than 6 µg/L are found in eutrophic or nutrient-enriched aquatic systems, whereas chlorophyll-*a* concentrations less than 2.2 µg/L are found in nutrient-poor or oligotrophic lakes. Chlorophyll-*a* is usually measured in micrograms per liter (µg/L) with Method SM 10200H. In Paw Paw Lake, both spring and summer chlorophyll-*a* concentrations have declined with time. This may be due to the presence of Zebra Mussels that selectively graze on favorable green algae but leave behind blue-green algae that is less palatable. This may also explain how higher nutrient levels are resulting in more blue-green algae than green algae given the drop in chlorophyll-*a*. Figures 19 and 20 show the trend in mean spring and summer chlorophyll-*a* with time, respectively.

In addition to algal concentration, the identification and enumeration of algae is important for understanding algal community composition. This provides important data relative to the food supply present for zooplankton and ultimately the lake fishery. To date, there is a lack of detailed data collected on the various algal genera in Paw Paw Lake. This is important to determine the health of the lake food chain relative to primary production. To determine the presence of algal genera from the composite water samples collected from the deep basins of Paw Paw Lake, a 500 ml of preserved sample should be collected, and a 1-mL subsample placed to settle onto a Sedgewick-Rafter counting chamber. The ocular micrometer scale should also be calibrated. The samples should be observed under a compound microscope at 400X magnification and scanned at 100X magnification to allow for the detection of a broad range of taxa present. All taxa should be identified to at least the Genus level in a table. This should be conducted during spring and late summer. Additionally, data on the growth form (i.e., filamentous versus colonial; Figure 21) should be collected for treatment purposes.

Diatoms convert CO_2 to oxygen and are thus an indicator of good water quality and blue-green algae are capable of secreting algal toxins that result in beach closures, toxicity to fish, and harm human health. Figures 22-23 display different methods for presenting algal community comparison data relative to cell counts and biovolume and also relative abundance. These metrics are very important in the evaluation of shifts in trophic status for determining lake health.

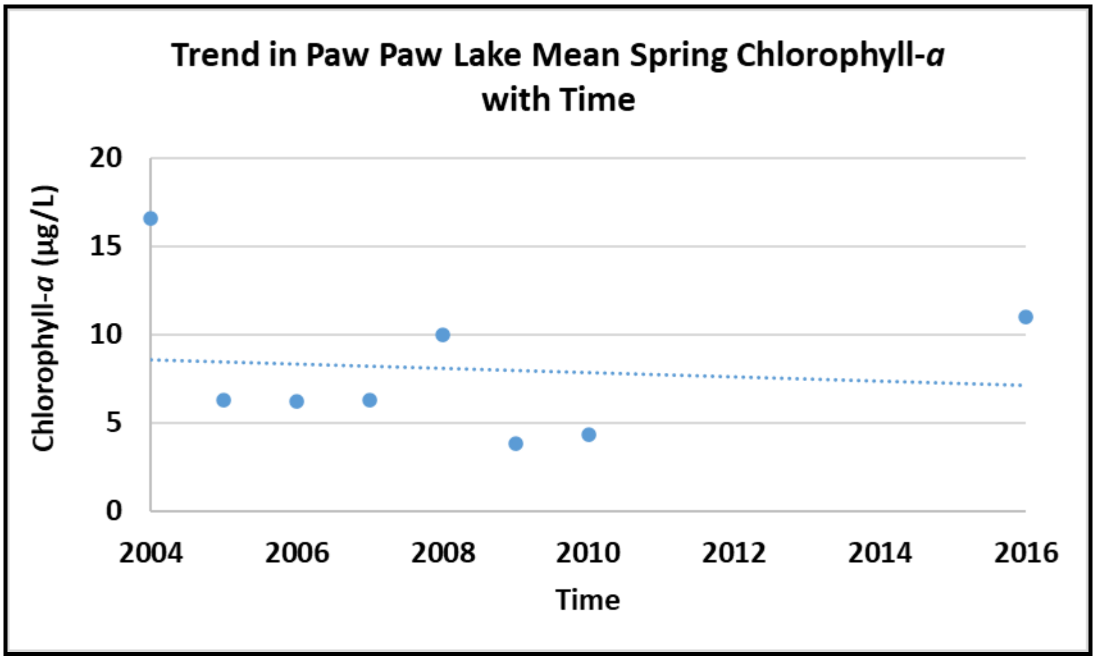

Figure 19. Trend in Paw Paw Lake mean spring chlorophyll-*a* concentrations with time.

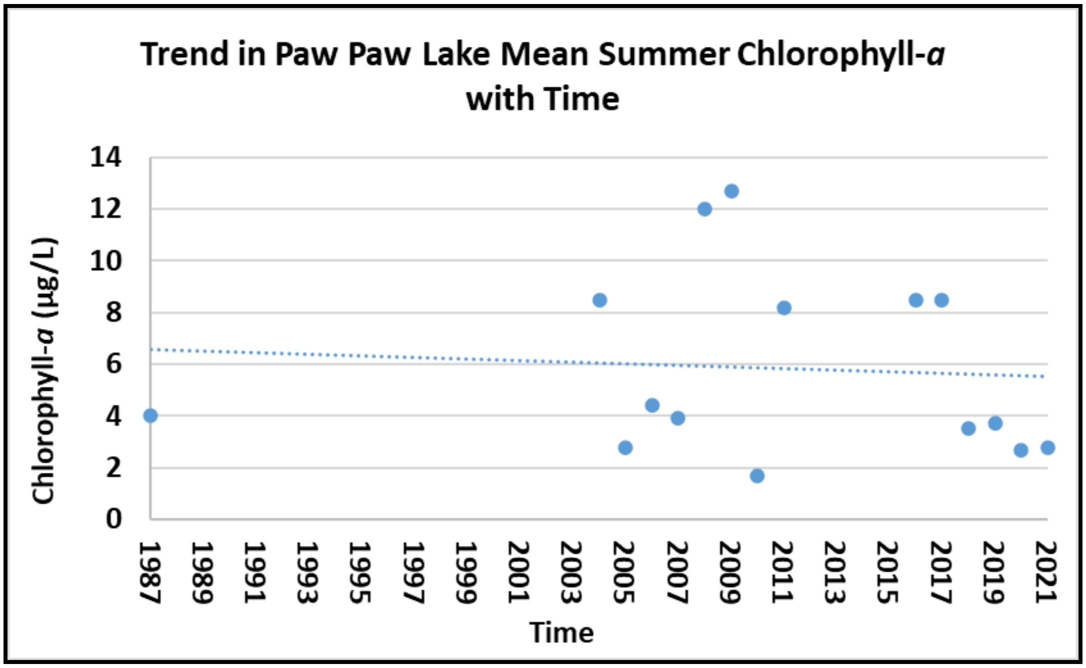

Figure 20. Trend in Paw Paw Lake mean summer chlorophyll-*a* concentrations with time.

Figure 21. Filamentous green algae in Paw Paw Lake (2022).

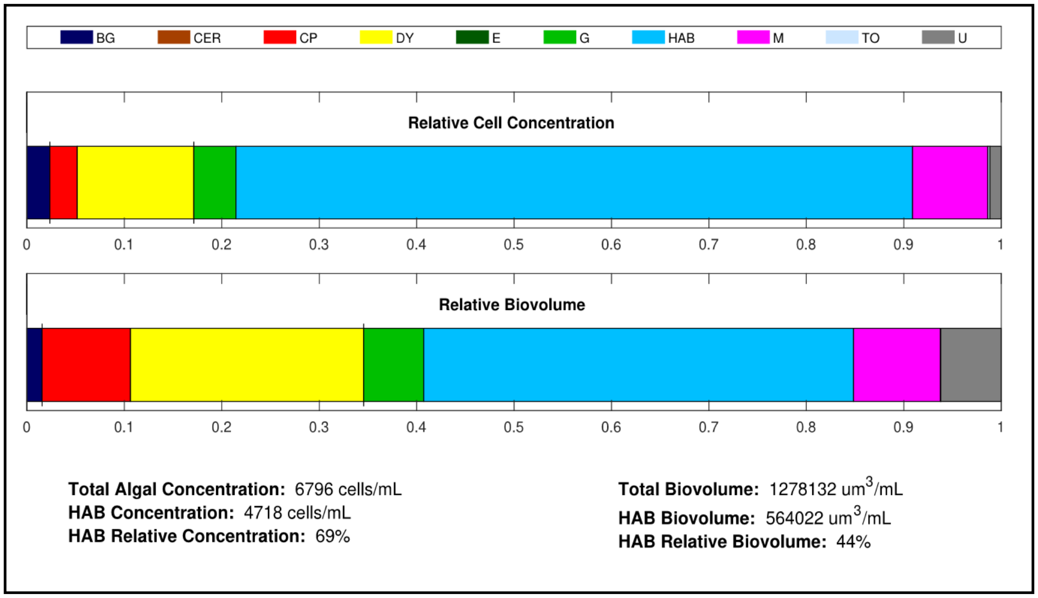

Figure 22. Example of graphical representation of algal cell counts and relative abundance of different algal taxa (PhycoTech).

Taxa	Group	NU/mL	Cells/mL	Biovolume um^3/mL	Relative Biovolume %
Aphanocapsa-Aphanothece	BG	45	160	19920	1.56
Cryptomonas	CP	13	13	56924	4.45
Rhodomonas	CP	177	177	58914	4.61
Detritus	DET	48	0	0	0
Aulacoseira	DY	5	48	11654	0.91
Centrics	DY	391	391	156926	12.28
Chrysophyta	DY	52	150	23690	1.85
Fragilaria	DY	7	111	71449	5.59
Haptophyta	DY	8	8	1532	0.12
Mallomonas	DY	90	90	32020	2.51
Navicula-Nitzschia	DY	13	13	8069	0.63
Pennate Diatoms	DY	2	2	609	0.05
Chlorophytes	G	144	159	53686	4.2
Closterium	G	3	3	2136	0.17
Crucigenia-Crucigniella	G	3	22	2537	0.2
Desmodesmus-Scenedesmus	G	3	20	952	0.07
Monoraphidium	G	8	8	1786	0.14
Quadrigula-Elakatothrix	G	12	42	6919	0.54
Schroederia	G	42	42	10727	0.84
Aph. gracile-Chrys.	HAB	2	25	4645	0.36
Aphanizomenon (Aph.)	HAB	185	4693	559376	43.77
Taxa below 9um	M	526	526	114094	8.93
Pseudanabaena	TO	2	15	377	0.03
unclassified	U	78	78	79189	6.2

Figure 23. Example of tabular representation of algal cell counts and relative abundance of different algal taxa (PhycoTech).

3.2 Blue-Green Algae (Cyanobacteria) in Paw Paw Lake

Blue-green algae such as *Microcystis* sp. have been prevalent in Paw Paw Lake. *Microcystis* colonies are a few micrometers in diameter and are evenly distributed throughout a gelatinous matrix. Younger colonies are spherical and older ones are more irregularly shaped. There are numerous gas vesicles, and the algae can thrive at the surface with minimal photo-degradation (breaking down) by the sun. When the sunlight is excessive, the algae can break down and release toxins and lower the dissolved oxygen in the water column. The algae are the only type known to fix nitrogen gas into ammonia for growth. This is one reason why measurement of ammonia is so critical since blue-green algae can use it freely and not have to expend the energy to fix nitrogen. *Microcystis* has also been shown to overwinter in lake sediments (Fallon et *al.*, 1981). *Microcystis* has also been shown to overwinter in lake sediments (Fallon et *al.*, 1981). In addition, it may thrive in a mucilage layer with sediment bacteria that can release phosphorus under anaerobic conditions (Brunberg, 1995). They assume a high volume in the water column (Reynolds, 1984) compared to diatoms and other single-celled green algae. The blue-green algae have been on the planet nearly 2.15 billion years and have assumed strong adaptation mechanisms for survival. In general, calm surface conditions will facilitate enhanced growth of this type of algae since downward transport is reduced. *Microcystis* may also be toxic to zooplankton such as *Daphnia* which is a zooplankton present in most lakes (Nizan et *al.*, 1986). Without adequate grazers to reduce algae, especially blue greens, the blue-green population will continue to increase and create negative impacts for water bodies. Sources of nutrients for this algae in Paw Paw Lake include drains, lawn fertilizers, and runoff.

The presence of algal blooms (Figures 24 and 25) that appear opaque and green and reside near the water surface usually consist of blue-green algae. Although not all blue-green algae produce toxins, samples collected from Paw Paw Lake in August of 2018 demonstrated above-detection levels for microcystin LA and LR, although blooms have been noted for several years. Loftin et *al.*, (2008) define a bloom as a count of algal cells between 20,000-100,000 cells per milliliter. In 2019, the U.S. EPA has established the lower limits for acceptable water use for the most common toxins which include microcystins and cylindrospermopsin. They have not differentiated between the different individual toxins or set thresholds for nodularians. These groups can also have consequences for human and wildlife health.

Figure 24. A widespread blue-green algal bloom on Paw Paw Lake (June 13, 2013).

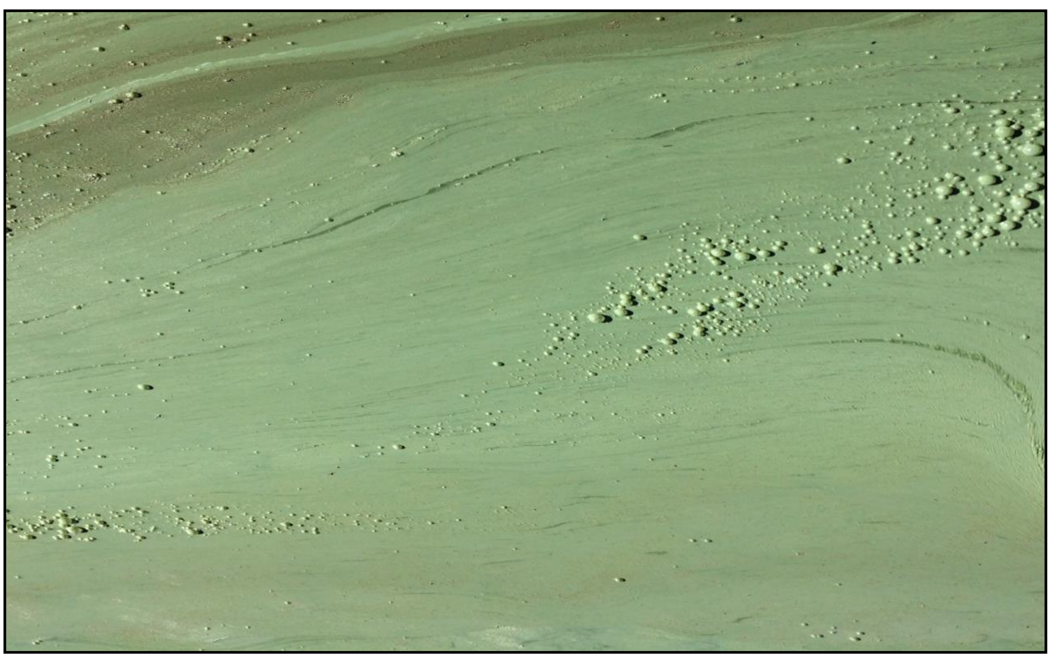

Figure 25. A close-up view of a blue-green algal bloom on Paw Paw Lake (June 13, 2013).

As previously stated, algaecides should only be used on green algal blooms since many treatments can exacerbate blue-green algae blooms. In late summer, the blue-green algae, *Microcystis* sp. was the most prevalent algae in the lake, which is an indicator of poor water quality. The EPA standard for microcystin is 8.0 µg/L and a no contact advisory can be issued by the Michigan Department of Health and Human Services (MDHHS) if samples exceed that concentration.

Additional data on the community composition of algae and concentrations of blue-green algae and associated toxins are lacking and RLS recommends this data be measured in 2023 and in future years and used to evaluate the current status of the lake relative to cyanobacteria blooms. RLS recommends a more detailed panel of cyanobacterial toxins that detects the concentrations of Anatoxin-a, Cylindrospermopsis, Microcystin-LA, Microcystin-LF, Microcystin-LR, Microcystin-LY, Microcystin-RR, Microcystin-YR, and Nodularin. This would allow for definitive concentration determination of possible toxins by other cyanobacteria species.

When cyanobacteria blooms are present, sampling locations should be selected and tested for blue-green algal toxins to determine which type(s) of toxins are present in the lake. The toxins can be analyzed using Eurofins® Eaton Analytical (EEA) Method L231. Table 14 below lists the algal toxins most commonly found in lake systems during blue-green algal blooms.

Table 14. A list of algal toxins found in common blue-green algal blooms.

Algal Toxin(s) Tested	MRL
Anatoxin-a	0.02
Cylindrospermopsin	0.05
Microcystin-LA	0.1
Microcystin-LF	0.1
Microcystin-LR	0.1
Microcystin-LY	0.1
Microcystin-RR	0.1
Microcystin-YR	0.1
Nodularin	0.1

4.0 PAW PAW LAKE WATERSHED IMPAIRMENTS

The sections below detail the immediate watershed and its relative size to the lake basin which is key to understanding the magnitude of the nutrient and sediment loading issues. Much effort has previously been made relative to delineation of Critical Source Areas along the Branch and Derby Drain which is the largest contributor of nutrients and solids to Paw Paw Lake.

4.1 The Paw Paw Lake Immediate Watershed Boundary

A watershed is defined as a region surrounding a lake that contributes water and nutrients to a waterbody through drainage sources. Watershed size differs greatly among lakes and also significantly impacts lake water quality. Large watersheds such as Paw Paw Lake with much development, numerous impervious or paved surfaces, abundant storm water drain inputs, and surrounding agricultural lands, have the potential to contribute significant nutrient and pollution loads to aquatic ecosystems.

Paw Paw Lake is located within the Paw Paw River extended watershed which covers an area of approximately 446 mi^2 in three Michigan counties which include Berrien, Kalamazoo, and Van Buren counties. There are over 150 miles of streams and approximately 5,800 acres of lakes and ponds. Paw Paw Lake occupies 15.9% of the total open water area and thus it is a critical waterbody for designated uses in the immediate watershed.

The immediate watershed of Paw Paw Lake consists of the area around the lake that directly drains to the lake and measures approximately 10,394 acres in size (Figure 26; RLS, 2023). The immediate watershed is about 11.9 times the size of the lake, which is considered a large immediate watershed. In 2022, RLS created the map in Figure 27 which displays the flow paths of water from drains into the lake. The lakefront itself has a diverse application of land uses such as beachfront for swimming, wetlands, and developed lands. Thus, management options should also consider all of these land uses and preserve their unique functions. Storm drain influxes of soils and possibly nutrients may be another unknown threat to the water quality of Paw Paw Lake. Some of the areas around the lake are also of high slope where unstable shorelines may be prone to erosion. RLS recommends a lake-wide shoreline erosion survey to determine if any locations require mitigation. Additional recommendations are given in the following section.

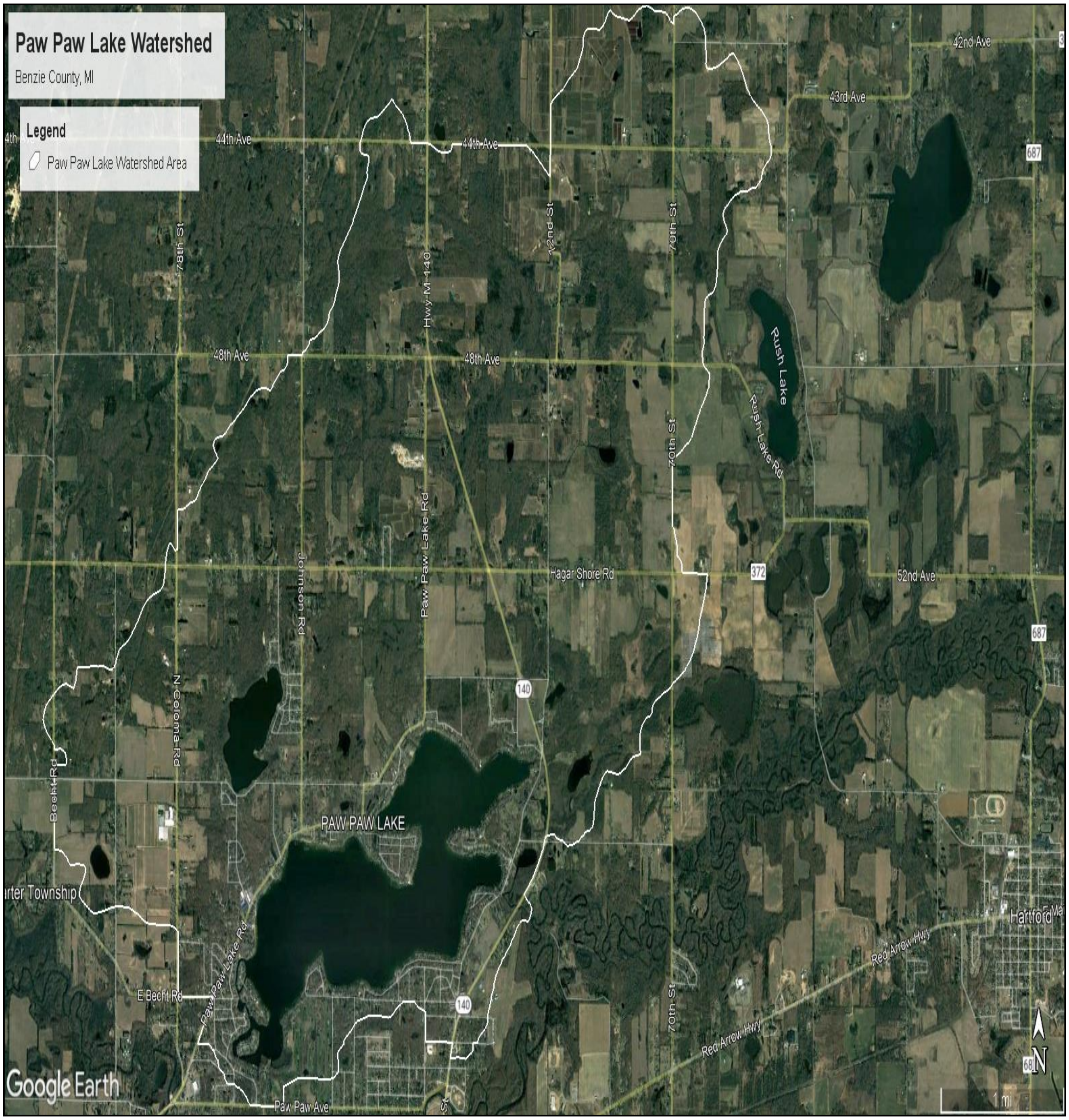

Figure 26. Paw Paw Lake immediate watershed boundary map (RLS, 2023).

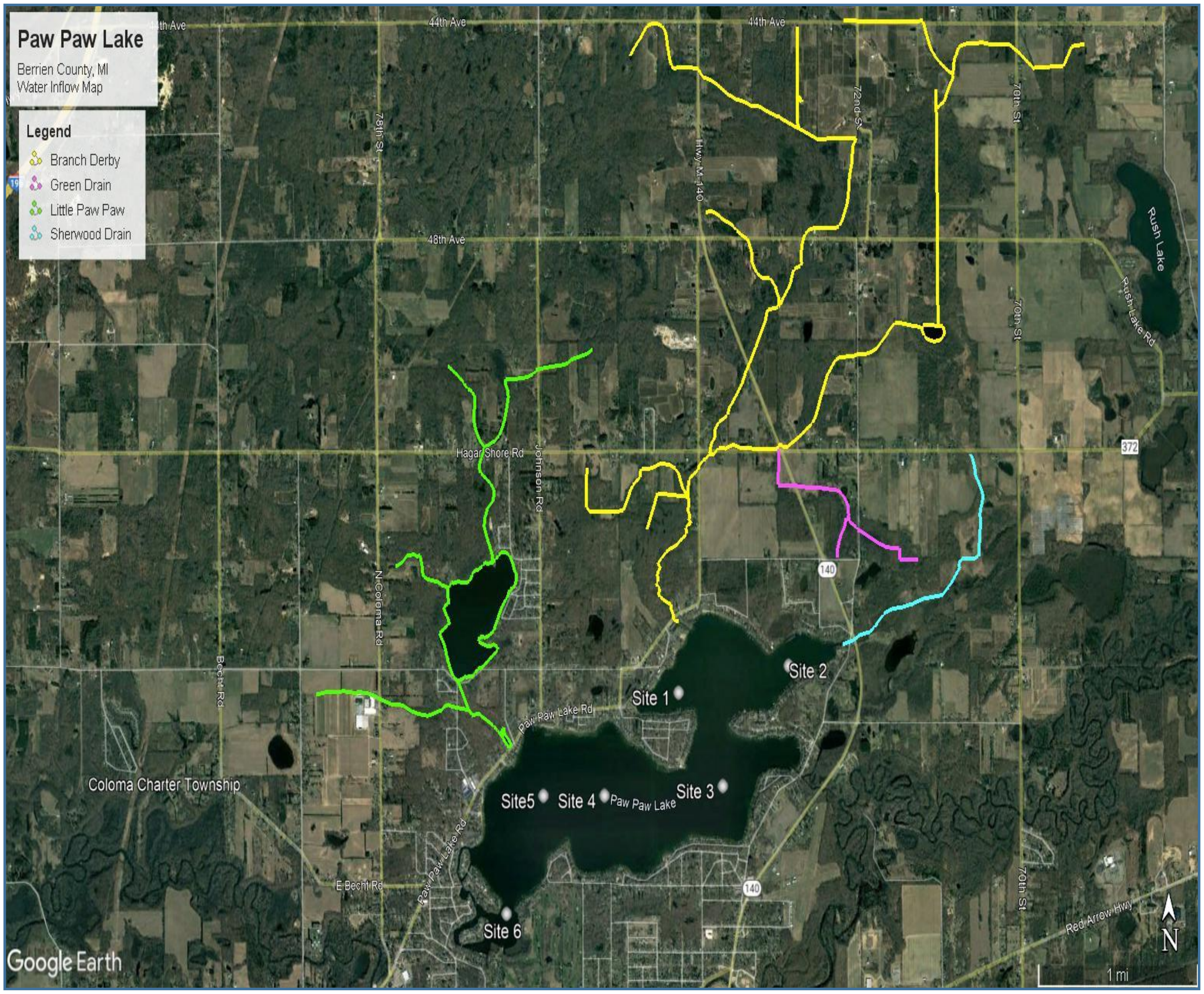

Figure 27. Paw Paw Lake drain inflow water courses including the Brach Derby Drain (yellow), Green Drain (pink), Little Paw Paw Drain (green), and Sherwood Drain (blue); RLS, 2022.

4.2 Paw Paw Lake Critical Source Areas (CSA's):

Critical Source Areas (CSA's) are those areas around a waterbody that contribute the greatest quantities of nutrients and solids. A previous evaluation of the Paw Paw Lake immediate watershed has determined that there are three major drains that enter into Paw Paw Lake: 1.) Little Paw Paw, 2.) Branch and Derby, and 3.) Sherwood. The Branch and Derby Drain annually contributes the largest nutrient and solid loads to the lake. Although there have been improvements to this drain with time, including straightening of the drain to offer better drainage, the sediment traps often are inundated and overflow in the lake during heavy rainfall events. In 2021 the TSS loading rate was estimated to be 102,189 lbs./day. The TP loading rate was estimated to be 611 lbs./day. The N loading rate was estimated to be 1,048 lbs./day. These loads indicate that the nutrients from the Drain are increasing over time and a new mitigation strategy is urgently needed.

Wetlands were previously present along North Watervliet road that are now developed and wooded (Figures 28-29). In 2022, RLS recommended additional mitigation improvements that should be considered for the Branch and Derby Drain. One such improvement was the consideration of an emergent filtration wetland upland of the drain-lake confluence. This would allow for adequate filtration of solids and nutrients prior to entering the lake but only during periods of low flow. Although restoring that area to a wetland would seem logical, the hydrologic connectivity would be limited due to development of impervious road surfaces and other structures.

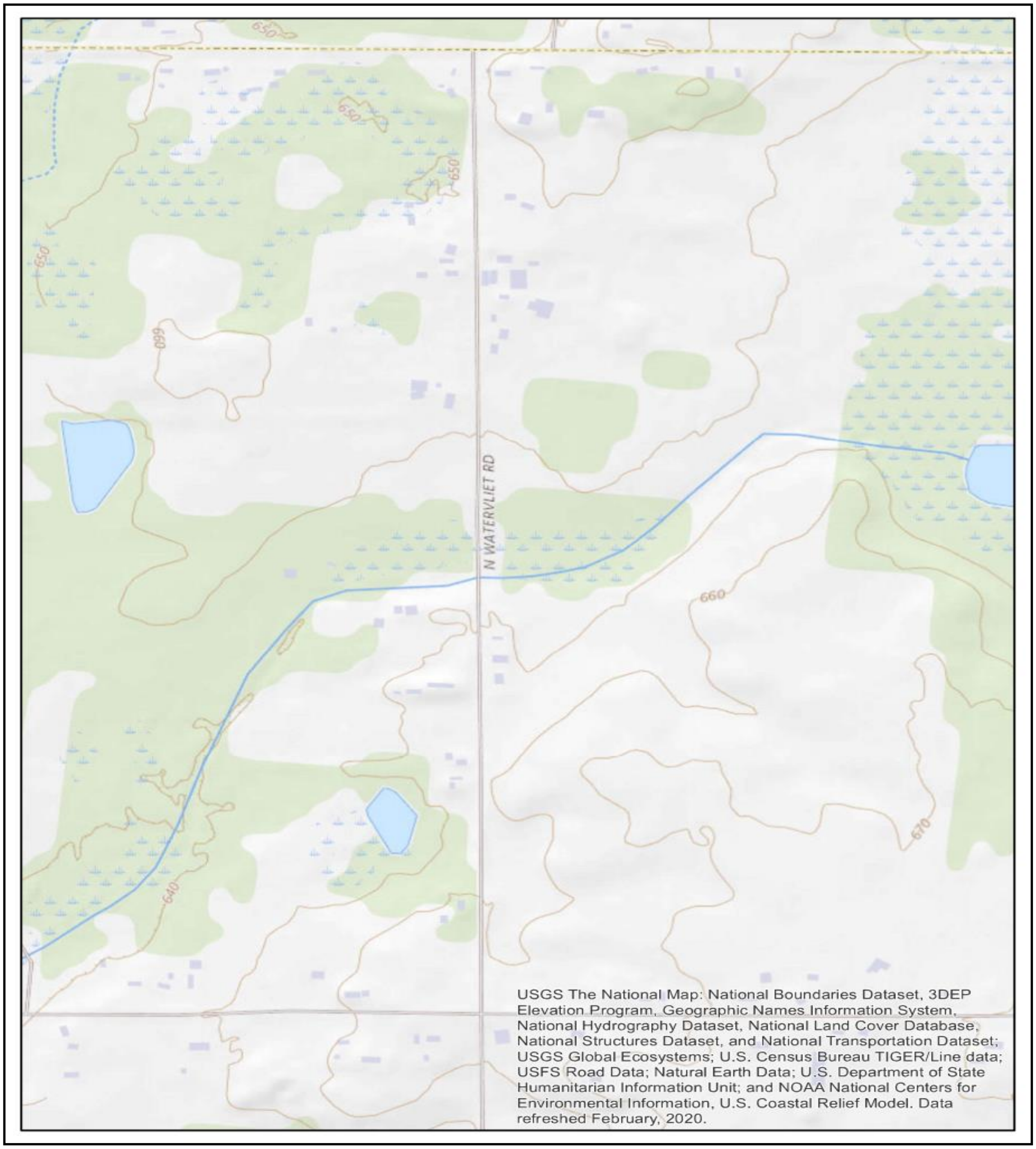

Figure 28. Pre-existing wetlands along the Branch Derby Drain prior to becoming wooded. Note: USGS data was refreshed but the current habitat in those wetlands is wooded.

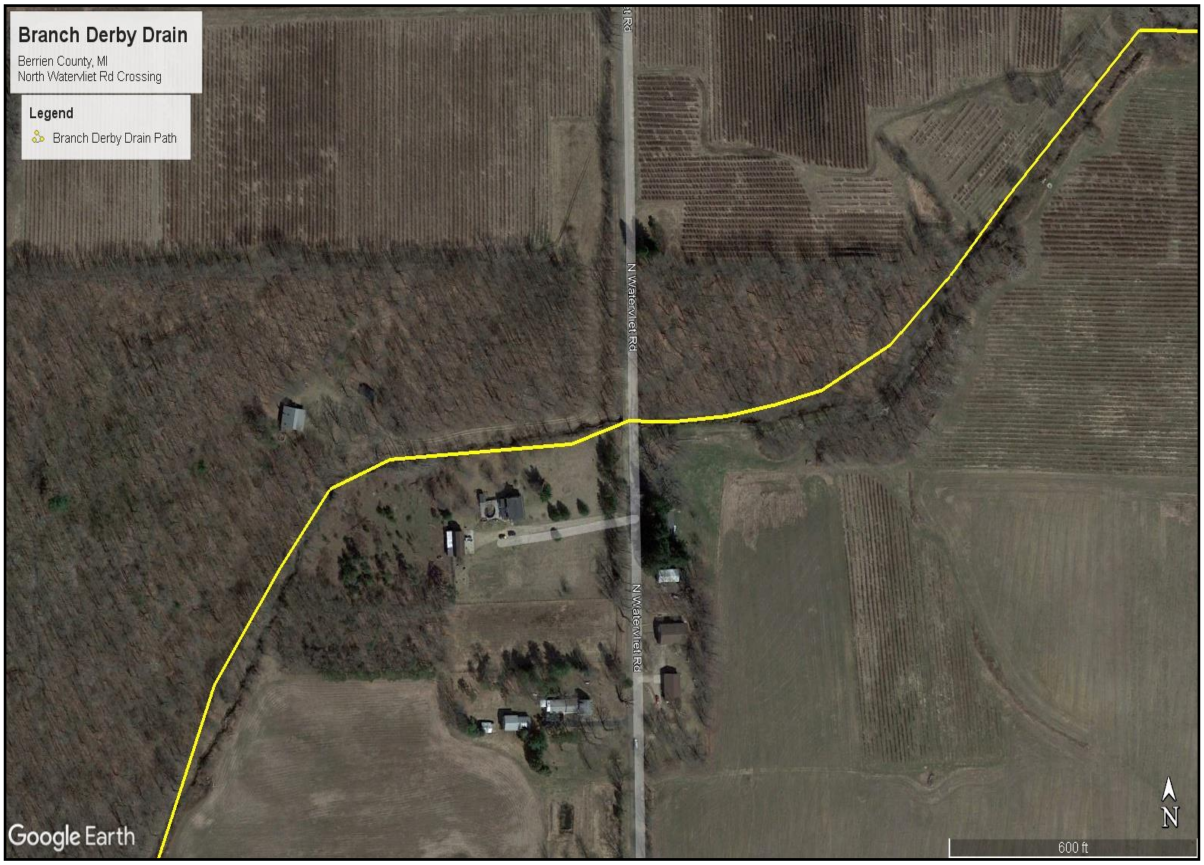

Figure 29. The Branch Derby Drain as it flows through wooded areas that were once wetlands. Note the adjacent farmlands to the drain.

Given that higher-intensity storm events have been occurring both locally and globally, another option should be considered to filter out the fine particulate organic matter (FPOM) that comes from farmlands and swamps that have mucks as the primary soil types. In particular, the mucks such as Palms mucks, Houghton mucks, and Edwards mucks have fines that are easily transported into waters. These muck types are present along both the Branch Darby and Green drains, but a much more focused review of these areas is needed. Previously proposed improvements to the Heater Farm would be limited to low flow events and there is a need to reduce the transport of these fines during moderate to heavy flow events. Another option would be to consider purchasing the farm as a Conservation Area in the future where farm production would be eliminated. Vegetative plantings may still be needed to ensure that FPOM from mucks are not transported downstream.

Ideally, a very large settling basin closer to the lake basin should settle these fines out but placement may be difficult. Another much less costly option would be to consider placement of check dams with biochar filters along areas of both drains. This should be approached cautiously to avoid any backups or flooding. This would help to reduce water flow velocity and settle out fines within the biochar filters. A natural charcoal technology called EarthFood Biochar US® is available for filtration of nutrients and pollutants that may enter inland waters (Figure 30). The Biochar is comprised of 87.4% organic carbon based on percentage of total dry mass. Particles range in size from 8-25 mm so there is inherent variability in particle size. This variability allows for the adsorption of nutrients and pollutants due to increased adsorptive surface area. Biochar may be placed in a multi-filament polypropylene sock (such as Silt Sock®) which has a life expectancy of up to 2 years. It is considered an inert product with no chemical effect on the environment. This product allows for the Biochar to be contained in an area and serves to consolidate the particles for optimum filtration efficiency. Previous data collected by RLS on an inland lake inlet that utilized the biochar showed significant reductions in nutrients such as phosphorus and nitrogen as well as total suspended solids (Jermalowicz-Jones, 2012-2016).

RLS recommends a complete inventory of all areas within the immediate watershed boundary where FPOM is present from specific soils such as the Palms and Houghton mucks. Once these areas have been determined, ground-truthing to specific sites may be needed to ascertain the degree of threat for transport to the lake. Regardless of whether these areas are present on farms or individual private properties, discussions can take place between the PPLA, PPLF, and the relevant stakeholders to recommend solutions to keep the mucks in place with existing or upcoming best management practices (BMP's) that have been successfully used in areas with similar soil types.

Figure 30. EarthFood Biochar US® product.

4.3 Paw Paw Lake Geese and Nuisance Waterfowl:

The Canada Goose (Figure 31) is largest and most widely distributed goose throughout the artic and temperate regions of North America. Historical hunting had reduced migrating geese populations, prompting a massive undertaking to reestablish the species within the United States. In the early 1940's, Canada goose populations were so low that there was some fear of extinction. Efforts by the federal government and many states to provide protection brought the populations back up to a more desirable level in the 1980's. In Michigan, their numbers presently exceed 300,000 (DNR 2018). Its distinctive cackling and V-shaped migrations are known by all as a signal of changing seasons. However, not all Canada goose embark on long distance journeys, some establish resident populations which are the cause of most conflicts today. This resident type has found the perfect environment in the urban-open water habitat dotting Michigan's landscape, including Paw Paw Lake (Figure 32). Modern land-use has encouraged the creation of open spaces, eliminating ground cover for predators and providing well-manicured lawns (Figure 33) adjacent to ponds and lakes in which Canada geese thrive. Extensive food resources, protected nesting areas, and refuge from predators has triggered a population explosion among resident geese.

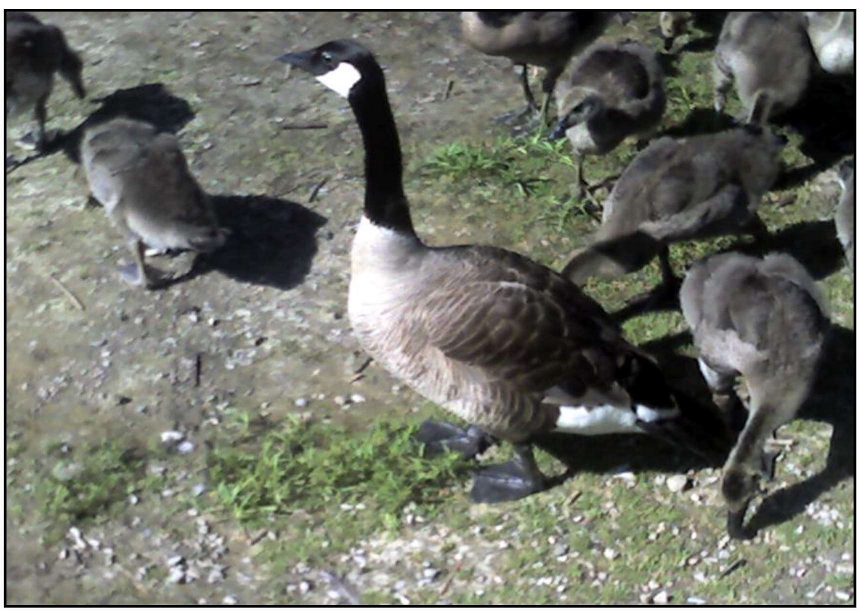

Figure 31. Canada Geese (*Branta canadensis*).

Figure 32. Nuisance geese on Paw Paw Lake during the winter of 2022-2023.

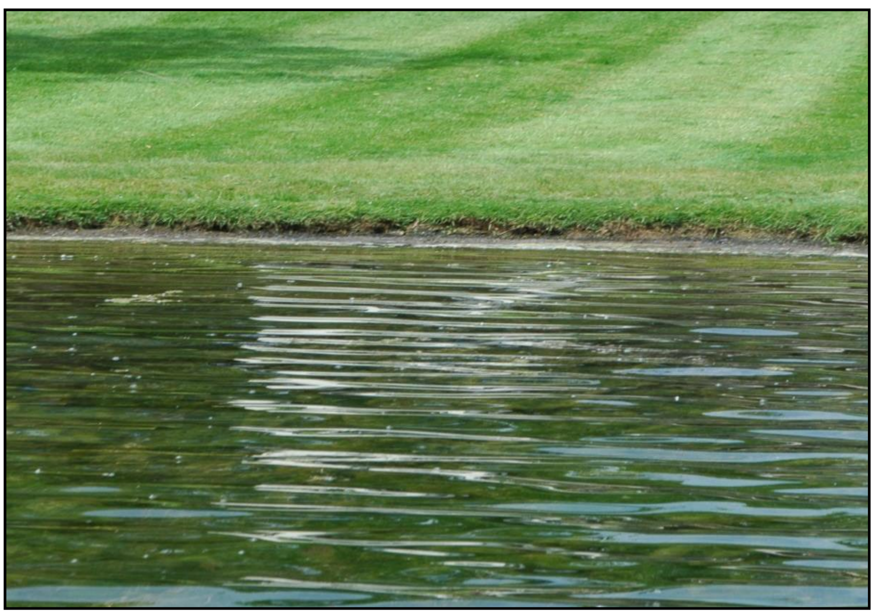

Figure 33. Example of a manicured lawn.

Both Canada geese groups share the well-known black-headed, white "chinstrap" characteristic, making them difficult to distinguish. Geese are grazing herbivores and prefer grass, aquatic vegetation, seeds, and various grains. Adults can weigh from 10 to 17 pounds, eat up to 4 pounds of grass a day, and return up to 2 pounds of that as feces (Crawford 1999). Canada geese live up to 24 years, keep the same mate for life, and return to nest in the same location, generally during the months of March thru May (DNR 2018). Adult geese are particularly aggressive during breeding and nesting season, and their behavior can cause problems for lake residents and visitors when they attack and nip (Eccher 2000). As the population rises nationwide and fierce turf wars follow, it is important to remember that Canada geese also provide recreational viewing and hunting opportunities for many. A continued expansion of ideal habitat requirements challenges managers and lake residents to find some level of tolerance. Further complicating management strategies for controlling resident populations, is the fact that Canada geese are managed and protected by the US Fish & Wildlife Service under the Migratory Bird Treaty Act of 1918. This has made it unlawful to kill, hunt, or disturb nests and eggs unless permitted by the Secretary of the Interior. They can be legally hunted during hunting season with the proper license; however, hunting access is often limited due to the proximity to human environments.

Water Quality Impairments from Canada Goose Droppings:

Many inland lakes in Michigan share an abundance of geese around the shorelines and in local wetlands and parks. In addition to being a nuisance on lawns, excess goose populations on lakes can have impacts on the water quality of the lake. Geese defecate both on land and in the lake and the droppings are high in organic matter and nutrients. These are the same nutrients that accelerate aquatic plant growth and algae blooms. Many of our lakes sustain year around populations of geese. It has been reported that one Canada goose can contribute about a half pound of phosphorus to the lake each year. Therefore, if we consider a resident population of twenty geese on your lake, that would be the same as dumping in two fifty pound bags of fertilizer with a N-P-K ratio of 0-10-0 each year (Lake Notes, 1996). This would be the same as a seasonal population of forty geese that spend six months on the lake. It has been estimated that one pound of phosphorus can support about 500 pounds of algae! (Van Buren Conservation District 2012).

A study by Manny et *al.* (1994) found that the annual contribution of carbon, nitrogen, and phosphorus from migratory waterfowl including Canada geese (*Branta canadensis*) can exceed the external loading contributions on some inland lakes. Thus, an overabundance of geese can lead to increased nutrient loads to lakes and other water bodies. Goose feces contain pathogenic protozoa and bacteria that may emerge has a human health risk to recreational freshwater beach areas invaded by resident geese (Gorham and Lee 2014). Means of direct oral contact include children playing on the beach sand, or individuals exposed while swimming and accidentally ingesting water. Furthermore, nutrients contained in fecal matter may have a significant impact on a lakes trophic status, causing excessive weed growth and algae blooms (Cote et. *al*., 2010).

Also, decomposition of animal waste depletes oxygen levels in shallow, warm waters during the summer months and elevates ammonia levels, producing a toxic environment for fish and other aquatic life.

Management of the Canada Goose for Water Quality Protection:

The long-term protection of lake water quality requires humane and effective strategies for nutrient reduction of all possible sources which includes local and migratory populations of Canada Geese. Fortunately, there are some strategies for reducing geese populations which include but are not limited to the following:

1. Encourage riparians to grow waterfront grass to ≥ 3 inches tall as geese prefer short grass. This does not have to include the entire lakefront lawn but can include a strip or buffer that extends along the shoreline and is at least 5 feet in thickness or width. Eventually tall grasses and sedges will grow at the lake/shoreline interface and will even benefit the shoreline from further erosion—especially if a seawall or rip-rap is not present. If rip-rap is present, the growth of tall grasses along the shoreline is still recommended as geese will likely not venture into a yard with an area of predatory risk.

2. Plant tall native plants near the shore to encourage a soft shoreline that geese may avoid due to the potential of predators hiding in the tall weeds (Figure 34). If tall grasses are not easily established by not mowing to the waters' edge, then intentional plantings may be needed. In these cases, it is best to call a certified Natural Shoreline professional and they can be found on the Michigan Natural Shoreline Partnership website at: www.mishorelinepartnership.org. These professionals have unique training on how to introduce native vegetation that will grow in local soils as well as techniques for reducing erosion and enhancing the natural beauty of lake shorelines.

Figure 34. Example of a natural (soft) shoreline.

3. Do not feed geese or waterfowl as this encourages their presence. This principle is difficult for wildlife enthusiasts and avid bird watchers but is really important. Geese have access to a multitude of natural food sources in and around aquatic habitats. They do not need foreign sources of food (such as bread, nuts, etc.) that will enable them to defecate more in nearby lawns.

4. Egg replacement, goose round-up, and nest destruction methods are effective to a degree but require a permit and training from the Michigan Department of Natural Resources (MDNR). Further information on these strategies and additional less invasive strategies can be found on the MDNR website at: www.michigan.gov/dnr. The Humane Society of the United States (U.S.) issued a guidebook in April of 2010 called: "Humanely Resolving Conflicts with Canada Geese: A Guide for Urban and Suburban Property Owners and Communities". This book can be found on their website at: www.humanesociety.org.

5. Coyotes or other intimidating effigies (owls, birds of prey, etc.) can scare geese away from beachfront areas and lawns (Figure 35). These decoys have a realistic appearance and are often to scale and are used in beachfront areas where tall grasses may not be favorable or possible. They can be used each season and are readily available at many home improvement stores. They can also be strategically placed in areas where geese are known to enter lawns.

Figure 35. Effigies used to deter geese and other waterfowl.

6. The Audubon Society recommends placement of string 6 inches above the ground followed by another row of string an additional 6 inches above the water if this shoreline method is used. More information on natural control methods can be found on their website at: www.audubon.org.

7. Another newer technology involves the use of beacons on a floating buoy (Figure 36) that deter geese with light signals. These are usually recommended for smaller water bodies such as ponds where they can be safely deployed with little navigational hazard.

Figure 36. A specialized beacon buoy used to deter geese.

8. Visit the following website for more methods and information:
http://icwdm.org/handbook/Birds/CanadadGeese/Default.aspx

5.0 PAW PAW LAKE RESTORATION METHODS, TIMING, AND EVALUATION OF EFFICACY

The following recommendations are a result of the review of data collected on the lake to date and are recommended for the best outcomes relative to lake basin and immediate watershed protection and also cost-effectiveness.

5.1 Aquatic Vegetation Surveying Methods and Treatments

Paw Paw Lake Aquatic Vegetation Survey Method Recommendations:

RLS recommends that the GPS Point Intercept method be used for aquatic vegetation surveys. This method will consequently allow for polygon maps to be accurately created for treatment prescriptions. These surveys should be conducted by an unbiased, independent lake manager with a strong aquatic botany background to avoid treatment bias. Surveys should be conducted in spring and mid to late summer with smaller surveys in mid-season as needed. Additionally, the lake should be scanned during mid-summer for aquatic vegetation biovolume to determine if invasive polygons are declining in area from the targeted treatments.

Paw Paw Lake Aquatic Herbicide Treatment Recommendations:

In addition to less usage of contact herbicides and chelated copper algaecides, RLS recommends the use of target-specific systemic herbicides for the control of EWM. This would include application of 2,4-D, triclopyr, or the new herbicide ProcellaCOR® that has demonstrated sustained efficacy with time and significant reduction of EWM in numerous inland lakes. The use of fluridone should be reduced as it can select for enhanced Starry Stonewort growth over time and also is applied to the entire littoral zone where it can impact other native submersed aquatic vegetation. EWM has also established a tolerance to the permitted doses of fluridone which is why it increases so readily within a year or so after treatment.

For the treatment of invasive Starry Stonewort, RLS recommends suction harvesting via a Diver Assisted Suction Harvesting (DASH) boat (Figure 37) that 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 is used on a spot-removal basis. It has been used to remove nuisance invasive aquatic vegetation in many lakes with good success and could remove bulbils that continue to spread growth in Paw Paw Lake. Because this activity may cause re-suspension of sediments (Nayar et *al*., 2007), increased turbidity and reduced clarity of the water can occur. 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. Figures 38 and 39 below show the conditions of the invasive aquatic vegetation growth in a lake area before and after DASH.

Figure 37. A DASH boat used in a lake for aquatic plant removal (©RLS, 2019).

Figure 38. Nuisance aquatic vegetation in a lake area prior to management (©RLS).

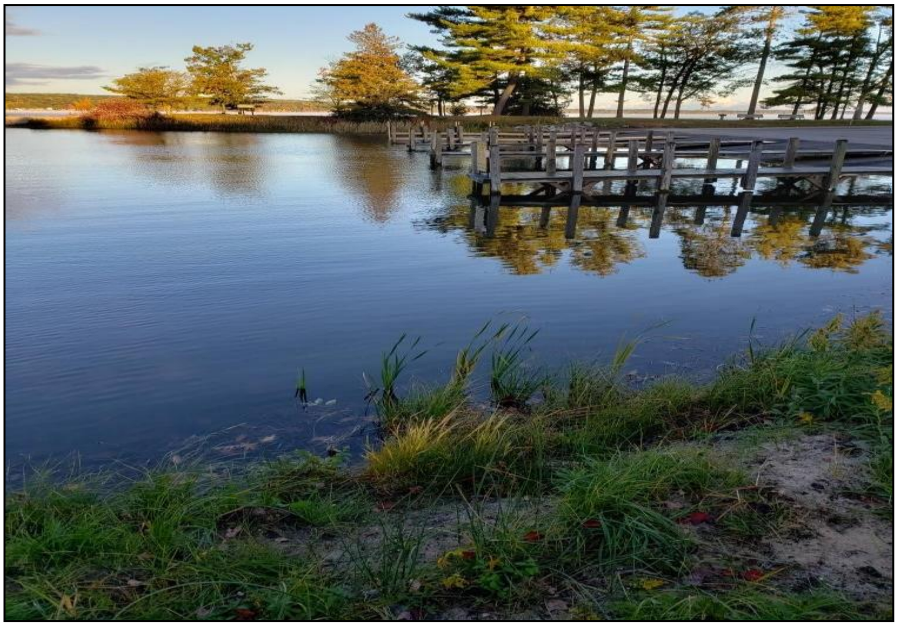

Figure 39. A lake area after DASH improvements in 2019 (©RLS).

5.2 Boat Washing Stations and AIS Prevention

The first ingredient to successful prevention of unwanted transfers of exotic species to Paw Paw Lake is awareness and education. Exotic species on the move could be introduced to the riparians around the lake through the use of a professionally developed educational newsletter such as the one distributed by the PPLA or PLF or through an annual lake-wide community workshop. In addition, signage should be placed at all launch sites. A boat washing station is recommended for the primary access launch site and there are mobile solar-power units available for the PPLA and PPLF to purchase. A typical boat washing station typically costs around $33,000 but lower cost ones are available for private lakes with restricted access (e.g., hand-held sprayer units). This will allow for all that use the lake to reduce further transfer and transport of invasives to and from the lake.

RLS also recommends an Early Detection Rapid Response (EDRR) protocol be developed for Paw Paw Lake to further reduce the probability of other invasives entering the lake and also allow for proactive treatment or mitigation approaches to rapid detection and reductions in spread. Many invasives not currently in the lake but occurring in the Midwest are far more aggressive than EWM and Starry Stonewort and thus this protocol is needed.

5.3 Algal Sampling and Cyanobacteria Mitigation

To date, the primary form of sampled nitrogen has been nitrate. However, ammonia is critical for understanding blue-green algal formation. We need to elucidate nitrogen speciation in order to effectively reduce cyanobacteria over time and make recommendations for reducing ammonia nitrogen. Nitrate is also important and thus total inorganic nitrogen (TIN) should be regularly sampled as a profile throughout the water column in spring, summer, and fall of each year in at least three of the deepest basins. TIN is a composite of nitrate, nitrite, and ammonia nitrogen.

In addition to the TIN parameter, *in situ* readings of total chlorophyll-*a* can be measured with a calibrated fluorimeter. These readings can be valuable in that they will allow for the prediction of cyanobacteria blooms if regularly monitored throughout the season in nearshore and open water areas of the lake. Bi-weekly measurements from April-October would be ideal. In addition to chlorophyll-*a* sampling, algal biovolume, cell count, and community composition are equally important. These parameters allow for an ecosystem approach to determining whether the lake balance is under threat from over-dominance of blue-green algae. They can also be used to evaluate efficacy of lake basin improvements relative to nutrient and algal reductions over time with monthly samples being sufficient. RLS recommends that PhycoTech® laboratories be used for these analyses.

The blue-green algae should decline as nitrogen and phosphorus decline, which may take many years. More imminent methods of cyanobacteria reduction could include the use of nutrient inactivation agents such as EutroSORB®, Phoslock®, or MetaFloc®. Pricing for these agents would need to be competitively sought which would require specific water quality parameter data as well as lake basin water volume data for proposed treatment zones. Direct applications to reduce cyanobacteria could be considered with the use of a peroxide additive Pak27® to reduce prominent localized blooms. RLS could assist the PPLA in the acquisition of competitive pricing bids from qualified vendors for lake specific treatments relative to blue-green algae and nutrient reduction.

Additionally, RLS recommends that a more detailed panel of algal toxins be conducted by Eurofins® laboratories to determine if certain toxins other than microcystins and nodularians are present and could be harmful. These samples are recommended during the summer months when strong blooms are present.

5.4 Immediate Watershed Improvements and Citizen Engagement

As previously mentioned, the locations of all areas within the immediate watershed that contain Palms and Houghton mucks should be inventoried for considerations of site-specific mitigation methods in the near future. RLS mentioned the potential use of filter material such as EarthFood™ Biochar that may be considered for nutrient reduction in drains or at the lake/drain confluences. Such material can be placed in the drains either in a retrofitted baffle box or within a filter sock. RLS also recommends that inputs from storm drains be evaluated in the near future if those drains enter the lake.

Stormwater can be a large source of nutrients and solids for lakes, especially during intense rainfall events. RLS recommends a complete inventory of all areas within the immediate watershed boundary where FPOM is present from specific soils such as the Palms and Houghton mucks. Once these areas have been determined, ground-truthing to specific sites may be needed to ascertain the degree of threat for transport to the lake. Regardless of whether these areas are present on farms or individual private properties, discussions can take place between the PPLA, PPLF, and the relevant stakeholders to recommend solutions to keep the mucks in place with existing or upcoming best management practices (BMP's) that have been successfully used in areas with similar soil types.

In 1997, the Michigan Department of Environment, Great Lakes, and Energy (EGLE, formerly MDEQ) and the United States Geological Survey (USGS) formed the Lake Water-Quality Assessment Monitoring Program (LWQA) to assess the conditions of over 700 inland lakes by 2015. Even though these efforts are critical to determine the baseline conditions of many recreational lakes in the state, they do not establish a long-term process for the conservation and management of these systems. Many environmental management programs have failed because of a scarcity in stakeholder participation. One major cause of this scant participation is due to a lack of adequate education regarding the complexities of environmental issues and resources to help assist individuals with solving challenging environmental problems. Yet, the State of Michigan has 1,240 townships and numerous other municipalities that incorporate many passionate minds to assist with service to their local communities.

There have been significant increases in public education and awareness in regards to issues that compromise inland lakes over the past decade and historically. The creation of the Michigan Lake and Stream Associations (MLSA) over 62 years ago along with the Michigan Sea Grant, the Michigan Chapter of the North American Lake Management Society (McNALMS), and many other small yet effective water resource protection programs have provided the public with awareness tools to begin protection strategies of a particular lake or water resource. Education is thus an important piece in the sustainability of a lake restoration program. Figure 40 demonstrates a sound model for stakeholder engagement that applies to both lake and immediate watershed management.

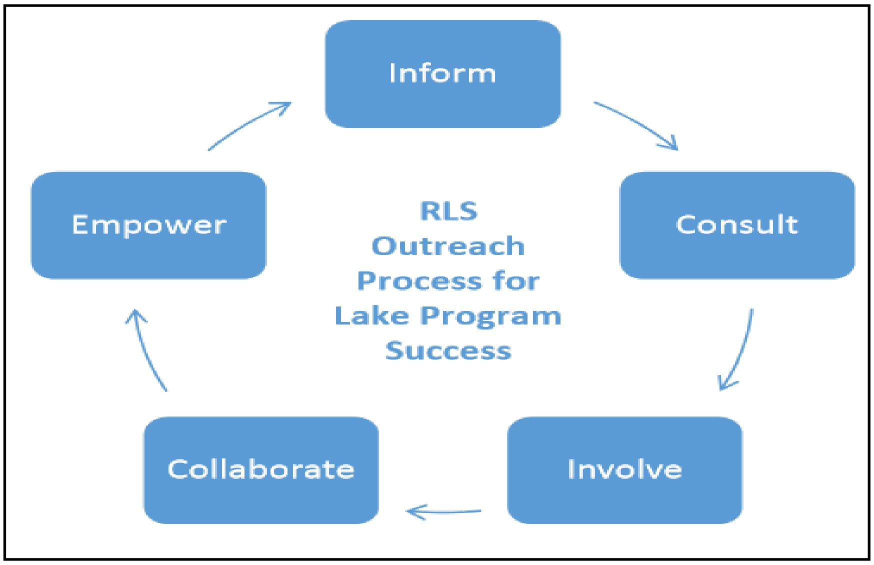

Figure 40. A flow model showing steps for successful lake and watershed program improvements.

Why Citizen Involvement is Recommended

An outside expert or group of lake science experts (such as RLS) is often contacted to recommend a lake management or restoration program and to educate the public of issues and possible solutions. These experts are not a part of the daily contact with the lake itself and cannot police the community for various poor practices or problems. Experts are in contact with the lake multiple times per year, but the residents have the most contact time with the lake. This makes riparians the optimum investigators for changes in and around the lake. Once riparians around the lake realize a specific impairment in the lake and how it affects their well-being, property values, etc., they bond with the lake in a constructive manner. Social scientists refer to this connection as a link between natural capital (the lake and surroundings) and human capital (the knowledge and skills of people in a community). In other words, these two capitals are not mutually exclusive once a person has interacted with an environment (lake). Thus, riparians have both the capacity to degrade water quality and improve water quality.

How the Paw Paw Lake Community Can Participate in Lake Improvements

Paw Paw Lake riparians are encouraged to attend regular Association meetings that are held regularly to discuss data trends and evaluate lake improvement progress. This would include meetings held by all groups such as the PPLA and the PPLF. Additionally, riparians would be encouraged to attend an annual lake workshop recommended by RLS. Education alone (i.e., meetings, brochures, etc.) will not adequately introduce all riparians to lake issues as many people are participatory learners. There is therefore a need to incorporate different educational strategies into this lake restoration program.

RLS proposes to develop an annual lake workshop where new data is presented (including post-BMP implementation data as it is obtained and analyzed) to the public and new research information is disseminated. Riparian BMP's would be openly discussed with attendants. There would be handouts at the workshop with modernized lake maps, water quality graphs, and other updated lake information. Lastly, there would be great opportunities for the lake community to consult with lake experts on key issues and assist individual riparians with lake concerns.

Tables 15 displays the recommended improvement methods along with proposed timing and evaluation of efficacy. It is highly encouraged that each of these items be implemented as soon as possible.

Table 15. List of Paw Paw Lake proposed improvement methods with timing and evaluation of method efficacy.

Proposed Management/restoration item	Methods to be Used	Timing	Evaluation of Method Efficacy
Aquatic vegetation surveys	GPS Point-Intercept; polygon maps; biovolume scans	Late spring, summer, late summer/early fall	Should result in less treatments each year
Targeted treatment of EWM w/systemic herbicides	Triclopyr, ProcellaCOR®, or 2,4-D	As needed for growth beginning in late April through early October	Should result in less EWM cover with time and less impact on natives
Targeted removal of Starry Stonewort	DASH	Summer	Should result in less cover over time
AIS prevention	Boat washing station; More AIS signage; EDRR protocol	Any time during 2023 season with use of boat washing station during season	Should result in a reduction in invasives and new invasives over time
Nutrient (N &P) reduction in lake basin	Nutrient inactivation agents such as PhosLock®, MetaFloc®, or EutroSORB®	In early summer and to early fall	Should result in a reduction in nutrient release especially during low DO concentrations
Blue-green algal bloom and algal community monitoring	In situ chlorophyll-a with fluorimeter; Algal composition with PhycoTech® analysis; Algal toxins with Eurofins®	Bi-weekly in open water and shallows for in situ Chl-a; Monthly for algal composition; during blooms for toxins	Should result in increased favorable algae and reduced blue-green algae and toxins with time
Blue-green algal bloom reduction and mitigation	Nutrient inactivation as described above plus use of PAK27® during intense blooms	Use of PAK27 during blooms only and where they are present	Should see measured reduction in bloom quantity and formation after treatment

Goose and waterfowl reduction	Goose nest destruction, MDNR program; other riparian methods as described	As permitted by MDNR; seasonal controls	Should see reduction in goose population as well as other nuisance waterfowl
Immediate watershed inventory of FPOM areas for mitigation	Intensive GIS survey of all areas in immediate watershed with FPOM mucks	During 2023 season/ongoing	Should see less FPOM in drains and lake once areas are delineated and mitigation occurs
Citizen engagement with community lake workshop	Lake-wide annual workshop with lake experts, resources, MDNR, EGLE, etc.	Beginning in late 2023 and/or annually thereafter	Should see more interest in lake issues from riparians; increased knowledge

6.0 COST ESTIMATES FOR PAW PAW LAKE MANAGEMENT AND RESTORATION RECOMMENDATIONS

The proposed lake management and restoration method costs are listed in Table 16. Note that there are few restoration items such as agents for nutrient inactivation, algal blooms, and aeration that would need to be specially priced based on abundant lake water quality and basin morphological data.

It should also be noted that proposed costs are estimates and may change in response to changes in environmental conditions (i.e., increases in materials or market costs). Furthermore, this table is adaptive and is likely to change but is useful for planning purposes.

Table 16. Paw Paw Lake proposed lake restoration and management costs (2023).

Proposed Management/restoration item	Approximate Cost
Aquatic vegetation surveys	$12,500 (RLS)
Targeted treatment of EWM w/systemic herbicides	Varies dependent upon herbicides and acreage used
Targeted removal of Starry Stonewort	Need vendor quote
AIS prevention	$35,000 (need formal quote on station) EDRR Protocol ($8,000)
Nutrient (N &P) reduction in lake basin	Need vendor quote
Blue-green algal bloom and algal community monitoring	In situ measurements ($1,000) Monthly PhycoTech® analysis ($2,000 per sample) EuroFins® algal toxins during bloom ($1,000 per sample)
Blue-green algal bloom reduction and mitigation	Need quote from vendor for various bloom sizes
Goose and waterfowl reduction	Price of annual permit fee plus need quotes for specific goose control technologies for riparians
Immediate watershed inventory of FPOM areas for mitigation	$15,000
Citizen engagement with community lake workshop	$10,000

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8.0 GLOSSARY OF SCIENTIFIC TERMS

Aerobic: Requiring oxygen to live or occurring in the presence of oxygen.

Anaerobic: The absence of oxygen (also anoxic).

Algae: Simple single-celled (phytoplankton), colonial, or multi-celled, mostly aquatic plants, containing chlorophyll and lacking roots, stems and leaves. Aquatic algae are microscopic plants that grow in sunlit water that contains phosphates, nitrates, and other nutrients. Algae, like all aquatic plants, add oxygen to the water and are important in the fish food chain. Algae is either suspended in water or attached to rocks and other substrates. Algae are an essential part of the lake ecosystem and provide the food base for most lake organisms, including fish. Phytoplankton populations vary widely from day to day, as life cycles are short.

Algal Bloom: A heavy growth of algae in and on a body of water. This usually is a result of high nitrates and phosphate concentrations entering water bodies.

Benthic: Located on the bottom of a body of water or in the bottom sediments.

Bioaccumulation: The process by which the concentration of a substance is increased through successive links in a food chain which may result in toxic concentrations at the top of the chain.

Best Management Practices (BMPs): An engineered structure or management activity that eliminates or reduces adverse environmental effects of pollutants.

Buffer Strip: Grass or other vegetation planted between a waterway and an area of intensive land use in order to reduce erosion. This is considered a best management practice.

Chlorophyll-*a*: The green pigment found in plants that are essential to photosynthesis. It is sometimes used to measure the amount of algae in the lake.

Chlorides: Sodium chloride (table salt) is often used to de-ice roadways during winter months. The salt (chloride) may then be washed into nearby lakes and streams resulting in elevated chloride levels in the water body. Elevated chloride levels can have an adverse effect on aquatic plants and animals. In public water supplies the EPA has set a standard that requires chloride levels not to exceed 250 mg/L due to possible health concerns.

Conductivity: A measure of the electrolytes in the water, which may be elevated by the presence of salts resulting from soil composition, faulty septic systems, or road salts.

Cultural Eutrophication: When human activities lead to the premature aging of a lake or pond.

Cyanobacteria (Blue-Green Algae): Bacteria that photosynthesize (use sunlight to produce food) and are blue-green in color. While cyanobacteria occur naturally in all lakes and ponds, elevated nutrient levels may cause cyanobacteria to "bloom" or grow out of control and cover the lake surface. The concern associated with cyanobacteria is that some species produce toxins that may affect domestic animals or humans through skin contact or ingestion.

Designated uses: For the state of Michigan, the nine designated use categories that can apply to state waters include: agriculture, industry, drinking water, navigation, partial body contact, total body contact, other indigenous aquatic life and wildlife, warm water fishery, and in some areas, cold water fishery.

Dissolved Oxygen: The amount of oxygen in the water. Dissolved oxygen may be produced by algae and aquatic plants or mixed into the water from the air. It is used by fish, aquatic insects, crayfish and other aquatic animals. Dissolved oxygen is usually measured in milligrams per liter.

Dredging: Removing solid matter from the bottom of a water body to make a deeper channel.

E. coli: A common bacteria that is specific to the intestines of warm blooded animals. It is often used as an indicator of the possible presence of other, more harmful (pathogenic) bacteria.

Ecology: The study of the interactions between organisms and their environments.

Erosion: The gradual wearing away of land surface materials, especially rocks, sediments, and soils, by the action of water, wind, or a glacier. Usually, erosion also involves the transport of eroded material from one place to another.

Eutrophic: Nutrient rich waters, generally characterized by high levels of biological production.

Exotic Species: A plant or animal species introduced to an area from another country or state that is not native to the area.

Food Chain: A succession of organisms in an ecological community that constitutes a continuation of food energy from one organism to another as each consumes a lower member and in turn is preyed upon by a higher member.

Groundwater: (1) water that flows or seeps downward and saturates soil or rock, supplying springs and wells. The upper surface of the saturated zone is called the water table. (2) Water stored underground in rock crevices and in the pores of geologic materials that make up the Earth's crust.

Headwater: The source and upper reaches of a stream or river.

Impaired: Being damaged or degraded as a result of pollution and therefore unable to meet the designated uses outlined by the State of Michigan.

Internal Loading: The release of phosphorus from the lake bottom sediments into the bottom layer of the water.

Leaching: The process by which soluble materials in the soil, such as salts, nutrients, pesticide chemicals or contaminants, are washed into a lower layer of soil or are dissolved and carried away by water.

Limiting Nutrient: An essential nutrient for plant growth, which has the least abundance in the environment relative to the needs of the plant. Phosphorous is usually the limiting nutrient in freshwater lakes and rivers.

Limnology: The study of the biology, chemistry, and physics of freshwater lakes and ponds.

Littoral: The shoreline zone of a lake where sunlight penetrates to the bottom and is sufficient to support rooted plant growth.

Nonpoint Source Pollution: Pollution that comes from diffuse sources, not an end-of-pipe outlet which is referred to as point source pollution. Typical nonpoint source pollutants include animal manure, storm water runoff, metals, nutrients, organic matter, pathogens, pesticides, petroleum by-products, and sediment.

Nutrients: Inorganic substances required by plants to manufacture food by photosynthesis. Phosphorus is the nutrient that usually limits the amount of aquatic plant growth in lakes.

Pathogens: Human disease causing bacteria or viruses that come from sewage spills, leaking septic tanks, manure runoff from farm fields, and even wildlife that live in the watershed.

pH: The measure of how acidic the water is, on a scale of 1-14; 1 is very acidic, and 14 is very basic.

Phosphorus: The nutrient most necessary for plant and algal growth in Michigan lakes, which comes from many sources including land application of farm animal manure, faulty septic systems, lawn fertilizers, and decaying plant matter.

Phytoplankton: Microscopic plants that float within or on top of lake water. (Refer to Algae)

Pollutant: Any substance of such character and in such quantities that when it reaches a body of water, soil or air, it contributes to the degradation or impairment of its usefulness.

Point Source Pollution: Pollution into a water body from a specific and identifiable source, such as industrial waste or municipal sewers.

Riprap: Large rocks placed along the bank of a waterway to prevent erosion.

Runoff: Water that travels over the land surface and ends up in streams and lakes.

Secchi Disk: An instrument used for measuring the transparency of lakes. It is a 20-cm diameter disk with black and white quadrants.

Sedimentation: The transport and deposition of soil particles by flowing water. Sediment is considered a pollutant.

Stratification (thermal): A process by which a deep lake becomes layered by temperature in the summer months. The layers will separate because colder water sinks to the bottom, leaving warmer water at the surface. Because these layers form chemical and biological barriers, limnologists sample each layer of the lake. During the winter months, when ice forms on the lake, Inverse Thermal Stratification occurs under the ice, in which colder, less dense water overlies warmer, denser water near the maximum density of four degrees Celsius.

Transparency: A measure of water clarity often determined by the depth at which a Secchi disk can be seen below the surface of the water. Transparency may be reduced by the presence of algae and suspended materials such as silt and pollen.

Tributary: A river or stream that flows into a larger river, stream, or lake.

Total Maximum Daily Load (TMDL): a regulatory term in the U.S. Clean Water Act, describing a value of the maximum amount of a pollutant that a body of water can receive while still meeting water quality standards. Alternatively, TMDL is an allocation of that water pollutant deemed acceptable to the subject receiving waters.

Trophic Classification: Biologically ranking the quality of lakes using a model that incorporates several parameters including; chlorophyll-a, Secchi disk transparency, aquatic plant abundance, and dissolved oxygen.

Trophic State: The trophic state of a lake is a general concept with no precise definition and no well-defined units of measure. In general, trophic state refers to the biological production, both plant and animal life, that occurs in a lake. The level of production that occurs is defined by several factors, but primarily by the phosphorus supply to the lake and the volume and residence time of the water in the lake.

Turbidity: A measure of the particles suspended in the water column which affect the clarity and transparency of the water. These particles may include silt, pollen, and algae.

Water Residence Time: The amount of time required to completely replace the water volume of a lake by incoming water, assuming complete mixing.

Watershed management plan: A document that assesses surface water resources impairments, land use activities, and development in a given watershed in order to provide the framework needed to implement projects and practices to restore, preserve, and sustain healthy watershed services.

Watershed: An area of land in which all the rainfall and snowmelt from that area drains to the lowest point, usually a stream or lake.

Zooplankton: Microscopic animals that live in lakes.